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ALTERNATE MITIGATION MATERIALS FOR ALKALI-SILICA REACTION (ASR) IN CONCRETE

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16. Abstract
Contractors are finding it difficult to obtain Class F fly ash for concrete paving projects, but CDOT specifications do not currently allow Class N pozzolan to be substituted for Class F fly ash. The purpose of this study was to determine the effectiveness of Class N pozzolan and other pozzolans for mitigating alkali-silica reaction (ASR) and resisting sulfate attack. First, a literature review was performed to find research on Class N pozzolan. Second, other state departments of transportation (DOTs) were contacted to determine if Class N pozzolan is used and how it is specified. Third, laboratory tests were conducted to determine the effectiveness of Class N pozzolan and other materials in mitigating ASR when compared to Class F fly ash. Using one source of Class F fly ash, one source of Class N pozzolan, and one source of reactive aggregate (fine and course), the effectiveness of Class N was determined by testing each combination in accordance to Colorado Procedures CP-L 4201 and CP-L 4202. Class N pozzolan was found to be effective in mitigating ASR. Once the effectiveness of Class N and other products tested was determined, further testing on Class D mix design was performed for potential effects on fresh and hardened concrete. Testing included entrained air on plastic concrete, rapid chloride permeability (ASTM C1202-05), and compressive strength at 7, 28, and 56 days.

Implementation:
CDOT should modify the concrete pavement specifications to allow the use of Class N pozzolan and other alternate materials. Implementation into concrete construction will involve economic evaluations by the contractors. Potential Class F fly ash shortages will likely promote mix designs with alternate materials.

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EXECUTIVE SUMMARY

Due to recent changes in the Environmental Protection Agency's regulations, the production of Class F fly ash that is acceptable for use in concrete pavement will be more limited in the future. This has led to a difficulty in obtaining Class F fly ash for Colorado Department of Transportation (CDOT) projects. Class N pozzolan isn't on CDOT's list of approved products, and until recently this was not a problem; Class F fly ash was more abundant and cheaper to acquire than Class N pozzolan.

Research was conducted to evaluate the performance of Class N pozzolan and other materials to mitigate Alkali Silica Reaction (ASR). The American Standard for Testing Materials (ASTM) test C 1260 was used to create a baseline for testing the expansion of reactive aggregates. C 1567 testing was conducted using a blend of reactive aggregates and various mitigating materials. Baseline mitigation testing were conducted with varying replacement levels of cement with supplementary cementitious materials (SCMs). These SCMs included one source of Class F fly ash and one source of metakaolin chosen by CDOT. Once the effectiveness of the various materials to mitigate 14-day expansion to 0.10% was determined using the above test methods, concrete mixes were prepared using the various materials. From these mix designs, slump and air entrainment on the plastic concrete was performed; compressive strength cylinders were cast and tested at 7, 28 and 56 days. Rapid chloride permeability test, in accordance with ASTM C 1202 was performed. Restrained cracking tendency testing (AASHTO PP 34) will be performed by CDOT on select mixtures in the future.

All materials tested were able to mitigate ASR expansions to below 0.10 at certain dosage rates. The metakaolin products mitigated ASR at dosages of approximately 10% replacement, as compared to an average replacement with fly ash of 24%.

This replacement reduction could either be used to maintain higher early strengths of concrete or to mitigate ASR with less cementitious materials (less costly).

Materials other than either Class N or F fly ash also successfully mitigated ASR, and can have applications in Colorado. Lithium can mitigate ASR without any cement replacement, although blends with fly ash tend to be more economical.

Lightweight sands can mitigate ASR by replacing reactive sands and giving a pore structure for gel from the coarse aggregate to grow in safely.

ASR mitigation with lightweight sand also brings the benefits of "internal curing" to dense, low water to cement (w/c) ratio concrete that can be difficult to cure in the field.

Implementation Statement

CDOT should modify the concrete specifications to allow the use of alternate materials, pending compliance to the new specifications and successful testing before being placed on the CDOT Approved Products List APL). A review of specifications in other states and this report should be helpful.

Implementation into concrete construction (after specifications allow alternate materials) will involve economic evaluations by the contractors. Potential Class F shortages will likely promote mix designs with alternate materials as a backup, or if strength gain (with less cement replacement) is beneficial to the project schedule.

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1. INTRODUCTION

1.1. Background

Recent changes in the Environmental Protection Agency's (EPA) regulations on air pollution have limited the supply of Class F fly ash acceptable for use in concrete pavements. The Colorado Department of Transportation (CDOT) currently specifies either 10-30% replacement of cement with Class F fly ash or 10-20% replacement with Class C fly ash. Contractors have found it increasingly difficult to obtain Class F fly ash for projects. CDOT currently has no specifications for using Class N pozzolan. Class N is classified either as a raw or calcined natural pozzolan that complies with the applicable requirements for this class of materials including diatomaceous earths; opaline cherts and shales; tuffs and volcanic ashes or pumicites, calcined or uncalcined; and various materials requiring calcination to induce satisfactory properties, such as some clays and shales. In the past, Class N pozzolan has been difficult to obtain, and more expensive than Class F fly ash. The CDOT wants to determine if other materials such as natural pozzolans could be used. A plant in Idaho is planning to start the production of Class N pozzolan, as well as several other metakaolin suppliers, giving contractors a viable alternative to Class F fly ash.

Metakaolin is a processed calcined-clay pozzolan classified as a Class N pozzolan by requirements of the American Standard for Testing Materials (ASTM) C618-05 Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use in Concrete. Because metakaolin is a pozzolan, it will provide increased workability, just as Class F fly ash. Based on this pozzolanic property, CDOT wishes to evaluate the effectiveness of metakaolin in mitigating ASR in concrete.

1.2. Scope and Objective of the Study

This study has several key elements. First, a literature review was performed to find research on Class N pozzolan. Second, other state departments of transportation (DOTs) were contacted to determine if Class N pozzolan is used and how it is specified. Third, laboratory tests were conducted to determine the effectiveness of Class N pozzolan and other materials in mitigating ASR when compared to Class F fly ash. Using one source of Class F fly ash, one source of Class N, and one source of reactive aggregate (fine and course), the effectiveness of Class N was determined by testing each combination in accordance with Colorado Procedures CP-L 4201 and

CP-L 4202[1]. Once the effectiveness of Class N and other products evaluated was determined, further testing on a Class D mix design was performed for potential effects on fresh and hardened concrete. The dosage levels of materials to mitigate the expansion less than 0.10% was defined from a graph, with an additional one percent added to ensure the mix design would indeed have that acceptable expansion property. Testing included entrained air on plastic concrete, rapid chloride permeability (ASTM C1202-05), and compressive strength at 7, 28, and 56 days. In addition to the above testing, CDOT will perform a shrinkage tendency test (American Association of State Highway and Transportation Officials, AASHTO PP 34 Restrained Shrinkage Cracking of Concrete (Ring Method)) on selected mix designs in the future.

The testing will determine the usefulness of Class N pozzolan and other materials in mitigating ASR as well as the compressive strength and permeability of the concrete produced with the various mitigation materials.

[1] CP-L 4201 is the CDOT's ASR expansion test with cement as aggregate baselines. The CP-L 4202 test is the expansion test with the mitigation materials at varying levels of replacement. These CDOT tests correspond closely to the ASTM C1260 and C1567 tests respectively.

2. LITERATURE REVIEW RELEVANT TO CDOT PRACTICES

2.1. ASR Research and Mitigation Implementation

ASR is a problem that has a well documented history, not just in the United States, but worldwide. Several countries and states in the U.S. have had problems with ASR. ASR is the reaction between alkali hydroxyl ions in portland cement and certain siliceous minerals found in the aggregate, such as opaline chert, and strained quartz. The product of this reaction is a gel that surrounds the aggregate in the concrete matrix. This gel can appear as a dark border around the aggregate or a white spot within the aggregate, sometimes the white area extending into the concrete matrix. With the introduction of moisture, the gel expands and causes the characteristic cracking of the concrete.

Because of the wide spread problem of ASR, and the expense of restoring concrete structures with ASR, many companies and state agencies have been researching admixtures to address this problem. The following sections provide discussion of efforts by both private and public sectors to address ASR mitigation measures:

2.1.1. New Zealand Alkali-Silica Reaction

New Zealand has had few problems with ASR despite the use of deleterious aggregate in concrete structures. BRANZ Limited has assisted in mitigating ASR problems by providing independent and unbiased research, testing, consultancy and information resource to the building and construction industry. BRANZ Limited provides this service to customers located in New Zealand, Australia and around the world(1). It has been recognized by BRANZ Limited that the most obvious way to eliminate ASR in concrete is to use a non reactive aggregate. However, this is not always possible, because certain geographical areas do not economically have access to non-reactive aggregates. BRANZ Limited has recognized this limitation and believes in the use of supplementary cementitious materials (SCMs) to mitigate ASR.

BRANZ Limited employs several mitigation techniques to allow a potentially reactive aggregate to be used. By understanding the chemistry behind the occurrence of ASR, the company has developed the following three mitigation techniques that consist of:

1. Lowering the pH of the concrete's pore solution to suppress the initial silica solubility;
2. Reducing the free alkali metal ion (sodium and potassium) concentrations present to restrict gel formation; and
3. Reducing the permeability of the concrete to restrict water ingress, hence preventing the gel from expanding.(1)

Generally, New Zealand has had an informal agreement with the local cement manufacturers to keep the equivalent alkali level in cement below 0.60%. By maintaining a maximum alkali limit of 0.16 pound per cubic foot (lb/ft), a normal concrete can last up to 50 years and experience only cosmetic effects. If the alkali levels cannot be limited, or the concrete is specified as high performance, SCMs can be used to control ASR. BRANZ Limited uses a minimum of 15% replacement of cement with metakaolin to mitigate ASR expansion.

SCMs reduce the permeability of the concrete by filling the voids and limit the reaction with available water to expand the ASR gel. Also, by replacing cement with a SCM, the total alkali content is reduced, lowering the number of free alkali ions in the concrete. It is also believed that by using a mineral admixture with pozzolanic properties, the pozzolans react with calcium to further lower the pH, reducing the potential for the formation of the ASR gel.

2.1.2. Cement and Concrete Association of New Zealand

The Cement and Concrete Association of New Zealand (CCANZ), recommends mineral admixtures to reduce ASR expansion, and reduce the cost of the concrete. Reactive aggregates can then be used satisfactorily with the addition of a SCM. With the addition of SCMs the strength of the concrete is generally increased as the permeability is decreased.

Metakaolin, a highly reactive pozzolan, has been found to resist ASR expansion when the SiO_2 content is above 45% by mass and used at a 15% replacement of cement. In addition, curing times are generally shorter with the use of metakaolin. However, because of the fast reacting nature of the pozzolan, temperatures may get much higher and additional preventive measures may need to be taken to maintain adequate temperature distribution, and reduce thermal cracking.

The specification for mineral admixtures in concrete, fly ash or pozzolan, is ASTM C 618-05. CCANZ also uses ASTM C 311-05 as the standard for acceptance and sampling of fly ash. These specifications are used explicitly for pozzolans that are used to mitigate ASR. The pozzolan shall be monitored to verify that the pozzolan meets these specifications. Test data must be provided for every purchase because the composition and uniformity of the pozzolan is directly related to the final performance of the concrete. CCANZ proposes that if a reactive aggregate is to be used for the first time with a given SCM, sufficient testing should be performed to understand how the concrete would react.

Signs of ASR have been found across New Zealand where the total alkali content was found to be less than 0.12 lb/ft^3. Because of this, CCANZ has determined there is no upper limit on alkalinity to mitigate ASR, it just becomes less frequent and more localized. This localization allows the strength of the concrete to overcome the expansion of the gel to minimize the apparent cracking. When visual cracking is undesirable, low alkali cement and an SCM should be used. Concrete that has had SCMs added has also shown to increase its resistance to chemical attack, and abrasion.

2.1.3. Department of Defense

The Department of Defense (DOD) uses pozzolans as the most common remedy to mitigate ASR when a reactive aggregate is used. Most commonly the cement content is replaced by 25 to 30% fly ash by weight. Currently there is little experience with the Class N pozzolan on military projects, however, the DOD does specify it as an acceptable material to mitigate ASR. The DOD has found that Class F fly ash is better than Class C fly ash in the mitigation of ASR. It has also been found that lower CaO levels in Class F fly ash better control ASR.

It is important to note that the DOD has had long term ASR problems in concrete slabs that were constructed using a non-reactive aggregate. These aggregates did pass acceptance tests as non-reactive. This is thought to be brought on by the manufacturing process of the Portland cement.

Recently, different cement manufacturing methods, wet versus dry, have had varying effects on the chemical content of the products.

Non-reactive aggregate is not always available or cost effective. If a reactive aggregate is to be used, several mitigation techniques must be employed. The United States Air Force does not use a “prescribed formula,” such as 25% Class F fly ash, for the mitigation of ASR. Testing must be done with actual construction materials, to demonstrate the mitigation of ASR.

2.2. Private Industry Metakaolin Research

A decrease in availability of Class F fly ash has made metakaolin much more cost effective as a replacement. Producers of metakaolin have found that to effectively market a product, testing the material and showing the benefits of the product has been effective in introducing a product to the market place.

2.2.1. Advanced Cement Technologies

Advanced Cement Technologies ACT) is a company out of Blaine Washington producing a high reactivity metakaolin (HRM) called PowerPozz. The main constituent in PowerPozz is kaolinite. Kaolinite is a siliceous clay mineral, which is calcined to obtain the pozzolanic properties. Calcination is a process that involves heating a material to drive off volatile matter while not oxidizing or pulverizing it. This material is white in color and is offered either in powdered or in compressed forms. ACT has done several tests on its product to determine the advantages metakaolin has over other mineral admixtures.

Because PowerPozz is an engineered material, the chemical composition is more consistent, the particles are uniform and round in shape. These properties enhance the workability and finishability of the concrete. PowerPozz, as a mineral admixture, has also shown to significantly reduce ASR expansion in mortar bars. The expansion test method used which is in accordance with Canadian test standards was performed at an independent testing firm. Canadian test, Canadian Standards Association (CSA) A23.2-25A (similar to ASTM C 1260-05) was performed with a known reactive aggregate, Portland cement, metakaolin, and Class F fly ash.

Expansion readings were taken at time zero and at two-day intervals after, up to 14 days. The control which is a Portland cement showed an expansion of 0.256% at 14 days. The 5% metakaolin replacement of Portland cement exhibited expansion of 0.200%. The 10% and 20% metakaolin replacement of Portland cement showed expansion levels of 0.040% and 0.010%, respectively. The 20% Class F fly ash replacement of Portland cement showed an expansion of 0.090%. All these expansion level measurements were taken at 14 days.

2.2.2. Engelhard

Engelhard is a multi-national company that produces MetaMax, a high reactivity metakaolin, which is advertised to increase the durability, strength, workability, and appearance of concrete. MetaMax is stocked throughout the U.S. and is available worldwide. As with any metakaolin, the same benefits have been realized. MetaMax has a denser concrete matrix and its metakaolin will react with the free CaO ions in the concrete to reduce efflorescence and mitigate ASR. A dense concrete matrix contributes to the durability of concrete in several ways. Firstly, a dense structure will increase the compressive strength of the concrete mortar, allowing use in high performance concrete. Secondly, a dense structure will not allow as much water intrusion. The benefits of reducing the water intrusion are two-fold. Not allowing as much water to enter the concrete will increase the freeze-thaw durability of the concrete and lessen the expansion of the ASR gel.

MetaMax meets the requirements of ASTM C 618-05 as a Class N pozzolan and the physical and chemical requirements of silica fume, although not produced in conformance with ASTM C 1240-04. Generally, MetaMax can be substituted directly for silica fume, and is approved under the American Concrete Institute (ACI) 318 (building code requirements for structural concrete) as an HRM. The slump of concrete is reduced with the addition of MetaMax, and will usually require the addition of a high range water reducer (HRWR) to maintain comparable workability.

Test data showed that with the addition of MetaMax to concrete with known reactive aggregates kept the expansion levels below 0.060% at two years (ASTM C1293, this has been recently changed to 0.040%) while the control, with no metakaolin addition, showed an expansion level of 0.200% to 0.260%. Compressive strength testing was performed using an addition of 8%

metakaolin, an 8% replacement of cement with metakaolin, and a control. The 8% addition of metakaolin to the concrete mix increased the compressive strength, on average, by 34% at all ages. The 8% replacement of cement by metakaolin resulted in an average compressive strength increase of 28% at all ages. Compressive strength measurements can be found below in Table 1.

Table 1. MetaMax compressive strength results.

Testing Age (days)	Control (psi)	8% addition of MetaMax (psi)	Replacement of cement by 8% MetaMax (psi)
7	8600	11600	10600
28	10000	13700	12500
56	11300	15200	13700
90	12200	16500	16400
180	13000	17300	17300
365	14100	18500	18700

Concrete's ability to resist chloride ion penetration testing (AASHTO T 277-89) was performed on the same additions and replacements of metakaolin in the concrete. The charge passed, in coulombs, by the control was 1800, while the 8% addition of metakaolin passed 900 coulombs, and the concrete with 8% cement replacement by metakaolin passed 1000 coulombs. According to the relevant AASHTO standard, the chloride ion permeability is very low when passing 100 to1000 coulombs, the permeability is low when passing 1000 to 2000 coulombs.

2.2.3. Thiele Kaolin Company

Thiele Kaolin Company in Sandersville Georgia manufactures a calcined kaolinite called KAOROCK which was supplied to the Civil Engineering Department of Georgia Institute of Technology to research the benefits of metakaolin over silica fume.

Georgia Institute of Technology performed compressive strength, splitting tensile strength, flexural strength (modulus of rupture), rapid chloride permeability (ASTM C 1202), sulfate resistance (ASTM C 1012), and ASR testing (ASTM C 1260). The compressive strength, splitting tensile strength, and flexural strength, and rapid chloride permeability tests were all performed using w/c ratios of 0.40, 0.50, and 0.60. KAOROCK (MK235) and KAOROCK F (MK349) were tested alongside silica fume (sf) and a control for all tests. The chemical makeup of each metakaolin sample can be found in Table 2 below. The main difference is in the surface area and the bulk density; MK349 is finer than MK235 and has more surface area.

Table 2. KAOROCK properties.

Characteristic	MK235	MK349
SiO_2 (%)	51.5	52.5
Al_2O_3 (%)	44.7	44.5
TiO_2 (%)	2.1	1.7
Fe_2O_3 (%)	0.4	0.9
Surface Area (m^2/g)	11.1	25.4
Bulk Density (lb/ft^3)	18	8.7
(kg/m^3)	288	139

The compressive strength test results show that at all water to cement ratios, the concrete with metakaolin exhibited higher strength than both the silica fume and control samples. The MK349 metakaolin had the highest compressive strength of either metakaolin at the w/c ratios of 0.40 and 0.50 At the w/c ratio of 0.60 the MK349 had higher strength up to the 28- and 90-day breaks. The MK349 28- and 90-day strengths were slightly lower than the MK235.

The rapid chloride permeability test showed much lower chloride ion penetration from the metakaolin samples than either of the silica fume or control samples. All samples exhibited higher chloride ion penetration at higher w/c ratios. This data has been summarized below in Table 3.

Table 3. KAOROCK ion penetrability.

Sample ID	Water to Cement (w/c) Ratio	Ion Penetrability (Coulombs)
Baseline	0.40	5000
Silica Fume	0.40	2000
MK235	0.40	500
MK349	0.40	500
Baseline	0.50	5200
Silica Fume	0.50	2800
MK235	0.50	1000
MK349	0.50	1500
Baseline	0.60	6100
Silica Fume	0.60	3900
MK235	0.60	2000
MK349	0.60	3000

ASTM C 1260 testing on the baseline and the ASTM C 1567 testing have been summarized below in Table 4. It is important to note here that according to ASTM C 1567, expansions of less than 0.10% are indicative of non-deleterious expansion. While only one of the combinations accomplished the expansion criteria, the data shows that the use of a natural pozzolan mitigates the effects of ASR to a better standard than does the baseline or silica fume tested.

Table 4. KAOROCK expansions.

Sample ID	Replacement Level of Cement	14-Day Expansion
Baseline	N/A	0.62%
Silica Fume	8%	0.53%
Silica Fume	15%	0.39%
MK235	8%	0.19%
MK235	15%	0.09%
MK349	8%	0.22%
MK349	15%	0.14%

2.2.4. *GCC of America*

GCC is a multi-national corporation with influence in the U.S. and Mexico producing cement and concrete. The popularity of pozzolans in the concrete sector has led to shortages of premium materials in the market. GCC recognizes the fly ash production process is not optimized and less than premium pozzolans are being produced.

Microsilex is a mined and processed, natural material with pozzolanic properties. The material is milled to exact standards to insure uniformity. The optimum particle size allows for better dispersion of particles which allows for increases in workability without the need for plasticizers. Finer materials are harder to disperse uniformly without adequate mixing power or plasticizers. GCC recommends the use of these admixtures to keep the w/c ratio down.

With 10% substitution of Microsilex in concrete, compressive strengths increased at all ages, except at 3 days. The peak curing temperature is reduced without being excessive. Expansions were conducted according to ASTM C 227 where Microsilex measured 0.01% at 180 days and the baseline Type I/II cement concrete mix had expansions of 0.10% at 180 days.

2.3. Technical Journal ASR Research

2.3.1. *American Concrete Institute*

The American Concrete Institute (ACI) issued a committee report, ACI 221.1R-98, State of the Art Report on Alkali Aggregate Reactivity where several influencing factors have been addressed as to the mitigation as well as avoidance of some of the contributing factors. These factors include limiting the amount of moisture intrusion into the concrete, avoiding use of reactive aggregate, minimizing alkali content in the concrete, and the use of finely divided materials other than Portland cement.

A concrete mix that has low permeability limits the amount of moisture intrusion, therefore reducing the ion mobility and slowing the reaction process. The use of finely divided materials, including pozzolans and other SCMs can reduce the permeability of the mix as well. In addition to the concrete having a lower permeability, the pozzolans react with calcium hydroxide and reduce its amount in the cement paste. Consequently, the ASR gels formed in concrete have lower swelling characteristics (2).

The ACI 221 report identifies natural pozzolans either as a naturally occurring amorphous siliceous material or a material that is processed to give the same general properties. Recently metakaolin has been proven effective in mitigating ASR, however the material properties are very different from one another and no recommendations can be made without testing (2).

2.3.2 Concrete International

Concrete International reported on ternary concrete in Canada. Ternary concrete is defined as having two SCMs in addition to Portland cement. These materials are generally silica fume with either fly ash or slag cement. The test results using the ternary concrete mixes have shown increases in compressive strength, and lower expansion (14). The substitution/addition of 4% silica fume and 25% slag resulted in an expansion of 0.006% compared to the baseline expansion of 0.238% using the ASTM C 1293 "Standard Test Method for Determination of Length Change Due to Alkali-Silica Reaction."

The long-term effects of these concrete mixes have been verified by field-testing in Ontario, Canada where slabs and beams were constructed with highly reactive aggregates and high alkali cements. After 10 years the slabs and beams that performed the best were constructed using 3.5% replacement of cement with silica fume and 25% replacement with slag cement (14).

These ternary concrete mixes have also shown good resistance to deicing salts when tested in accordance with ASTM C672, "Standard Test Method for Scaling Resistance of Concrete Surfaces Exposed to Deicing Chemicals". There have been reported incidents of scaling of sidewalks but further testing and investigation is underway to determine the actual cause of the scaling (14). A high replacement level of cement using slag has shown some problems with early strength development and scaling.

3. METAKAOLIN SPECIFICATIONS BY STATE DOTS

A survey of state Departments of Transportation (DOTs) was conducted to determine if either Class N pozzolan, or metakaolin, is specified, and how. Some DOTs found that Class N is either not readily available or too costly which has kept contractors from using the product. Because contractors had not approached the state DOT about using Class N, no standard had been formed to accommodate this type of fly ash. Below are state DOTs that allow Class N pozzolan. A summary of this information can be found in Appendix A.

3.1. Florida

Metakaolin shall meet the requirements of Class N pozzolan in ASTM C618-05. The ASTM C618 chemical requirements for the sum of silicon dioxide (SiO_2) plus aluminum oxide (Al_2O_3) plus iron oxide (Fe_2O_3) as a minimum of 70%; Florida modified this to a minimum of 85%. The amount of crystalline silica shall be less than 1% when measured by the National Institute of Safety and Health (NIOSH) method 7500 after the removal of mica interference. Florida Department of Transportation (FDOT) specifies the loss on ignition (LOI) shall be less than 3.0% rather than 10.0% as allowed in ASTM C 618. Other FDOT's changes to ASTM C 618 are as follows: Na_2O equivalent must be less than 1.0%, >99% passing the no. 325 sieve, and a minimum 85% strength activity index at 7 days. If metakaolin is to be used in concrete, it must be demonstrated that the produced concrete has comparable strength, sulfate resistance, corrosion protection properties, and other durability factors as compared to silica fume concrete. The strength and durability testing should follow the appropriate ASTM testing standards C 39, C 157, C 1012, C 1202, C 109 and Florida standards FM 5-516 and FM 5-522. An independent testing laboratory should perform all testing, and sampling should follow ASTM C 311.

For metakaolin to be used, monthly test reports and copies of their mill certificates should be provided to the DOT. Samples should be provided with a copy of the mill certificate monthly upon request. If using fly ash, replacement levels should be 18-50% by weight. If using Type IP or Type IS cement, fly ash should not be used as a mineral admixture.

3.2. Illinois

The Illinois Department of Transportation uses AASHTO M321-04 (High-Reactivity Pozzolans for Use in Hydraulic-Cement Concrete, Mortar, and Grout) for metakaolin after its introduction in 2004, replacing AASHTO M 295. Illinois has no modifications to the standard and can be used as an admixture in concrete mix design.

3.3. Montana

Metakaolin must meet the requirements of AASHTO M 295-07[2]. As an admixture, the use of metakaolin is limited to 20% replacement of the total cementitious material by weight. The source of metakaolin must be on the state's approved supplier list.

3.4. Nebraska

Nebraska Department of Transportation uses ASTM C 618, for a Class N natural pozzolan. The pozzolanic content in concrete is limited to 15-25% of the total cementitious material. If Type IP cement is used, the maximum pozzolanic content should not exceed 27%. No modifications to the standard have been implemented.

3.5. Nevada

Pozzolanic admixtures must conform to ASTM C 618, Class N pozzolan or otherwise. The only modification being the loss on ignition is limited to 5%. If pozzolans are to be used, the replacement level may not be more than 20% of the total cementitious material.

Type IP cement must have an alkali content of no more than 0.60% by weight. If the alkali content of Type IP cement is above the limit, it may still be used if ASTM C 277 testing is performed and the expansion of the mortar bars is less than 0.05% at 6 months using a selected reactive aggregate.

3.6. New York

Metakaolin in New York is treated as silica fume (microsilica). The metakaolin must meet the requirements in AASHTO T 307 including the optional chemical and physical requirements;

[2] AASHTO M295 has been revised for 2007 and currently references ASTM C618.

only the material origin and definition will not apply. In addition to the requirements, metakaolin used in production must have a silicon dioxide content with a range of +/- 7% from the acceptance value and the chloride content should not be more than 0.20% as determined by AASHTO T 260 Procedure B. For gradation, a maximum of 5% retained on the #325 sieve is required.

For metakaolin to be used, it must be shown to conform to the specifications herein by an independent testing laboratory. The product must be on the state's APL.

3.7. North Carolina

North Carolina's only provision for Class N pozzolan is adherence to ASTM C 618, except that the LOI is limited to 4%. However, the state DOT has never been approached about using a Class N pozzolan. However, the product PowerPozz by Advanced Cement Technologies is on the state's Qualified Product List.

3.8. Oregon

Fly ash must conform to AASHTO M 295, Class C, F, or N. Except that LOI is limited to1.5%, shall not have a moisture content greater than 1%, and the amount retained on the #325 sieve should not exceed 30%. For any fly ash to be placed on the Qualified Products List, a copy of the Product Evaluation Form, a copy of the Material Safety Data Sheet (MSDS), testing results of 3 different batches showing conformance to the specifications, and a copy of the specification sheet shall be provided.

3.9. Pennsylvania

For use with Portland cement concrete, fly ash must conform to AASHTO M 295, except that the LOI is limited to 6%. If a known or potentially reactive aggregate is used, the fly ash should conform to the optional chemical requirements in Table 1 of AASHTO M 295, have an alkali content of less than 1.5%, and show a 50% reduction in mortar expansion when tested in accordance to ASTM C 441. If the fly ash is used to reduce ASR, it should replace 15-25% of the total cementitious material by weight. If aggregate expansion is above 0.40%, use a replacement level of 20% fly ash of cementitious material by weight in which no more than 15%

replacement of portland cement should be by fly ash and the rest of the replacement fly ash should be for the fine aggregate.

3.10. Texas

Metakaolin is specified under ASTM C 618 as a Class N natural pozzolan. The admixture must conform to all the chemical and physical requirements and the specifications below provided in Table 5. The fly ash will be subject to sampling and testing throughout the project to determine its conformance with the standards.

Table 5. Metakaolin additional specifications.

Item	Limit (%)
$SiO_2 + Al_2O_3 + Fe2O_3$ minimum	85.0
Alkali maximum	1.0
LOI maximum	3.0
Maximum amount retained on 45-μm sieve	1.0
Strength Activity Index of control, 7 days	85
Increase of mortar bar shrinkage at 28 days, maximum	0.03
Density of last ten samples, average percent deviation should not exceed	5

3.11. Utah

Natural pozzolans must conform to ASTM C 618 Class N. ASTM C 1260 testing must also show job aggregate and job cement expansion is less than the Utah Department of Transportation approved Class F fly ash with the same job aggregate and cement.

3.12. Wisconsin

Metakaolin must conform to specifications of ASTM C 618 Class C fly ash, however the material definition of origin will not apply. The material must be from an approved supplier on the department's approved product list. The supplier must have an in place quality management program, where daily testing is performed to determine uniformity. This will include testing the specific gravity, percent retained on the No. 325 sieve, LOI, moisture content, and the activity index.

4. PRODUCT MATERIAL EXPANSION TESTS

All material tests were measured out to 14-days. The expansion measurements for the 28-day results can be found in Appendix C.

4.1. Baseline Aggregate Tests

The aggregate sources used for the testing were obtained from Grand Junction Pipe, a concrete supplier located in Grand Junction which is in CDOT's Engineering Region 3. These aggregates were chosen for their known high reactivity and because their use is approved for CDOT's class D mix designs. These aggregates have been processed as a 3/4" rock and a -3/8" gravel blended to respectively achieve a #67 gradation. The concrete sand is from a different Grand Junction pit also owned by Grand Junction Pipe where the sand is also known to be very reactive.

4.1.1. Coarse Aggregate Baseline

The coarse aggregates were proportioned 70% of 3/4" rock and 30% of -3/8" gravel by weight prior to crushing the gravel. Once this was accomplished, the aggregate was prepared for baseline testing in accordance with ASTM C 1260. Mortar bars of these materials were cast and placed in a solution of sodium hydroxide (NaOH), where expansions were measured periodically up to the final readings at 14 days and 28 days. The 14-day and 28-day expansions on the coarse aggregate were found to be 0.36% and 0.44% respectively (all expansion results can be found in Appendix C). The CDOT research scope of work dictated 14-day testing. The 28-day testing on all materials was privately funded by FMC-Euclid Chemical (lithium admixture).

4.1.2. Concrete Sand Baseline

The concrete sand was also prepared for baseline expansions in accordance with ASTM C 1260. The 14- and 28-day expansions were found to be 0.41% and 0.45% respectively (all expansion results can be found in Appendix C).

4.2. Class F Fly Ash Material Tests

Several Class F fly ash products were tested in accordance with ASTM C 1567 and evaluated based on their ability to resist expansion. The baseline Class F fly ash is produced by the Salt River Materials Group. Other Class F fly ash products include Headwaters Incorporated's Jim

Bridger and Coal Creek power plants and Boral Material Technologies, Inc. Monticello and Craig plants. The fly ash from Boral's Craig plant was modified with the company's so called "FACT" treatment to neutralize the impact of activated carbon used to adsorb mercury from the flue gas stream of coal-fired power plants.

4.2.1. Salt River Materials Group

Salt River Materials group provided the baseline Class F fly ash as chosen by CDOT, from the San Juan generating station for testing and evaluation. This material was tested at the following 3 different replacement levels: 10, 20, and 30% of cement corresponding to CDOT's minimum and maximum limits and a mid-point. The expansions after 14 days were 0.33%, 0.10% and 0.02% respectively. These expansions indicated a successful mitigation level of 21% cement replacement for our mix verifications.

4.2.2. Boral Material Technologies

Boral's Monticello Class F fly ash, as well as FACT-treated Craig Class F fly ash were also tested. These fly ashes were tested at 10, 20 and 30% replacement of cement. The Monticello fly ash exhibited expansions of 0.35%, 0.17% and 0.03% respectively after 14 days. The FACT-treated Craig fly ash showed similar results with slightly less expansion with 0.29%, 0.13% and 0.04% respectively. Based on this information, the mix designs will contain a 26% replacement of cement with the Monticello and 24% replacement with FACT-treated Craig Class F ashes.

4.2.3. Headwaters Incorporated

Headwaters Incorporated submitted two of its fly ash products for testing, Coal Creek and Jim Bridger plants. These fly ashes were also tested at 10, 20 and 30% replacement of cement. During the expansion testing, these bars seemed to exhibit lower strength. Some of the bars had to be re-fabricated because they would break during the un-molding process. The Coal Creek generating station fly ash had expansions of 0.29%, 0.08% and 0.07% at the cement replacement levels of 10%, 20% and 30%, respectively. The Jim Bridger generating station's fly ash had expansions of 0.41%, 0.39% and 0.08% at the same replacement levels as the Coal Creek fly ash. These 14-day expansion results gave a cement replacement level of 19% for the Coal Creek Class F, and 28% for the Jim Bridger Class F in the mix designs.

4.3. Metakaolin Products

There were various other products that were evaluated for their resistance to ASR expansion by ASTM C 1567. The baseline metakaolin chosen by the Colorado Department of Transportation was from the Burgess Pigment Company. GCC of America, Holcim, Thiele Kaolin, and Western Pozzolan also submitted materials to be evaluated. Of the group, Western Pozzolan's product is a natural pozzolan with minor processing. FMC Euclid Chemical and TXI also submitted materials, but because of these required modifications to the test procedures, they are discussed in the appendix.

4.3.1. Burgess Pigment Company

The Burgess Pigment Company provided its metakaolin product called Optipozz as the CDOT chosen baseline metakaolin. This material is white in color and is somewhat less dense than traditional Class F fly ash or cement with its specific gravity of 2.20. This material was tested at cement replacement levels of 5, 10, and 15%. The Optipozz had expansions of 0.23%, 0.06% and 0.03% respectively after 14 days. This data then gave a successful mitigation level of 9% to utilize in the concrete mix verifications.

4.3.2. GCC of America

GCC submitted their product called Microsilex. This material is off-white to slightly brown in color, and claimed to be a material based on natural silica with pozzolanic properties which can improve the performance and durability of concrete. This material is normally recommended to be used in replacement levels of 5% to 15%. GCC requested testing this material at 15%, 20% and 25% replacement levels due to the highly reactive aggregate. With these replacement levels, expansions experienced at 14 days are found to be 0.28%, 0.19% and 0.12% respectively. Because the highest replacement level did not reduce the expansion to the required 0.10%, the expansion graph was extrapolated to give a cement replacement level of 28% to be utilized in the mix designs.

GCC also requested the Microsilex be combined with Boral's Monticello fly ash as a ternary concrete blend. This test was performed with 10% Microsilex and 10% Boral fly ash, as well as 13% Microsilex and 7% Boral fly ash. These blends mitigated the expansions down to 0.05%

and 0.03% respectively at 14 days. The 10% Microsilex and 10% fly ash blend was utilized for the mix design in the following phase of testing.

4.3.3. Holcim

Holcim submitted a product from White Mud Resources. This metakaolin was tested with the replacement levels of 10, 15 and 20% of cement content. These levels chosen by Holcim were somewhat conservative in order to ensure the expansions below 0.10% were achieved. The expansions at these replacement levels were 0.09%, 0.01% and 0.00% respectively at 14 days. Because the expansions of the bars were at 0.09% at 10% replacement of cement, that value of cement replacement was used in the mix design.

4.3.4. Thiele Kaolin

Thiele Kaolin submitted their Kaorock product. This material is a white in color and is significantly less dense than cement, with a specific gravity of 2.30. This material was tested at 10%, 15% and 20% levels of cement replacement. These replacement levels were far in excess of what was actually needed to get the expansion down below 0.10% at 14 days. The expansions were 0.02%, 0.02% and 0.01% respectively, indicating that at even 10% replacement, the expansion was significantly reduced. A replacement level of 10% was used in the mix designs, with possibly 5% being more realistic for future mixes.

4.3.5. Western Pozzolan

Western Pozzolan submitted a product called Lassenite SR. This is a true natural pozzolan that is somewhat gray and white in color. Lassenite SR is claimed to react with the free lime released during cement hydration forming another compound that is cementious and will reduce the permeability of the concrete. This product was tested at 5%, 10% and 15% replacement levels of cement. The expansions at 14 days were 0.35%, 0.24% and 0.11% respectively. To achieve the desired amount of expansion below 0.10% at 14 days for the mix designs, the graph of percent replacement level versus expansion was extrapolated to determine the required replacement level which was 16% for the concrete mix designs.

4.4. Additional Products

The products in this category do not fit into either one of the previous categories of fly ash products or Class N products. This is due to the suppliers' requests to modify the ASTM C 1567 test to accommodate the evaluation of their materials. TXI Inc. submitted a lightweight fine aggregate, Holcim submitted a product called GranCem and FMC-Euclid Chemical submitted lithium nitrate admixture. The data information on the TXI lightweight sand and FMC-Euclid Chemical's lithium nitrate can be found in Appendices D and B respectively.

4.4.1. Holcim

Holcim's GranCem material is a granulated blast slag cement that is ground into a fine powder, to be mixed with water and Portland cement. Because of this, the GranCem material is claimed to provide ASR and sulfate resistance, low permeability and lower heat of hydration. GranCem was tested at 35%, 40% and 50% replacement of cement and had expansions at 14 days of 0.26%, 0.17% and 0.04% respectively. These bars turned into a very dark green color as the bars were soaked in the sodium hydroxide solution. However, no color changes were observed in the concrete mix. The expansion results dictated a cement replacement level of 46% in the mix design.

5. CONCRETE PHYSICAL PROPERTIES

All of the materials tested for ASR expansion mortar bar tests were tested as modifications to the approved Class D mix design. The three expansion tests indicated a replacement level of cement that would yield an expansion of less than 0.10% at 14 days. This replacement level was used to modify Grand Junction Ready Mix's CDOT Class D mix with the following specifications: 0.44 max w/c ratio, 5-8% air content, 615 to 660 pounds of cementitious, and 4,500 psi field compressive strength at 28 days. All of the concrete batch information stayed the same, while varying the pozzolans in the mixes. Because of the varying properties of the pozzolans, the batch water per cubic yard could not be held constant.

Instead, the water was adjusted for all the mixes. Almost all the mixes showed no air entrainment when tested. The amount of air entraining admixture recommended by Grand Junction Ready Mix design was even doubled in an effort to get the air content up, but this was still not effective. Later, when confirming the approved mix design, the air entrainment listed was 1.0 ounce (oz.) per cubic yard, when the actual amount needed was 5.3 oz. per cubic yard. Because slump was not achieved from air, there are varying swings of w/c ratios. Each mix had air, slump and cylinders cast. The cylinders were tested for compressive strength at 7, 28, and 56 days while some cylinders were also used for rapid chloride permeability tests (permeability measured at 56 days will typically be lower than specimens tested at 28 days), the raw data results from this test had to be modified in accordance with the standard, because of the use of a non-standard diameter test specimen. All testing was performed in general accordance with the applicable ASTM standards. All mix design sheets can be found in Appendix E. The individual mixes are discussed below with the data summarized in Table F.

5.1. Baseline CDOT Mix Design

The San Juan generating station Class F had a slump of 6 inches, air content of 2.0%, and a unit weight of 145.2 pcf. This slump was achieved with a w/c ratio of 0.47. However, with the consideration of less batch water, the mix would still be very workable and the maximum w/c ratio of 0.44 could be easily maintained. The compressive strength values were 3,200 psi, 5,080 psi, and 6,570 psi at 7, 28, and 56 days, respectively. The rapid chloride permeabilities of the specimens were 4,816 and 4,903 coulombs with an average of 4,860 coulombs.

5.2. Fly Ash Mixes

Each of the conventional Class F fly ash mixes performed well within expectations with good workability and a less overall affinity for additional moisture in the batch.

5.2.1. Boral Material Technologies

The Monticello fly ash was very workable, with a slump of 5.25 inches, air content of 2.1%, and a unit weight of 146.2 pcf. This slump was achieved at a w/c ratio of 0.44 with an additional 18 pounds of water per cubic yard. The compressive strength values were 3,680 psi at 7 days, 5,710 psi at 28 days and 7,510 psi at 56 days. The rapid chloride permeability specimens averaged 3,352 coulombs at 28 days.

The Craig FACT fly ash had the same workability of the Monticello fly ash, with a slump of 5 inches, air content of 2.7%, and a unit weight of 145.4 pcf. This batch also had an additional 18 pounds of water added per cubic yard to bring the w/c ratio up to 0.44. The compressive strength of this mix design was 4,090 psi at 7 days, 6,030 psi at 28 days and 7,490 psi at 56 days. The rapid chloride permeability averaged 3,026 coulombs upon testing at 28 days.

5.2.2. Headwaters Incorporated

The Coal Creek fly ash had a slump of 3.75 inches, with a w/c ratio of 0.43, air content of 2.9%, and a unit weight of 146.1 pcf. The slump had been achieved by increasing the amount of batch water by 9 lbs/cy. The compressive strength results were 4,210 psi, 6,230 psi and 7,310 psi at 7, 28 and 56 days respectively, with an average reading of 2,704 coulombs for the rapid chloride permeability testing at 28 days.

The Jim Bridger fly ash exhibited many of the same characteristics of the Coal Creek ash. The mix had a slump of 5.25 inches with a w/c ratio of 0.44 (again with addition of 18 lbs/cy of water), air content of 3.3%, and a unit weight of 138.2 pcf. The compressive strength of the mix at 7 days was 3,460 psi, with strengths of 5,960 psi and 7,020 psi realized at 28 and 56 days. The average rapid chloride permeability level was 3,801 coulombs at 28 days.

5.3. Metakaolin Products

All of the following products exhibited a much higher water demand than did the fly ash mixes. With the same amount of batch water for the fly ash mixes, these batches did not have the same plastic concrete properties. The aggregate would roll around in the mixer with the cement and pozzolan sticking to the pieces, and would not "flow" until the w/c ratio was brought up to around 0.47 or higher.

5.3.1. Burgess Pigment Company

Additional water required to achieve a w/c ratio of 0.47 yielded a slump of one inch. The mix was very stiff, sticky and hard to finish. The air content was 1.9% and the unit weight was 145.8 pcf. The compressive strength was 5,860 psi at 7 days, 6,720 psi at 28 days, and 7,020 psi at 56 days, exceeding the baseline numbers for all the same respective strength data. The rapid chloride permeability of the specimens averaged 853 coulombs, this value being significantly lower than the baseline, indicating a lower permeability.

5.3.2. GCC of America

The Microsilex had good workability with the 2.25 inch slump and a w/c ratio of 0.54. This slump and water to cement ratio was achieved with the addition of 81 pounds of water per cubic yard over the anticipated batch water. The air content was 2.1% and the unit weight was 143.7 pcf. The compressive strength of the mix was 3,550 psi at 7 days, 5,270 psi at 28 days, and 6,740 psi at 56 days. The average 28-day rapid chloride permeability level was 1,809 coulombs which was significantly lower than the baseline mix permeability.

The second mix for the Microsilex had the addition of Boral's Monticello Class F fly ash, for a ternary concrete mix. This mix had the cement replaced by 10% of both the Microsilex and the Class F fly ash. This mix had a slump of 3.5 inches with a w/c ratio of 0.44, air content of 2.3% and a unit weight of 146.3 pcf. This mix only had a slightly higher affinity for moisture by the addition of the Microsilex, with the fly ash keeping the mix very workable. The compressive strength of the mix was 3,457 psi, 5,880 psi and 7,070 psi for 7, 28, and 56 days respectively. The average rapid chloride permeability of the 28-day specimens was 2,359 coulombs.

5.3.3. Holcim

The White Mud Resources product was very workable with a slump of 4.5 inches and a w/c ratio of 0.50, air content of 2.8% and a unit weight of 144.5 pcf. The compressive strength of the mix was 4,300 psi at 7 days with 6,300 psi and 6,740 psi at 28 and 56 days respectively. The average rapid chloride permeability reading for the 28-day specimen was significantly lower than baseline level of 1,064 coulombs.

5.3.4. Thiele Kaolin

The Kaorock product had good workability with somewhat less additional water compared to other metakaolins. The mix needed an additional 36 pounds of water per cubic yard, bringing the w/c ratio up to 0.47, achieving a slump of 2 inches. The air content was 1.9% with a unit weight of 145.4 pcf. The compressive strength of this mix also exceeded the same respective strengths for the baseline with a 7 day strength of 5,340 psi, 6,980 psi at 28 days and 7,600 psi at 56 days. The rapid chloride permeability readings were the lowest of the group with an average of 546 coulombs for the 28-day specimens.

5.3.5. Western Pozzolan

The Lassenite SR product exhibited a high water demand, requiring an additional 54 lbs/cy to the batch water to achieve a slump of only one inch, bringing the w/c ratio up to 0.50. The air content was 2.5% and the unit weight was 146.2 pcf. The compressive strength of the mix was 3,980 psi at 7 days, 5,480 psi at 28 days and 5,760 psi at 56 days, with the 56-day results being much less than the baseline mix. The average rapid chloride permeability of the two 28-day specimens was 1,972 coulombs.

5.4. Additional Products

The products from TXI Inc. a lightweight fine aggregate, Holcim’s product called GranCem and FMC-Euclid Chemical submitted lithium nitrate, fit into this category since they are neither a fly ash nor a metakaolin. The data information on the TXI lightweight sand and FMC-Euclid Chemical’s lithium nitrate can be found in appendices D and B respectively.

5.4.1. Holcim

The GranCem product from Holcim is a granulated blast furnace slag cement. This material performed much like the baseline mix. While the cement replacement level is higher than that of the metakaolins and the fly ash, the strength will not be overly compromised because the replacement is still a cement that will keep strengths up and lower the permeability. The slump achieved was 4 inches with a w/c ratio of 0.46, with an air content of 2.2% and a unit weight of 146.3 pcf. The compressive strengths were 3,670 psi at 7 days, 5,860 psi at 28 days and 6,610 psi at 56 days. The rapid chloride permeability readings averaged 1,040 coulombs at 28 days.

Table 6. Mix design summary.

Product	Replacement Rate (%)	Slump (in)	Air Content (%)	w/c ratio	7-day Strength (psi)	28-day Strength (psi)	56-day Strength (psi)	Coulombs (average)
Burgess Optipozz	9	1.0	1.9	0.47	5,860	6,720	7,020	853
SRM San Juan	21	6.0	2.0	0.47	3,200	5,080	6,570	4,860
Boral Monticello	26	5.25	2.1	0.44	3,680	5,710	7,510	3,352
Boral Craig-FACT	24	5.0	2.7	0.44	4,090	6,030	7,490	3,026
White Mud Resources	10	4.5	2.8	0.50	4,300	6,300	6,740	1,064
Western Pozzolan Lassenite SR	16	1.0	2.5	0.50	3,980	5,480	5,760	1,972
GCC Microsilex	28	2.25	2.1	0.54	3,550	5,270	6,740	1,809
GCC Microsilex/ Boral	10/10	3.5	2.3	0.44	3,457	5,880	7,070	2,359

Monticello								
Thiele Kaorock	10	2.0	1.9	0.47	5,340	6,980	7,600	546
TXI Lightweight sand	89	2.0	4.5	0.53	3,380	5,580	6,570	3,136
Holcim GranCem	46	4.0	2.2	0.46	3,670	5,860	6,610	1,040
Headwaters Jim Bridger	28	5.25	3.3	0.44	3,460	5,960	7,020	3,801
Headwaters Coal Creek	22	3.75	2.9	0.43	4210	6,230	7,310	2,704
FMC-Euclid Lithium Nitrate	50	5.0	4.3	0.52	2,670	4,420	5,380	4,077

6. CONCLUSIONS AND RECOMMENDATIONS

The conclusions and recommendations presented in this report are based on the research, observations, and data collected from laboratory testing.

6.1. Conclusions

Class N SCMs, as well as other materials, are effective in the mitigation of ASR. These finely divided materials can limit the intrusion of moisture into the concrete matrix reducing the water available for the gel to expand. These materials also reduce the permeability of the concrete thus reducing the chloride-ion penetrability. The average rapid chloride permeability of the three metakaolins was 821 coulombs; the average rapid chloride permeability of all materials classified as Class N was 1,249 coulombs, compared to a permeability of 3,549 coulombs for all the fly ash mixes. With the exception of one mitigation material, and an isolated 28-day strength test on one other metakaolin, the strengths of all the materials produced have improved based upon the baseline compressive strength figures.

6.2. Recommendations

We recommend that CDOT alter the current specifications, allowing for the use of alternative materials for the mitigation of ASR in concrete. This should include allowing Class N, metakaolin, and other supplementary materials found to be effective alternatives to using Class F fly ash. These materials will require additional mix evaluations performed to demonstrate their ability to mitigate ASR and to allow the development of proper proportions, and plastic concrete characteristics.

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APPENDIX A: STATE METAKAOLIN SPECIFICATIONS

State	Fly Ash (Class N/metakaolin)	ASTM/ AASHTO Std.	Modifications	Date std. was implemented	Contact Information	Comments
Florida	Metakaolin	C 618	See note 1 below	Jan. 2006	Mike Bergen (352) 955-6666	Replacement of cement should be 18-50% by weight
Illinois	Metakaolin (HRM)	M 321	None	Jan. 1, 2002	Doug Dirks (217) 782-7208	Should be supplied in dry, undensified form
Montana	Metakaolin	M 295	See note 2 below	Jan. 2006	Matt Strizich (406) 444-6297	Replace up to 20% of cementitious material by weight
Nebraska	Class N natural pozzolan	C 618	None	Jan. 2007	Mostafa Jamshidi (402) 479-4750	If Class N natural pozzolan is used in the Type IP cement, fly ash substitution is allowed to a maximum pozzolan content of 25%
Nevada	Class N	C 618	LOI < 5%	2005 spec book	Dean Weitzel (775) 888-7000	Constitute 20% or less of cement content by weight
New York	Treated as Silica Fume	M 307	Including optional chemical and physical requirements	May 4 2006	State Mat. Bureau (505) 827-5589	New York DOT treats metakaolin as silica fume and the applicable specifications, except material definition
North Carolina	Class N	C 618	LOI < 4%	Feb. 15, 2006	Owen Cordal (919) 329-4120	PowerPozz made by Advanced Cement Technologies is on QPL
Oregon	Class N	M 295	See note 3 below	June 13 2001	Mike Dunning (888) 275-6368	No products on QPL
Pennsylvania	Class N	M 295	Maximum alkali content of 1.5% and produces a 50% reduction in mortar expansion when tested in accordance to ASTM C 441	Aug. 6 2002	Material Testing (717) 787-1950	If fly ash is added to reduce alkali-silica reactivity, use a quantity of fly ash between 15% and 25%, by mass, of the total cementitious material. Minimum 15% of cementitious material
Texas	Class N	C 618	See note 4 below	Aug. 2004	Jennifer Moore (512) 506-5850	
Utah	Class N natural pozzolan	C 618	None	Jan. 31 2005	Degen Lewis (801) 965-3814	May use instead of fly ash provided that the 14-day expansion test (ASTM C 1260) with job aggregates and job cement does not exceed that for the same aggregates and cement with a UDOT approved Class F fly ash
Wisconsin	Pozzolan	C 618	Conform to Class C specifications	Dec. 2006	Materials Testing (608) 246-7930	Pozzolan content cannot be mixed with cement, used in whole. Meeting Class C specifications, except LOI < 2%. Material definition will not apply

note 1 The sum of $SiO_2 + Al_2O_3 + Fe_2O_3$ shall be at least 85%. The Material Safety Data Sheet shall indicate that the amount of crystalline silica, as measured by National Institute of Occupation Safety and Health (NIOSH) 7500 method, after removal of the mica interference, is less than 1.0%.

The loss on ignition shall be less than 3.0%.

The available alkalies, as equivalent Na_2O, shall not exceed 1.0%.

The amount of material retained on a No. 325 mesh sieve shall not exceed 1.0%

The strength activity Index, at 7 days, shall be at least 85%.

When metakaolin is used in concrete, the test results shall verify improved or comparable strength, sulfate resistance, corrosion protective properties and other durability performance properties of concrete, as compared to the performance of silica fume concrete. The comparison strength and durability tests shall be performed in accordance with ASTM C 39, ASTM C 157, ASTM C 1012, ASTM C 1202, ASTM G 109, FM 5-516 and FM 5-522, by an approved independent testing laboratory. Sampling and testing of metakaolin shall follow the requirements of ASTM C 311.

note 2 Metakaolin must meet the chemical requirements of Table 1, and the physical requirements of Table 3 in AASHTO M 295.

note 3 Loss on Ignition (LOI) shall be 1.5% maximum.

Moisture content shall be 1% maximum.

Amount retained on the 45 μm sieve shall be 30% maximum.

note 4 Silicon dioxide (SiO_2) plus aluminum oxide (Al_2O_3) plus iron oxide (Fe_2O_3), minimum, 85%

Available alkalies, maximum, 1.0%

Loss on Ignition, maximum, 3.0%

Fineness: amount retained when wet-sieved on 45-µm sieve, maximum, 1.0%

Strength activity index, at 7 days, 85% of control

Increase of drying shrinkage of mortar bars at 28 days, maximum, 0.03%

Density variation in percentage points of density from the average of the last 10 samples (or less provided 10 have not been tested) must not exceed ± 5.

APPENDIX B: FMC-EUCLID CHEMICAL ADDITIONAL TESTING RESULTS

While soliciting other vendors to participate in this study, FMC-Euclid Chemical submitted their lithium product to be included in this study. The original scope of this study was to have the mortar bar expansion readings taken up to 14 days without any modifications to the test procedure, FMC-Euclid Chemical requested modifications to the test procedure to properly test its product. FMC – Euclid also requested all the tests be measured at 28 days. This provided a comparison to the Federal Aviation Administration (FAA) data requiring 28-day expansion readings. FMC-Euclid Chemical paid to have all the test results taken up to 28 days. This was done to provide a uniform knowledge base for all the products in the study.

The lithium admixture was used in dosage rates of 50%, 100% and 150%. These rates correspond to the total amount of alkali equivalent within the cement. These bars seemed to exhibit a lower strength, noted by some broken bars when removed from the molds. The bars were then placed in a sodium hydroxide soak solution modified with lithium nitrate with 40 grams (g) of lithium nitrate per liter of the required strength of sodium hydroxide (NaOH) solution. The soak solution has to be modified when testing is performed on specimens containing lithium because the lithium in the specimens will tend to migrate towards the lower concentration in the soak solution and leach out of the bars. A gel came out of the bars within a few days of being in the soak solution; this made the bars somewhat slick on the outside. The specimens at 50% dosage showed 0.09% expansion at 14 days, the 100% dosage rate had an expansion of 0.01%, and the 150% dosage had 0.00% expansion at 14 days. These expansions stayed low even through 28 days, with expansions of 0.17%, 0.02%, and 0.00% for the dosage rates of 50%, 100% and 150% respectively.

The mix design for the lithium was performed at the 50% dosage rate because of the 0.09% expansion at 14 days. This mix was very workable and had a higher slump. While finishing, it was noted that there was more bleed water on these specimens than any other. The slump was 5.0 inches with an air content of 4.3% and a unit weight of 142.4 pcf. The compressive strengths for the mix were low with values of 2,670 psi, 4,420 psi, 5,380 psi for 7, 28 and 56 days respectively. The average rapid chloride permeability reading of the two 28-day specimens was 4,077 coulombs.

APPENDIX C: MORTAR BAR EXPANSION TEST RESULTS

Vendor/Product	Replacement Level	14 days, %	28 days, %	0.10% Expansion Replacement Level
Baseline F.A.		0.41	0.45	
Baseline C.A.		0.36	0.44	
Baseline metakaolin – Burgess Optipozz	5%	0.23	0.32	
	10%	0.06	0.07	9%
	15%	0.03	0.04	
Baseline Class F – SRM San Juan	10%	0.33	0.42	
	20%	0.10	0.20	21%
	30%	0.02	0.06	
Boral Monticello Class F	10%	0.35	0.44	
	20%	0.17	0.27	26%
	30%	0.03	0.11	
Boral Craig FACT Class F	10%	0.29	0.37	
	20%	0.13	0.21	24%
	30%	0.04	0.09	
Holcim White Mud	10%	0.09	0.16	
	15%	0.01	0.03	10%
	20%	0.00	0.01	
Western Pozzolan Lassenite SR	5%	0.35	0.43	
	10%	0.24	0.29	16%
	15%	0.11	0.14	
GCC of America Microsilex	15%	0.28	0.42	
	20%	0.19	0.39	28
	25%	0.12	0.34	
GCC/Boral (Microsilex / fly ash)	10%/10%	0.05	0.13	10%/10%
	13%/7%	0.03	0.11	
Thiele Kaolin Kaorock	10%	0.01	0.04	
	15%	0.02	0.04	10%
	20%	0.02	0.04	
TXI Lightweight Sand (Replacement of WCS)	50%	0.28	0.40	
	75%	0.16	0.24	89%
	100%	0.05	0.09	
Holcim GranCem	35%	0.26	0.35	
	40%	0.17	0.26	46%
	50%	0.04	0.12	

Headwaters Jim Bridger Class F	10%	0.41	0.48	
	20%	0.39	0.47	28%
	30%	0.08	0.21	
Headwaters Coal Creek Class F	10%	0.29	0.36	
	20%	0.08	0.30	22%
	30%	0.07	0.13	
FMC – Euclid Lithium Nitrate	50%	0.09	0.17	
	100%	0.01	0.02	50%
	150%	0.00	0.00	

APPENDIX D: TXI LIGHTWEIGHT SAND ADDITIONAL TESTING RESULTS

The TXI Corporation submitted their lightweight sand for testing against the other more conventional admixtures. The lightweight sand would replace some of the reactive concrete sand, rather than replacing some percentage of the cement content.

This material has very different properties than does normal weight concrete sand. Because of this the ASTM C 1567 test had to be modified so that this material could be tested. The test method has a specific gradation of the aggregate that has to be put in the mix. However, the lightweight sand has a much different specific gravity than the concrete sand, and the absorption is much higher, both differences requiring test modifications.

The concrete sand was tested in the Federal Aviation Administration (FAA) apparatus to determine bulk density. The lightweight sand was also tested in the FAA apparatus to determine its bulk density. These two densities were then compared to determine the correct weight of lightweight sand that would yield the same volume of 990 grams (g) of concrete sand. This modification allowed consistent volumes of paste and sand.

To the right in Figure 1 you can see the volume of concrete sand with the normal 990 g C 1260 gradation on the left. In the center of the picture, 990 g of the TXI lightweight sand yields a much larger volume. From this photo it is essential to make the volumetric correction on the lightweight sand so the cement paste to sand volumetric ratio remains the same. On the far right is the volumetrically corrected weight (~675 g) for the lightweight sand.

The TXI lightweight sand also has a higher absorption than does the concrete sand. To accommodate this, the TXI mortar bars are batched at saturated-surface-dry (SSD) condition. This retains the test method w/c ratio of 0.47.

Figure 1. Volumetric Comparison

This material replaces some of the concrete sand, which is also reactive in the mortar bar test. By removing some of the reactive aggregate the expansions will invariably decrease due to that fact alone. Additionally, the porosity of the lightweight sand provides a volume for any gel created by the coarse aggregate to “grow into”, thus further reducing expansion. This material was tested in replacement values of 50, 75 and 100% of the concrete sand volume. The expansions at 14 days were 0.28%, 0.16% and 0.05% respectively. Expansion results for 28 days were 0.40%, 0.24% and 0.09% respectively. This data shows that lightweight fine aggregates made from expanded shales reduce some of the expansion caused by the ASR.

The concrete mix used an 89% replacement of concrete sand, based on graphical analysis to achieve 0.10% expansion. This replacement level, and the appropriate batch water corrections, yielded a very workable mix. A w/c ratio of 0.53 yielded a slump of 2.0 inches, with an air content of 4.5% and a unit weight of 134.1 pcf. The unit weight was lower than a traditional mix, because of the substitution of the lightweight fine aggregate. The compressive strengths were 3,380 psi at 7 days, 5,580 psi at 28 days, and 6,570 psi at 56 days. The average rapid chloride permeability reading of the two 28-day specimens was 3,136 coulombs, somewhat lower than the baseline.

Using the full amount of cement still yielded a mix that was almost equal in strength at all ages to the baseline mix. To this effect, the lightweight fine aggregate seems to retard the overall strength development, much the same way a fly ash does.

APPENDIX E: MIX DESIGN INFORMATION

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CONCRETE MIX DESIGN VERIFICATION

Project Number:	D06.348	Report Date:	
Project Name:	Mitigation Materials for ASR in Concrete	Technician:	mw/zb
Lab ID Number:	75191.M	Reviewer:	
Date Batched	12/10/2007		
Description:			
Client:			
Concrete Mix Design by:	Grand Junction Ready Mix	Date Performed:	10-Dec-07
Client Mix Design ID:	CDOT class D	Lab Batch Size, CF	1.5

Design						Verification
Material	Source and Type	Specific Gravity	Batch Weights (yd^3)		Cubic Feet	Calculated Batch Weights (lbs)
Cement (ASTM C 150)	Holcim Type I/II GU	3.15	521	lb	2.65	28.94
Fly Ash (ASTM C 618)	Salt River Materials Group, San Juan Generating Station, Class F	1.99	139	lb	1.12	7.72
*Coarse Aggregate (ASTM C 33)	Grand Junction Pipe Soaring Eagle Pit #67	2.64	1219	lb	7.40	67.72
*Coarse Aggregate (ASTM C 33)	Grand Junction Pipe Soaring Eagle Pit #8	2.61	528	lb	3.24	29.33
*Fine Aggregate (ASTM C 33)	Grand Junction Pipe 23rd Road Pit	2.65	1165	lb	7.05	64.72
Water	Municipal	1.00	275	lb	4.41	15.28
Air Entraining Agent (ASTM C 260)	BASF Micro Air	n/a	1.0	oz	0.00	0.06

Water Reducer-Normal (ASTM (C494)	BASF 3030NS	n/a	5.0	oz	0.00	0.28
Target Air Content, %	6.0	--	--		1.62	
*Aggregate mass determined in SSD condition		Total:	3847	lb	27.48	214

Coarse Aggregate Absorption, %	1.3	Theo. Unit Wt., pcf:	140.0	Coarse MC% :	**1.8**
Fine Aggregate Absorption,%	1.5	W/C Ratio:	0.42	Fine MC% :	**14.4**

Physical Properties (Test Results)		**JAC/CTS COMPRESSIVE STRENGTH DATA**				**Laboratory Batch Weights**		**Actual Mass, lb**
	JAC/CTS	Date	Age, days	Compressive Strength	Average, psi	Cement		28.94
Slump, in.	6	12/17/07	7	3250		Fly Ash		7.72
Air Content, %	2	12/17/07	7	3110	**3203**	Coarse Aggregate		97.55
Temperature, F	66	12/17/07	7	3250		Fine Aggregate		72.95
Unit Weight, pcf	145.2	01/07/08	28	5310		Batch Mix Water		6.55
Yield, CF/CY	23.11	01/07/08	28	5060	**5077**	Air Entraining , ml	3	1.6
W/C Ratio	0.471	01/07/08	28	4860		Water Reducer, ml	10	8.2
		02/04/08	56	6030		Water Adjustments for slump		2.00
		02/04/08	56	7070	**6570**	Net Mix Water for Trial Batch		17.28
		02/04/08	56	6610		Net Mix Water / Cubic Yard		311

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CONCRETE MIX DESIGN VERIFICATION

Project Number:	D06.348	Report Date:	
Project Name:	Mitigation Materials for ASR in Concrete	Technician:	
Lab ID Number:	75192.M	Reviewer:	
Date Batched			
Description:			
Client:			
Concrete Mix Design by:	Grand Junction Ready Mix	Date Performed:	
Client Mix Design ID:	CDOT class D	Lab Batch Size, CF	1.5

Design						Verification
Material	Source and Type	Specific Gravity	Batch Weights (yd^3)		Cubic Feet	Calculated Batch Weights (lbs)
Cement (ASTM C 150)	Holcim Type I/II GU	3.15	601	lb	3.06	33.39
Fly Ash (ASTM C 618)	Burgess Optipozz, Metakaolin	2.20	59	lb	0.43	3.28
*Coarse Aggregate (ASTM C 33)	Grand Junction Pipe Soaring Eagle Pit #67	2.64	1219	lb	7.40	67.72
*Coarse Aggregate (ASTM C 33)	Grand Junction Pipe Soaring Eagle Pit #8	2.61	528	lb	3.24	29.33
*Fine Aggregate (ASTM C 33)	Grand Junction Pipe 23rd Road Pit	2.65	1165	lb	7.05	64.72
Water	Municipal	1.00	275	lb	4.41	15.28
Air Entraining Agent (ASTM C 260)	BASF Micro Air	n/a	1.0	oz	0.00	0.06
Water Reducer-Normal (ASTM (C494)	BASF 3030NS	n/a	5.0	oz	0.00	0.28

Target Air Content, %	6.0	--	--	1.62	
*Aggregate mass determined in SSD condition		Total:	3847 lb	27.20	214

Coarse Aggregate Absorption, %	1.3	Theo. Unit Wt., pcf:	141.4	Coarse MC% :	**1.8**
Fine Aggregate Absorption,%	1.5	W/C Ratio:	0.42	Fine MC% :	**14.4**

Physical Properties (Test Results)		**JAC/CTS COMPRESSIVE STRENGTH DATA**				**Laboratory Batch Weights**		**Actual Mass, lb**
	JAC/CTS	Date	Age, days	Compressive Strength	Average, psi	Cement		33.39
Slump, in.	1	01/07/00	7	5960		Fly Ash		3.28
Air Content, %	1.9	01/07/00	7	5790	**5863**	Coarse Aggregate		97.53
Temperature, F	66	01/07/00	7	5840		Fine Aggregate		72.95
Unit Weight, pcf	145.8	01/28/00	28	6870		Batch Mix Water		6.57
Yield, CF/CY	23.01	01/28/00	28	6510	**6720**	Air Entraining , ml	3	1.6
W/C Ratio	0.471	01/28/00	28	6780		Water Reducer, ml	10	8.2
		02/25/00	56	7040		Water Adjustments for slump		2.00
		02/25/00	56	7020	**7023**	Net Mix Water for Trial Batch		17.28
		02/25/00	56	7010		Net Mix Water / Cubic Yard		311

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CONCRETE MIX DESIGN VERIFICATION

Project Number:	D06.348	Report Date:	
Project Name:	Mitigation Materials for ASR in Concrete	Technician:	mw/zb
Lab ID Number:	75208.M	Reviewer:	
Date Batched	1/3/2008		
Description:			
Client:			
Concrete Mix Design by:	Grand Junction Ready Mix	Date Performed:	3-Jan-08
Client Mix Design ID:	CDOT class D	Lab Batch Size, CF	1.5

Design						Verification
Material	Source and Type	Specific Gravity	Batch Weights (yd^3)		Cubic Feet	Calculated Batch Weights (lbs)
Cement (ASTM C 150)	Holcim Type I/II GU	3.15	594	lb	3.02	33.00
Fly Ash (ASTM C 618)	Holcim, White Mud Metakaolin	2.50	66	lb	0.42	3.67
*Coarse Aggregate (ASTM C 33)	Grand Junction Pipe Soaring Eagle Pit #67	2.64	1219	lb	7.40	67.72
*Coarse Aggregate (ASTM C 33)	Grand Junction Pipe Soaring Eagle Pit #8	2.61	528	lb	3.24	29.33
*Fine Aggregate (ASTM C 33)	Grand Junction Pipe 23rd Road Pit	2.65	1165	lb	7.05	64.72
Water	Municipal	1.00	275	lb	4.41	15.28
Air Entraining Agent (ASTM C 260)	BASF Micro Air	n/a	1.0	oz	0.00	0.06
Water Reducer-Normal (ASTM (C494)	BASF 3030NS	n/a	5.0	oz	0.00	0.28

Target Air Content, %	6.0	--	--	1.62	
*Aggregate mass determined in SSD condition		Total:	3847 lb	27.16	214

Coarse Aggregate Absorption, %	1.3	Theo. Unit Wt., pcf:	141.6	Coarse MC% :	**2.1**
Fine Aggregate Absorption,%	1.5	W/C Ratio:	0.42	Fine MC% :	**7.5**

Physical Properties (Test Results)		**JAC/CTS COMPRESSIVE STRENGTH DATA**				**Laboratory Batch Weights**		**Actual Mass, lb**
	JAC/CTS	Date	Age, days	Compressive Strength	Average, psi	Cement		33.00
Slump, in.	4.5	01/10/08	7	4340		Fly Ash		3.67
Air Content, %	2.8	01/10/08	7	4310	**4297**	Coarse Aggregate		97.82
Temperature, F	67	01/10/08	7	4240		Fine Aggregate		68.55
Unit Weight, pcf	144.5	01/31/08	28	6140		Batch Mix Water		10.69
Yield, CF/CY	23.34	01/31/08	28	6420	**6300**	Air Entraining , ml	3	1.6
W/C Ratio	0.498	01/31/08	28	6340		Water Reducer, ml	10	8.2
		02/28/08	56	6690		Water Adjustments for slump		3.00
		02/28/08	56	6750	**6740**	Net Mix Water for Trial Batch		18.28
		02/28/08	56	6780		Net Mix Water / Cubic Yard		329

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CONCRETE MIX DESIGN VERIFICATION

Project Number:	D06.348	Report Date:	
Project Name:	Mitigation Materials for ASR in Concrete	Technician:	mw/zb
Lab ID Number:	75196.M	Reviewer:	
Date Batched	12/13/2007		
Description:			
Client:			
Concrete Mix Design by:	Grand Junction Ready Mix	Date Performed:	13-Dec-07
Client Mix Design ID:	CDOT class D	Lab Batch Size, CF	1.5

Design						Verification
Material	Source and Type	Specific Gravity	Batch Weights (yd^3)		Cubic Feet	Calculated Batch Weights (lbs)
Cement (ASTM C 150)	Holcim Type I/II GU	3.15	554	lb	2.82	30.78
Fly Ash (ASTM C 618)	Western Pozzolan, Lassenite SR	2.28	106	lb	0.75	5.89
*Coarse Aggregate (ASTM C 33)	Grand Junction Pipe Soaring Eagle Pit #67	2.64	1219	lb	7.40	67.72
*Coarse Aggregate (ASTM C 33)	Grand Junction Pipe Soaring Eagle Pit #8	2.61	528	lb	3.24	29.33
*Fine Aggregate (ASTM C 33)	Grand Junction Pipe 23rd Road Pit	2.65	1165	lb	7.05	64.72
Water	Municipal	1.00	275	lb	4.41	15.28
Air Entraining Agent (ASTM C 260)	BASF Micro Air	n/a	1.0	oz	0.00	0.06
Water Reducer-Normal (ASTM (C494)	BASF 3030NS	n/a	5.0	oz	0.00	0.28

Target Air Content, %	6.0	--	--	1.62	
*Aggregate mass determined in SSD condition		Total:	3847 lb	27.28	214

Coarse Aggregate Absorption, %	1.3	Theo. Unit Wt., pcf:	141.0	Coarse MC% :	**2.1**
Fine Aggregate Absorption,%	1.5	W/C Ratio:	0.42	Fine MC% :	**16.5**

Physical Properties (Test Results)		**JAC/CTS COMPRESSIVE STRENGTH DATA**				**Laboratory Batch Weights**		**Actual Mass, lb**
	JAC/CTS	Date	Age, days	Compressive Strength	Average, psi	Cement		30.78
Slump, in.	1	12/20/07	7	4080		Fly Ash		5.89
Air Content, %	2.5	12/20/07	7	3730	**3980**	Coarse Aggregate		97.82
Temperature, F	67	12/20/07	7	4130		Fine Aggregate		74.29
Unit Weight, pcf	146.2	01/10/08	28	5700		Batch Mix Water		4.95
Yield, CF/CY	23.07	01/10/08	28	4900	**5483**	Air Entraining , ml	4	1.6
W/C Ratio	0.498	01/10/08	28	5850		Water Reducer, ml	10	8.2
		02/07/08	56	5760		Water Adjustments for slump		3.00
		02/07/08	56	5750	**5763**	Net Mix Water for Trial Batch		18.28
		02/07/08	56	5780		Net Mix Water / Cubic Yard		329

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CONCRETE MIX DESIGN VERIFICATION

Project Number:	D06.348	Report Date:	
Project Name:	Mitigation Materials for ASR in Concrete	Technician:	mw/zb
Lab ID Number:	75195.M	Reviewer:	
Date Batched	12/13/2007		
Description:			
Client:			
Concrete Mix Design by:	Grand Junction Ready Mix	Date Performed:	13-Dec-07
Client Mix Design ID:	CDOT class D	Lab Batch Size, CF	1.5

Design						Verification
Material	Source and Type	Specific Gravity	Batch Weights (yd^3)		Cubic Feet	Calculated Batch Weights (lbs)
Cement (ASTM C 150)	Holcim Type I/II GU	3.15	488	lb	2.48	27.11
Fly Ash (ASTM C 618)	Boral, Monticello Class F	2.30	172	lb	1.20	9.56
*Coarse Aggregate (ASTM C 33)	Grand Junction Pipe Soaring Eagle Pit #67	2.64	1219	lb	7.40	67.72
*Coarse Aggregate (ASTM C 33)	Grand Junction Pipe Soaring Eagle Pit #8	2.61	528	lb	3.24	29.33
*Fine Aggregate (ASTM C 33)	Grand Junction Pipe 23rd Road Pit	2.65	1165	lb	7.05	64.72
Water	Municipal	1.00	275	lb	4.41	15.28
Air Entraining Agent (ASTM C 260)	BASF Micro Air	n/a	1.0	oz	0.00	0.06
Water Reducer-Normal (ASTM (C494)	BASF 3030NS	n/a	5.0	oz	0.00	0.28

Target Air Content, %	6.0	--	--	1.62	
*Aggregate mass determined in SSD condition		Total:	3847 lb	27.40	214

Coarse Aggregate Absorption, %	1.3	Theo. Unit Wt., pcf:	140.4	Coarse MC% :	**1.8**
Fine Aggregate Absorption,%	1.5	W/C Ratio:	0.42	Fine MC% :	**14.4**

Physical Properties (Test Results)		**JAC/CTS COMPRESSIVE STRENGTH DATA**				**Laboratory Batch Weights**		**Actual Mass, lb**
	JAC/CTS	Date	Age, days	Compressive Strength	Average, psi	Cement		27.11
Slump, in.	5.25	12/20/07	7	3640		Fly Ash		9.56
Air Content, %	2.1	12/20/07	7	3820	**3683**	Coarse Aggregate		97.53
Temperature, F	67	12/20/07	7	3590		Fine Aggregate		72.95
Unit Weight, pcf	146.2	01/10/08	28	5600		Batch Mix Water		6.57
Yield, CF/CY	22.82	01/10/08	28	5930	**5710**	Air Entraining , ml	3	1.6
W/C Ratio	0.444	01/10/08	28	5600		Water Reducer, ml	10	8.2
		02/07/08	56	7730		Water Adjustments for slump		1.00
		02/07/08	56	7230	**7513**	Net Mix Water for Trial Batch		16.28
		02/07/08	56	7580		Net Mix Water / Cubic Yard		293

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CONCRETE MIX DESIGN VERIFICATION

Project Number:	D06.348	Report Date:	
Project Name:	Mitigation Materials for ASR in Concrete	Technician:	mw/zb
Lab ID Number:	75194.M	Reviewer:	
Date Batched	12/13/2007		
Description:			
Client:			
Concrete Mix Design by:	Grand Junction Ready Mix	Date Performed:	13-Dec-07
Client Mix Design ID:	CDOT class D	Lab Batch Size, CF	1.5

Design						Verification
Material	Source and Type	Specific Gravity	Batch Weights (yd^3)		Cubic Feet	Calculated Batch Weights (lbs)
Cement (ASTM C 150)	Holcim Type I/II GU	3.15	502	lb	2.55	27.89
Fly Ash (ASTM C 618)	Boral, Craig FACT Class F	2.30	158	lb	1.10	8.78
*Coarse Aggregate (ASTM C 33)	Grand Junction Pipe Soaring Eagle Pit #67	2.64	1219	lb	7.40	67.72
*Coarse Aggregate (ASTM C 33)	Grand Junction Pipe Soaring Eagle Pit #8	2.61	528	lb	3.24	29.33
*Fine Aggregate (ASTM C 33)	Grand Junction Pipe 23rd Road Pit	2.65	1165	lb	7.05	64.72
Water	Municipal	1.00	275	lb	4.41	15.28
Air Entraining Agent (ASTM C 260)	BASF Micro Air	n/a	1.0	oz	0.00	0.06
Water Reducer-Normal (ASTM (C494)	BASF 3030NS	n/a	5.0	oz	0.00	0.28

Target Air Content, %	6.0	--	--		1.62	
*Aggregate mass determined in SSD condition		Total:	3847	lb	27.37	214

Coarse Aggregate Absorption, %	1.3	Theo. Unit Wt., pcf:	140.6	Coarse MC% :	**1.8**
Fine Aggregate Absorption,%	1.5	W/C Ratio:	0.42	Fine MC% :	**14.4**

Physical Properties (Test Results)		**JAC/CTS COMPRESSIVE STRENGTH DATA**				**Laboratory Batch Weights**		**Actual Mass, lb**
	JAC/CTS	Date	Age, days	Compressive Strength	Average, psi	Cement		27.89
Slump, in.	5	12/20/07	7	4120		Fly Ash		8.78
Air Content, %	2.7	12/20/07	7	4140	**4093**	Coarse Aggregate		97.53
Temperature, F	69	12/20/07	7	4020		Fine Aggregate		72.95
Unit Weight, pcf	145.4	01/10/08	28	6070		Batch Mix Water		6.57
Yield, CF/CY	22.95	01/10/08	28	5920	**6027**	Air Entraining , ml	3	1.6
W/C Ratio	0.444	01/10/08	28	6090		Water Reducer, ml	10	8.2
		02/07/08	56	7600		Water Adjustments for slump		1.00
		02/07/08	56	7580	**7487**	Net Mix Water for Trial Batch		16.28
		02/07/08	56	7280		Net Mix Water / Cubic Yard		293

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CONCRETE MIX DESIGN VERIFICATION

Project Number:	D06.348	Report Date:	
Project Name:	Mitigation Materials for ASR in Concrete	Technician:	mw/zb
Lab ID Number:	75199.M	Reviewer:	
Date Batched	1/3/2008		
Description:			
Client:			
Concrete Mix Design by:	Grand Junction Ready Mix	Date Performed:	3-Jan-08
Client Mix Design ID:	CDOT class D	Lab Batch Size, CF	1.5

Design						Verification
Material	Source and Type	Specific Gravity	Batch Weights (yd^3)		Cubic Feet	Calculated Batch Weights (lbs)
Cement (ASTM C 150)	Holcim Type I/II GU	3.15	475	lb	2.42	26.39
Fly Ash (ASTM C 618)	GCC Microsilex	2.30	185	lb	1.29	10.28
*Coarse Aggregate (ASTM C 33)	Grand Junction Pipe Soaring Eagle Pit #67	2.64	1219	lb	7.40	67.72
*Coarse Aggregate (ASTM C 33)	Grand Junction Pipe Soaring Eagle Pit #8	2.61	528	lb	3.24	29.33
*Fine Aggregate (ASTM C 33)	Grand Junction Pipe 23rd Road Pit	2.65	1165	lb	7.05	64.72
Water	Municipal	1.00	275	lb	4.41	15.28
Air Entraining Agent (ASTM C 260)	BASF Micro Air	n/a	1.0	oz	0.00	0.06
Water Reducer-Normal (ASTM (C494)	BASF 3030NS	n/a	5.0	oz	0.00	0.28

Target Air Content, %	6.0	--	--	1.62	
*Aggregate mass determined in SSD condition		Total:	3847 lb	27.42	214

Coarse Aggregate Absorption, %	1.3	Theo. Unit Wt., pcf:	140.3	Coarse MC% :	**2.1**
Fine Aggregate Absorption,%	1.5	W/C Ratio:	0.42	Fine MC% :	**16.5**

Physical Properties (Test Results)		**JAC/CTS COMPRESSIVE STRENGTH DATA**				**Laboratory Batch Weights**		**Actual Mass, lb**
	JAC/CTS	Date	Age, days	Compressive Strength	Average, psi	Cement		26.39
Slump, in.	2.25	01/10/08	7	3600		Fly Ash		10.28
Air Content, %	2.1	01/10/08	7	3270	**3550**	Coarse Aggregate		97.82
Temperature, F	69	01/10/08	7	3780		Fine Aggregate		74.29
Unit Weight, pcf	143.7	01/31/08	28	3490		Batch Mix Water		4.95
Yield, CF/CY	23.66	01/31/08	28	6240	**5267**	Air Entraining , ml	3	1.6
W/C Ratio	0.539	01/31/08	28	6070		Water Reducer, ml	10	8.2
		02/28/08	56	6490		Water Adjustments for slump		4.50
		02/28/08	56	6930	**6737**	Net Mix Water for Trial Batch		19.78
		02/28/08	56	6790		Net Mix Water / Cubic Yard		356

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CONCRETE MIX DESIGN VERIFICATION

Project Number:	D06.348	Report Date:	
Project Name:	Mitigation Materials for ASR in Concrete	Technician:	mw/zb
Lab ID Number:	75199-2.M	Reviewer:	
Date Batched	1/9/2008		
Description:	GCC Microsilex / Boral Monticello (combination of Microsilex and fly ash)		
Client:			
Concrete Mix Design by:	Grand Junction Ready Mix	Date Performed:	9-Jan-08
Client Mix Design ID:	CDOT class D	Lab Batch Size, CF	1.5

Design						Verification
Material	Source and Type	Specific Gravity	Batch Weights (yd^3)		Cubic Feet	Calculated Batch Weights (lbs)
Cement (ASTM C 150)	Holcim Type I/II GU	3.15	528	lb	2.69	29.33
Fly Ash (ASTM C 618)	GCC Microsilex	2.30	66	lb	0.46	3.67
Fly Ash (ASTM C 618)	Boral Monticello	2.30	66	lb	0.46	3.67
*Coarse Aggregate (ASTM C 33)	Grand Junction Pipe Soaring Eagle Pit #67	2.64	1219	lb	7.40	67.72
*Coarse Aggregate (ASTM C 33)	Grand Junction Pipe Soaring Eagle Pit #8	2.61	528	lb	3.24	29.33
*Fine Aggregate (ASTM C 33)	Grand Junction Pipe 23rd Road Pit	2.65	1165	lb	7.05	64.72
Water	Municipal	1.00	275	lb	4.41	15.28
Air Entraining Agent (ASTM C 260)	BASF Micro Air	n/a	1.0	oz	0.00	0.06

Water Reducer-Normal (ASTM (C494)	BASF 3030NS	n/a	5.0	oz	0.00	0.28
Target Air Content, %	6.0	--	--		1.62	
*Aggregate mass determined in SSD condition		Total:	3847	lb	27.32	214

Coarse Aggregate Absorption, %	1.3	Theo. Unit Wt., pcf:	140.8	Coarse MC% :	**2.2**
Fine Aggregate Absorption,%	1.5	W/C Ratio:	0.42	Fine MC% :	**7.5**

Physical Properties (Test Results)		**JAC/CTS COMPRESSIVE STRENGTH DATA**				**Laboratory Batch Weights**		**Actual Mass, lb**
	JAC/CTS	Date	Age, days	Compressive Strength	Average, psi	Cement		29.33
Slump, in.	3.5	01/16/08	7	3490		Fly Ash / Microsilex		3.67 / 3.67
Air Content, %	2.3	01/16/08	7	3350	**3457**	Coarse Aggregate		97.92
Temperature, F	68	01/16/08	7	3530		Fine Aggregate		68.55
Unit Weight, pcf	146.3	02/06/08	28	5830		Batch Mix Water		10.59
Yield, CF/CY	22.36	02/06/08	28	5990	**5880**	Air Entraining , ml	3	1.6
W/C Ratio	0.444	02/06/08	28	5820		Water Reducer, ml	10	8.2
		03/05/08	56	7000		Water Adjustments for slump		1.00
		03/05/08	56	7280	**7073**	Net Mix Water for Trial Batch		16.28
		03/05/08	56	6940		Net Mix Water / Cubic Yard		293

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CONCRETE MIX DESIGN VERIFICATION

Project Number:	D06.348	Report Date:	
Project Name:	Mitigation Materials for ASR in Concrete	Technician:	mw/zb
Lab ID Number:	75193.M	Reviewer:	
Date Batched	12/10/2007		
Description:			
Client:			
Concrete Mix Design by:	Grand Junction Ready Mix	Date Performed:	10-Dec-07
Client Mix Design ID:	CDOT class D	Lab Batch Size, CF	1.5

Design						Verification
Material	Source and Type	Specific Gravity	Batch Weights (yd^3)		Cubic Feet	Calculated Batch Weights (lbs)
Cement (ASTM C 150)	Holcim Type I/II GU	3.15	594	lb	3.02	33.00
Fly Ash (ASTM C 618)	Thiele Kaolin, Kaorock	2.30	66	lb	0.46	3.67
*Coarse Aggregate (ASTM C 33)	Grand Junction Pipe Soaring Eagle Pit #67	2.64	1219	lb	7.40	67.72
*Coarse Aggregate (ASTM C 33)	Grand Junction Pipe Soaring Eagle Pit #8	2.61	528	lb	3.24	29.33
*Fine Aggregate (ASTM C 33)	Grand Junction Pipe 23rd Road Pit	2.65	1165	lb	7.05	64.72
Water	Municipal	1.00	275	lb	4.41	15.28
Air Entraining Agent (ASTM C 260)	BASF Micro Air	n/a	1.0	oz	0.00	0.06
Water Reducer-Normal (ASTM (C494)	BASF 3030NS	n/a	5.0	oz	0.00	0.28

Target Air Content, %	6.0	--	--	1.62	
*Aggregate mass determined in SSD condition		Total:	3847 lb	27.20	214

Coarse Aggregate Absorption, %	1.3	Theo. Unit Wt., pcf:	141.5	Coarse MC% :	**1.8**
Fine Aggregate Absorption,%	1.5	W/C Ratio:	0.42	Fine MC% :	**14.4**

Physical Properties (Test Results)		**JAC/CTS COMPRESSIVE STRENGTH DATA**				**Laboratory Batch Weights**		**Actual Mass, lb**
	JAC/CTS	Date	Age, days	Compressive Strength	Average, psi	Cement		33.00
Slump, in.	2	12/17/07	7	5380		Fly Ash		3.67
Air Content, %	1.9	12/17/07	7	5340	**5343**	Coarse Aggregate		97.53
Temperature, F	64	12/17/07	7	5310		Fine Aggregate		72.95
Unit Weight, pcf	145.4	01/07/08	28	7280		Batch Mix Water		6.57
Yield, CF/CY	23.07	01/07/08	28	6690	**6983**	Air Entraining , ml	3	1.6
W/C Ratio	0.471	01/07/08	28	6980		Water Reducer, ml	10	8.2
Good Workability		02/04/08	56	7780		Water Adjustments for slump		2.00
		02/04/08	56	7360	**7600**	Net Mix Water for Trial Batch		17.28
		02/04/08	56	7660		Net Mix Water / Cubic Yard		311

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CONCRETE MIX DESIGN VERIFICATION

Project Number:	D06.348	Report Date:	
Project Name:	Mitigation Materials for ASR in Concrete	Technician:	mw/zb
Lab ID Number:	75459.M	Reviewer:	
Date Batched	1/9/2008		
Description:			
Client:			
Concrete Mix Design by:	Grand Junction Ready Mix	Date Performed:	9-Jan-08
Client Mix Design ID:	CDOT class D	Lab Batch Size, CF	1.5

Design						Verification
Material	Source and Type	Specific Gravity	Batch Weights (yd^3)		Cubic Feet	Calculated Batch Weights (lbs)
Cement (ASTM C 150)	Holcim Type I/II GU	3.15	356	lb	1.81	19.78
Fly Ash (ASTM C 618)	Holcim GranCem	2.90	304	lb	1.68	16.89
*Coarse Aggregate (ASTM C 33)	Grand Junction Pipe Soaring Eagle Pit #67	2.64	1219	lb	7.40	67.72
*Coarse Aggregate (ASTM C 33)	Grand Junction Pipe Soaring Eagle Pit #8	2.61	528	lb	3.24	29.33
*Fine Aggregate (ASTM C 33)	Grand Junction Pipe 23rd Road Pit	2.65	1165	lb	7.05	64.72
Water	Muncipal	1.00	275	lb	4.41	15.28
Air Entraining Agent (ASTM C 260)	BASF Micro Air	n/a	1.0	oz	0.00	0.06
Water Reducer-Normal (ASTM (C494)	BASF 3030NS	n/a	5.0	oz	0.00	0.28

Target Air Content, %	6.0	--	--	1.62	
*Aggregate mass determined in SSD condition		Total:	3847 lb	27.21	214

Coarse Aggregate Absorption, %	1.3	Theo. Unit Wt., pcf:	141.4	Coarse MC% :	**2.2**
Fine Aggregate Absorption,%	1.5	W/C Ratio:	0.42	Fine MC% :	**7.5**

Physical Properties (Test Results)		**JAC/CTS COMPRESSIVE STRENGTH DATA**				**Laboratory Batch Weights**		**Actual Mass, lb**
	JAC/CTS	Date	Age, days	Compressive Strength	Average, psi	Cement		19.78
Slump, in.	4	01/16/08	7	3750		Fly Ash		16.89
Air Content, %	2.2	01/16/08	7	3670	**3670**	Coarse Aggregate		97.92
Temperature, F	70	01/16/08	7	3590		Fine Aggregate		68.55
Unit Weight, pcf	146.3	02/06/08	28	5650		Batch Mix Water		10.59
Yield, CF/CY	22.87	02/06/08	28	5730	**5863**	Air Entraining , ml	3	1.6
W/C Ratio	0.458	02/06/08	28	6210		Water Reducer, ml	10	8.2
		03/05/08	56	6320		Water Adjustments for slump		1.50
		03/05/08	56	7190	**6613**	Net Mix Water for Trial Batch		16.78
		03/05/08	56	6330		Net Mix Water / Cubic Yard		302

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CONCRETE MIX DESIGN VERIFICATION

Project Number:	D06.348	Report Date:	
Project Name:	Mitigation Materials for ASR in Concrete	Technician:	mw/zb
Lab ID Number:	75207.M	Reviewer:	
Date Batched	1/3/2008		
Description:			
Client:			
Concrete Mix Design by:	Grand Junction Ready Mix	Date Performed:	3-Jan-08
Client Mix Design ID:	CDOT class D	Lab Batch Size, CF	1.5

Design						Verification
Material	Source and Type	Specific Gravity	Batch Weights (yd^3)		Cubic Feet	Calculated Batch Weights (lbs)
Cement (ASTM C 150)	Holcim Type I/II GU	3.15	475	lb	2.42	26.39
Fly Ash (ASTM C 618)	Headwaters, Jim Bridger Class F	2.30	185	lb	1.29	10.28
*Coarse Aggregate (ASTM C 33)	Grand Junction Pipe Soaring Eagle Pit #67	2.64	1219	lb	7.40	67.72
*Coarse Aggregate (ASTM C 33)	Grand Junction Pipe Soaring Eagle Pit #8	2.61	528	lb	3.24	29.33
*Fine Aggregate (ASTM C 33)	Grand Junction Pipe 23rd Road Pit	2.65	1165	lb	7.05	64.72
Water	Muncipal	1.00	275	lb	4.41	15.28
Air Entraining Agent (ASTM C 260)	BASF Micro Air	n/a	1.0	oz	0.00	0.06
Water Reducer-Normal (ASTM (C494)	BASF 3030NS	n/a	5.0	oz	0.00	0.28

Target Air Content, %	6.0	--	--	1.62	
*Aggregate mass determined in SSD condition		Total:	3847 lb	27.42	214

Coarse Aggregate Absorption, %	1.3	Theo. Unit Wt., pcf:	140.3	Coarse MC% :	**2.1**
Fine Aggregate Absorption,%	1.5	W/C Ratio:	0.42	Fine MC% :	**7.5**

Physical Properties (Test Results)		**JAC/CTS COMPRESSIVE STRENGTH DATA**				**Laboratory Batch Weights**		**Actual Mass, lb**
	JAC/CTS	Date	Age, days	Compressive Strength	Average, psi	Cement		26.39
Slump, in.	5.25	01/10/08	7	3420		Fly Ash		10.28
Air Content, %	3.3	01/10/08	7	3510	**3460**	Coarse Aggregate		97.82
Temperature, F	69	01/10/08	7	3450		Fine Aggregate		68.55
Unit Weight, pcf	138.2	01/31/08	28	6020		Batch Mix Water		10.69
Yield, CF/CY	24.15	01/31/08	28	6010	**5963**	Air Entraining , ml	3	1.6
W/C Ratio	0.444	01/31/08	28	5860		Water Reducer, ml	10	8.2
		02/28/08	56	7030		Water Adjustments for slump		1.00
		02/28/08	56	7260	**7017**	Net Mix Water for Trial Batch		16.28
		02/28/08	56	6760		Net Mix Water / Cubic Yard		293

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CONCRETE MIX DESIGN VERIFICATION

Project Number: D06.348 | Report Date:
Project Name: Mitigation Materials for ASR in Concrete | Technician: mw/zb
Lab ID Number: 75206.M | Reviewer:
Date Batched: 1/3/2008
Description:
Client:
Concrete Mix Design by: Grand Junction Ready Mix | Date Performed: 3-Jan-08
Client Mix Design ID: CDOT class D | Lab Batch Size, CF: 1.5

Design						Verification
Material	Source and Type	Specific Gravity	Batch Weights (yd^3)		Cubic Feet	Calculated Batch Weights (lbs)
Cement (ASTM C 150)	Holcim Type I/II GU	3.15	515	lb	2.62	28.61
Fly Ash (ASTM C 618)	Headwaters, Coal Creek Class F	2.30	145	lb	1.01	8.06
*Coarse Aggregate (ASTM C 33)	Grand Junction Pipe Soaring Eagle Pit #67	2.64	1219	lb	7.40	67.72
*Coarse Aggregate (ASTM C 33)	Grand Junction Pipe Soaring Eagle Pit #8	2.61	528	lb	3.24	29.33
*Fine Aggregate (ASTM C 33)	Grand Junction Pipe 23rd Road Pit	2.65	1165	lb	7.05	64.72
Water	Muncipal	1.00	275	lb	4.41	15.28
Air Entraining Agent (ASTM C 260)	BASF Micro Air	n/a	1.0	oz	0.00	0.06
Water Reducer-Normal (ASTM (C494)	BASF 3030NS	n/a	5.0	oz	0.00	0.28

Target Air Content, %	6.0	--	--	1.62	
*Aggregate mass determined in SSD condition		Total:	3847 lb	27.34	214

Coarse Aggregate Absorption, %	1.3	Theo. Unit Wt., pcf:	140.7	Coarse MC% :	**2.1**
Fine Aggregate Absorption,%	1.5	W/C Ratio:	0.42	Fine MC% :	**16.5**

Physical Properties (Test Results)		**JAC/CTS COMPRESSIVE STRENGTH DATA**				**Laboratory Batch Weights**		**Actual Mass, lb**
	JAC/CTS	Date	Age, days	Compressive Strength	Average, psi	Cement		28.61
Slump, in.	3.75	01/10/08	7	4170		Fly Ash		8.06
Air Content, %	2.9	01/10/08	7	4290	**4207**	Coarse Aggregate		97.82
Temperature, F	67	01/10/08	7	4160		Fine Aggregate		74.29
Unit Weight, pcf	146.1	01/31/08	28	6380		Batch Mix Water		4.95
Yield, CF/CY	22.78	01/31/08	28	6160	**6233**	Air Entraining , ml	3	1.6
W/C Ratio	0.430	01/31/08	28	6160		Water Reducer, ml	10	8.2
		02/28/08	56	7290		Water Adjustments for slump		0.50
		02/28/08	56	7190	**7307**	Net Mix Water for Trial Batch		15.78
		02/28/08	56	7440		Net Mix Water / Cubic Yard		284

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CONCRETE MIX DESIGN VERIFICATION

Project Number:	D06.348	Report Date:	
Project Name:	Mitigation Materials for ASR in Concrete	Technician:	mw/zb
Lab ID Number:	75197.M	Reviewer:	
Date Batched	12/13/2007		
Description:			
Client:			
Concrete Mix Design by:	Grand Junction Ready Mix	Date Performed:	13-Dec-07
Client Mix Design ID:	CDOT class D	Lab Batch Size, CF	1.5

Design						Verification
Material	Source and Type	Specific Gravity	Batch Weights (yd^3)		Cubic Feet	Calculated Batch Weights (lbs)
Cement (ASTM C 150)	Holcim Type I/II GU	3.15	535	lb	2.72	29.72
Sand Admixture	TXI, Lightweight Sand	1.98	775	lb	6.27	43.06
*Coarse Aggregate (ASTM C 33)	Grand Junction Pipe Soaring Eagle Pit #67	2.64	1219	lb	7.40	67.72
*Coarse Aggregate (ASTM C 33)	Grand Junction Pipe Soaring Eagle Pit #8	2.61	528	lb	3.24	29.33
*Fine Aggregate (ASTM C 33)	Grand Junction Pipe 23rd Road Pit	2.65	129	lb	0.78	7.17
Water	Muncipal	1.00	275	lb	4.41	15.28
Air Entraining Agent (ASTM C 260)	BASF Micro Air	n/a	1.0	oz	0.00	0.06
Water Reducer-Normal (ASTM (C494)	BASF 3030NS	n/a	5.0	oz	0.00	0.28

Target Air Content, %	6.0	--	--	1.62	
*Aggregate mass determined in SSD condition		Total:	3461 lb	26.44	192

Coarse Aggregate Absorption, %	1.3	Theo. Unit Wt., pcf:	130.9	Coarse MC% :	**1.8**
Fine Aggregate Absorption,%	1.5	W/C Ratio:	0.21	Fine MC% :	**14.4**

Physical Properties (Test Results)		**JAC/CTS COMPRESSIVE STRENGTH DATA**				**Laboratory Batch Weights**		**Actual Mass, lb**
	JAC/CTS	Date	Age, days	Compressive Strength	Average, psi	Cement		29.72
Slump, in.	2	12/20/07	7	3610		TXI Sand *		43.06
Air Content, %	4.5	12/20/07	7	3220	**3377**	Coarse Aggregate		97.53
Temperature, F	65	12/20/07	7	3300		Fine Aggregate		8.08
Unit Weight, pcf	134.1	01/10/08	28	5650		Batch Mix Water		13.89
Yield, CF/CY	21.94	01/10/08	28	5590	**5577**	Air Entraining , ml	4.0	1.6
W/C Ratio	0.531	01/10/08	28	5490		Water Reducer, ml	10.0	8.2
		02/07/08	56	6520		Water Adjustments for slump		0.50
		02/07/08	56	6700	**6573**	Net Mix Water for Trial Batch		15.78
		02/07/08	56	6500		Net Mix Water / Cubic Yard		284

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CONCRETE MIX DESIGN VERIFICATION

Project Number: D06.348

Report Date:

Project Name: Mitigation Materials for ASR in Concrete

Technician: mw/zb

Lab ID Number: 75460.M

Reviewer:

Date Batched: 1/9/2008

Description:

Client:

Concrete Mix Design by: Grand Junction Ready Mix

Date Performed: 9-Jan-08

Client Mix Design ID: CDOT class D

Lab Batch Size, CF: 1.5

Design						**Verification**
Material	Source and Type	Specific Gravity	Batch Weights (yd^3)		Cubic Feet	Calculated Batch Weights (lbs)
Cement (ASTM C 150)	Holcim Type I/II GU	3.15	515	lb	2.62	28.61
Lithium Nitrate	FMC-Euclid Chemical, Lithium Nitrate	1.20	12.67	lb	0.17	0.70
*Coarse Aggregate (ASTM C 33)	Grand Junction Pipe Soaring Eagle Pit #67	2.64	1219	lb	7.40	67.72
*Coarse Aggregate (ASTM C 33)	Grand Junction Pipe Soaring Eagle Pit #8	2.61	528	lb	3.24	29.33
*Fine Aggregate (ASTM C 33)	Grand Junction Pipe 23rd Road Pit	2.65	1165	lb	7.05	64.72
Water	Muncipal	1.00	265	lb	4.25	14.72
Air Entraining Agent (ASTM C 260)	BASF Micro Air	n/a	1.0	oz	0.00	0.06
Water Reducer-Normal (ASTM (C494)	BASF 3030NS	n/a	5.0	oz	0.00	0.28

Target Air Content, %	6.0	--	--	1.62	
*Aggregate mass determined in SSD condition		Total:	3705 lb	26.34	206

Coarse Aggregate Absorption, %	1.3	Theo. Unit Wt., pcf:	140.6	Coarse MC% :	**2.2**
Fine Aggregate Absorption,%	1.5	W/C Ratio:	0.50	Fine MC% :	**7.5**

Physical Properties (Test Results)		**JAC/CTS COMPRESSIVE STRENGTH DATA**				**Laboratory Batch Weights**		**Actual Mass, lb**
	JAC/CTS	Date	Age, days	Compressive Strength	Average, psi	Cement		28.61
Slump, in.	5	01/16/08	7	2680		Lithium Nitrate		0.70
Air Content, %	4.3	01/16/08	7	2620	**2667**	Coarse Aggregate		97.92
Temperature, F	68	01/16/08	7	2700		Fine Aggregate		68.55
Unit Weight, pcf	142.4	02/06/08	28	4340		Batch Mix Water		10.03
Yield, CF/CY	22.37	02/06/08	28	4510	**4423**	Air Entraining , ml	3	1.6
W/C Ratio	0.519	02/06/08	28	4420		Water Reducer, ml	10	8.2
		03/05/08	56	5240		Water Adjustments for slump		0.50
		03/05/08	56	5490	**5380**	Net Mix Water for Trial Batch		15.22
		03/05/08	56	5410		Net Mix Water / Cubic Yard		274