An *IPRF* Research Report

Innovative Pavement Research Foundation

Airport Concrete Pavement Technology Program

Report IPRF-01-G-002-04-1A

Supplemental Report for Proposed Specification for Construction of Concrete Airfield Pavement

Programs Management Office
5420 Old Orchard Road
Skokie, IL 60077

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Supplemental Report for Proposed Specification for Construction of Concrete Airfield Pavement

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PREFACE

This report has been prepared by the Innovative Pavement Research Foundation (IPRF) under the Airport Concrete Pavement Technology Program. Funding is provided by the Federal Aviation Administration (FAA) under Cooperative Agreement Number 01-G-002-04-1. Dr. Satish Agrawal is the Manager of the FAA Airport Technology R&D Branch and the Technical Manager of the Cooperative Agreement. Mr. Jim Lafrenz is the IPRF Cooperative Agreement Program Manager.

The IPRF and the FAA thank the Technical Panel that willingly gave of their expertise and time for the development of this report. They were responsible for the oversight and the technical direction. The names of those individuals on the Technical Panel follow.

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The project team would also like to acknowledge that the proposed specification incorporates the collective experience of a broad range of experts who have, over the years, contributed so much to the developments in airport concrete pavement construction technology. As a result of their contributions, which have produced long lasting concrete pavements, the United States enjoys one of the best aviation systems in the world.

EXECUTIVE SUMMARY

The Standards for Specifying Construction of Airports, FAA Advisory Circular: AC 150/5370-10B incorporates Item P-501 – Portland Cement Concrete Pavement. Airport concrete pavement project funded under the federal airport improvement program (AIP) are typically developed in accordance with the requirements contained in Item P-501 and sometimes in conjunction with specific project requirements and local practices related to material availability and regional concerns, and as approved by the FAA.

The current version of Item P-501, released in 1989 and since modified several times, provides guidance on the following:

1. Concrete materials (including composition and materials requirements)
2. Construction methods (including equipment, concrete placement, finishing, jointing, curing, and sealing)
3. Method of acceptance (including sampling and testing)
4. Contractor quality control
5. Basis for payment

Since the early 1990's, significant changes have taken place in concrete technology as well as concrete pavement construction technology. Although Item P-501 has been modified several times, many of the changes and new concepts have not been formally incorporated in the specification. As part of a recent IPRF study, a proposed specification for concrete airfield pavement has been developed for possible adoption by the FAA.

The proposed specification places emphasis on the need to produce a durable end product, that is, a durable concrete pavement. The product requirements that are specified are a combination of prescriptive requirements for certain materials as well as end product requirements for the as-delivered concrete and for the as-placed concrete. There is less emphasis on the means and methods to produce the end product. This should allow the contractor reasonable flexibility to use innovative construction methods and equipment that will result in cost savings to owner agencies without sacrificing the quality of the product.

Specifically, the proposed specification will allow constructors to identify sources of variability in the airfield concrete pavement construction process and to minimize the variability; thus delivering an end product that is consistent and durable. The proposed specification intent is to:

1. Inspire creativity and maintain a standard for the evaluation of the construction
2. Incorporate a system of measurement consistent with acceptance criteria that will validate the design parameters
3. Encourage innovation and be "results-oriented"
4. Result in a product of the highest quality and consistent with the available local materials.

The key items of the proposed specification are listed below:

1. Emphasis on end product requirements for the concrete and the concrete pavement.

2. Denoting aggregates as a generic material and not as coarse and fine aggregates.
3. Requirement to optimize the combined aggregate gradation which results in a dense concrete matrix that has the attributes needed for workability and long-term durability.
4. Requirement of a plan for mitigation of reactive aggregates.
5. Allowing use of splitting tensile strength testing for concrete strength acceptance.
6. No prescriptive requirements of paving equipment.
7. Construction of a test section to demonstrate and validate the Contractor's concrete production and concrete placement processes.
8. Requiring a Weather Management Plan, as applicable, for larger projects.
9. Contractor's process control testing to include the following new requirements:
    a. Combined aggregate gradation
    b. Limit on hand finishing at edges
10. Concrete strength and pavement thickness acceptance testing to be performed by the contractor. The Engineer observes the contractor's testing and performs other required acceptance testing.
11. A pavement construction lot to include five sublots. This provides for improved statistical evaluation of the end product requirements.
12. The number of strength specimens to be tested per lot is three when the splitting tensile strength testing option is used. This provides for improved statistical sampling of the concrete.
13. Graduated requirements for projects requiring less than 10,000 cubic yards of concrete placement.

This Supplemental Report for the proposed specification has been prepared to provide explanatory notes and guidance on key specification items incorporated in the proposed specification and to clarify the intent of the specification. The Supplemental Report also discusses the impacts of deviations from specifications and provides guidance on recommended practices.

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SUPPLEMENTAL REPORT FOR THE PROPOSED SPECIFICATION FOR CONSTRUCTION OF CONCRETE AIRFIELD PAVEMENTS

INTRODUCTION

General

The Federal Aviation Administration (FAA) Advisory Circular (AC) 150/5370-10, Standards for Specifying Construction of Airports, includes Item P-501 - Portland Cement Concrete Pavement (Ref. 1). A proposed construction specification for concrete airfield pavement has been developed as a possible replacement for Item P-501. This Supplemental Report (SR) provides explanatory notes and guidance on key specification items incorporated in the proposed specification and clarifies the intent of the specification. The report also discusses the impacts of deviations from specifications and provides guidance on recommended practices.

The intended users of this document are airport pavement design and construction engineers, contractors, materials suppliers, and construction inspectors. The user should be familiar with characteristics of local construction materials and be aware of durability concerns related to use of concrete constructed with locally available concrete materials.

The engineer is encouraged to make necessary modifications to the proposed specification to account for local conditions and to ensure that the owner obtains the best quality materials at the most reasonable cost. Making a specification too rigid when local conditions do not require that results in specifications that influences the cost of the project but may not improve the durability or the constructability of the pavement.

A fundamental assumption made during the preparation of plans and specifications for an airport pavement project is that a quality pavement performs well. Quality is an inherent property of a well-constructed pavement. Good materials and construction practices are vital for producing high quality and long lasting airfield concrete pavements. Even if a pavement is designed to the highest standards, it will not perform well if it is not constructed well. A pavement that is constructed well using good quality materials will require less maintenance and repairs over the years. As such, construction requirements and specification items need to be well defined, can be quantified, are measurable, and are not arbitrary. In addition, the project specifications need sufficient flexibility to allow for innovations by the contractor dictated by availability of materials, equipment, and projects size and requirements..

Pavement performance is significantly affected by the variability in the properties of key design features. While a certain amount of variability is unavoidable, excessive variability in the construction process can lead to random performance of pavements, as well as higher cost to the contractor in case of corrective work required for early age failures. Construction variability can be controlled by making effective use of quality control plans.

A pavement performance item of significant interest to owners is elimination of foreign object damage (FOD). Airfield closures are primarily due to joint and crack spall repairs and cracked slab repairs, all of which pose a significant cost and operational impact. The reduction of FOD from spalls is a key durability related property addressed in the proposed specification. However, because there is no single objective or practical test that can be specified to achieve this durability requirement, a focus of the specification is to ensure that good materials and construction related practices are adhered to throughout the project.

The purpose of the specification is to provide the minimum prescriptive requirements to ensure a desired level of concrete pavement durability and a fair bidding environment, yet providing substantial flexibility to the contractor who best knows the interaction of the materials, equipment and construction processes. An example of the best practices focus is the limitation on keeping hand-finishing behind the paver to the minimum as it is well accepted that excessive hand finishing of the edges of the concrete is a significant contributor to joint spalls. These spalls often occur after joint sealing but before aircraft use the pavement. As a safeguard against construction processes that are not in control or do not follow good practice, the specification has limitations on the amount of hand finishing, and requires substantial slab repairs if early age joint spalling develops.

Scope of the Supplemental Report

The SR primarily provides explanatory notes and guidance on key specification items incorporated in the proposed specification and discusses the impacts of deviations from specifications and general recommended practices. As such, the SR addresses only items related directly to the proposed specification. The SR, by itself, is not a compendium on the best practices for specifying and constructing airport concrete pavements. Specifically, the scope of the SR includes the following:

1. Clarification of key construction specification items
2. Discussion of the need for key specification requirements
3. Discussion of advantages and disadvantages of techniques or practices where more than one method may be used
4. Identification of practices that result in durable airport concrete pavements
5. Identification of practices that may result in early age or premature failures and poor long-term performance and discussion on how to mitigate such problems.
6. Discussion of commonly encountered problems with meeting project specifications.

The Supplemental Report follows the outline and the heading and sub-heading numbering system of the proposed specification. Explanatory notes and detailed discussions are provided, as necessary, for the appropriate sections of the proposed specification. Where no clarification is necessary, no notes are provided. As appropriate, additional external reference materials are also cited for in-depth discussion of specific items. It should be noted that the SR is not intended to provide a comprehensive discussion on studies related to items discussed in this report. The SR cannot replace sound engineering knowledge and successful local experience.

For additional information on best practices for construction of airfield concrete pavements, the reader should refer to the IPRF publication, “Best Practices for Airport Portland Cement

Concrete Pavement Construction", published April 2003 by the American Concrete Pavement Association (Ref. 2).

Key Changes in the Proposed Specification

The proposed specification incorporates several significant changes. The revised specification places emphasis on the need to produce a durable end product, that is, a durable concrete pavement. The product requirements that are specified are a combination of prescriptive requirements for certain materials as well as end product requirements for the as-delivered concrete and for the as-placed concrete. There is less emphasis on the means and methods to produce the end product. This should allow the contractor reasonable flexibility to use innovative construction methods and equipment that will result in cost savings to owner agencies without sacrificing the quality of the product.

The key changes are listed below:

1. Emphasis on end product requirements for the concrete and the concrete pavement.
2. Graduated requirements for projects requiring less than 10,000 cubic yards of concrete placement.
3. Inclusion of ASTM C 1157 performance-based cements.
4. Denoting aggregates as a generic material and not as coarse and fine aggregates.
5. Emphasizing use of combined aggregate gradations to develop optimum aggregate gradations that result in a workable concrete mixture that has the attributes needed for workability and long-term durability.
6. Requirement of a plan for mitigation of reactive aggregates.
7. Requirement of a dense (impermeable) concrete matrix for severe weathering regions. Testing is required to determine the impermeable nature of concrete.
8. Allows use of splitting tensile strength testing for concrete strength acceptance.
9. No prescriptive requirements of paving equipment. The Contractor needs to demonstrate that his paving equipment is capable of placing and consolidating the concrete uniformly across the width of the placement.
10. Requirement of a Weather Management Plan, as applicable, for larger projects.
11. Construction of a test section to demonstrate and validate the Contractor's concrete production and concrete placement processes.
12. Contractor's process control testing to include the following new requirements:
    a. Combined aggregate gradation
    b. Concrete consolidation
    c. Limit on hand finishing at edges
13. All acceptance testing to be performed by the contractor. The engineer is to perform 10% verification testing and may observe the contractor's testing.
14. A pavement construction lot will include five sublots.
15. The number of strength specimens to be tested per lot is three when the splitting tensile strength testing option is used. This provides for improved statistical sampling.
16. For projects less than 2,000 cubic yards of concrete, the full project is designated as a single lot and a sublot is 400 cubic yards or one day's placement.

1.0 DESCRIPTION

1.1 General

The Standards for Specifying Construction of Airports, FAA Advisory Circular: AC 150/5370-10A incorporates Item P-501 – Portland Cement Concrete Pavement. Airport concrete pavement project funded under the federal airport improvement program (AIP) are typically developed in accordance with the requirements contained in Item P-501 and sometimes in conjunction with specific project requirements and local practices related to material availability and regional concerns, and as approved by the FAA. Item P-501 provides appropriate language to specify the items necessary to construct a durable airport concrete pavement conforming to the lines, grades, thickness, and typical cross sections shown on the plans. The following airport concrete pavement types are considered:

1. Jointed plain concrete pavement - most commonly used pavement type for airport applications and may be doweled or non-doweled at transverse joints.
2. Jointed reinforced concrete pavement - typically not used for new airport pavement applications, except at fillet locations or for special-use applications.
3. Continuously reinforced concrete pavement - typically constructed without any transverse joints. Not widely used for airport applications.

The proposed specification incorporates requirements for the following:

1. End product
2. Construction materials, including concrete mixture
3. Submittals
4. Testing laboratory requirements
5. Construction equipment
6. Test section
7. Concrete paving
8. Contractor process control testing
9. End product acceptance testing
10. Treatment of defective product
11. Payments

Primary assumptions of the proposed specification are:

1. The constructed concrete pavement will be durable regardless of concrete mix design and proportioning, placement and finishing, project size or climatic conditions.
2. The pavement should exhibit failure due to anticipated aircraft loadings over the design period and not due to material deficiencies that are a result of construction quality and soundness of materials used.

1.2 End Product

All work and all materials furnished shall be in reasonably close conformity with the lines, grades, grading sections, cross sections, dimensions, material requirements, and testing requirements that are specified (including specified tolerances) in the contract, plans or specifications. If the engineer finds the materials furnished, work performed, or the finished product are not in conformity with the plans and specifications and have resulted in an unacceptable finished product, the affected work or materials shall be removed and replaced or otherwise corrected by and at the expense of the contractor in accordance with the engineer's written orders.

A concern with concrete pavement construction is that both the process control testing and acceptance testing deal primarily with the as-delivered concrete. There is little testing performed to characterize the properties of the as-placed concrete. There is a need to ensure that the fresh concrete that is accepted for placement can be placed and consolidated without segregation or excess surface paste or without requiring excessive hand finishing at the corners and edges.

The end product requirements related to concrete and concrete pavement are listed next. The significance of each element is discussed later in the appropriate sections.

1. Surface smoothness (as discussed in Para. 9.3.1 – Straightedge) - Surface smoothness testing is required to assess the pavement roughness and considers impact to the aircraft traffic in terms of ride quality and the potential for hydroplaning to develop as a result of ponding.

2. Vertical grade (as discussed in Para. 9.3.2 – Vertical Grade) - This requirement ensures compliance with the plan requirements for grade.

3. Edge slump (as discussed in Para. 9.3.3 – Edge Slump) - Edge slump is a critical item for airport concrete pavements. Excessive edge slump indicates that the contractor's process is out of control and the in-place concrete can be expected to exhibit early durability failure. Excessive edge slump can also contribute to joint distress and higher potential for hydroplaning.

4. Dowel bar alignment (as discussed in Para. 9.3.4 – Dowel Bar Alignment) – Dowel bars provide load transfer across pavement joints to greatly reduce slab stresses and deflections, thereby reducing the potential for slab cracking. Proper alignment of the dowel bar is important to proper functioning of the dowel bars. Pavement areas having joints with misaligned dowel bars are considered defective.

5. Cracking (as discussed in Para. 9.3.5 – Cracking) – Structural cracking is detrimental to long-term performance of concrete pavements. However, shallow cracking, less than 2 in. in depth, is not considered structural cracking and can be mitigated. Pavement areas with deeper cracking are considered defective.

6. Sliver Spalls (as discussed in Para. 9.3.6 – Sliver Spalls) – Sliver spalls are spalls that extend within 1 inch of the joint and are confined within the sealant reservoir. Sliver spalls result in FOD and affect joint sealant performance. Pavement areas with excessive amount of sliver spalls are considered defective.

7. Joint Spalls (as discussed in Para. 9.3.7 – Joint Spalls) – Joint spalls are larger and deeper than sliver spalls and are primarily due to equipment damaging the concrete during the early age. Pavement areas with excessive amount of joint spall are considered defective.

8. Slab thickness (as discussed in Para. 9.4.1 – Thickness) - This requirement ensures compliance with the design considerations for the pavement. Acceptance of thickness is based on the percent-within-limit provision. Pavement areas with PWL less than 55 are considered defective.

9. Flexural strength (as discussed in Para. 9.4.2 – Flexural Strength) - This requirement ensures compliance with the design requirements for the pavement. The concrete mixture is required to attain the specified flexural strength at the specified age. Acceptance of flexural strength is based on the percent-within-limit provision. Pavement areas with PWL less than 55 are considered defective.

1.3 End Product Responsibility

> A basic tenet of this specification is that the early age distresses are a result of marginal materials and marginal construction if the distresses develop before use by aircraft, and especially if the distresses are isolated.
>
> Therefore, the specification requires that the contractor develop appropriate strategies to correct any distress and implement these strategies, at his cost, after review by the engineer.
>
> The repair strategies should be based on specified repair guidelines or industry accepted procedures and should be applied within the framework of the appropriate provisions of the specification.

The contractor is entirely responsible for the materials and processes that produce the end products specified in this section. It is the Contractor's responsibility to prove, at the start of construction, that the process for constructing the concrete pavement is valid.

The engineer will determine if the contractor's materials and processes produce an end product that is in reasonably close conformity with the plans and specifications. Tolerances to determine reasonably close conformity for measurable components of the materials, processes, and end product are provided in the proposed specification.

In accordance with Section 50 of the General Provisions of FAA's standard construction specifications, if the engineer finds "that the materials furnished, work performed, or the finished product are not within reasonably close conformity with the plans and specifications but that the portion of the work affected will, in his/her opinion, result in a finished product having a level of safety, economy, durability, and workmanship acceptable to the owner, he will advise the owner of his/her determination that the affected work be accepted and remain in place". In this event, the engineer will document his/her determination and recommend to the owner a basis of acceptance that will provide for an adjustment in the contract price for the affected portion of the work.

If the engineer finds the materials furnished, work performed, or the finished product are not in reasonably close conformity with the plans and specifications and have resulted in an unacceptable finished product, the affected work or materials will need to be removed and replaced or otherwise corrected by and at the expense of the contractor in accordance with the engineer's written directions.

1.4 Pre-Paving Conference

The pre-paving conference is hosted by the engineer to review, with the contractor and airport personnel, specific project requirements related to the concrete paving and related project planning activities. The following items should be reviewed by the Engineer and the contractor:

1. Submittals and status of submittals.
2. Critical material supply/availability issues.
3. Concrete plant and aggregate stockpile management.
4. Concrete paving requirements.
5. Paving schedule.
6. Weather management plan.
7. Test section requirements.
8. Contractor process testing.
9. Contractor acceptance testing requirements.
10. Engineer monitoring of acceptance testing.
11. Who on Contractor's staff has stop work authority?
12. Who on Owner's staff has stop work authority?
13. Issues and disputes resolution hierarchy.

The concrete pre-paving conference is the last opportunity to discuss concrete paving process issues before the equipment starts moving. If these items are discussed before paving begins, the parties are able to review potential problems and create solutions that work for everyone on the project. Meeting minutes need to be distributed to all parties.

Construction Workshop

For projects involving more than 50,000 sq. yd of concrete paving, it is recommended that a ½-day concrete pavement construction workshop be conducted that would also include discussion of project specific plans and specifications. Attendees at this workshop may include key staff from the contractor's field crew and the testing and inspection crews. A workshop such as this will ensure that all involved parties have the same understanding of project requirements and that all parties are committed to a successful project.

Graduated Requirements

The proposed specification incorporates comprehensive requirements to assure that the end product, the concrete pavement, is durable and will provide the expected service without occurrence of premature distresses. These requirements have been developed for production paving involving more than about 10,000 cubic yards of concrete placement.

For projects involving less than about 10,000 cubic yards of concrete, it is not considered cost-effective to require the contractor to develop the extensive amount of submittals or to require extensive amount of new testing to qualify his materials. The proposed specification makes allowance for smaller projects, projects generally requiring less than 10,000 cubic yards of concrete.

However, the end product requirements for small as well as large projects are similar to ensure the concrete pavement will be durable and FOD-free.

2.0 SUBMITTALS

Submittals are required from the contractor to assess the level of conformance with the project specifications. The submittals list is always a challenge for both the contractor and the engineer. The contractor may not fully understand what needs to be provided to the engineer and many engineers may not fully understand what to specify and how to review many of the submittals, including the submittal for the concrete mixture proportions.

The submittals to be provided to the engineer may include information provided by equipment makers, material suppliers, State DOT certification, and contractor sponsored material test data.

All personnel and laboratories conducting the aggregate and concrete related testing for the project need to meet the requirements of Para. 8.1 – Testing Personnel and Para. 8.2 – Testing Laboratory Requirements, respectively. These requirements are important to assure that the testing is reliable, accurate and precise. Highly variable test results can be costly to the contractor and may result in time delays.

Three categories of submittals are required, as follows:

2.1 Pre-construction Submittals

These submittals are related to qualification of materials, concrete mixtures and equipment. These submittals should be submitted to the engineer before concrete placement activities can begin. These submittals include, but are not limited to, the following:

1. Qualifications of the plant inspector, if applicable.

2. Concrete plant checklist as per the National Ready Mix Concrete Association (NRMCA) QC 3 process.
3. Concrete testing laboratory certification.
4. Contractor testing personnel certification.
5. Cement mill certificates.
6. Supplementary cementing material mill certificates.
7. Aggregate certification.
8. Admixture certification.
9. Water certification.
10. Expansion board certification.
11. Embedded steel certification.
12. Tie bar steel certification.
13. Dowel bar coating certification.
14. Dowel bar bond breaker certification.
15. Dowel anchoring mortar certification.
16. Curing material certification.
17. For each concrete mixture to be used:
    a. Combined aggregate grading.
    b. Concrete mixture proportions.
    c. Flexural versus splitting tensile strength correlation data, if applicable.
    d. Concrete uniformity test results.
18. Weather management plan.
19. Contractor quality control/acceptance testing program.

2.2 Process Control Submittals

These submittals are related to the contractor's process control to ensure that quality control measures are integrated during each day of production paving. These submittals include, but are not limited to, the following process control tests:

1. Accuracy of plant batching.
2. Aggregate quality.
3. Combined aggregate gradation – Workability and Coarseness Factors.
4. Air content.
5. Concrete temperature.
6. Dowel bar alignment.

2.3 Contractor Acceptance Testing Submittals

These submittals are related to the required acceptance testing to ensure that the owner is provided with a product that has been specified. These submittals include, but are not limited to, the following acceptance testing tests:

1. Concrete thickness.
2. Concrete flexural strength.

Some key submittals related issues are listed below:

1. Cement supplies need to be secured to ensure supply during the peak construction season. If the cement source is changed, additional mix design and compatibility testing is required. It is advisable to pre-qualify mixture designs using different cementitious materials so that if a substitution needs to be made, the mix design data are already available and the new materials can be accommodated without delay.
2. Typically, about 60 to 90 days lead-time is available from contract award to start of work, so aggregate acceptance needs to be done within that time or before the award.
3. The materials related submittals need to be submitted for the engineer's review before new materials are used for the work.
4. For aggregate and concrete mixtures to be used on the project, the pre-construction certifications, except for the reactive aggregate mitigation plan, developed using materials sampled not more than 180 days before the start of concrete placement are acceptable. The certification shall include flexural versus splitting tensile strength correlation data, if applicable, for the concrete mixture to be used for the project.
5. Cement and supplementary cementing material mill certification need to be submitted for each truckload of the material for the engineer's review within 24 hours of material delivery.

3.0 MATERIALS

The engineer and the contractor need to understand the many and sometimes complex requirements related to concrete materials. The contractor needs to be aware that if alternate materials are going to be proposed, he needs to ensure that the testing requirements of the specification are met. Testing requirements for concrete aggregates may have long lead times and scheduling conflicts could arise if materials are not pre-qualified in a timely manner.

3.1 Cementitious Materials

Cementitious materials include hydraulic cements such as Portland cement and ground granulated blast furnace slag (GGBFS) and pozzolanic materials such as fly ash. Fly ash and GGBFS are also referred to as supplementary cementitious materials (SCMs). Current practice for paving concrete is to incorporate Portland cement and a SCM. Although not a common practice, some agencies allow use of ternary concrete mixtures that incorporate Portland cement and two SCMs. Because there is not yet long-term experience with ternary mixes, its use should be considered with caution and balanced with the need for considering the ternary mix.

The use of supplementary cementitious materials may offer the potential of improved performance of concrete and/or reduced cost. These materials, as partial replacement of Portland cement, may provide some benefits more economically and sometimes more effectively than use of 100% Portland cement. The benefits include:

1. Control of expansions due to alkali-silica reaction.
2. Sulfate resistance.

3. Reduced heat of hydration.
4. Long-term strength gain.
5. Improved workability.
6. Reduced permeability.

Engineer Notes

1. Check local availability of cements before specifying cement types.
2. Do not specify cements with special properties unless these properties are necessary.
3. Limiting a project to a single cement type or a single brand may result in increased costs, and project delays.
4. Specifications should focus on the specific needs of the project and allow use of a variety of materials to accomplish these needs.

Contractor Notes

1. Cement supplies need to be secured to ensure supply during the peak construction season. If the cement source is changed, additional mix design and compatibility testing is required.
2. It is advisable to pre-qualify mixture designs using different cementitious materials so that if a substitution needs to be made, the mixture design data are already available and the new materials can be used without delay.

3.1.1 Hydraulic Cement

Hydraulic cements need to conform to one of the following ASTM standards:

1. ASTM C 150 (portland cement)
2. ASTM C 595 (blended cement)
3. ASTM C 1157 (hydraulic cement).

ASTM C 150 specifies five types of cement, not all of which are available in all areas of the United States and Canada. The cement types are:

1. Type I, the most widely available, is used when the special properties of the other types are not required.
2. Type II is for general use, but particularly when either moderate sulfate resistance or moderate heat of hydration is required. Some cements meet the requirements for both Types I and II and are designated Type I/II.
3. Type III cement is used for high early strength.
4. Type IV is used when low heat of hydration is required. However, Type IV cement is not readily available in the U.S.
5. Type V is used for high sulfate resistance.

Additional notes related to ASTM C 150 cements:

1. ASTM C 150 specifies optional chemical requirements, such as limits on the maximum alkali content, and optional physical requirements, such as heat of hydration. These need to be specified carefully, if at all, since they will often add to the cost and/or limit the available options. Frequently there are equally acceptable or even preferable alternatives. For example, deleterious expansions due to alkali-silica reaction may be controlled as well or better by a combination of cement with Class F fly ash and/or slag than with low-alkali cement.
2. It is generally not advisable to specify a maximum limit on the alkali content of the cement. This may not be sufficient to control deleterious expansions. In some cases, higher alkali content may be desirable to increase the rate of hydration during cool weather or when supplementary cementitious materials are being used.
3. Sulfate resistance may be obtained by the use of sufficient quantities of slag or an appropriate fly ash as well as (or better than) a Type II or Type V cement.
4. Heat of hydration may be reduced by the use of some combination of slag, Class F fly ash, and/or natural pozzolan with Portland cement.
5. If the cement is to be used on its own (that is, without supplementary cementitious materials), it may be advisable to specify the optional requirement for false set. However, setting characteristics need to be evaluated on concrete.

ASTM C 595 specifies blended cements as follows:

1. Type IS cement (portland blast-furnace slag cement) contains blast furnace slag.
2. Types IP cement (portland-pozzolan cements) contains pozzolan (fly ash or natural pozzolan).

The cements designated under ASTM C 595 have comparable strength requirements as those specified by ASTM C 150 for Type I cement. However, the actual strengths at early ages will generally be somewhat lower because slag and pozzolans included in blended cements react more slowly than cement alone. The naming practice for blended cements requires addition of a suffix (X) to the type designation, where (X) equals the targeted maximum percentage of slag or pozzolan in the product expressed as a whole number by mass of the final blended product.

ASTM C 1157 is a specification for hydraulic cements that sets limits on their performance attributes. These cements must meet physical performance test requirements, as opposed to prescriptive restrictions on ingredients or cement chemistry as found in other cement specifications. This specification is designed generically for hydraulic cement to include Portland cement and blended cement and includes six types of Portland and blended cements as follows:

1. Type GU is for general use.
2. Type HE is for high early strength.
3. Type MS is for moderate sulfate resistance.
4. Type HS is for high sulfate resistance.
5. Type MH is for moderate heat of hydration.

6. Type LH is for low heat of hydration.

As of 2007, ASTM C 1157 has not been widely used for airport pavement applications.

Cement Certification and Uniformity

Concern has been expressed by agencies that cements and clinkers are being imported to the US from a variety of sources and that these materials are not being adequately tested. There is also a concern that cement delivered on one day may be from one source and another day from another source, possibly leading to variability in the fresh concrete properties and performance of the concrete.

The mill certificates are often provided monthly by cement manufacturers. These certificates report an average of multiple tests conducted on composite samples taken at intervals (typically daily) from the plant. While these may confirm that, on average, the cement was compliant with the specification, there is little assurance that every load delivered to the project site has done so. The primary warrant for better characterization of the as-delivered cement is that the contractor is then able to respond in a timely manner if the cement is varying sufficiently in composition and properties. This is a contractor quality control issue. A difficulty inherent in asking for frequent reporting is that the testing, by definition, will take several days to conduct, therefore a full report is likely only available some time after the cement has been used. In addition, the contractor typically does not have excess storage capacity available at the site to hold the cement while testing is performed on the delivered cement.

The contractor should review the cement chemical analyses and the mortar cube strength data for each cement load delivered to monitor the overall uniformity of the cement being delivered.

The following recommendations on interpreting cement data are intended as broad guidelines.

- High C_3A cements (>8 percent) are more likely to be prone to aluminate/sulfate imbalances. Changes of more than 2% may indicate potential changes in the performance of the mixture, especially with respect to the risk of early stiffening of the concrete.
- Likewise, it is not the total sulfate content that is of concern, but materials with low sulfate contents (<3 percent) are more likely to be problematic. Changes of more than 0.5% may indicate potential changes in the performance of the mixture, especially with respect to the risk of early stiffening of the concrete.
- Cements with high alkali contents (>0.8) are generally more reactive and may therefore be more prone to unexpected or imbalanced reactions including greater risk of cracking and air-void system problems. Changes of more than 0.2% may indicate potential changes in the performance of the mixture.

- The finer the cement, the greater the risk of uncontrolled C_3A reactions with other ingredients in the concrete. Changes of more than 50 m^2/kg may indicate potential changes in the performance of the mixture.

In addition, cement sources should be identified for each cement load. A change in cement source will require submittal of new concrete mixture proportions.

3.1.2 Supplementary Cementitious Materials

For airport paving applications, the choice of SCM should be limited to fly ash and GGBFS. The delayed set time and lower shrinkage with mixtures containing SCMs may be a benefit on high-friction bases such as open-graded stabilized drainage layers.

The replacement dosage for SCMs (flyash and GGBFS) should be compatible with the needs for strength and durability. The desired SCM content should be established considering the importance of early strength, durability concerns, the curing temperatures, and the properties of the SCMs, the cement, and other concrete materials. The replacement dosage rates are discussed in Para. 4.1.

<u>Contractor On-Site Cement Testing</u>

It is recommended that the contractor retain 10 lb of cement and 10 lb of each SCM as weekly composite samples to be available for forensic analyses should concrete placement or concrete testing problems or early age distress develops.

In addition, it is recommended that the contractor perform a simple reactivity test for cement deliveries for internal quality control. This could be simply mixing a small amount of cement, water (at the target water cement ratio), sand and chemical admixtures and recording the temperature gain in an insulated 4x8-in. cylinder mold. Developing a baseline on the test section cements will provide an indicator of the relative reactivity for each day's delivery. Changes in the peak temperature (>10°F) and/or the time when temperature starts to rise (>30 minutes) will indicate potential changes in the performance of the mixture.

The contractor may also wish to perform a 3-day or a 7-day cement strength test as per ASTM C 109 for each day of concrete paving.

During warm summer months, the contractor should monitor the temperature of cement as delivered. Hot (fresh from the mill) cement use during peak construction season may result in:

- Tendency to false set
- Admixture demand increase – May need more in the field than required in the laboratory.

It should be noted that fly ash and slag are covered under the Environmental Protection Agency's Comprehensive Procurement Guidelines (CPG). The CPGs are Federal Law that requires federally funded construction projects to include certain recycled materials in construction specifications. Concrete specifications, therefore, must include provisions that allow use of fly ash and slag. The CPGs state that no preference should be given to one of these materials over another; rather, they should all be included in the specification.

3.1.2.1 Fly Ash

Fly ash must meet the requirements of ASTM C 618. However, care should be taken in applying ASTM C 618, as it is rather broad. Class F fly ash is the preferred choice for controlling ASR and it also improves sulfate resistance. Selection of fly ash type and dosage for ASR mitigation should be based on the guidelines provided in the proposed specification.

Key items related to fly ash use are:

1. Typical dosages for Class F fly ash are generally between 15 percent and 25 percent by mass of cementitious materials. Sources must be evaluated for typical usage rates.
2. In cool weather, concrete with Class F fly ash may not gain strength rapidly enough to allow joint sawing before shrinkage cracks begin to form. Generally this does not occur at lower (about 20 percent) dosage, but appears frequently at 25 percent and higher dosage rates.
3. As the amount of fly ash increases, some air entraining and water reducing admixtures are not as effective and require higher dosage rates due to interactions with the carbon in the fly ash. The dosage of admixtures will further increase as the daytime temperature increases. This generally occurs when the fly ash content is 25% or more.
4. While ASTM C 618 permits up to 6% LOI, experience has shown that materials containing 4% or more LOI will likely result in difficulties in achieving the required air void system consistently. Changes in LOI will indicate changes in the amount of air-entraining admixture required in the mixture. If the source of the fly ash is likely to be variable, it is advisable to conduct a “Foam Index Test” on each delivery so that such changes can be accommodated (Ref. 3).
5. Some Class C fly ashes perform very well, while others have been problematic. Sources must be evaluated independently. Class C fly ashes with high C3A contents may cause problems with premature stiffening, particularly in hot weather. The potential for early stiffening in the presence of certain water reducers and in hot weather should be verified.
6. If fly ash will be used to control expansions due to ASR, the lower the CaO content the more effective it will be. Ideally, the CaO content should not exceed 8 percent. The fly ash effectiveness and dosage requirements should be verified by test.
7. Natural pozzolans are available either as components of Type IP cement or as additives. They can be effective in controlling expansions due to alkali-silica reaction and in reducing heat of hydration.
8. Some regions of the country only have a fly ash that may vary from a Class F to a Class C from day to day due to small changes in their chemistry. These fly ashes should meet the uniformity requirements of ASTM C 618, Table 3.

Additional guidance on the use of fly ash in paving concrete is given in Ref. 4.

3.1.2.2 Ground Granulated Blast Furnace Slag (GGBFS)

Finely ground granulated blast furnace slag must meet the requirements of ASTM C 989. The following three grades are based on their activity index:

1. Grade 80. This is the least reactive and is typically not used for airport projects and is not allowed.
2. Grade 100. This is moderately reactive.
3. Grade 120. This is the most reactive, with the difference obtained primarily through finer grinding. Grade 120 is often difficult to obtain in some regions of the U.S.

Typical dosages of slag should be between 25 percent and 50 percent of cementitious materials. It should be noted that concrete strength at early ages (up to 28 days) may be lower using slag-cement combinations, particularly at low temperatures or at high slag percentages. The desired concrete properties must be established considering the importance of early strengths; the curing temperatures; and the properties of the slag, the cement, and other concrete materials.

If the concrete is to be used when the air temperature is expected to be lower than 55 F, the percent of the slag should not exceed 30 % by weight of the cementitious materials.

3.1.2.3 Other SCMs

Fly ash and slag are the two most common SCMs used for airport paving applications. Another SCM that is used for certain applications, e.g., bridge deck concrete, is silica fume. Use of silica fume results in very low permeability concrete and can also increase concrete strength. However, because of cost considerations, use of silica fume is not a standard practice for airport concrete paving.

3.2 Aggregates

Aggregates are a key component of concrete and can affect the properties of fresh and hardened concrete. Aggregate selection should allow for maximizing the volume of aggregate in the concrete mixture in order to minimize the volume of cementitious paste without compromising the workability, durability and strength of the concrete mixture. The specification does make references to aggregates as coarse and fine aggregates. Rather, the aggregate size distinction is based on aggregates passing the No. 4 sieve or that retained on the No. 4 sieve.

<u>Maximum Aggregate Size</u>

The concern with size involves selecting an aggregate that will maximize aggregate volume and minimize cementitious materials volume. The method of placement and finishing also influences aggregate size selection. In general, the larger the maximum size of the coarse aggregate, the less cementitious materials are required, potentially leading to lower costs, less heat of hydration during hot weather and reduced shrinkage. Ideally, the contractor should determine the maximum aggregate size to be used. He should base his selection on project specific needs and locally available aggregates. Exceptions to this include the following cases:

1. Use of smaller maximum size aggregate (e.g., ¾-in. maximum size) for D-cracking regions. However, the use of ¾ inch maximum aggregate size alone does not prevent D-cracking, and many state agencies have criteria for D-cracking other than maximum aggregate size. The ¾ inch is only to be specified by the engineer after careful consideration of D-cracking mitigation methods, discussed in Para. 3.2.2 Aggregate Quality.

2. Owner-specific criteria.

Aggregate Sizes

The contractor is permitted to use any number of aggregate sizes to optimize the combined aggregate gradation (discussed next). Typically, three aggregate sizes can result in an optimized combined gradation that will produce a workable concrete mixture for slipform paving.

3.2.1 Gradation Evaluation of the Proposed Aggregates

This specification is targeted for a combined aggregate gradation. This approach evaluates the mixture properties based upon the combination of all of the aggregates, and does not require specification of individual coarse, intermediate and fine aggregates. The aggregate grading should be based upon a combined gradation of all the aggregates to be used for the mixture proportioning studies. Grading reports should include the following sieve sizes: 2 ½ inch, 2 inch, 1.5 inch, 1 inch, ¾ inch, ½ inch, 3/8 inch, No. 4, No. 8, No. 16, No. 30, No. 50, and No. 100.

Method of Evaluation

Shilstone (Ref. 8) first published information on the use of combined gradations for concrete applications. The U.S. Air Force first implemented the use of combined aggregates for airfield pavements in 1997 with their specification and handbook, ETL 97-5 (Ref. 6), which was based in part on the Shilstone publication. The Air Force requirement was initiated due to joint and surface spalling that developed within one year of paving. The problem was investigated by the U.S Army Waterways Experiment Station (Ref. 7). One conclusion was that the failures were "primarily due to poor construction practices that may be caused or at least exacerbated by poor concrete mixture proportioning." The U.S. Air Force conducted a follow-up study (Ref. 8) and concluded that projects "constructed with aggregates near to being dense graded perform better than those with gap graded or poorly graded aggregates."

It is recognized that the use of combined gradations is a positive direction for airfield pavements, especially in the reduction of joint spalls and FOD potential. However, there is no single industry standard for establishing the optimum combined aggregate gradation that is directly applicable for all airfield applications. The military specification for airfield concrete pavement construction requires use of combined aggregate gradation. Several State Departments of Transportation have also developed combined gradation requirements for highway concrete pavements. The proposed specification incorporates a Standard Method to evaluate the combined aggregate gradation. The Standard Method is based on the Shilstone method and allows for material variation in various regions.

It is mandatory that the method given in the specification be used to evaluate if the aggregates meet the criteria for an optimized combined gradation. If the criteria for an optimized combined aggregate gradation are not met, the aggregates proportions may need to be adjusted or new aggregates may be required.

Concrete mixtures produced with a combined aggregate gradation that produces a dense aggregate matrix tend to:

1. Reduce the water demand
2. Reduce the cementitious material demand
3. Reduce the shrinkage potential
4. Improved workability
5. Require minimal finishing
6. Consolidate without segregation
7. Enhance strength and long-term performance.

Concrete mixtures produced with a gap graded aggregate combination may:

1. Segregate easily
2. Contain higher amounts of fines
3. Require more water
4. Require more cementitious material to meet strength requirements
5. Increase susceptibility to shrinkage
6. Limit long-term performance.

Key items to note:

1. The contractor may choose to purchase the individual aggregates based upon ASTM C33 or State DOT gradations. However, it is advisable for the contractor to specify the standard stone size or name, the gradation and the tolerances on each sieve of the gradation. Use of ASTM C33 or State DOT materials does not negate meeting the aggregate quality requirements of the proposed specification.

2. There is no limit on the number of aggregates that may be used. In many instances, the mixture proportioning studies will indicate a need for aggregates in the 3/8 to No. 4 range to improve the workability of the mixture. Typically, contractors use three aggregates to produce a dense graded aggregate.

3. The combined gradation approach does allow the use of materials that would not normally meet individual gradations for ASTM C33 or state DOT products.

4. There are significant differences between the optimum particle distribution of natural rounded gravel and sand and elongated stone, flat crushed stone, and manufactured sand. Generally, as the particles become flatter, elongated, or sharper on the edges; the greater is the need for fine aggregate, admixtures and water to lubricate the concrete and facilitate placement and finishing.

5. In the past, gap graded aggregates meeting the gradation limits of ASTM C 33 were routinely used for airport paving concrete. The proposed specification emphasizes that the aggregate gradation be optimized by using a combined aggregate gradation that produces a dense aggregate matrix that can be easily placed, consolidated and finished.

The prescribed method of evaluation is based on the Workability and Coarseness Factors Method. The Workability and Coarseness Factors are determined for the combined aggregate gradation as follows:

1. The Workability Factor is the percent of the combined aggregate that passes the No. 8 sieve.

2. The Coarseness Factor is the percent of material retained on the 3/8-inch sieve divided by the percent of all the aggregate retained on the No. 8 sieve and multiplying the ratio by 100.

The Workability Factor indicates how much of the total aggregate is fine aggregate and provides an estimate of the degree of the mobility of the mixture or the ease of placement of paving mixtures. It has no relationship to consistency or slump of concrete. The Workability Factor can vary from inadequate to excessive. Maintaining the Workability Factor within the range of recommended limits provides a greater assurance that the concrete mixture has been optimized for workability, durability, and strength.

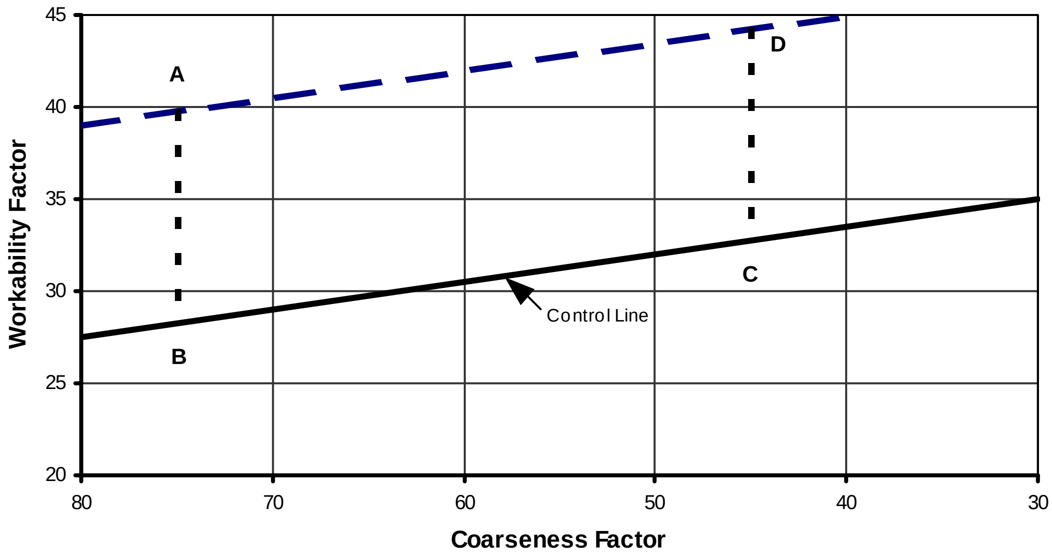
A Coarseness Factor of 100 describes a gradation that has no intermediate aggregate, i.e. no particles retained on the No. 4 and No. 8 sieves. A value of zero describes a mixture with no coarse aggregate, i.e. no particles retained on the 3/8-inch sieve. Maintaining the Coarseness Factor within the range of recommended limits provides a greater assurance that the concrete mixture has been optimized for workability, durability, and strength.

Combined Aggregate Gradation Criteria

The aggregates, as proportioned, shall be deemed to have met the requirements of a combined aggregate gradation when the following criterion is achieved:

- The WF and CF shall be within the parallelogram ABCD of the Aggregate Constructability Chart (Figure 1).

In accordance with the Shilstone method, materials with WF and CF within parallelogram ABCD of Figure 1 are considered as meeting the criteria for optimized combined aggregate gradation. The diagonal control line defines a region where combined rounded or cubical crushed stone and well-graded natural sand are in balance. However, such mixtures have limited application, as the aggregate gradation must be well controlled. These mixtures are often excellent for bucket placed concrete in large footings. Mixtures represented by plots above the control line identify mixtures with increasing amounts of fine aggregate. Those below the control line generally contain an over abundance of coarse particles and are not desirable for concrete paving.



Point A – CF = 75; WF = 40; Point B – CF = 75; WF = 28
Point C – CF = 45; WF = 32; Point D – CF = 45; WF = 44

Figure 1 – Aggregate Constructability Chart

It is recognized that some airports and contractors may not have used a combined aggregate gradation due to availability of local materials. However, the use of gap graded concrete is not acceptable in the proposed specification. Gap-graded aggregates are prone to workability issues, segregation and joint spalling - elements that affect long-term durability of the concrete pavement.

Based on field experience, not all mixes contained within parallelogram ABCD of the Aggregate Constructability Chart may be workable and durable. The contractor may still need to further refine the mixes to be workable for the paving equipment and conditions.

<u>Aggregates Not Meeting Optimized Combined Aggregate Gradation Criterion</u>

In regions where achieving an optimal combined gradation is difficult because of availability of aggregate types, other innovative methods should be explored. The economics of the project will dictate the methods to be used. If possible, a four bin plant will provide a significant amount of flexibility to the contractor to adapt to local aggregate markets. The aggregate supplier may also have the ability to pre-blend aggregates. Some contractors use double-washed asphalt sand to provide the proper sizing to improve the combined gradation.

3.2.2 Aggregate Quality

Deleterious Substances

Deleterious substances are contaminants that are detrimental to the aggregate's use in concrete and need to be considered for the aggregate portion retained on the No. 4 sieve as well as for the aggregate portion passing the No. 4 sieve. ASTM C 33 lists the following as deleterious substances:

1. Clay lumps and friable particles
2. Chert (with saturated surface dry specific gravity < 2.40)
3. Material finer than No. 200 sieve
4. Coal and lignite

For the coarser portion of the aggregate, the maximum allowable portions of the deleterious substances are dependent on the weathering region. Inclusion of larger than allowable amounts of the deleterious substances can seriously impact both the strength and durability of concrete.

Soundness

The soundness test measures the aggregate's resistance to weathering, particularly frost resistance. ASTM C 88 test for soundness has a poor precision record. Aggregates that fail this test may be re-evaluated using ASTM C 666 or its suitability determined on the basis of local service history.

Flat and Elongated Pieces

Flat and elongated particles impact workability of fresh concrete and may negatively affect the strength of hardened concrete. Thus, the amount of these particles needs to be limited.

Los Angeles Abrasion Test

The Los Angeles Abrasion Test provides a relative assessment of the hardness of the aggregate. Harder aggregates maintain skid resistance longer and hardness is an indicator of aggregate quality.

Durability (D-Cracking)

Durability cracking (D-Cracking) is a concern for aggregate particles that have a coarse pore structure and which are saturated and subjected to freezing. It is a good practice to review the successful State DOT practices to determine if locally available materials are susceptible to D-cracking and to identify successful mitigation measures implemented by the DOT. The engineer must carefully incorporate successful DOT methods for D-cracking to avoid conflicting with other necessary criteria in this specification.

The following is recommended.

1. The engineer shall determine if D-cracking related requirements are necessary based on local experience. Typically, the State DOT will have already identified D-Cracking issues, and the engineer shall insert the State DOT provisions for appropriate approved aggregate sources. Note that the State DOT requirements for D-cracking may be different than for maximum aggregate size. Therefore, this item should be coordinated with Para. 3.2 - Aggregates. The engineer is cautioned to carefully refer to the applicable State DOT specifications related to D-cracking to ensure that these requirements will not conflict with other coarse aggregate requirements in the proposed specification. Do not make a blanket reference to DOT standards; carefully select and cite the appropriate paragraphs and sections; and ensure non-applicable references in the DOT manual to other DOT requirements are stricken.

2. If the Contractor uses an out of state aggregate source and the State from where the aggregates are originating from does not have D-cracking related requirements that equal or exceed the requirements of the local State DOT, the engineer will require the conduct of ASTM C-666 testing, knowing that a lead time of about 4 months will be necessary to conduct the ASTM C-666 testing. The Durability Factor shall be $\geq$ 95 (Method A).

3. Some airport projects may be close to state borders where importing better quality aggregates is desirable by the Contractor. In these situations the engineer shall consider the surrounding state materials and include applicable provisions discussed above.

4. There is no specific requirement of service record as this requirement is incorporated in a State DOT's approval of an aggregate source. Also, there is no specific discussion of mitigation methods such as use of smaller sized aggregates as such guidance and requirement will be incorporated in the State DOT's approval of an aggregate source.

5. Some state-specific requirements in severe D-cracking states that have been used for FAA projects in the past may be used after a determination is made that these requirements are still applicable.

Slag Aggregates

Properly aged air-cooled iron ore blast-furnace slag aggregates should only be used as a coarse aggregate if there is substantial history of successful pavement performance at the airport

1. Control of moisture content is very important when slag aggregates are used. Potential problems include variations in workability and consolidation. The porosity of the individual slag aggregates may vary, therefore the moisture demand may vary.
2. If slag aggregate moisture is not managed well, the in-place concrete may exhibit honeycombing and poorly formed edges.

Steel-making slag (from open-hearth basic oxygen or electric arc processes) should not be used as concrete aggregate because of the expansive nature of the steel slag aggregates. Also, fine aggregate manufactured from steel slag should not be used in paving concrete.

Recycled Concrete Aggregates

Use of recycled aggregate for airport concrete paving is cautioned. If specified, recycled concrete aggregate needs to be from a single known source, such as a pavement that is being demolished as part of the project. Use of recycled concrete from a commercial recycle yard should not be permitted as it may include reactive, deleterious or variable materials and it is not possible to quantify the sources. The engineer needs to have petrographic testing conducted, especially for Alkali Silica Reactivity (ASR) and Durability Cracking (D-Cracking) prior to specifying recycled aggregates and not allow the recycled concrete if these or other detrimental properties are present. Additional concerns with recycled aggregate include:

1. Recycled concrete generally has a higher absorption than virgin aggregates and may require more water to achieve the same workability than with virgin aggregates.
2. Recycled aggregate may also require added cement to achieve desired workability.
3. A critical problem with recycled aggregate use is that the variability in the properties of the old concrete may affect the properties of the new concrete.

Manufactured Sand

Manufactured sand should be accepted only if it is the primary product of a crushing operation and is sized by a sand classifier. The sharpness and angularity of manufactured sands may result in a harsher concrete mixture that is difficult to finish. Such concrete mixtures may require more water. The proportion of the manufactured sand should be adjusted during the test section construction if there is difficulty with concrete workability and finishing.

3.2.3 Aggregate Reactivity

Alkali-silica reaction (ASR) is a deleterious chemical reaction between the reactive silica constituents in the aggregates and alkali hydroxides in the concrete. The product of this reaction often results in significant expansion and cracking of the concrete. In addition, use of deicing chemicals can also result in a reactivity problem. Additional information on ASR can be found in FAA Advisory Circular 150/5380-8 – *Handbook for Identification of Alkali-Silica Reactivity in Airfield Pavements*.

In the past few years, several documented field observations have indicated an increase in ASR activity in the presence of deicing chemicals. Research sponsored by the FAA through IPRF indicate that distress in the surface of the concrete pavement is caused by exposure to deicing chemicals such as Potassium Acetate (KA), Sodium Acetate (NaA), and Sodium Formate (NaF) (Ref. 5). These deicers provide high levels of alkali and accelerate alkali-silica reactions at the pavement surface. Concrete pavements that are otherwise resistant to ASR may show rapid deterioration when exposed to these high alkali-based deicers (Ref. 5).

The research in the area of ASR and the impact of deicers is on-going at the time of this report. The provisions related to ASR testing are based on best current practices. The provisions related to ASR testing and mitigation for deicer use airports are based on the recommendations given in FAA Engineering Brief 70 – *Accelerated Alkali-Silica reactivity in Portland Cement Concrete Pavement exposed to Runway Deicing Chemicals*, dated December 13, 2005.

The engineer will determine if the airport pavement is subject to deicer use. Delete Para. 3.2.3.1 and Para. 3.2.3.2 when the airport pavements are to be subjected to deicer use. The engineer shall delete Para. 3.2.4, Para. 3.4.1, Para. 3.4.2, and Para. 3.4.3 if the airport pavements are not to be subject to deicer use.

The engineer will consider the time requirement for ASR-related testing when the project is advertised and when it is let to allow the contractors adequate time to perform the necessary ASR-related testing.

3.2.3.1 Reactive Aggregate Screening

The Contractor shall determine if the aggregates are deleteriously reactive with alkalis in accordance with ASTM C 1260. The aggregate used for the coarse fraction and the aggregate used for the fine fraction are evaluated independently. Test results that have a measured expansion equal to or greater than 0.10% at 16 days from casting indicates an aggregate that is reactive. The results of testing shall be submitted to the Engineer.

Aggregates determined to be reactive shall be rejected or the Contractor shall develop an alkali-silica reactivity (ASR) mitigation plan in accordance with Para. 3.2.3.2 – [Not Used] [ASR Mitigation for Airport Pavements.

3.2.3.2 ASR Mitigation

The Contractor shall establish the reactive aggregate mitigation plan in accordance with ASTM C 1567 with components of the mortar bar (e.g. coarse aggregate, fine aggregate, cementitious materials, and/or specific reactivity reducing mineral admixtures or chemicals) in the proportions proposed for the concrete mixture. If the expansion of the proposed mixture design test specimens does not exceed 0.08% at 16 days from casting, the aggregates will be accepted. If the expansion of the proposed mixture design test specimens is greater than 0.08% at 16 days from casting, the aggregates will not be accepted unless adjustments to the mixture design can reduce the expansion to less than 0.08% at 16 days, or new aggregates shall be evaluated and tested. The results of testing shall be submitted to the Engineer.

3.2.4 Aggregate Reactivity- Deicer Use Airports

The testing requirements of this section are based on FAA Engineering Bulletin 70. The bulletin should be referred to for additional details on the testing requirements.

3.2.4.1 Reactive Aggregate Screening

This testing is similar to that of Para. 3.2.3.1 – Reactive Aggregate Screening, except use of ASTM C 1567 is not allowed. The aggregate used for the coarse fraction and the aggregate used for the fine fraction are evaluated independently using ASTM C 1260. Test results that have a measured expansion equal to or greater than 0.10% at 30 days from casting indicates an aggregate that is reactive. The results of testing shall be submitted to the Engineer.

Aggregates determined to be reactive shall be rejected or the Contractor shall develop an alkali-silica reactivity (ASR) mitigation plan in accordance with Para. 3.2.4.3 – Reactive Aggregate Mitigation.

3.2.4.2 Reactive Aggregate Screening with Deicer Soak Solution

This testing is similar to that of Para. 3.2.4.1, except the ASTM C 1260 test is conducted using a 50% potassium acetate soak solution and test results at 30 days from casting are used. The aggregate used for the coarse fraction and the aggregate used for the fine fraction are evaluated independently. Test results that have a measured expansion equal to or greater than 0.10% at 30 days from casting indicates an aggregate that is reactive. The results of testing shall be submitted to the Engineer.

Aggregates determined to be reactive shall be rejected or the Contractor shall develop an alkali-silica reactivity (ASR) mitigation plan in accordance with Para. 3.2.4.3 – Reactive Aggregate Mitigation.

3.2.4.3 Reactive Aggregate Mitigation

Comprehensive guidance for mitigation of reactive aggregates is given in FAA Engineering Bulletin 70. The following should be noted:

1. Reactivity of aggregates vary with different cements, pozzolans, and slags at different dosages.
2. For Class F fly ash to be effective, replacements greater than 15% are probably necessary.
3. When using Class F fly ash or other SCM, the impact of high replacement quantities (> 20% cement replacement) on the plastic properties of production concrete must be considered.
4. Strengths for opening to traffic may not be met in the time desired when high replacement rates of SCMs are used.
5. Concrete with high replacement quantities of fly ash must be evaluated for workability, finishability, and higher than normal dosage of air-entraining agents.
6. When lower cement contents are used as part of the mitigation, the impact on strength requirements should be evaluated.
7. When Lithium Nitrate is used as a mitigation tool, the normal dosage is the amount necessary to maintain a 0.74 molar ration. This is equivalent to 0.55 gallons per pound of sodium equivalent from the cement per cubic yard. When used within these dosage rates, the impact on the properties of plastic concrete are minimal. However, total water and air content must be monitored to ensure concrete consistency.

> <u>Updated Guidelines to Screen for and Mitigate Aggregate Reactivity</u>
>
> It is expected current guidelines related to ASR will continue be updated or replaced as more research findings become available. In regions where ASR is a concern, the engineer needs to seek expert advise on the most current guidance for screening and mitigating procedures for ASR and the engineer should insert the most current language into the specification.

3.3 Water

Suitable mixing water for making concrete includes potable water (fit for human consumption), non-potable water, and recycled water from concrete production operations. Testing is required for the last two sources or any questionable water to ensure that they do not contain impurities that affect strength, set time or other concrete properties. Acceptance criteria for water to be used in concrete are given in ASTM C 1602.

3.4 Chemical Admixtures

Chemical admixtures are ingredients commonly used in paving concrete and their use is well established. They are used to obtain or enhance specific properties of concrete, such as, workability, setting time, or air content. The following practices related to chemical admixtures should be observed:

1. Chemical admixtures must meet the requirements of ASTM C 260 or ASTM C 494. ASTM C 260 specifies the requirements for air-entraining admixtures.
2. For concretes with multiple admixtures, the admixtures need to be purchased from the same manufacturer. The large manufacturers test their own admixtures for incompatibility and other interactions and can provide helpful advice for avoiding undesirable reactions.
3. Not all admixtures work well in all applications. For example, the low slumps typical of paving concrete make certain air-entraining admixtures less effective.
4. The contractor is encouraged to seek the advice of the manufacturer on applying and using admixtures. Batching requirements, mixing procedures, and recommended dosages need to be obtained from the manufacturer. Exact dosages for the particular concrete mixture design need to be determined through the use of trial batches.
5. Placement temperatures affect the required dosages of chemical admixtures. Trial batches should be developed accordingly.
6. Admixtures are never used to compensate for marginal concrete mixtures.
7. The admixtures must be added separately to the concrete. Admixtures should not be put directly on dry aggregate or on dry cement, as they may be absorbed and not available to readily mix with the concrete.
8. Consult the manufacturer for information about potential interactions between admixtures.
9. Some water reducers may retard setting and/or strength gain when used in higher dosages.

> Proper Use of Admixtures
>
> As stressed by Neville (Ref. 20), while properly used admixtures are beneficial to concrete, they are no remedy for poor quality materials, for use of incorrect mixture proportions, or for poor workmanship in transporting, placing, and consolidating the concrete.

3.4.1 Air-Entraining

Air-entraining admixtures entrain a system of finely divided air bubbles in the cement paste. They are essential protection for any concrete that will be exposed to freezing, as they provide outlets for freezable water to expand so that it does not disrupt the internal structure of the concrete. Air-entraining admixtures may also be used to improve the workability of fresh concrete. They may also reduce water demand, bleeding, and segregation.

The selection of an admixture, meeting the requirements of ASTM C 260, needs to be appropriate for pavement use; some admixtures are meant to be used only in concretes with higher slump allowances than that typical of airfield pavements. Also, the dosage rate needed to obtain the desired air content will be affected by ambient temperature, w/cm ratio, types of cementitious materials, aggregate gradation, mixing time, and other admixtures in the concrete mixture.

Synthetic Air-Entraining Admixtures

Since late 1990's, it has been recognized that use of synthetic AEAs may lead to low concrete strengths due to clustering of air voids around coarse aggregate particles, for concrete delivered by transit truck mixers. Studies conducted by the Portland Cement Association, South Dakota DOT and others have confirmed this behavior. In summary, use of synthetic AEAs may lead to the following:

1. Air voids may randomly flocculate around aggregate particles and become similar to entrapped air.
2. Air void clustering around aggregates particles reduce the paste-aggregate bond interface area, leading to low compressive and flexural strengths.
3. Air void clustering typically develops after late addition of water to the concrete mixture, even though the added water may be within the allowable w/cm ratio.
4. The severity of air void clustering may increase when the retempered concrete is mixed for a longer period of time.

With reference to the air void clustering and subsequent strength loss in concrete, the Product Note for a synthetic air entraining admixture has the following precaution note:

> "In a 2005 publication from the Portland Cement Association (PCA R&D Serial No. 2789), it was reported that problematic air-void clustering that can potentially lead to above normal decreases in strength was found to coincide with late addition of water to air-entrained concretes. Late additions of water include the conventional practice of holding back water during batching for addition at the jobsite. Therefore, caution should be exercised with delayed additions to air-entrained concrete. Furthermore, an air content check should be performed after any post-batching addition to an air-entrained concrete mixture."

Weak paste-aggregate bond can result in aggregate popout (dislodgement) during sawing, grinding and grooving operations.

3.4.2 Water Reducing, Set Retarding, and Accelerating Admixture

Water reducing, set retarding and accelerating admixtures are specified in accordance with ASTM C 494. The types of admixtures specified by ASTM C 494 include:

1. Type A, water-reducing admixtures
2. Type B, retarding admixtures
3. Type C, accelerating admixtures
4. Type D, water-reducing and retarding admixtures
5. Type E, water-reducing and accelerating admixtures
6. Type F, water-reducing, high range admixtures
7. Type G, water-reducing, high range, and retarding admixtures.

Types A, B, C, D, and E are typically used for paving applications to obtain one of the following benefits:

1. Reduce the water/cement ratio at a given workability.
2. Increase the workability for a given water content.
3. Reduce the water and cement contents for a given workability.

Items to note:

1. Some Type A water-reducing admixtures act as Type D (water-reducing and retarding) admixtures at higher dosages.
2. Some mixtures containing Type A water-reducing admixtures and supplementary cementitious materials may stiffen and set unexpectedly, particularly at elevated temperatures. This should be assessed using trial batches. Changing the source or dosage of either the water reducer or the SCM often solves this problem.
3. High dosages of water-reducing admixtures may lead to excessive set retardation.
4. The concrete workability may be affected when high dosage of water-reducing admixtures is used.
5. Some water-reducing admixtures enhance the effectiveness of air-entraining admixtures so that a lower dosage of the air entraining admixture achieves the required air content.
6. Typically, the water-reducing admixtures reduce the water content by approximately 5% to 10%.
7. Mid-range and high-range water reducers are not widely used in pavement concrete and their use should be approached with caution.

High-range Water Reducing Admixtures

High-range water reducing (HRWR) admixtures are not needed for airfield paving. Although, increased fluidity may be desired by some placement crews, the use of HRWRs may lead to segregation, paste at the surface and excessive early age shrinkage. Concrete workability can be better achieved with combined aggregate gradations. Improper use of HRWRs may result in some placement problems and may impact durability of the concrete. If the purpose of HRWR is to improve workability, these issues need to be resolved at the time of the test section.

There are situations where marginal concrete mixtures may work satisfactorily in cooler temperatures, but in the heat of the summer the mixture become unworkable. This is a situation that may create a desire to use HRWR. A problem in this situation is the use of the marginal concrete mixtures and refinement of the combined gradation would avoid the problem. As a short-term solution, until the combined gradation is improved, the engineer may consider allowing the use of HRWR if the contractor can demonstrate good experience with the admixture. It should be incumbent upon the contractor to refine the gradation before the next day's use of HRWR.

Set Retarding Admixtures

Retarding admixtures, classified as Type B (Retarding Admixture) and Type D by ASTM C 494, delay the initial and final setting times.

Items to note:

1. Retarding admixtures slow down the rate of hydration of the freshly placed concrete and extend the period during which concrete remains workable.
2. Retarding admixtures will not prevent loss in workability due to moisture loss through surface evaporation.
3. Retarding admixtures affect the rate of strength gain for as little as 1 or 2 days, or as long as 7 days, depending on the dosage.
4. They may be used in hot weather for longer haul times (if permitted) or to prevent the formation of cold joints.
5. Increasing the setting time of a mixture may increase the risk of cracking because sawing cannot start before excessive shrinkage occurs.
6. Changes in temperature may require adjustments in admixture dosage to maintain the desired setting time.

Accelerating Admixtures

Accelerating admixtures are classified as Type C (Accelerating Admixture) and Type E by ASTM C 494. They accelerate the setting and/or early strength gain of concrete. Normally they would be used only in cold weather or for repairs when the reduction of an hour or two in the setting time is important. They are also used when some increase in the early-age strength is needed. If any of these properties are needed over the course of the job, it is preferable to design the concrete accordingly rather than rely on accelerating admixtures.

Accelerating admixtures affect primarily the setting time, heat evolution, and strength development. The strength at later ages may decrease, and in aggressive environments the durability may also be adversely affected. Alternate means of obtaining early strength development include:

1. Use of Type III cement
2. Higher cement contents
3. Heating the water and/or aggregates
4. Improving curing and protection of the concrete
5. Some combination of the above.

3.4.3 Other Admixtures

Chemical admixtures, other than those discussed in the preceding sections, may be used to obtain or enhance certain properties of the concrete mixtures. For example, shrinkage reducing admixtures are reported to reduce the total shrinkage of a concrete mixture by modifying the capillary forces of the pore solution. Their use may assist in reducing the risk of shrinkage related cracking.

However, it is important that admixtures that are used be compatible with other admixtures to be used in the concrete. Material incompatibility may be induced by temperature changes. Therefore, trial batches need to be tested at the extremes of temperature anticipated at the project site. The incompatibility can be minimized when admixtures from the same manufacturer are used in a given concrete mixture.

The engineer may exclude certain admixture types or specific admixtures based on local experience and airport requirements.

Additional Guidance on Chemical Admixtures for Concrete

Excellent guidance on use of chemical admixtures is provided in the American Concrete Institute's publication, ACI 212.3R – *Chemical Admixtures for Concrete*.

3.5 Forms

The form length should be not less than half the joint spacing when grades are provided at each transverse joint in the case of a vertical curve. Longer forms may be used for straight sections without any vertical curves.

Forms should be cleaned each time before concrete is placed.

3.6 Expansion Board

Standard specification item.

3.7 Embedded Steel

Standard specification item.

3.8 Tie Bars

Tie bars need to be corrosion resistant in coastal regions to minimize the risk of tie bar corrosion. Therefore, as dictated by local experience or practice, the engineer should consider requiring tie bars to be epoxy coated.

3.9 Dowel Bars

Standard specification item.

3.9.1 Dowel Bar Corrosion Protection Coating

The U.S. practice is to use epoxy-coated bars in harsh environment for highway application to resist the effect of deicing chemicals and salt in the environment. Use of epoxy-coated dowel bars is not necessary for airport applications, but may be used in coastal regions. Dowel bars may also be coated with black paint or zinc-based paint. However, epoxy coating is considered to provide more effective protection against salt-based corrosion. It is not necessary to coat the ends of the dowel bars for airport applications.

3.9.2 Dowel Bar Bond Breaker

Dowel bars should be coated with a bond breaking material to ensure that the dowel bars do not bond to the concrete. The bond-breaking material may be applied at the factory or applied at the site. If dowel bars with factory applied bond-breaking coating are exposed to the weather at the project site over several months, the effectiveness of the dowel bar coating should be verified in accordance with AASHTO M-254.

3.9.3 Grout Retention Rings

These rings, commonly made of plastic, are used for the dowel bars along longitudinal joints to prevent the epoxy mortar from flowing out of the holes. This is considered a good practice and also helps to repair minor chipping around the drilled holes.

3.9.4 Expansion Sleeves

Standard specification item.

3.9.5 Dowel Anchoring Grout Material

Standard specification item.

3.9.6 Dowel Basket Assemblies

Stability of dowel basket assemblies is very important. The dowel assembly details should be included in the plan drawings. Many engineers specify that the connecting wires of the dowel basket assembly be cut prior to concrete placement. This practice is not necessary. The connecting wires do not need to be cut. Not cutting the connecting wires provides a more stable basket assembly during concrete placement.

3.10 Evaporation Retardants

Approved evaporation retardants, also referred to as monomolecular evaporation reducers, may be considered by the contractor to supplement the curing application. These materials form a thin continuous film and prevent rapid moisture loss of bleed water from the concrete surface. These materials are useful for reducing the risk of plastic shrinkage cracking occurring between initial placing and final finishing/curing of a surface, particularly in hot, dry weather.

There are no standard specifications for use of these materials. However, State DOTs typically maintain an approved list of vendors for the evaporation retardants. The manufacturer's instructions should be followed.

The use of evaporation retardants is recommended for hot weather conditions, typically when the ambient temperature is over 85 F and the risk for plastic shrinkage cracking is high.

3.11 Curing Materials

Curing is the maintenance of adequate moisture and temperature conditions to allow development of required physical properties of the concrete and is one of the most important construction activities. Poor curing practices can result in excessive slab warping, early age cracking, poor surface abrasion resistance, surface deterioration, and reduced strength and durability.

> Curing compounds, properly applied, need to have the following properties:
>
> 1. Maintain the relative humidity of the capillaries in the concrete surface above 80 percent for 7 days.
> 2. Be uniform and easily maintained in a thoroughly mixed solution.
> 3. Not sag, run off peaks, or collect in grooves.
> 4. Form a tough film that is able to withstand early construction traffic.

In the U.S. curing is typically viewed in terms of concrete moisture retention. In practice, curing should involve retaining the concrete mixing water as well as protecting the concrete from extreme temperature events of hot and cold weather. Specific curing practices, as applicable, should be addressed in the Weather Management Plan.

It should be noted that concrete hydration is reduced when the relative humidity within the capillary pores is less than 80 percent and this effect is pronounced at the concrete surface if curing is not applied correctly or is not timely. Poorly cured concrete can result in an increase in the amount of large pores at the surface and this can seriously affect concrete durability.

Key items to note:

1. Curing compound use is the most common method for retaining mixing water for normal weather conditions. Curing compounds (liquid membrane-forming compounds) need to conform to the requirements of ASTM C 309, Type 2, Class B.
2. ASTM C 309 restricts water loss to a given volume over a fixed period of time and several State Department of Transportations restrict the water loss to a quantity less than specified by ASTM C 309. Depending on local experience, the engineer may specify the local State Department of Transportation or other requirement for curing.
3. Pigmented curing compounds are recommended because they make it easy to verify proper application. For concrete placement on sunny days and in hot weather, the curing compound selected should contain a white pigment to reflect the sun's heat.

Other curing materials include white polyethylene film, burlap sheeting, and waterproof paper, all meeting the requirements of ASTM C 171. However, these materials are not commonly used for production paving, except for emergency needs. The engineer shall carefully consider allowing polyethylene or paper curing materials, because these materials may be dislodged or removed by jet blast from aircraft, and these materials and their anchoring systems may be ingested as FOD.

ASTM C 156 specifies a method for determining the efficiency of curing compounds, waterproof paper, and plastic sheeting.

4.0 CONCRETE MIXTURE

The engineer shall specify the design properties of the concrete. In this specification, slump testing is not a design or acceptance requirement.

4.1 Concrete Mixture Requirements

The concrete mixture requirements are as follows:

Concrete Strength

The engineer determines the concrete strength. A key consideration is that the concrete strength specified for construction acceptance at 28 days is 5% less than the strength used for the thickness design. The FAA's AC 150/5320-6D recommends that the design flexural strength used to determine the concrete slab thickness should be the strength (typically, at least 5% higher than the 28-day strength) when aircraft begin to use the pavement (typically, at about 60 to 90 days after concrete placement).

> Use of Splitting Tensile Strength Testing
>
> It should be noted that although the concrete strength is specified in terms of flexural strength, the specification allows acceptance testing for concrete strength to be performed using flexural or splitting tensile strength. If splitting tensile strength testing is selected by the contractor, a project specific correlation between flexural strength and splitting tensile strength will need to be developed for each concrete mixture during the laboratory stage of the mixture proportioning study. The correlation is then used to establish flexural strength data for the as-delivered concrete from the cylinder splitting tensile strength.

To optimize a pavement design, it is good practice to increase the slab thickness rather than increasing concrete strength above the recommended design levels of 600 to 650 psi. Design concrete strengths higher than 650 psi are not necessary. High concrete strength is not considered necessary for long-term performance of the concrete pavement. Use of the higher design strength levels need to be coordinated with the FAA prior to incorporation on a project.

The engineer should consider other design features (e.g., slab thickness) as an alternate to specifying higher concrete strengths.

Minimum Cementitious-Material Content

The minimum cementitious materials content required for durability is greater than the amount required for strength and workability. Although it is possible to optimize a mix to achieve the lowest possible cementitious materials content and still achieve strength requirements, a minimum cementitious materials content is required to ensure that long-term durability of concrete is not compromised.

In fresh concrete, a minimum cement content is required for sufficient paste to coat the aggregates and thus make the mix workable. The minimum amount of paste required to fill all voids will be dependant on aggregate grading (i.e. the amount of space between aggregate particles).

In hardened concrete, a minimum cement content is required to ensure that there is sufficient paste to coat all of the aggregate particles, and to fill all the spaces between them. Too little cement will mean that there is percolation of voids, i.e. aggressive fluids will be able to penetrate through the matrix. Both strength and potential durability decrease with increasing void content. A well-graded system will require less cement than a poorly graded system to achieve the same performance. Again, this amount will be largely dependant on aggregate properties.

In mild and moderate exposure regions, 470 pounds per cubic yard is acceptable, and 517 pounds per cubic yard is acceptable in severe exposure regions, based on industry-accepted requirements. For most projects, use of the combined aggregate gradation will allow the strength requirements to be readily achieved with these minimum cementitious materials contents. In optimized combined gradations, it is possible to exceed the specified strength and even the design strength following the minimum cementitious content, but with the limitations on water to cementitious ratio and excessive water reducers, it is not likely to achieve a brittle condition.

Water-to-Cementitious Materials Ratio

The optimum water to cementitious materials (w/cm) ratio is the minimum ratio that satisfies the need for concrete strength and durability. Very low w/cm ratios are not recommended. There is a field practice to achieve a higher concrete strength with less cement by using very low w/cm ratio (< 0.38) and mid-range or high range water reducing admixtures. A combination of low w/cm ratio (0.35 to 0.40) and a mid or high range water reducer used as a plasticizer may produce high concrete flexural strength that can easily reach or exceed 1,000 psi at 28 days. Very high strength concrete can be brittle and result in lower fatigue life. Use of very low w/cm ratio is not recommended as it may also lead to concrete durability issues.

A maximum ratio is specified to ensure that the cementitious materials use is optimized to achieve the desired strength levels, to limit drying shrinkage, and to minimize the amount of capillary porosity in the hardened concrete.

Supplementary Cementing Materials

The U.S. practice, based on field experience, is to limit the use of the supplementary cementing materials as follows:

a. Fly ash – not to exceed 25% of total cementitious content
b. Slag – not to exceed 50% of total cementitious content
c. If both fly ash and slag are used, the total supplementary cementing material shall not exceed 50% of total cementitious content
d. Total supplementary cementitious content shall not exceed 50% for mixtures using C 595 or C 1157 cements.
e. In case of reactive aggregates, the use of the supplementary cementing material will be governed by the contractor's reactive aggregate mitigation plan.

Air Content

A certain level of entrained air is necessary to ensure protection in freezing environments. The target percentage of air in the mix should be based upon the exposure condition and maximum aggregate size in accordance with ASTM C94/C 94M, unless local experience suggests otherwise. The ASTM C 94/C 94M (as of 2004) recommendations for air content (in percentage) for the 1, 1 ½, and 2 inch maximum aggregate sizes are as follows:

Exposure Condition	1 inch	1 ½ inch	2 inch
Mild	3.0	2.5	2.0
Moderate	4.5	4.5	4.0
Severe	6.0	5.5	5.0

Air content should be determined by testing in accordance with ASTM C 231 or ASTM C 173/C 173M, as appropriate. ASTM C 231 procedure is intended for use with concretes made with relatively dense aggregates. The ASTM C173/C 173M procedure is for concrete made with any type of aggregate, whether it is dense, cellular, or lightweight.

Although not a specification requirement, the Contractor should consider using a small amount of air-entraining admixture even in non-freezing environments to enhance concrete workability. However, the entrained air for such applications should not exceed about 4% to minimize the impact on concrete strength.

Testing for Concrete Slump

Historically, slump testing has been used as a surrogate measure of concrete workability. For slipform paving, slump has no relationship to workability of the concrete mixture under vibration. Slump testing is an indicator of concrete consistency and is better suited as a contractor quality control test to identify changes that may occur as a result of changes in the characteristics of the concrete materials, mixture proportions, mixing, and haul times.

For slipform paving, acceptable concrete workability is best determined by observing the amount of hand finishing that is required behind the paver to correct the edges and corners and by performing consolidation testing of the in-place concrete. A workable concrete with sound concrete materials is easy to place, consolidate and finish and produces durable concrete.

4.2 Concrete Mixture Proportions

Mixture proportioning addresses the combination of the individual concrete making materials to produce a concrete mixture that will meet the project requirements discussed in the previous section. The contractor may use any method to develop the concrete mixture. Some of the common methods, but not the only methods, are discussed in Ref. 6, 8, and 9. However, the proposed specification is targeted for a combined aggregate gradation that results in a dense concrete matrix. .

There is also no limit to the number of mixtures a contractor may develop and submit for the engineer's review. Concrete mixtures need to be developed for:

1. Each expected method of concrete placement.
2. The anticipated ambient temperatures. Concrete that can be placed at one temperature may not be workable at another.
3. Specific construction requirements – normal paving versus fast-track paving, anticipated changes in material supply, etc.

Once the laboratory mixture proportions that meet project mix requirements have been developed and reviewed, the test section is built. The laboratory mixture proportioning is only a starting point and the contractor should verify his mixture at the test section and adjust the individual proportions within the allowed limits to ensure that the concrete mixture is workable for his paving equipment. There is no concern with strength or durability related issues if the mixture proportions are adjusted within the allowed limits. The allowed limits for adjusting the concrete mixture proportions are detailed in Para. 7.4 – Production Paving Adjustments to the Concrete Mixture Proportions.

Incompatible Concrete Materials

Incompatible reactions between some cements, supplementary cementitious materials and chemical admixtures have been known to occur, often in hot weather. It is recommended that trial mixtures be run at the maximum temperature expected in the field to determine whether there is a significant change in admixture dosages, the rate of slump loss, setting time, or in the air void system. If problems occur, they can often be resolved by changing the source or dosage of cementitious materials, or type of chemical admixture.

The replacement dosage for SCMs (fly ash and GGBFS) should be compatible with the needs for strength and durability. The desired SCM content should be established considering the importance of early strengths; durability concerns; the curing temperatures; and the properties of the SCMs, the cement, and other concrete materials.

Approved Water to Cementitious Materials Ratio

The approved water cementitious ratio is that submitted with the laboratory mixture proportioning submittal. The laboratory proportioning study is also where the strength correlation is determined. The water cementitious materials ratio is a key element that impacts concrete strength as well as concrete durability, therefore it can not be exceeded in the field. Field mixing is commonly more efficient than laboratory mixing, therefore field mixes typically require less water than the laboratory study indicates, which is acceptable.

Strength Correlation Data

The proposed specification allows the contractor the option of using flexural strength or splitting tensile strength testing to determine concrete strength at the specified age. If the contractor elects to use splitting tensile strength testing, he needs to develop a one-point correlation between the flexural strength and the splitting tensile strength for the specified age of testing. The one-point correlation should be developed as soon as the final mixture proportions have been established on the basis of the laboratory testing.

The contractor should note that the development of the correlation data may require an extra month beyond the completion of the mixture proportioning study.

Acceptable Adjustments in Mixture Proportions

Some minor changes in the concrete mixture proportions are permissible on a routine basis if these changes do not detrimentally impact concrete durability or strength. These changes may be considered acceptable without requiring multiple reviews by inspectors, especially if these minor variations may vary during day. The emphasis with the concrete mixture proportioning is to achieve a consistent end product, not rigidly established material proportions.

Shortages of cement or other concrete-making ingredients may occur during the construction season. If any changes in type, source, or brand of cementitious material, admixtures, or aggregate source need to be made, trial batches need to be carried out to verify that the required properties are retained.

Certain minor adjustments to the concrete mixture proportions (e.g., air entraining and water reducing admixtures) may be necessary due to changes in the weather and to maintain the required workability and air content. However, if air content is increased or water is added above the design w/cm ratio, the concrete strength may decrease.

Minor variations in aggregate proportions in the field do not have a significant impact on the strength correlation.

5.0 EQUIPMENT

The Contractor is required to furnish all equipment and tools necessary for handling materials and performing all parts of the concrete pavement construction.

5.1 Concrete Batching Plant

Concrete is a manufactured product, the quality and uniformity of which depend upon the control exercised over its manufacture. The concrete batch plant needs to be in good condition, operate reliably, and produce acceptable concrete uniformly from batch to batch. The National Ready Mix Concrete Association (NRMCA) QC3 (Plant Certification Check List) process is the recommended standard and should be used for projects where it is anticipated a batch plant will be dedicated to the project, either on or off site.

It is not required that the NRMCA QC3 certification be prepared by a professional engineer; the specification identifies the qualifications for the inspector. A NRMCA QC3 certificate is not required, only that the checklist be completed and be acceptable.

The plant should be inspected prior to the start (or re-start) of each paving project and when uniformity or strength problems are encountered during production.

5.1.1 Existing Plant Certification

If an existing plant or ready mix operation is to be used, some State DOT certifications are equal to or more stringent than NRMCA QC3 and may be used. It is incumbent upon the engineer to determine if the State DOT requirements are permissible and edit the specification accordingly.

Plants that are moved should be checked using the NRMCA QC3 process.

5.1.2 Plants without Certification

The Contractor should complete NRMCA QC3 checklist for each concrete plant to be used for the work. Each plant shall pass in all categories.

Trucks for truck-mixed concrete, if used, also need to pass the NRMCA QC3 checklist. The NRMCA provided certificates are not required.

The NRMCA QC3 checklist should be performed not less than 6 months from the start of production paving. In addition, the checklist inspection should be repeated if the plant is relocated.

The NRMCA QC3 checklist is not required to be completed by a Registered Professional Engineer. However, personnel performing the inspection in accordance with the NRMCA QC3 checklist shall provide documentation of knowledge of batch plant operations and concrete production. A Statement of Qualifications shall be maintained for all personnel involved in the inspection process.

5.1.3 Mixers

Most central plants in the U.S. are drum mixers with a tilting drum, non-tilting drum or reversing drum. There is also a horizontal shaft type mixer that is available that uses two rotating shafts with paddles. All the plant types are acceptable provided the mixture design parameters are achieved. Plant data recorders shall record all of the concrete mixture batch weights.

The mixers should be inspected for hardened concrete around blades. Concrete is mixed by shearing. For drum mixers, the higher the fall from the top of the drum, the better the mixing action. If the blades are worn or have concrete buildup, then the materials will not be carried as high in the drum and this will reduce mixing efficiency.

For truck mixers, the delivery tickets should show the information as provided for in NRMCA QC3. This will allow rapid determination at the site if any water can be added to the mixture.

5.1.4 Concrete Uniformity Tests

Concrete uniformity testing is required prior to the start of paving using ASTM C 94. Uniformity testing is required for all batch plants that are moved or are set up for the project.

Uniformity testing determines the ability of the mixer to mix the concrete and to establish minimum mixing times. Uniformity tests compare differences in concrete sampled at approximately 15 percent and 85 percent drum discharge. Differences shall be less than the maximum allowable differences stated in Appendix 1 of ASTM C 94/C 94M. The tests include:

1. Unit weight
2. Air content
3. Slump

4. Coarse aggregate content
5. 7-day concrete average compressive strength.
6. Water content.

The number of revolutions for truck-mixed and shrink-mixed concrete should be determined by uniformity tests in accordance with ASTM C 94/C 94M.

Moisture Control

Aggregate moisture control is an important process control item and can affect the consistency of the concrete production. Concrete with varying aggregate moisture content will exhibit difficulties during placing and finishing operations and may also exhibit low strength. Therefore, it is important that the contractor manage his aggregate stockpiles well and regularly monitor the aggregate moisture.

It should be noted that batches of concrete with variable water to cementitious materials content will exhibit poor durability. This is also the reason for not allowing water additions to truck-mixed concrete beyond the allowable w/cm ratio for that concrete and for not allowing water addition by spraying ahead of and behind the paving equipment.

5.2 Concrete Hauling Equipment

NRMCA QC3 provides guidelines on items to inspect for hauling equipment. It is beneficial for field personnel if each delivery truck has a large, clear, unique placard, e.g. No. 1, to improve references for communication between the paver and the plant, to cross-reference batch tickets, and to monitor delivery times.

5.3 Transfer and Spreading Equipment

Use of the transfer and spreading equipment is a contractor option. The contractor is the one most familiar with the capabilities of the paver and the concrete delivery planned for a project. The test section will validate the contractor's equipment choices.

5.4 Paving Equipment

Paver selection needs to be at the option of the contractor. However, paving equipment for production paving are required to be fitted with internal vibrators and be equipped with a vibrator monitoring device that indicates the frequency of each installed vibrator.

Slipform Paver

Slipform pavers are generally capable of handling the larger projects where there is sufficient room to maneuver. For thicker sections, typically more than 12 inches, some light-weight pavers may need a placer-spreader in front to pre-shape the concrete, otherwise the machine may not have enough tractive force to extrude the concrete or the paver frame may flex and lose flatness control of the pan. There are large machines available that have sufficient tractive force and weight to effectively spread and pave the concrete. The effectiveness of the paver can be determined at the test section.

If the engineer designs the paving joint layout on the plans, care must be exercised in coordinating the paving direction with the grading plans. A slipform paver cannot readily respond to rapid grade changes, such as paving over a crown or through an invert. The paver will flatten the extreme grade change for the pilot lane. For the adjacent fill-in lanes, the edges of the pan will spall the pilot lane concrete edges. Generally vertical curves that meet aircraft grade change criteria do not cause this effect.

Sideform Paver

Sideform pavers can achieve an excellent pavement but have a slower production rate and may require more manpower than slipform pavers. Highly effective sideform pavers will have similar immersion vibrators and split augers as a slipform paver. It is common to use a slipform paver with side forms. A key issue with sideform pavers is the weight of the machine may damage the edges of the pilot lanes when paving the fill-in lanes. The paver will slide along the concrete and may cause spalls on the transverse joints within about a foot of the pilot lane edge.

Longitudinal Mechanical Float

If a longitudinal mechanical float is used on a paver, it will correct any minor surface issues, but if it is not properly weighted and adjusted, it will cut the surface or pool slurry on the low edge. Pooling the slurry is an indication that the mixture is incorrect or the float is not properly adjusted. Simply removing the slurry is not the solution; the float must be adjusted and calibrated.

Form Riding Finishers

Form riding machine finishers ride on the forms but do not have the multiple immersion vibrators as do side and slipform pavers. These finishers will be necessary on most jobs, but are typically used for paving the fillets or near buildings where there is insufficient clearance for a paver. Form riding machine finishers include vibrating trusses and roller screeds.

Form riding finishers have a higher tendency for excess paste to accumulate at the surface and joints. Use of these finishers should be discontinued when excessive paste develops at the surface.

Bridge Deck Finishers

Bridge deck finishers with internal vibrators that travel transversely across the slab are acceptable for production paving. However, their use is more effective for placement of thinner concrete pavements. The rate of paving is also slower than slipform paving. Bridge deck finishers have a tendency to develop excess paste at the surface and along longitudinal edges.

Use of the bridge deck finisher should be discontinued when excessive paste develops at the surface or along the edges.

Rotary Trowels

Rotary trowels or other equipment that can burn or polish the concrete surface shall not be used to finish the concrete surface.

Internal Vibrators

Concrete needs to be internally vibrated to achieve desired consolidation to ensure adequate strength and durability. The energy imparted by vibration needs to ensure that concrete is neither over-consolidated nor under-consolidated. The energy to be imparted by internal vibration is a function of the concrete mixture, paver speed, vibrator rotor force, vibrator frequency, vibrator spacing, and concrete head.

Slipform and some side-form pavers are equipped with internal vibrators that are typically spaced no more than 18 inches across a paving lane. Bridge deck pavers commonly have one or two vibrators that are mounted on a trolley that traverses across the paving lane. This type of consolidation is adequate for thin pavements, but becomes less effective as the slab thickness increases for heavy airfields.

Vibration Monitoring Device

Vibration monitoring devices, also known as smart vibrator systems, are readily available and their use is considered very cost-effective. These devices monitor the vibrator frequency continuously and ensure that the proper level of vibration energy is imparted into the concrete mixture. These devices also immediately identify poorly operating or inactive vibrators.

The frequency of a vibrator may be changed by the operator. The common range for concrete vibration is 5000 to 8000 Hz. Need for use of frequencies outside this range indicates that the mixture is not dense graded or there are other workability issues with the mixture. Since vibrator effectiveness is dependant upon vibrator type, mixture properties, slab thickness and paver speed, the engineer should not specify frequencies or amplitudes.

Many concrete paving machines arriving on an airfield project have vibrators tuned to high settings for mixtures that are gap graded, have low workability, or are for thinner pavements. Dense graded concretes are significantly more responsive to vibration than traditional gap graded mixes. Airfield pavements are commonly thicker than highway pavements, therefore the paver speed is slower (due to delivery and spreading) and there is more time for the vibrator to impart the required level of energy into the concrete mass.

Over vibration of dense graded mixtures, especially on fill-in lanes, is a significant contributor to sliver spalls at the joint seal reservoir. The vibrator frequencies at the edges of the fill in lanes normally need to be reduced due to the energy reflected from the pilot lane.

Vibrators should be positioned 4 to 6 inches below the finished surface and positioned at an attitude of 5 to 10 degrees. Vibrators too close to the surface will leave mortar trails that will crack and affect pavement durability.

Vibrator spacing is a function of the radius of action. The radius of action is a function of the vibrator rotor force and vibration amplitude and frequency. The vibrators should be spaced to ensure there is an overlap in the radius of action of adjacent vibrators.

The contractor should demonstrate or determine the optimum frequency and vibration to be used with the project concrete mixture at the test section, based on a designated paver speed. The contractor needs to be aware that as the paver speed and concrete head vary, the vibrator frequency may need to be adjusted, based on experience or pre-established protocol.

Hand Vibrators

Insertion, operation and withdrawal of the vibrator should be done with the vibrator in vertical alignment to avoid segregation and sand streaks that will reduce pavement durability. ACI 309 provides guidance on vibrator selection and operation.

5.5 Texturing Equipment

For production paving, texturing shall be done using automated equipment. The texturing equipment should be capable of providing uniform surface texture in plastic concrete across the full width of the paving lane. The texture may be applied with a brush or broom, burlap drag, or artificial turf finish. The texturing equipment should be capable of providing an average macrotexture depth of 0.04 in., plus or minus 0.008 in., when tested in accordance with ASTM E 965. The texture depth requirement permits the contractor to consider other innovative techniques to apply surface texture.

A hand broom may be used to apply texture on small, isolated handwork areas.

5.6 Curing Machines

Curing should be applied by a curing machine, which provides more uniform coverage than hand spraying. The curing equipment should be capable of applying the curing compound at the specified rate and coverage. The operation of the curing compound should be regularly calibrated in conformance with ASTM D 2995, Method A and spray nozzles should be checked regularly.

Minimum size of paving lane to require self-propelled curing machine may be determined by the engineer. Generally, if the area is large enough to accommodate a slipform or a side-form paver, then a self-propelled curing machine should be used.

Hand sprayers are intended to be used in isolated areas only and when approved by the engineer.

5.7 Concrete Saws

The concrete saw blade should be matched to the concrete aggregate. Improper saw blade use can lead to joint raveling and spalling. Also, the saw blade needs to match the arbor. The sawing equipment should be in good operating condition and should not exhibit chattering behavior.

The Contractor shall provide sawing equipment adequate in number of units and power to complete the sawing to the required dimensions in a timely manner, for transverse joints as well as longitudinal joints, if applicable. The Contractor should provide standby saws in good working order and a supply of saw blades at the site at all times during sawing operations.

5.8 Drills

Drill used to drill dowel bar holes should be sized to ensure that there is no excessive chipping or spalling of concrete around dowel bars.

6.0 WEATHER MANAGEMENT

On most concrete paving projects that extend into several weeks, there is a good possibility that the project will be subjected to extreme weather conditions, defined here as hot weather, cold weather or unforeseen rainstorms. Adequate precautions need to be taken during these extreme weather events to ensure concrete durability and functionality are not compromised. The weather management plan must be practical and can be implemented under short notice. An inherent requirement of the plan is that the contractor monitors the changing weather conditions and anticipates changes in the weather that may impact the paving operation.

It is wise to stop paving on extreme weather event days if the contractor is not prepared to take adequate precautions as detailed in the weather management plan. Otherwise, the contractor risks potential problems – plastic shrinkage cracking, full-depth cracking in advance of joint sawing, delayed concrete set, excessive curling/warping, and damaged surface concrete.

A written weather management plan is not required for smaller projects requiring less than about 10,000 cubic yards of concrete. However, it is the contractor’s responsibility to take necessary precautions to ensure that the extreme weather conditions do not impact his paving operation. Other than the submission requirements for a written weather management plan, all requirements for the protection of the fresh concrete and the placed concrete are the same for small as well as large projects. This is because concrete strength and durability needs are the same for all concrete placed in the critical areas of the airport’s airside facilities.

It should be noted that the weather management plan needs to incorporate only the elements of the extreme weather conditions that are applicable for the specific project. For example, cold weather paving items need not be included for projects in the southern parts of the U.S.

An example weather management plan is given in Appendix A.

6.1 Hot Weather Paving

See Appendix A.

6.2 Cold Weather Paving

See Appendix A.

6.3 Protecting Concrete from Rain Damage

See Appendix A.

7.0 EXECUTION

7.1 Underlying Material Preparation

The grade is accepted after the base layer is placed, trimmed, leveled, and compacted. Once the grade is accepted, a traffic control plan must be implemented. Heavy construction trucks traveling on the prepared surface can damage the grade. Traffic management must be enforced if logistics require use of the prepared grade by construction equipment.

The variability of the base layer grade will affect the variability of the concrete slab thickness and this variability may impact payment for thickness. Therefore, it is important that the base layer variability be minimized.

7.2 Paving on Stabilized Bases

There are many issues to be addressed in the design to prevent early age cracking on stabilized bases. Reference 10 identifies acceptable practices. The engineer shall incorporate the appropriate treatments into the design, and clearly identify in the plans and specifications.

7.3 Test Section

The test section is a critical element to enable the contractor to adapt the mixture and paving equipment to the site conditions, and demonstrate to the owner that the acceptance criteria can be achieved using his materials and his processes. A test section is not required for small projects that involve less than about 2,000 cubic yards of concrete production.

The test section should be constructed on the first day of paving with a maximum placement of one lot for the

> <u>Test Section Expectation</u>
>
> Contractor is expected to adjust his process and concrete mixture, so when the test section is started, the specified end product is attained.
>
> The test section is rejected if it has deficient or defective pavement areas or the thickness percent within limit value is 55 or less (see Section 9.0 – Acceptance Testing)

selected paving method. The test section width and thickness should be most representative of the production paving area. Ideally, a non-critical area that is also representative of the majority of paving should be selected as the site for the test section. It is expected that some adjustments may be made to the laboratory based concrete mixture proportions as well as some of the contractor's operations to achieve the desired end products.

It is emphasized that the test section is being used to validate the contractor's concrete mixture and his paving process, especially with respect to the ability to place, consolidate and finish the concrete within the limits of the specification requirements. If a contractor is not using a combined aggregate gradation and paving equipment capable of internal vibration, the specification requires that consolidation testing be performed to assess the degree of consolidation by depth. There is a concern that adequate consolidation of thick concrete slabs may not be achieved using consolidation techniques other than closely spaced internal vibrators. The consolidation testing using cores from newly placed concrete pavement will verify if there is excessive segregation, poor consolidation (as manifested by honey-combing or large amount of entrapped air) at the slab bottom or over consolidation in the upper portion (as manifested by excessive paste at the surface).

7.3.1 Requirements

The acceptance criteria for the test section are the same as for production paving; however, partial or conditional acceptance is not allowed. Partial or conditional acceptance of a test section is not allowed because the contractor must demonstrate control over all materials and equipment. A project cannot begin without acceptable control of the process as demonstrated at the test section.

A period of time to evaluate the test section is necessary. The time used by the contractor to evaluate the test section and to submit the test section data to the engineer. This evaluation period is mandatory and cannot be waived. It is expected that the contractor and engineer will agree in advance upon the actual time of the test section, evaluation and response if the paving occurs at odd hours, weekends or holidays.

Removal of unacceptable portions of the test section is determined by the engineer. Partial payment and corrective action methods can be utilized. If the total length of paving on the first day does not produce an acceptable test section of the minimum continuous length/volume specified, then another test section shall be built.

The concrete mixture proportions determined from the test section become the approved proportions for the project. Throughout the paving process, additional minor adjustments may be made in the mixture proportions, but within the limits given in the specification and discussed in the next section. When these minor adjustments are made, a revised mixture proportioning submittal is not required.

7.4 Production Paving Adjustments to the Concrete Mixture Proportions

Shortages of cement or other concrete-making ingredients may occur during the construction season. If any changes in type, source, or brand of cementitious material, or aggregate source need to be made, new mixture proportions will need to be developed by the contractor and approved by the engineer. Certain minor adjustments to the concrete mixture proportions may be necessary due to changes in the weather and to maintain the required workability and air content. However, if air content is increased or water is added above the design w/cm ratio, the concrete strength may decrease.

If a new mixture proportions needs to be developed because of changes in concrete materials, the contractor should be allowed to proceed with paving once the early-age breaks indicate that the new mixture will provide the specified strength at the specified age.

Allowable adjustments in the mixture proportions are given in the specification and are listed below:

1. Individual aggregate proportions may be adjusted as necessary. However, the combined aggregate gradation may be adjusted only within the limits of Para. 8.3.4 – Combined Aggregate Gradation.

2. As necessary, cementitious materials may be increased by up to 10 percent by mass of the approved mixture proportions. Cementitious material content shall not be reduced from the approved mixture proportions.

3. As necessary, cement may be replaced with the approved SCM in an amount not to exceed 10 percent of the original SCM mass. When applicable, the Contractor's mitigation plan for reactive aggregates shall be re-evaluated.

4. As necessary, any SCM may be replaced with the approved cement. When applicable, the Contractor's mitigation plan for reactive aggregates shall be re-evaluated.

5. Quantities of admixtures may be adjusted in accordance with the manufacturer's recommendations.

6. Field adjustment for water is permitted provided that the water-cementitious materials ratio does not exceed the ratio for the approved concrete mixture and is not less than that listed in Para. 4.1 – Concrete Mixture Requirements.

7. For truck mixed concrete, additional water may be added only once to adjust the workability of concrete, provided the approved water-to-cementitious-materials ratio is not exceeded. The maximum amount to be added shall be adjusted based upon the volume of concrete already discharged. The drum or blades shall be turned a minimum of 30 additional revolutions at mixing speed after water addition.

8. Water addition to the concrete by spraying in front of and behind the paving equipment is not allowed.

7.5 Tie Bar Placement

The tie bars should be placed at mid-depth and centered along the longitudinal joint. However, alignment of tie bars is not critical. Tie bars may be skewed up to 1 in. per 15 in. length of the tie bar.

Self-loading tie bar inserters mounted on slipform pavers can be used along longitudinal sawed contraction joints when paving multiple lanes. Injectors push rebar into plastic concrete and vibrate the concrete above bars. Distance meters are used to trigger the tie bar insertion at pre-determined spacing. Longitudinal positioning of bars needs to be observed to ensure that the minimum specified distance from transverse joints is maintained.

Tie bars should not be placed within 15 in. of doweled transverse joints.

7.6 Doweled Contraction Joints

Dowel bars may be installed at transverse and longitudinal contraction joints using a basket assembly or using an automatic dowel bar inserter device.

<u>Basket Assembly</u>

Dowel baskets must be securely fastened to the base. Clips are generally adequate when fastening a basket to stabilized base. Long pins are required to securely fasten baskets in granular and open graded bases. The basket assemblies should be pinned at the bottom rung of the assemblies regardless of the length of the pins. Pinning on the top rung can result in dowel bar misalignment due to bending of the top rung from over-zealous hammering of the pins into the grade.

Cutting or crimping of longitudinal dowel basket wires is not necessary. Field experience and theoretical analysis indicate that the tie wires will yield before excessive stress develops in the freshly place concrete.

<u>Dowel Bar Inserter</u>

Effectiveness of the dowel bar inserter is dependent on the operation of the paver and the inserter unit. Dowel bar alignment and correct location of joints are two critical items. A positive method must be used to mark joint locations to be at mid-location of the inserted dowel bars.

7.7 Doweled Construction Joints

Dowel bars may be installed after the concrete has cured sufficiently to allow loading of the new pavement by the drilling equipment and to allow drilling of the holes without excessive chipping and spalling. However, some minor chipping should be expected. Minor chipping, filled by the epoxy mortar, and covered up by the grout retention ring is acceptable. Chipping beyond the area of the grout retention ring is considered not acceptable. Inserting dowels into fresh concrete is not acceptable for construction joints. Dowels in construction joints can only be anchored into properly sized holes in the concrete.

Dowel bars need to be inspected to verify adequacy of the epoxy coverage. Proper epoxy grouting is important to ensure that the dowels are bearing on a sound interface and voids do not exist. Otherwise, load transfer effectiveness may be compromised.

7.8 Doweled Expansion Joints

Care must be taken to ensure that the specified expansion gap in the expansion sleeve is maintained until the time of concrete placement. Use of sleeves with a foam insert is beneficial.

7.9 Concrete Production

The contractor is responsible for determining the process used for production of concrete. Concrete production involves the following two critical steps:

1. Batching – measuring concrete mix ingredients by mass and introducing them into the mixer.
2. Mixing concrete – thoroughly mixing concrete until it is uniform in appearance, with all ingredients evenly distributed. Concrete may be mixed at a stationary plant at the project site or may be ready-mixed concrete that is batched and mixed off-site. Properly batched and mixed concrete is consistent from batch to batch.

Concrete batching and mixing is demonstrated and validated at the test section. The validated processes should be used during the production paving.

7.9.1 Batch Tickets

The engineer should review the concrete batch tickets regularly to verify that the approved proportions of materials are used for concrete production and in the case of truck-mixed concrete, water is not being added without exceeding the approved water-to-cementitious-materials ratio.

7.10 Hauling

The haul time is defined as from addition of cementitious material until the time that the paving equipment has passed over the concrete. This is different than the time in ASTM C94 that ends when it is deposited in front of the paver. Maintaining a limit on the haul time is very important as excessive haul times can affect the properties of fresh concrete, which may affect the long-term durability of the concrete. The allowable haul times are as follows:

1. Normal Weather Conditions

    a. Non-agitating trucks – 45 minutes
    b. Agitating trucks – 105 minutes
2. Hot Weather Conditions (concrete deposited at the paver is at a temperature > 85 F)
    a. Non-agitating trucks – 30 minutes
    b. Agitating trucks – 90 minutes

Note that the specified haul times are 15 minutes longer than allowed in ASTM C 94.

7.11 Paving

Concrete may be placed using a transfer and spreading equipment or placed directly in front of the paver. The transfer and spreading equipment use is the recommended method.

The disadvantages of directly unloading in front of the paver are:

1. Trucks backing into the paver may disturb non-stabilized bases, utility structures, stringlines or forms.
2. Dowel baskets need to be placed just ahead of the paver – placing dowel baskets just ahead of the paver may not allow time to verify dowel bar alignment or verify that baskets are securely fastened to the base. Safety of laborers fastening baskets in areas between the forward moving paver and backward moving dump trucks needs to be considered.
3. Additional time for staging and positioning of trucks may be necessary.

Concrete should be deposited on grade within reasonable time after the addition of mixing water. When placed, there should be time remaining for consolidation, strike-off, and finishing before initial set. The consistent delivery of concrete is necessary to minimize stopping and starting of the paver. If paving operations are stopped to wait for concrete from the batch plant, additional trucks must be used or the paver speed should be slowed.

<u>Concrete Consolidation</u>

Adequate concrete consolidation is essential to long-term pavement performance. As discussed previously, concrete is extensively tested as-delivered, in the plastic state. In addition, strength specimens are prepared using the as-delivered concrete. The assumption is that the concrete as-placed will exhibit the same characteristics of a well consolidated concrete as tested in the laboratory during the mixture proportioning phase and as reflected in the strength specimens.

Adequate consolidation of concrete is very important for strength and durability. Inadequate consolidation results in lower concrete strength and honeycombing. Inadequate consolidation can be due to:

1. Poorly functioning or dead vibrator
2. Paver speed too high
3. A concrete mixture with poor workability.

Over-consolidation can lead to freeze-thaw durability problems if the air void system is adversely altered and can also result in excessive paste at the surface. Over consolidation can be due to:

1. Excessive vibrator frequency, especially along edges in fill-in lanes
2. Reducing paver forward speed without an adjustment to vibrator frequency
3. Concrete mixture with poor workability.

The requirement of optimized combined gradation and use of internal vibration ensures that the concrete is well consolidated with proper paver operation.

Finishing, Surface Correction and Testing

Concrete finishing is a critical step in the paving process. Concrete finishing is the hand finishing that is typically applied to obtain a smooth surface necessary to correct any unevenness behind the paver. Concrete finishing efforts are to be kept to a minimum. Ideally, the correct concrete mixture will result in an acceptable surface finish behind the paver.

A 12-foot straightedge is used to check the fresh concrete surface behind the paver or finishing machine. This check needs to be continuous to ensure the machine is functioning properly. Common irregularities are transverse bumps across the lane and longitudinal dips within 2 feet of the edge. It is important for the straightedge to be checked with a stringline to ensure it is straight. If the paving machine is properly calibrated, the most common cause for surface irregularities are stopping/starting the paver, frequently a result of waiting for concrete delivery.

Excessive Hand Finishing Behind the Paver

The concrete surface does not need to be very tight and every small blemish on the surface does not need to be corrected. Hand finishing behind the paving equipment must be kept to a minimum. A properly adjusted and operated paving machine will provide the desired surface grade. Hand finishing behind the paving equipment must be kept to a minimum to fill any small holes and trim excess concrete from the corner. A properly proportioned concrete mixture with a properly adjusted and operated paving machine will provide the desired edges and surfaces.

It should be noted that the specification has a limit on the amount of hand finishing that is performed behind the paving equipment to correct edges and corners. Minor surface irregularities may be corrected using appropriate tools.

Texturing

Concrete texturing is the most common technique used to provide concrete with required skid resistant pavement surface. Texturing is applied while the concrete is still in plastic condition. The texture may be applied with a brush or broom, burlap drag, or artificial turf finish. Burlap drag is the preferred texturing method. The burlap rating should be about 15 ounces/sq yd. The corrugations produced by burlap drag need to be uniform in appearance and about 1/16 in. (1.5 mm) deep. Using burlap too soon, especially when manufactured sand is in the mix, may result in the sand being rolled to the surface by the burlap. In these cases, delaying the burlap drag may help.

7.12 Curing

Curing is an important process for constructing durable concrete pavements. Curing of concrete is defined as the maintenance of adequate moisture and temperature conditions for a period of time immediately following finishing. Proper curing allows the development of required physical properties in the concrete. Poor curing practices can result in excessive curling, early age cracking, surface deterioration, low early strengths, and reduced durability. Most of the damage caused by poor curing is irreversible. The start of curing and the maintenance of curing for the specified period are critical items.

Curing should be initiated as soon as possible after placing the concrete to prevent excessive water loss and drying of the surface. Curing compounds work by sealing the concrete surface and reducing the rate of moisture loss. Rising bleed water can become trapped under a prematurely finished surface layer. Bleed water that rises after the application of a curing compound can disrupt the curing membrane and can form a lens that causes spalling or delaminations. Bleeding typically stops at about the time of initial setting when the aggregate particles interlock with cement hydration products. Slipform paving concrete typically does not bleed until 20 minutes after concrete placement and may never bleed. For slipform paving concrete, the evaporation rate almost always exceeds the bleed rate of the concrete.

Curing should not be applied to pavement surface that has standing water as a result of a rainfall. Application of curing compound over standing water will not be effective. Curing compound should be applied as soon as the standing water has evaporated and the surface is still damp.

Evaporation retardants may be applied immediately after placing and before texturing work to limit the risk of early drying in hot and high evaporation conditions.

For extreme weather events (hot weather and cold weather concreting), the curing procedures established under the Weather Management Plan should be followed.

<u>Curing Material Coverage</u>

Curing application needs to be uniform and at the specified rate. Large paving surfaces will lose water rapidly. Inadequate curing application may result in a variety of early age cracking and durability issues. If the application does not appear uniformly white, then it needs to be re-sprayed.

<u>Hand Spraying</u>

A two coat application, the second in direction at right angle to the first, is necessary to ensure proper coverage.

7.12.1 Curing Protection

Membrane curing needs to be protected from damage to be effective. Curing compound can be damaged by traffic on the pavement surface. For this reason, no traffic except that required for sawcutting should be permitted for the first 12 hours. Curing compound needs to be re-applied if damaged from rain or traffic within 72 hours of initial application.

7.13 Form Removal

Forms should not be removed prematurely. If removed prematurely, the concrete edges may be damaged. The specification requires that forms shall not be removed until the concrete has attained a compressive strength of 500 psi. Concrete strength can be most economically monitored by using maturity sensors, as prescribed in the specification.

It is necessary that curing compound be applied along the exposed faces of the concrete immediately after form removal. Otherwise, weak paste may develop along the exposed concrete faces, possibly contributing to joint spalling.

7.14 Sawcutting

Joint sawing and sealing is an art rather than a science. It requires an experienced crew to carry out the associated tasks correctly. Although improved guidelines for estimating the time at which sawing can begin are available, the timing of sawing, the speed of the saw, condition of the blade, the condition of the sawing equipment, and care of the operator all combine to influence the final product. In addition, blade type should match the aggregate type. Use of improper blades can result in joint raveling.

Too early sawing can result in joint raveling and tearing of the concrete and late sawing can result in slab cracking. Therefore, the contractor should be aware of the available sawcutting window. The factors that can impact the sawcutting window include the following:

1. Sudden temperature drop (approaching cold or rain front)
2. High wind, low humidity
3. High friction base
4. Bonding between base and slab
5. Porous base (e.g., permeable asphalt treated base)
6. Retarded set
7. Delay in curing application

Skip sawing of transverse joints may be considered for long paving lanes, provided the skipped joints are sawed right after completion of initial sawing of every second joint. Sawing of intermediate longitudinal joints should commence at the same time as the sawing of transverse joints.

All contraction joints should be saw cut. Use of joint forming inserts should not be allowed, irrespective of project type or size.

7.15 Opening to Construction Traffic

Contractors need access to a recently placed concrete pavement for a number of reasons, a primary reason being construction of fill-in lanes. In this case, a number of different construction equipment may need to use the recently placed pavement.

In addition, certain areas may need to be opened to aircraft traffic at an early age. This can be addressed directly by the engineer by specifying high early strength concrete and/or by making appropriate adjustments in the pavement's structural section.

With respect to construction traffic, the following items need to be addressed:

1. Damage to the curing system
2. Damage to the pavement surface
3. Damage to transverse and longitudinal joint edges
4. Structural damage to the concrete slab
5. Damage at the Dowel/Concrete Interface

Damage to the Curing System

There is a general consensus that construction traffic, except for joint sawing equipment, should not be allowed on a freshly placed concrete until the curing membrane has completely dried. This period is typically considered to be about 24 to 36 hours. In addition, it is necessary that any curing membrane that is damaged by construction traffic during the specified curing period (typically 72 hours) be immediately repaired.

Damage to the Pavement Surface

Early use of a concrete pavement can damage the pavement surface. However, this concern is superseded by the concern related to the structural damage to the pavement. If the construction equipment use will not result in structural damage to the concrete, it is unlikely that the equipment will result in surface damage to the concrete. However, special precautions may need to be taken to ensure there is no damage from paver tracks riding along the concrete pavement edges.

Damage to Transverse and Longitudinal Joint Edges

Early use of a concrete pavement can damage transverse and longitudinal joint edges. Similar to the concern related to damage to the pavement surface, this concern is superseded by the concern related to the structural damage to the pavement. If the construction equipment use will not result in structural damage to the concrete, it is unlikely that the equipment will result in joint edge damage.

Structural Damage to the Concrete Slab

The concern with structural damage to the concrete pavement is in relation to the development of excessive stresses in the concrete slab that may result in early age cracking or may affect the long-term performance of the pavement. It is therefore necessary to keep the bending stresses that develop as low as possible in comparison to the strength level at time of use. This requires that the actual stress level that develops due to specific equipment and for a given pavement section be taken into account. For example, the stress levels in the concrete slab due to a haul truck riding on an 18 in. thick slab will be much less than for the same truck riding on a 12 in. thick slab. Similarly, the stress levels will be much less for a pickup truck.

In order to minimize any detrimental effects of the construction traffic loading, it is necessary that these stress levels (typically along an edge) be maintained at a level much less that the concrete strength at time of use. In other words, the concrete strength at the time of early loading should be much higher than the anticipated stresses. Typically, a stress multiplier of 2.0 is used to determine a minimum strength level for unlimited stress applications without resulting in damage. However, a stress multiplier of 2.5 is recommended to account for curling/warping stresses and accuracy in determination of early age in-situ concrete strength. The calculated edge bending stress multiplied by 2.5 is referred to as the "Zero Fatigue Stress". Thus, if an edge stress of 80 psi is computed for a haul truck for an 18 in. thick project pavement, the concrete flexural strength level would need to be at least 200 psi (zero fatigue stress value) at time of use by the haul trucks.

The proposed specification provides the contractor the option of waiting until the in-place concrete flexural strength is 450 psi or demonstrating by approved computation method that his construction equipment will not result in excessive stresses on the pavement. In any case, the flexural strength of the concrete cannot be less than 300 psi to minimize damage at the joints (aggregate interlock or dowel bar bearing stress damage – see next section).

Damage at the Dowel/Concrete Interface

A concern with early use of the pavement is with high dowel bearing stresses at the dowel/concrete interface. For a 20,000 lb haul truck tandem axle load, the dowel bar shear load can exceed 3,000 lb for the corner dowels (about 1,200 lb for interior dowels) for trucks riding along the edges. The corner dowel loads decrease if the trucks are kept away from the edge/corner. The 3,000 lb dowel load can result in about 3,000 to 4,000 psi dowel bearing stress and can be accommodated by mature concrete. However, this load level is considered very high for a recently placed normal concrete. The simplest way to mitigate this concern is to keep heavy traffic at least 2 ft away from the slab longitudinal edges. The flexural strength requirement of 300 psi for the calculated Zero Fatigue Stress value ensures that dowel bearing damage does not develop due to early use of the pavement.

Bending Stress Computation

Slab bending stress may be computed for the critical construction equipment using one of the following procedures:

1. Use of ACPA's computer program AirPave (Ref. 11)
2. Use of approved slab-on-grade finite element analysis software, such as, ISLAB 2000 (Ref. 12) and JSLAB (Ref. 13).
3. Other methods approved by the engineer

An example of the computed stress levels due to different construction vehicle for a 16 in. thick concrete pavement is given below (Ref. 15):

Construction Equipment Type	**Maximum Edge Bending Stress, psi**	**Zero Fatigue Stress, psi**
Light Duty Trucks	27	67
Concrete Trucks (Loaded)	72	180
Slipform Paver	124	310
Belt Placer/Spreader	139	347

Thinner pavements result in higher zero fatigue stress for the same construction equipment. Therefore, thinner pavements require higher strength development before opening to construction traffic.

In-situ Strength Determination

If the concrete pavement is to be used by construction traffic within a few days of construction, it is necessary to monitor in-situ concrete strength. Concrete strength may be monitored by testing strength specimens cured at the project site or by use of maturity testing. Use of maturity testing is strongly recommended as this technique is reliable and reasonably easy to implement. Information on maturity testing is summarized in Ref. 14.

Additional guidelines on early opening of pavement to construction traffic are given in Ref. 15.

8.0 PROCESS CONTROL

Contractor process control typically refers to the contractor's roles and responsibilities. The goal of the process control program is to provide testing, monitoring, and reporting of information to adequately document that the contractor is meeting the project specifications and to allow the contractor to make timely adjustments to the construction process. The contractor needs to develop a written project specific Quality Control Program plan that is available for review and approval by the owner. The Quality Control Program plan should be developed in accordance with Section 100 of the General Provisions (Ref. 16). The program should address all elements that affect the quality of the pavement, as required by the General Provisions.

Overall Process Control Philosophy

- Provide necessary safeguards to ensure that owner receives an end product with the specified characteristics
- Recognize that a certain amount of variability exists in materials, construction process and testing
- Material is rejected or process is stopped when the trend indicates that the end product requirements are not being met
- Minimizes placement of marginal or non-acceptable concrete
- Process control requirements are not arbitrary nor punitive

The specification requires the contractor to also perform all acceptance testing. The Quality Control plan should also address the conduct of acceptance testing.

The components of a good contractor QC plan are as follows:

1. Introduction
   - Project Description
   - Key Contact Information (contractor, owner, and owner's representative)
   - Contract Plans and Specifications Highlights
2. Purpose of QC plan
3. Organization chart – Clearly delineating the flow of responsibility from ground up to top management
   - QC roles (testing laboratory, contractor, etc.)
   - Project personnel
4. Duties and Responsibilities
   - QC manager
   - Project engineers
   - Technicians/inspectors
5. Inspections (Include tests required and frequency and acceptance criteria)
6. Process control testing
   - Testing plan
   - Report submittals
7. Contractor acceptance testing
   - Testing plan
   - Report submittals
8. Deficiencies reporting
9. Conflict resolution
10. Defective pavement repair
11. Changes to the QC plan
12. Appendices (as needed).

The QC plan needs to be clearly written to minimize the potential for misunderstanding. The plans also need to be reviewed for ambiguity with respect to sampling locations, number of tests, test procedures, special provisions, and acceptance limits. It is important that copies of all test procedures referred to in the plan be readily available at the project site or at the project test facility.

The contractor management needs to fully support the QC process. Without the support of management, urgent deadlines and outside pressures may dominate the project activities and the QC testing and inspection could suffer.

Process Control Testing Concept

The process control testing requirements are based on multiple tests before materials are rejected or paving operation stopped. Typically, tests are routinely performed at the frequency specified for each test. If a test results in a failure, a second test is conducted on the same batch of materials. If the second test results in a failure, tests are conducted at a higher frequency. If more tests result in failure, then the paving operation is stopped or the materials are rejected, as applicable. This practice ensures that materials are not rejected or the paving process is not stopped on the basis of individual tests. It is the pattern of failed tests that is of concern.

8.1 Testing Personnel

The specification requires technicians to be certified for strength testing. This is especially important when using beams for acceptance testing.

If the State DOT has a concrete technician certification program, certification from that program is also acceptable. The key elements are that the testing personnel are experienced in testing the particular elements of the concrete, otherwise test discrepancies will arise.

8.2 Testing Laboratory Requirements

The Contractor may use an in-house or a hired laboratory. The testing laboratories used by the contractor are required to meet the requirements of ASTM C 1077 that relate to the minimum technical requirements for laboratory equipment utilized in testing concrete and concrete aggregates for use in construction. The Contractor's curing process for strength specimens need to meet the requirements of ASTM C 31. The local State DOT's concrete laboratory certification is also acceptable. AASHTO accredited laboratories may also be used.

Field storage and curing environment for strength specimens during the first 24 hours is very critical and proper measures must be taken. Improper curing during the first 24 hours can lead to lower strength at 28-days. Use of commercially available or contractor fabricated controlled curing chambers is strongly recommended. In addition, proper procedures must be followed for transporting and final curing of the strength specimens.

8.3 Process Control Testing

The contractor is responsible for controlling the process. The test section is to demonstrate the process is under control, and the production paving requires maintaining of that process. The process control testing should be a major component of the Quality Control Plan. The Process Control plan should also identify the appropriate corrective action from measured responses.

8.3.1 Accuracy of Plant Batching

During production paving, the accuracy of batching for all weighed concrete ingredients shall be rechecked in accordance with the provisions of NRMCA QC 3 document at the specified frequency. Accuracy of batching does not imply recalibration of the scales, but it is the checking of the desired quantity against the actual quantity, making required adjustments, and recording the activity. Most modern plants have the capability to print the target weight versus the actual weight for each load.

8.3.2 Aggregate Quality

Aggregate quality at the plant site is impacted by stockpile management methods. NRMCA QC3 requires stockpile management methods to be developed and followed. Issues that should be addressed include:

1. Preventing contamination and clay balls by having a stockpile foundation. The foundation may be the bottom one or two feet of the pile or a hard paved surface.
2. Drainage should be away from the stockpile.
3. Separation between piles to prevent cross contamination.
4. Labeling of the stockpiles and plant bins, by the material names that the delivery truck and loader operators are accustomed to.

All aggregate materials have the potential to segregate. Proper stockpiling methods are required to prevent segregation. In no case shall materials be allowed to free-fall more than 3 feet from a conveyor. Two acceptable methods include numerous small cones and loader built piles. For the first method, numerous cones about 3 feet in height are built adjacent to each other. The next layer of cones are built to fill the space between the first cone layers. The process is continued to the desired height. This is easily accomplished with a telescoping radial stacker that is computer controlled.

For loader built piles, the first layer should not be higher than the maximum dump of the loader. Equipment shall not be allowed to travel on top of the aggregate pile to prevent degradation. Stockpiles should not be built with trucks, loaders or dozers driving up a slope and dumping or pushing over the end of the pile. This creates some of the worst segregation.

The following ASTM C 33 aggregate quality tests are required to be performed on the day of test section construction and on every seventh day of paving thereafter.:

1. Deleterious substances in accordance with ASTM C 33, Table 3, for the portion of the combined aggregate retained on the No. 4 sieve.
2. Deleterious substances in accordance with ASTM C 33, Table 1, for the portion of the combined aggregate passing the No. 4 sieve.
3. Flat and elongated pieces for aggregate retained on the No. 4 sieve.

8.3.3 Combined Aggregate Gradation

Grading for each aggregate type shall be determined at least once before start of paving for each day of paving in accordance with ASTM C 136 on samples representative of that day's paving. The mathematical combined aggregate gradation shall be determined using the aggregate proportions of the established concrete mixture. At the beginning of a project, it may be advantageous to the contractor to conduct additional gradations at the midpoint of each day's paving until the variability from the supplier is determined.

The purpose of the combined aggregate gradation determination is to make any adjustments to the individual material batch weights to remain within combined gradation requirements. This requires that positive stockpile management methods must be used. More specifically, it is considered a deviation to feed the plant from the same face of the stockpile that is being replenished, as the actual gradations will not be known.

For projects that have limited stockpile sites at the plant, it is common to build a dedicated stockpile at another location, such as at the quarry or vacant lot. The dedicated stockpile can be the one that is managed where replenishment occurs in a different location than the face used to haul to the plant site. For these off-site stockpiles, it would be reasonable to conduct the daily gradations at that location if the plant site can not store even one day's production.

8.3.3.1 WF and CF

The combined-aggregate grading shall be used to determine the Workability Factor (WF) and the Coarseness Factor (CF). The combined-aggregate grading tolerance is plus or minus 3 points for the WF and plus or minus 5 points for the CF from the production paving proportions established at the test section. These limits are reasonable and if a combined gradation exceeds these, then one or more of the materials has changed substantially.

8.3.3.2 Combined-Aggregate Gradation Controls

These provide the assurance that the individual aggregate proportions will be adjusted to maintain a consistent combined gradation, which will provide a consistent product for production.

8.3.4 Air Content

The purpose of the specified process control testing is to ensure that only a minimal amount of marginal concrete with poor air system is placed.

8.3.5 Concrete Temperature

The purpose of the specified process control testing is to ensure that only a minimal amount of marginal concrete with excessively high temperature is placed.

8.3.6 Hand Finishing at Edges

Hand finishing of the edges and corners of the concrete surface behind the paving equipment to remediate excessive edge slump is limited to 25 percent of the edge per slab panel. Hand finishing of the edges and corners in excess of 25 percent of the edge per slab indicates the process is not within the specified level of conformance and the contractor should make the necessary adjustments in the concrete proportions and construction process.

The more concrete is worked and finished, the more likely it is to bring excess paste to the surface. The longitudinal edges of a slab are in a high stress zone. Stresses result from the sawing of longitudinal joint seal reservoir, from saw blade chatter that may occur, from tensile stresses due to joint seal pull, and from surface stresses from snow plows. These stresses contribute to the development of spalls at the longitudinal joints.

The most common and severe FOD generating spall is the sliver spall. It is associated largely with the joint sawing and sealing operation, and is typically contained within 1 inch of the seal at the surface and does not penetrate below the reservoir. The distress is a series of flakes within this zone that typically develop after the seals are installed. Observations of airfield projects in Michigan, Wisconsin, Indiana, and North Dakota show a tendency for the slivers develop more along the fill-in lane side of the joint than on the pilot lane. The slivers typically develop within 90 days of sealing, and almost always before aircraft use the pavement.

Snow plow spall damage occurs at transverse and longitudinal joints. Transverse spalls are either from the cutting edge spalling the joint or from the blade bearing pads, behind the blade, crushing the joint. Normal plow operations have the blade traversing the joints at an angle, so the potential is minimized. These are mechanically caused spalls and are typically not the responsibility of the contractor provided the concrete was placed in conformance with the specifications.

Longitudinal joint snow plow damage is usually due to mismatch of the joints, a more frequent issue for slipform paving than for sideform paving. When paving the fill-in lane, if the paver pan rests on the pilot-lanes, there is a strong possibility the weight of the machine will crush the edge of the pilot lane. Therefore, common practice is to set the pan about ¼ inch above the pilot lane surface, which is where the joint mis-match occurs. To avoid violating the criteria, finishers will work the outer 18 to 24 inches of the fill in lane to match the pilot lane, thereby creating the excess paste that contributes to the development of the sliver spalls.

Another aspect that is not good practice is to use a higher water to cementitious materials ratio for the fill-in lanes. This is viewed as a construction expedient by increasing the workability, reducing work force requirements, and increasing production. The risks are segregation and excess paste accumulation at the joints. Part of the safeguard against this practice is the requirement of the minimum water to cementitious materials ratio contained in the specification.

A common practice that is often overlooked is the settings of the outer vibrators. The outer 2 or 3 vibrators are often set very high for paving the pilot lanes to ensure the edge stands. However, for a fill-in lane, the vibrator efficiency is greatly increased because the energy reflects off the pilot lane. Therefore, the outer vibrators need to be turned down for the fill-in lanes to avoid segregation and excessive paste accumulation.

All of these issues are contributing factors to the limitation on hand finishing behind the paver. The requirement will be applied to slipform and sideform paving. The use of cutting straightedges, which are channels several feet long and attached to a handle, is not considered hand finishing. Hand finishing is the use of floats, trowels, darbys, edgers or tools with similar functions, and to work the edge to fill in voids left from the paver. It also includes the use of boards or forms to prop up, repair or restore the free edge.

When the mixture is matched to the paving method and the climate, then there is not a need for excessive hand finishing. The ability to match these elements is the primary reason that the contractor is afforded complete control of the process, and adjustments to his process are allowed. The test section is the arena to demonstrate the process is in control. It is recognized that there is an occasional disruption in the process and that some hand finishing is required, which is addressed by the maximum limitation in the specification. However, continuous hand finishing indicates the paving elements are not matched and/or the process is not in control.

8.4 Control Charts

Control charts provide the contractor and the engineer an easy to digest summary of the key construction processes. Control charts are excellent tools to track trends and anticipate problems. The benefits of using control charts include the early detection of problems, monitoring variability, and establishing the process capabilities.

Similar to other documentation on a construction project, control charts are only useful when updated and adjustments implemented on a timely basis. The CQC plan should address the detailed procedures, identifying which items require control charts, the information to be presented on each control chart, the required posting time, and the distribution of information.

The aggregate grading and aggregate moisture contents are the largest sources of variability in the concrete. These items should be tracked regularly using control charts

As a minimum, the contractor is required to maintain linear control charts for combined aggregate WF and CF values, air content, and concrete temperature.

Corrective Action

Corrective actions should be implemented before the process becomes out of control. The process control testing should identify developing trends in key construction activities. If the trends indicate recurring quality problems, the contractor should take appropriate actions to bring the processes back into control. Continual feedback of the process is therefore necessary.

9.0 ACCEPTANCE TESTING

Acceptance testing process involves testing conducted to determine the degree of compliance with contract requirements and is typically linked to pay items and may involve corrective work and removal and replacement of defective items.

The proposed specification requires acceptance testing to be performed by the engineer as well as the contractor. The engineer's testing is performed on hardened concrete and is not subject to the contractor's schedule. In addition, the engineer's testing does not require laboratory facilities. The contractor's acceptance testing items should be incorporated in the contractor's QC plan.

Acceptance Testing Philosophy

The intent of acceptance testing is not to discriminate absolutely between good and bad end product. Otherwise, we would be testing every cubic yard of concrete and every square yard of the pavement. The intent of acceptance testing is to discriminate sufficiently to minimize the contractor's risk of good end product being rejected and the owner's risk of a bad end product being accepted. The balance between rejecting a good product and accepting a bad product is maintained by type and extent of testing and rules used to accept test results.

The test requirements must have direct relevance to concrete pavement performance. Arbitrary tests should never be specified. The impact of acceptance items on pavement performance is illustrated below:

1. Thickness and Concrete Strength → Affects Structural/Fatigue Cracking → Impacts Structural Performance
2. Concrete Air Content → Affects Freeze-Thaw Response → Impacts Durability
3. Straight Edge/Grade/Edge Slump → Affects Geometry and Surface Drainage → Impacts Functional Performance (Safety)
4. Dowel Alignment → Affects Early Cracking and Load Transfer at Joints → Impacts Structural Performance
5. Cracking and Spalling → Affects Serviceability → Impacts Structural and Functional Performance (Safety/FOD)
6. Material Requirements → Affects Material related Distresses → Impacts Durability and Functional Performance (Safety/FOD)

9.1 Control Charts

The contractor should prepare control charts for his acceptance testing to track trends and anticipate problems related to the acceptance testing items.

9.2 Lot Size

Two project sizes are delineated in the specification: less than 10,000 cubic yards and larger than 10,000 cubic yards. The break points are not rigid and should be selected by the engineer. It is recommended that a lot equal 2,000 cubic yards. Each lot is required to be divided into five sublots.

9.2.1 Partial Lots

Standard specification item.

9.3 Engineer Performed Acceptance Tests

The following are the engineer performed acceptance tests:

1. Straightedge
2. Vertical grade
3. Edge slump
4. Dowel bar alignment
5. Cracking
6. Sliver spalls
7. Joint spalls

The acceptance tests discussed next are required to be conducted on a sublot basis, unless otherwise noted.

9.3.1 Straightedge

The purpose of straight edge testing, using a 16 foot straightedge, is to identify deficiencies in flatness across and along a paving lane and flatness across joints. The deviations of any of these measures typically result in a high exposed edge of the adjacent slab, which becomes susceptible to spalling from tire pressures and snow plows. The deviations will also identify areas that will trap water which can cause safety issues.

The procedure is to place the straightedge on the concrete surface. Gaps that occur anywhere along the straightedge, not just between two contact points, are measured and checked against the specified tolerances. Measurements are made with a metal wedge with the appropriate calibration marks that slide under the straightedge; rulers are difficult to read accurately. For uneven pavements and at joints, the straightedge placement producing the greatest gap is recorded. If there is a problem on both sides of a joint, then non-conforming areas on both slabs are recorded.

Research is on going regarding the application of automated devices that can electronically simulate a straightedge. When such methods are approved by the FAA, the Engineer may elect to include these devices. However, use of a manual 16-foot straightedge is still recommended to identify any localized issues, especially associated with vertical deviations at joints. The Engineer is cautioned that most grading plans to accommodate drainage at intersections and other areas of warping will not meet straightedge requirements. In these areas, the straightedge should be applied to identify trapped water and any joint deviations.

9.3.2 Vertical Grade

Meeting grades is an issue because of the need to match the surrounding pavements than any negative impact on the project itself. Grades are typically not a concern when using fixed-form paving and for slipform paving that utilize well managed stringlines and have a stable base for the paver. There is not much experience with string-less paving (as of 2006) and information on the precision of concrete placement with respect to grade is not known. However stringless paving is expected to be more common in future.

9.3.3 Edge Slump

The edge slump criterion is necessary to minimize trapping of water along the longitudinal joints and to minimize exposing a vertical edge to spalling from tires and snow plows. A concrete mixture that is properly matched to the paving equipment and conditions will not have an edge slump issue. Note that to meet the edge slump criteria, the paver side mold is cantered in towards the top of the slab, and the outer edge of the pan is warped upwards. These combine to create overbuild which when the slab settles behind the paver will not be an edge slump issue.

The edge of the concrete should be relatively flat, but not vertical. The flatness indicates the concrete held its shape and the mix is stable. If there is a readily noticeable bulge in the edge of the slab, then it is an indicator that something in the process is not adjusted properly. The bulge itself is not sufficient to be a deficiency, but it may produce excessive edge slump, which may require excessive hand finishing and create the sliver spall potential.

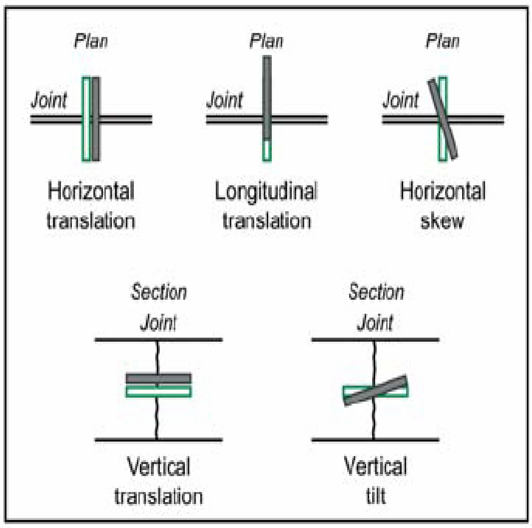
Note that the edge slump criterion is slightly different from the straightedge criterion. Also, a common problem is when edge slump occurs, the adjacent lane is hand worked to meet the lower edge, creating a ponding problem and potentially unsafe condition. Therefore, it is imperative that edge slump measurements be conducted prior to paving the adjacent lane, and any corrective actions completed before paving the adjacent lane.

9.3.4 Dowel Bar Alignment

Dowel bar alignment is a critical item and must be checked on a regular basis. Dowel misalignment does have a significant effect on pavement performance. The dowel misalignment categories are illustrated below in Figure 2.

Dowel bars should be placed within the allowable tolerances. Improved dowel bar alignment testing methods are now available (Ref. 21). These methods provide accurate information on the misalignment categories identified above. However, evaluation of this information should be done carefully. In-service performance evaluation of pavements indicates that dowel alignment at transverse joints may not be an issue for airfield pavements.

Dowel alignment should not be rejected on the basis of individual dowel bars. Dowel alignment data should be considered on the basis of a whole joint and a group of adjacent joints. If a problem is determined with dowel misalignment during construction, the contractor should immediately stop paving and remedy the problem before continuing.



Type of Misalignment	Effects on Spalling	Cracking	Load Transfer
Horizontal translation	No	no	Yes
Longitudinal translation	No	no	Yes
Vertical translation	Yes	no	Yes
Horizontal skew	Yes	yes	Yes
Vertical tilt	Yes	yes	Yes

Figure 2 – Dowel Bar Misalignment Categories

9.3.5 Cracking

Two types of cracking are designated in the specification, as follows:

1. Shallow cracking
2. Deeper cracking

Shallow cracking is defined as cracking that is 2 inches or less in depth. Shallow cracking may be closely spaced, random, appear in a spider-web form, or be a series of parallel cracks that may be at a diagonal to the paving direction. Typically, shallow cracking is plastic shrinkage cracking that develops due to loss of water from the concrete surface before the concrete completes releasing bleed water. Thus, the importance of the use of the moisture evaporation chart (see Appendix A). The key defining issue is the depth of cracking. If the crack depth is less than 2 inches, then the severity of the distress is low and epoxy repairs can resolve the problem. Cracks deeper than 2 inches indicate that the process was not under control. Pavement areas with cracking deeper than 2 inches are considered defective.

9.3.6 Sliver Spalls

Sliver spalls are spalls generally within 1 inch of the joint face and generally do not extend beyond the depth of the joint seal reservoir. They typically develop after joint sealing and are commonly a result of segregation causing excessive paste at the corner and saw chatter. The spalls resemble a series of flakes at the joints. Sliver spalls are perhaps the largest contributor to spalling on new airfields. As such, they are the primary reason that limitations on hand finishing are imposed.

9.3.7 Joint Spalls

Joint spalls are larger or deeper than sliver spalls and are typically the result of equipment damaging early age concrete. Usually these distresses are isolated and can be repaired using proper methods and regular concrete mixtures.

Key issues are that exotic spall repair materials are generally not effective due to the differences in the coefficient of thermal expansion with the concrete and the repair material. It has been observed that regular concrete, with a smaller aggregate size appropriate for the repair area, will perform better than most of the proprietary materials. The keys to performance are proper preparation, proper concrete mixture, and effective curing. Improper repairs will seldom last one year, and failure is usually by debonding which can be determined by sounding.

9.4 Contractor Performed Acceptance Tests

The following acceptance tests are to be performed by the contractor:

1. Thickness
2. Strength

Testing is conducted on a sublot basis; however, acceptance of the pavement is on a lot basis. Each lot is to consist of five sublots.

The specification provides for acceptance of the pavement based on the method of estimating percentage of material within specification limits (PWL). All test results for a lot will be analyzed statistically to determine the total estimated percent of the lot that is within specification limits. The PWL is computed using the sample average (X) and sample standard deviation (S_n) of the specified number (n) of sublots for the lot and the lower specification tolerance limit, L, for the particular acceptance parameter. From these values, the Lower Quality Index, $Q_{L,}$ is computed and the PWL for the lot is determined as the percentage of the material above the lower specification tolerance limit. Details of the PWL procedure are given in Section 110 of the General Provisions (Ref. 17).

The lower specification tolerance limit, L, for flexural strength and thickness are:

- Flexural Strength: 0.93 x Specified Strength
- Thickness: Lot Plan Thickness in Inches less 0.50 Inches

The lower specification tolerance limits incorporate the normal variability in the respective measures.

9.4.1 Thickness

The sampling, testing and acceptance procedures for thickness are defined in the specification. The thickness of a pavement can be tested in several ways. It can be checked by using paving stringline as a guide, performing destructive testing by taking cores from the concrete pavement, or surveying elevations before and after placement. Coring is the preferred method. If core testing is used for thickness verification, the cores (typically 4 in. in diameter) need to be labeled and stored, preferably on site, until the end of the project.

9.4.1.1 Sampling

Standard specification item.

9.4.1.2 Thickness Acceptance

Standard specification item.

9.4.2 Strength

Concrete pavements are designed on the basis of flexural strength and FAA policies require that the flexural strength of the as-delivered concrete be determined to establish payment factor for the concrete pavement. However, there is no compelling technical reason to determine flexural strength of the concrete using beam testing, as per ASTM C 78. Although the ASTM C 78 flexural strength test procedure is reasonably simple, it requires strict adherence to specified procedures because minor variations in the preparation, handling, curing and testing of the beam specimens can result in highly variable test results.

Field experience indicates that production use of flexural strength is not very effective as there are too many issues with obtaining reliable test results. The specification allows use of flexural strength testing or splitting tensile strength testing. The use of the splitting tensile strength option is strongly recommended.

The splitting tensile strength option is based on splitting tensile strength testing for production paving concrete acceptance and conduct of a limited amount of flexural testing under controlled conditions to develop correlations between the flexural and splitting tensile strengths.

Concrete Strength Testing

The FAA P-501 specification uses flexural strength for acceptance of concrete. The payment for meeting the specified strength requirement is greatly influenced by both the lot average strength and the lot standard deviation. The lot average strength needs to be sufficiently higher that the specified strength and/or the lot standard deviation needs to be significantly lower to qualify for full or bonus payment. This requires good control over the concrete production process as well as over the strength testing process. The P-501 requires the percent within limits (PWL) to be 90 for strength to qualify for full strength-based payment for a lot. The pay factor has a potential benefit to the contractor above a PWL of 96.

In the past, only flexural strength testing was allowed for determination of the flexural strength of production paving concrete. Proposed specification allows use of either flexural testing (ASTM C 78) using beam specimens or splitting tensile strength testing (ASTM C 496) using cylinders to determine the concrete flexural strength. Both flexural strength and the splitting tensile strengths are similarly influenced by changes in air content, aggregate quality, and aggregate shape and amount of fractured faces. If the splitting tensile strength testing is used, a correlation needs to be developed between the flexural and the splitting tensile strengths for each project-specific concrete mixture as detailed in the specification.

The splitting tensile strength test involves compressing the cylinder on its side until a crack forms down the middle, causing failure of the specimen. The loading induces tensile stresses on the plane containing the applied load causing the cylinder to split.

Flexural strength testing using beams is very sensitive to field specimen preparation, initial curing and handling of the test beams in the field, testing techniques, and calibration of testing machines. Variability is an inherent part of all construction testing. However, flexural strength testing is particularly sensitive to variability in the testing process and test results are affected by minor changes in handling of the large beam specimens and the test procedures, especially the moisture condition during testing.

On the other hand, even though the laboratory precision of the two strength test methods is similar, the cylinder specimens for the splitting tensile strength testing are less vulnerable to damage due to handling in the field and due to transport. In addition, most testing laboratories routinely prepare test cylinders for compressive strength testing and are familiar with issues related to specimen preparation, handling and curing. Flexural strength testing is not a common event for most testing laboratories, except at time of airport paving projects.

The use of the splitting tensile strength testing allows more sample testing and use of more sublots, without impacting testing costs, while realizing improved statistical basis for interpreting the test data. Fifteen strength specimens are now tested per lot instead of eight specimens in the past. The use of the splitting tensile strength testing option by the contractor is recommended.

9.4.2.1 Strength Method 1 - Flexural Strength using Beams

The flexural strength testing option requires testing of two replicate beam specimens per sublot for each of five sublots per lot.

Beam testing continues to be a matter of concern because of the overall reliability of beam testing under field conditions. Beams are vulnerable to damage in handling and transport. Damaged beams will yield low strength results. In addition, beam testers need to be calibrated at more frequent intervals for accuracy and rate of loading and uniformity of loading (load distribution) between the two supports and across the width of the beam.

9.4.2.2 Strength Method 2 – Splitting Tensile Strength using Cylinders

The splitting tensile strength testing option requires testing of three replicate cylinder specimens per sublot for each of five sublots per lot. A larger number of cylinder specimens are used with the cylinder option because of the low cost of making and testing the cylinder specimens.

This option requires development of a correlation between the flexural strength and the splitting tensile strength in the laboratory before the start of production paving. If time permits, the correlation should be developed using the on-site plant concrete. The correlation is based on a single point, at the specified age for testing. Fifteen beams and 15 cylinders are tested at the specified age. The average values of the flexural and splitting tensile strengths are used to develop the correlation factor. Outlier test data should not be incorporated in the correlation factor.

An example of the correlation development is given below:

1. Three concrete batches are prepared in the laboratory. These batches can be prepared during a single day or over several days. Five beams and five cylinders are fabricated from each batch. The test specimens are tested at the specified age, in this case, 28 days. The test data are listed below:

a. Batch 1
    i. Flexural strength, psi: 755, 770, 745, 710, 735
    ii. Splitting tensile strength, psi: 475, 485, 500, 435, 480
b. Batch 2
    i. Flexural strength, psi: 790, 775, 825, 840, 820
    ii. Splitting tensile strength, psi: 485, 540, 550, 515, 430
c. Batch 3
    i. Flexural strength, psi: 765, 820, 830, 840, 820
    ii. Splitting tensile strength, psi: 455, 420, 455, 590, 525

2. The following statistics are computed:

Property	Flexural Strength, psi	Splitting Tensile Strength, psi
Average	789	489
Maximum Value	840	590
Minimum Value	710	420
Range	130	170
Standard Deviation	42	48
Coefficient of Variation, %	5.3	9.8

3. Outlier testing in accordance with ASTM E 178 indicates that there are no outliers in the data set at the 5% significance level.
4. The strength correlation, COR, is established as follows:

COR = Average Splitting Tensile Strength/Average Flexural Strength
COR = 489/789 = 0.62

Note: The COR value typically ranges from about 0.60 to about 0.70 and is dependent on many factors including mixture proportions, aggregate type, aggregate shape and maximum aggregate size. The COR is required to be established for each concrete mixture to be used at the project.

Referee Testing for Strength

When beam or cylinder strength tests have not been performed adequately or if tests results are considered suspect, core strength testing may be considered to determine if the strength testing was in error or if there is a strength deficiency in the as-delivered and as-placed concrete. If core testing is used for this purpose, the following items need to be considered:

1. Cores should be obtained and conditioned in accordance with ASTM C 42.
2. Cores should be tested for splitting tensile strength in accordance with ASTM C 496.
3. Core strength test results need to be used in accordance with the FAA Engineering Brief No. 34A (Ref. 18) that provides guidelines for determining if the testing was in error. If the testing was in error, then the guidelines provided in the engineering brief should be used to estimate the representative flexural strength of the suspect lots.

4. Core testing should be initiated at a test age close enough to the specified test age for the flexural or compressive strength testing.
5. Core conditioning prior to testing is very important and the guidelines provided in the engineering brief should be followed.

It should be noted that the acceptance testing beams or cylinders represent the strength of the as-delivered concrete, while core testing represents the strength of the as-placed concrete.

9.4.2.3 Strength Acceptance

Standard specification item.

FLEXURAL STRENGTH VERSUS PWL REQUIREMENTS:

The specification uses flexural strength acceptance criteria in terms of PWL statistical criteria. Under this procedure, the payment for meeting the specified flexural strength requirement is greatly influenced by both the lot average flexural strength and the lot standard deviation. The lot average strength needs to be sufficiently higher than the specified strength and/or the lot standard deviation needs to be significantly lower to qualify for full or bonus payment. This requires good control over the concrete production process as well as over the flexural beam testing process. The specification requires the PWL to be 90 to qualify for full payment for a lot. The pay factor has a potential benefit to the contractor above a production quality level (PWL) of 96. An example computation is given below to illustrate how the lot pay factor is affected by the strength statistics.

Specified flexural strength: 650 psi
Lower flexural strength tolerance limit (93 percent): 604.5 psi
Standard deviation: 50 psi (representing good quality control) based on 4 tests

Lot Average Strength, psi	Lot PWL	Lot Pay Factor
625	64	77.6
650	81	95.5
675	97	106.0

As seen in the above example, in order to qualify for the 100 percent pay factor for a lot, the target flexural strength of the concrete needs to be about 660 psi or higher versus the specified strength of 650 psi, even when the standard deviation is limited to 50 psi (representing good control over the production as well as the testing processes). Therefore, it is important that the contractor considers both the average flexural strength and the concrete uniformity/consistency. The contractor can achieve a lower standard deviation (reduce variability) by controlling concrete production at all of the different phases, by producing concrete with consistent properties from batch to batch, and by ensuring that proper procedures are followed to fabricate, handle, store, and test specimens.

10.0 DEFICIENT AND DEFECTIVE PAVEMENT

Defective pavement that is of the greatest concern is that which will create FOD. This will primarily be from spalling, which will largely occur at the joints, and cracked slab panels. The specification and the supplemental report provide substantial guidance on avoidance of spalling and early age slab cracking, and provide the contractor the authority to control and refine the paving process. However, when specified tolerances are exceeded and defective pavement areas result, it is imperative that strict repair standards be enforced. Pavement areas that are not in compliance with the specification requirements are designated as follows:

1. Deficient pavement – localized pavement areas that exhibit minor levels of non-compliance, such as:
    a. Shallow cracking
    b. High spots
    c. Sliver spalls
    d. Joint spalls

    Deficient pavement areas can be left in place after corrective treatment and are not considered to impact long-term pavement performance.

2. Defective pavement – pavement areas that cannot be corrected and left in place. Defective pavement areas require removal and replacement. Defective pavement areas include the following:
    a. Deeper cracking
    b. Excessive sliver spalls
    c. Excessive joint spalls
    d. Excessive edge slump
    e. Low areas that impede surface drainage
    f. Severely rain damaged areas

<u>Repairs Mitigated as Directed By Engineer</u>

Industry standards are considered the best methods for repairing concrete pavements. The FAA recognizes the following documents as the industry standards for repairing concrete airfield pavements, which have been adopted by the U.S Army, Navy and Air Force:

> *Concrete Pavement Repair Manual JP002P*, American Concrete Pavement Association, Skokie, IL, May 2003.
>
> *Concrete Crack and Partial-Depth Spall Repair Manual JP003P*, American Concrete Pavement Association, Skokie, IL, May 2004.

It is important that nothing in these documents supersede the direction of the project specification or the direction of the Engineer.

10.1 Deficient Pavement

10.1.1 Shallow Cracking

Shallow cracking, which is 2 inches or less in depth as determined by cores, can remain in place after treatment by application of free-flowing capillary methyl methacrylate by a skilled installer. Shallow cracking is not considered a structural deficiency and does not impact long-term pavement performance.

10.1.2 High Spots

High spots, as determined by straightedge testing, not exceeding 0.5 inch, should be marked for grinding. Care must be exercised so that excessive material is not removed during the grinding operation. Deeper grinding can trap water and create a safety hazard for aircraft. If deeper grinding results, then the affected slab areas would be considered defective and should be removed and replaced.

Surface Grinding

Surface grinding shall be performed with a grinding machine utilizing diamond blades, mounted on a self-propelled machine that has been designed for grinding and texturing of pavements. The equipment shall be such that it will not cause damage to the pavement. Grinding equipment that causes excessive raveling, aggregate fractures, spalls, or disturbance of the transverse and/or longitudinal joints shall not be permitted. Limits of grinding will be approved by the Engineer. Grinding shall remove the high spot deficiencies and not trap water. Corrective work required shall be performed before thickness determinations, joint sealing, and grooving operations.

10.1.3 Sliver Spalls

Minor amounts of sliver spalls can be corrected by removing loose material in the affected length of the joint , cleaning the area, and applying liquid joint sealant in the affected area.

10.1.4 Joint Spalls

Minor amounts of joint spalls can be corrected by using the partial depth patching technique. The key steps for the partial depth patching are described in the specification. Partial depth patching requires great care. Some of the key items to note are as follows:

1. Surface preparation is critical. The prepared surface must be sound and clean.
2. A joint forming insert must be used.
3. The repair material must be compatible with the vase concrete. When a proprietary repair material is used, the manufacturer's directions must be strictly followed.

10.2 Defective Pavement

Defective pavements are those pavement areas that are considered to pose safety hazard or result in future performance problems. Because it is more difficult and more costly to perform repairs to defective pavements after the pavements are operational, it is necessary that all defective pavement areas be corrected by removing the affected pavement areas and replacing with concrete meeting project requirements.

The key steps for slab removal and replacement are given in the specification. The removal and replacement may be required to be performed on a fast-track basis. In such a case, use of a concrete mixture that results in high early strength may be required. The contractor should have such a concrete mixture developed and submitted to the engineer at the start of production paving.

11.0 MEASUREMENT

Standard specification item.

12.0 PAYMENT

Standard specification item.

12.1 Pay Adjustment

The percent within limit (PWL) procedure is used to determine the pay factor on a lot-by-lot basis for concrete strength and thickness. The price adjustment is determined for thickness and strength in accordance with the schedule given below.

PRICE ADJUSTMENT SCHEDULE [1]

Percentage of Material Within Specification Limits (PWL)	Lot Pay Factor (Percent of Contract Unit Price)
96 – 100	106
91 – 95	PWL + 10
75 – 90	0.5PWL + 55
55 – 74	1.4PWL – 12
Below 55	Reject [2]

[1] Although it is theoretically possible to achieve a maximum pay factor of 106 percent for each lot, actual payment in excess of 100 percent shall be subject to the total project payment limitation in the contract.
[2] The lot should be removed and replaced. However, the engineer may decide to allow the rejected lot to remain if it is in a non-critical area. In that case, if the engineer and contractor

agree in writing that the lot should not be removed, it should be paid for at 50 percent of the contract unit price and the total project payment limitation should be reduced by the amount withheld for the rejected lot.

For each lot accepted, the adjusted contract unit price shall be the product of the lot pay factor for the lot and the contract unit price. Payment shall be subject to the total project payment limitation specified in the contract. Payment in excess of 100 percent for accepted lots of concrete pavement should be used to offset payment for accepted lots of concrete pavement that achieve a lot pay factor less than 100 percent.

Examples are provided below to illustrate the lot pay factor criteria.

Example 1: Both pay factors equal or exceed 100%

Strength pay factor = 102%; thickness pay factor = 105%

Then, the lot pay factor is the larger of the two values, or 105%.

Example 2: Only one pay factor equals or exceeds 100%

Strength pay factor = 95%; thickness pay factor = 105%

Then, the lot pay factor is the value obtained by multiplying the two values, or 99.75%.

Example 3: Both pay factors are less than 100%

Strength pay factor = 95%; thickness pay factor = 97.5%

Then, the lot pay factor is the smaller of the two values, or 97.5%.

12.2 Pay Items

Standard specification item.

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APPENDIX A – EXAMPLE WEATHER MANAGEMENT PLAN ITEMS

The following is an example of an acceptable weather management plan. This plan may be used with edits, and expanded as necessary, by the contractor to meet the needs of his concrete mixtures, haul units, evaporation modeling method or software, paving hours and other items that are project specific.

CONTRACTOR XYZ WEATHER MANAGEMENT PLAN

Project: XYZ
Location: XYZ
Submitted By and Title: XYZ
Date: XYZ

The following project specific plan details actions that will be taken during concrete placement in hot weather, cold weather and times when a rainstorm is imminent.

1.0 Hot Weather Paving

Hot weather paving is defined as paving when the concrete temperature is greater than 85 degrees F or the moisture evaporation rate at the concrete surface is greater than 0.20 lb/square foot/hour (0.10 lb/ft^2/hr for concrete mixtures containing fly ash or slag), as determined using the American Concrete Institute (ACI) moisture evaporation rate chart. During hot weather, the following actions will be taken:

1) Mixing Requirements - Paving will be suspended when the concrete temperature exceeds 95˚F, mitigation measures to prevent the concrete temperature from exceeding 95˚F when measured directly in front of the paver include:

   a) Chilled water shall be used to prevent the concrete temperature from exceeding 95˚F as measured directly in front of the paver.
   b) Night placement may be initiated during prolonged periods of hot weather.
   c) Aggregate stockpiles may be sprinkled lightly to cool the outside of the stockpile.
   d) The use of specific supplementary cementing materials may be reconsidered.

2) Hauling Requirements - No provision for alternative haul units is included. Non-agitating dump trucks will be used for all placements. The actions detailed in Section 1 will be used for controlling the concrete temperature.

3) Placing Requirements:
   a) A water truck shall be utilized to sprinkle the subbase ahead of the area where concrete is deposited. The subbase will be kept damp with no areas of standing water.
   b) When side forms are used, they will be sprinkled to maintain a surface temperature below 120˚F.
   c) The ambient conditions for relative humidity (%), concrete temperature (˚F), and wind velocity (mph) will be measured and recorded every 30 minutes during concrete

placement. These measured values will be used to determine the evaporation rate ($lb/ft^2/hr$) utilizing Chart 1 or appropriate software.

d) The anticipated placement and finishing techniques listed in order are: 1) dump concrete in front of the paver, 2) consolidate and extrude the pavement using a slipform paver, 3) hand finishing using mops and straightedges, 4) burlap drag, and 5) curing. When the evaporation rate exceeds 0.20 $lb/ft^2/hr$ (0.10 $lb/ft^2/hr$ for concrete mixtures containing fly ash or slag) **and** the curing application is more than 20 minutes behind the burlap drag, the pavement will be fog-sprayed immediately behind the burlap drag to prevent plastic shrinkage cracking.

e) Windscreens and/or shades as referenced in ACI 305R-99 will not be used.

f) The use of an evaporation retardant will be considered if the potential for plastic shrinkage cracking is considered to be high.

4) Necessary Concrete Placement in Hot Weather:
   a) When schedule conflicts with airport tenant traffic cannot avoided, concrete temperatures above 95˚F will be allowed for placements that are less than 200 feet long. Under these conditions, evaporation retardant will be sprayed at the manufacturers recommended rate between the finishers and the burlap drag and again directly behind the burlap drag.

The above sections are in accordance with standard practices and applicable recommendations of ACI 305R-99.

2.0 Cold Weather Paving

Cold weather paving is defined as paving when the air temperature is 40 degrees F and dropping and/or the temperature of the surface on which the concrete is to be placed is less than 32 degrees F. During cold weather, the following actions will be taken:

1) Mixing Requirements - Paving will be suspended when the concrete temperature is less than 50˚F, mitigation measures to prevent concrete temperatures lower than 50˚F when measured directly in front of the paver include:
   a) Heated water shall be used to maintain the concrete temperature above 50˚F as measured directly in front of the paver.
   b) An approved accelerating admixture may be used to promote earlier sawing than would otherwise be possible.
   c) Approved mixes containing Class F Fly Ash will not be used.

2) Hauling Requirements - No provision for alternative haul units is included. Non-agitating dump trucks will be used for all placements. The actions detailed in Section 1 will be used for controlling the concrete temperature.

3) Placing Requirements - Concrete will be placed only when the subbase temperature is 32˚F or greater and the ambient temperature is at least 40˚F. Placement will cease any time the subbase temperature is less than 32˚F or when the ambient temperature is less than 40˚F.

4) Protection of Concrete:
   a) Concrete pavement surface temperature shall be maintained at or above 32˚F for a period of 72 hours or until in-place concrete compressive strength of 500 psi is attained. As necessary, the pavement shall be covered with one layer of polyethylene sheeting and two layers of burlap or curing blankets.
   b) Maturity sensors that record the temperature of the pavement at 15 minute intervals will be placed in the edge of the pavement approximately 2 inches below the surface in the first and last 200 feet of placement. These sensors will be monitored to determine when the maturity equivalent of 500 psi is achieved. Protective insulation may be removed after the pavement reaches the maturity equivalent of 500 psi and the pavement temperature is essentially in equilibrium with the ambient temperature.
   c) Protective insulation will be temporarily removed to enable joint sawing at the earliest possible time.
   d) Pavement will be opened to traffic in accordance with the proposed specification requirements.

The above sections are in accordance with standard practices and applicable recommendations of ACI 306R-88.

3.0 Protecting Concrete from Rain Damage

The following steps will be taken, as necessary:

1) Paving will be canceled or ceased when rain storms are imminent. Weather radar will be monitored at the project office at a minimum of 1 hour intervals when the forecast probability of precipitation is 40% or greater.
2) 14 rolls of 4.0 mil polyethylene sheeting, 20 feet by 100 feet, will be stored on the curing machine for use in protecting the pavement from rain damage. In addition, an adequate number of 12-foot by 2-inch by 8-inch boards will be stored on the form truck for use as ballast to prevent the polyethylene from being removed by wind. The quantity of polyethylene is based on the following estimate:
   a) Average initial set time = 3.5 hours
   b) Average plant production = 250 cubic yard per hour
   c) Placement dimensions – 25 feet wide by 18 inches thick ≈ 1.4 cubic yard/lineal foot of paving
   d) 3.5 hours x 250 cubic yards/hour ÷ 1.4 cubic yard/lineal foot = 625 feet of exposed pavement that has not reached initial set.
3) Polyethylene sheeting will be removed after the rain storm to enable curing operations and joint sawing.
4) Cores of rain damaged pavement will be taken at intervals of 100 feet center to center.

Remedial actions for rain damaged pavement shall conform to the proposed specification requirements related to diamond grinding or remove and replace.

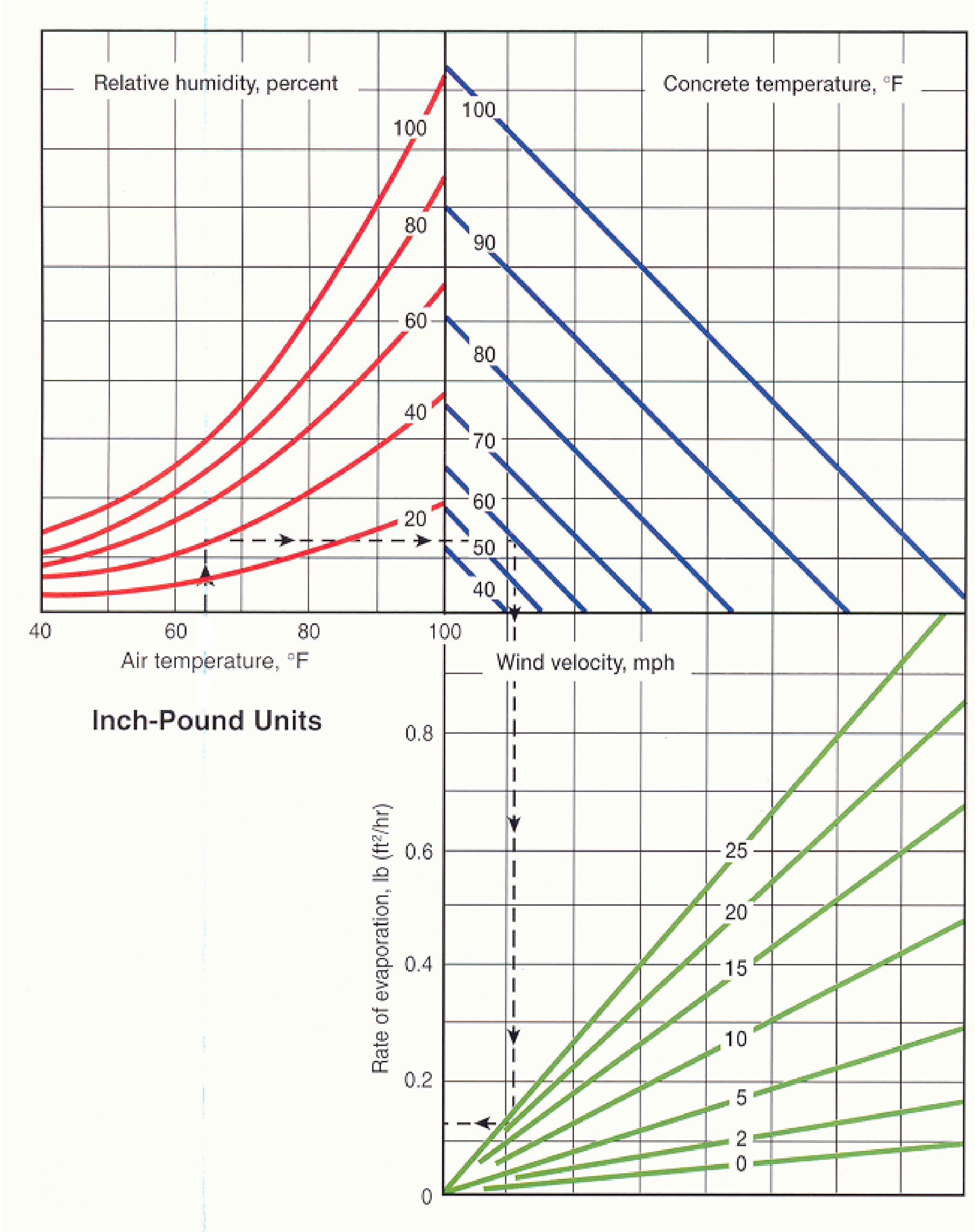

Chart 1 - Rate of evaporation as affected by ambient conditions (courtesy PCA)