Some pavements constructed in the last several years have not performed as expected. Structurally, the pavements have been performing as intended, but the concrete used to construct them in some instances experienced durability issues. A study of local concrete pavements in Oakland, Macomb, and Wayne Counties was conducted by the National Concrete Pavement Technology Center to answer two questions. One, why have we started to experience durability problems with some pavements? The other, what can we do to prevent it from occurring in the future?

As a result of the study, MCA has developed a recommended durability specification that is intended to provide a means to assure both the owner and contractor that the pavement being constructed on a project will be durable. The study determined that there is no single silver bullet solution; in order to provide a high level of confidence three specific areas must be simultaneously addressed. They are as follows: alkali-silica reactivity (ASR), air void system quality, and construction operational processes.

The specification is not intended to qualify or disqualify individual component materials used in the concrete mix; it is intended to qualify the specific combination of materials proposed for the project along with the process by which they will be mixed and placed.

Alkali- Silica Reactivity (ASR)

Cement paste contains small interconnected pores through which water can move. Water combines with the excess alkalis in the cement paste to form a solution that can now react with certain siliceous material found in some sands. This reaction forms a gel that fills the pores and then in some cases swells as it continues to draw in water. When the gel swells, it fractures the concrete and opens it up to additional water infiltration. **For ASR to become a problem you must have a supply of water, excess alkali and reactive silica. One or more of these must be removed in order to prevent the problem.** The following procedures have been shown to successfully mitigate the ASR problem:

Excess Alkali:
Reduce the total amount of alkali in the mix by using a low alkali cement **or** tie up and reduce the total amount of alkali in the mix through the replacement of portland cement either with slag cement, fly ash, silica fume, or a blend of these SCM's.

Water infiltration:
Densify the mix by reducing the total cement paste volume and include slag cement or fly ash particles that fill very small voids which further reduces the permeability. Reduce the amount of capillaries created, when excess water required for workability leaves the mix, through the use of water reducers, aggregate gradation, and aggregate moisture control.

Reactive silica:
Testing has shown that the sand sources in Southeast Michigan and some elsewhere in the State are potentially reactive and some form of mitigation should be utilized on all projects. Each source will likely have a unique potential level of reactivity and require a specific level of mitigation.

There are several test procedures that have been developed to identify the potential reactivity of the aggregate materials:

ASTM C 1260 – Accelerated mortar bar test was developed in South Africa in the 1980's as a rapid screening test for identifying aggregates that could potentially be reactive. A mortar bar is produced with the aggregate in question and it is soaked in a high alkali solution at an elevated temperature for 14 days, a before and after length measurement is taken, if it changes in length by more than 0.10% it is considered to be potentially reactive. Aggregates that pass this test are considered non-reactive, but because this test is very severe and can lead to false positive results for reactivity. Materials that are determined to be reactive should be re-tested or could be tested under ASTM C 1293.

ASTM C 1293 – Accelerated concrete prism test can be used to evaluate materials that show potential ASR reactivity when tested under ASTM C 1260. Concrete prisms are made with high amounts of cementitious materials and additional alkalis are added to simulate a high alkali loading. The expansion is measured after *one year*. The length of time for this test may preclude the use of an aggregate for a specific project, but can provide acceptance for its use on future projects.

ASTM C 1567 – Is a modified version of the C 1260 test. It is used to determine the effectiveness of the proposed mitigation technique. The aggregate as well as the proposed cementitious material are tested for 14 days. Combinations of aggregates and cement materials that pass this test when tested have a very low risk of resulting in damage when the same proportions are used to make concrete. The minimum level of mitigation required to control expansion with a given aggregate can be determined using this test.

Specification Recommendations for ASR:

1. Require some form of ASR mitigation on all projects. The following are the most cost effective methods available in Michigan:
    - Use Low Alkali cement and limit the total alkali to 3.0 pounds per cubic yard.
    - Replace the cement with slag cement at the replacement rates of a minimum of 25% to a maximum of 40%. (Note: FAA allows a maximum replacement rate of 55% on thicker runway pavements)
    - Replace the cement with Type F fly ash at the replacement rate of 15 to 25%.
    - Replace the cement with silica fume at replacement rate of 8%.

- Replace the cement with a ternary cement blend of slag cement, fly ash or silica fume at the specified percentages.

2. When using slag cement, fly ash or a ternary blend, test the proposed combination of materials with ASTM C 1567 to establish that the ASR potential has been mitigated. This test requires approximately a one month lead time and is conducted during a 16-day period. This test is not suitable for evaluation the mitigation when using low alkali cement in the absence of slag cement, Type F fly ash, or a ternary blend.

3. During cooler weather (below 70 degrees F) the set times for mixes with high cement replacement rates will likely increase as the temperature drops. The possibility that cracking may occur before the concrete reaches sawing strength increased. However, the placement of mixes that are not ASR resistant is not an option. The use of accelerators, heated aggregates, silica fume and/or additional forms of cold weather protection will be required. Prior to cool weather placement the set time of the proposed mix should be verified under anticipated field conditions so crews can adjust their procedures to minimize the cracking potential.

<u>Air Void System Quality</u>

The entrained air system developed within the cement paste is designed to protect it from damage as the moisture in the cement paste freezes. As concrete pavement freezes moisture that is present travels to the air voids where it then has room to expand without damaging the concrete. The key is to have many small stable entrained air bubbles that are spaced closely together so the moisture does not have far to travel. When we measure air content with standard testing equipment we are looking at total air including both entrained and large entrapped air bubbles. Many of the problem pavements studied had adequate total air content, but lacked proper entrained air bubbles.

A quality air system begins with the chemical compatibility relationship of the air entraining admixture with the cement. This must be followed up with sufficient mixing energy to produce the small stable air bubbles. During placement operations vibration will eliminate most of the entrapped air as well as many unstable air bubbles. Normal vibration does not have an adverse affect on small stable air bubbles. By comparing the amount of air in the concrete prior to placement with the amount of air in the in-place concrete we can get an idea of the quality of the air system. You should expect to see a drop of between 1% and 2% with a good stable system, when you start to see differences over 2% it is time to investigate the material compatibility and/or the mixing process. The targeted air content at the time of production should be raised to account for the actual drop incurred during placement. A practice of taking all air tests with samples of the in the in-place concrete is not necessary, but regular monitoring of the loss to establish and verify the pre-placement target is recommended.

Test data from other states has shown that raising the minimum air content required 1% provides a better overall air system. An increase in air content typically results in some loss of strength, but there have been very few projects that have had strength problems.

Specification Recommendations for Quality Air Void Systems:

1. For machine placed concrete. Set a target for the air content of the in place plastic concrete at approximately 6%. The measured air loss through the paver should be added to the target of 6% to establish the Acceptance Air Content (AAC). This will be the target for normal air tests for quality control and acceptance. It will have a tolerance of +2 to -1%. Control the air content by testing at time of placement with daily verification checks of the finished product.
2. For hand placed concrete. Raise the minimum air content required, prior to placement, to 7%.

Construction Operational Processes:

Construction practices must reflect the fact that operations, such as mixing and placing materials, have as great an effect on the performance of the pavement as does the quality of the individual materials.

Controlling the aggregates used in concrete production has been shown to be a critical item. A well graded aggregate mix is much easier for a crew to place than a segregated mix. If the crews have to work hard to place the mix it takes longer and they may experience problems with getting their work done within the optimum working window. In addition, maintaining the moisture in the aggregate stockpile at the saturation point or above has been recognized as a critical point of concern. Several reports on distressed pavements state that un-hydrated cement particles were discovered surrounding absorptive aggregate particles. The aggregates likely absorbed the water before the cement was able to react with it. This is equivalent to not curing the surface. In addition, the absorption of water leads to a reduction in workability and may make the mix difficult to place and finish.

As stated earlier, it is imperative to impart the necessary amount of energy into the concrete through mixing to produce a stable air void system. The cement paste including the air entrainment must be uniformly spread through out the mix. When there is a question of the quality of the mixing process or when a reduction in mixing time is requested, ASTM C 94 section 11.3 can be used to address the issue. Two samples are taken and tested at separate points during the discharge and results compared with each other for uniformity. The samples are taken after approximately 15 and 85% of the batch have been discharged. Each sample is tested for unit weight (+/- 1 #/cf), air content (+/- 1%), slump (+/- 1 inch), coarse aggregate content retained on the #4 sieve (+/- 6%), mass per unit volume of air-free mortar (+/- 1.6%), and average 7 day compressive strength (+/- 7.5%). When five of these six tests are within the limits, the concrete is considered uniform.

The practice of adding water on site should be discouraged. A clustering of air bubbles around aggregate particles has been observed in some pavements. Studies have investigated this phenomenon and one particular study was able to reproduce the clustering when the mix was re-tempered. Expect to adjust the first few loads delivered to a project each day, but after the first round of trucks have been delivered the adjustment should be made at the plant.

Once the concrete has been successfully placed it is important to insure that a sufficient supply of water is available for it to fully hydrate. Today's mixes have low water contents and admixtures that do not allow much bleed water to migrate to the surface. Proper curing is critical to prevent the surface from drying out. Without sufficient water, during the curing period, the concrete will not develop proper strength. Also capillaries that allowed the moisture to leave now will in time let water back in contributing to the adverse attack of freezing and thawing or a potential ASR reaction. Properly applying a curing compound prior to surface drying is a critical step. The cure system should be on site and tested prior to concrete placement. Typically an application rate is specified little definition of what the finished product should look like has been given. The finished surface should look like a solid white painted surface. The surface should not appear spotty or blotchy. If it does not look like a plain white sheet of paper it will require the immediate re-application of cure.

Specification recommendations for construction operational processes:

1. Require a detailed stockpile management plan that addresses aggregate gradation and maintains the stockpile moisture at SSD.
2. The crews should not have to fight the mix into place; it should be workable and finish with ease.
3. Verify that the concrete supplied to the project has been properly mixed.
4. Require that the curing compound be applied immediately after finishing operations are complete, but no longer than 30 minutes after placement. The finished product should appear as a uniformly painted solid white surface. If the surface looks blotchy it needs to have additional cure placed on it immediately.