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CONCRETE PAVEMENT PROGRESS

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Mix Design

What You Don't Know Can Kill You

By Tom Olson

AS I EXPLAINED IN THE 1ST QUARTER ISSUE, because mix design specifications are based on *ranges of minimums and maximums,* contractors have *discretion* within these *ranges.* Because of this discretion the contractor, not the owner, may be responsible if the concrete pavement experiences performance problems such as random cracking, spalling, raveling, etc. This may be true *notwithstanding that the contractor satisfied the owner's design parameters!*

While we believe that the owner's warranty of design keeps the liability on the owner, we have heard engineers argue that this discretion shifts the liability to the contractor. If an engineer or owner takes this position, it will cost you time and money proving they are wrong. To avoid this from happening, you need to be aware of the interplay between the various tolerance specifications so that you can raise any potential issues at the pre-bid phase. If the engineer refuses to change the tolerances, you need to know how to best address it yourself.

Given that, contractors need to be as educated as they can be on how specific components of the mix design can cause performance problems to *protect against them from occurring.* To help provide further education on this, I have summarized examples of technical guidance provided by the American Concrete Pavement Association, Federal Highway Administration, Innovative Pavement Research Foundation, Airport Concrete Pavement Technology Program, Portland Cement Association, Oklahoma Department of Transportation, and Caltrans.[1] For further information, I encourage you to listen to my ACPA podcast on the same topic. To see this and other podcasts, please visit www.acpa.org/acpa-podcasts.

As a starting point, remember that concrete is basically a mixture of two components: aggregate and paste. In this mixture, the aggregate particles are completely coated with paste. The paste consists of cementitious materials and water and incorporates entrapped air or purposely entrained air. With that in mind, let's examine these components.

Water Content

The chemical composition of water can affect concrete, but more important is the *ratio of water-to-cement paste* used in the mix. Cement needs only 25% water for hydration to take place. To improve its workability, the ratio is commonly increased to around 45%.

Increasing the ratio of water makes concrete more porous; as this extra water rises to the surface as bleed water and through evaporative drying, it leaves behind capillary voids. These capillary voids weaken concrete and make it more absorbent, increasing the chances of freeze damage and attached from liquid chemicals.

Total water volume is directly related to volume shrinkage. Consequently, the potential for uncontrolled cracking is directly related to water demand.

Aggregate

Contractors should use the largest size of aggregate that is economically available and can be place and consolidated. A larger aggregate has several advantages. It reduces water and paste demand, leading to less drying shrinkage. The larger sized aggregates also provide better aggregate interlock and load transfer at joints and cracks for crack bridging.

The course aggregate type will influence the amount of temperature expansion or contraction of concrete. Concrete that is more temperature sensitive has an increased potential for uncontrolled cracking. That is because concrete that is more temperature sensitive will expand or contract more with temperature change, increasing cracking potential.

Sand

Many pavement specifications require the sand for pavement to meet the requirements of ASTM C-33. It is not uncommon for sands to meet the grading requirements of ASTM C-33 and lack the characteristics that are desired for use in concrete pavement. Concrete made with such sand may exhibit a high bulking volume, which will increase water required to mobilize the fine material and consequently the potential for uncontrolled cracking.

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1 To be clear, I have **quoted** information from each of these sources although not presented as such in this article. I did that to save space.

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Some state specifications do not require the sand to meet the requirements of ASTM C-33. The problem in this case is that it can result in use of an extra fine sand which requires a higher water volume, which increases the potential for uncontrolled cracking.

Air

Concrete that is subject to freezing must contain a well-distributed system of finely divided air voids to protect it from frost damage. While the specifications typically provide a required volume of air as measured by ASTM C 231 (pressure method) or ASTM C 173 (volumetric method), these methods to not distinguish between a good air void system and a poor one. As a consequence, important considerations include:

- Trial batches need to be done to determine the correct dosage of the admixture for the conditions, including temperature, expected on the job site.
- Typical air content requirements for pavements range from 5% to 7% depending on exposure.
- The volume of air required for frost protection increases with decreasing aggregate size because of the corresponding increase in paste content.
- All other factors being equal, an increase in air content results in a decrease in concrete strength.

Cement

The strength of concrete is directly influenced by the quantity of cement and the water-cement ratio. Increasing the quantity of cement and lowering the water-cement ratio generally helps produce a denser and more durable mixture with higher early strength, but it may also contribute to a higher potential for uncontrolled cracking. Mixtures with higher quantities of portland cement require more mixing water and consequently shrink more. Even if the water to cementitious materials ratio is minimized, the actual volume of water increases with higher cementitious material content.

High early strength can also be obtained by lowering the w/c ratio rather than increasing the cement content.

Admixtures

Chemical admixtures are commonly used to improve or control workability, entrained air, water demand, setting time, and other properties. Admixes can reduce the tendency for thermal cracking by reducing the heat of hydration. Air-entraining admixes enhance long-term concrete performance by creating a matrix of air bubbles so water in the pavement can expand when frozen or contract when thawed.

The drying shrinkage of the concrete is the function of several parameters such as fraction volume of paste, water content, cement content, type of the cement, and type and size distribution of the aggregate. Fly ash may be detrimental to the performance of the concrete, causing premature stiffening of the fresh concrete, thermal cracking, and/or reduced sulfate resistance. The addition of fly ash into the mix increases the volume of the paste that may increase the drying shrinkage if the water content remains the same. However, by reduction of the water content, the drying shrinkage of the concrete may be about the same as concrete without fly ash. It is also important to properly evaluate weather conditions for use of fly ash.

- The usage period applied by many agencies for fly ash and other mineral additives is based on average weather conditions. The requirements attempt to control use of the additives when prevailing conditions are cool or cold. Need to ensure that anticipated actual weather conditions will align with this.
- Admixes containing certain fly ashes may experience a delay in early-age strength of development in cooler weather. Depending upon the air, subbase and concrete temperature, this could delay the concrete set time and the ability to saw without excessive raveling. After setting, the time available for sawing before the onset of cracking is usually much shorter than normal. This decrease in available sawing time increases the risk of uncontrolled cracking in cooler weather.

Admixes have limitations, side effects, and compatibility issues that must be anticipated to obtain desirable results. Some supplementary cementitious materials may make things worse, not better. Therefore, each combination of such materials, aggregates, and admixture needs to be tested. Incompatibility issues are compounded because:

- Factors that result in incompatibility among various cementitious materials and admixtures are not well known.
- Tests to determine material incompatibility are lacking.
- Material incompatibility may be induced by temperature changes. Therefore, trial batches need to be tested at the extremes of temperature anticipated at the project.

Incompatibility characteristics may include early loss of workability (early stiffening), delayed set (retardation), early-age cracking due to excessive autogenous and drying shrinkage of concrete, and lack of proper air-void system.

Steps to minimize incompatibility problems include:

- All admixtures used on the project need to be from the same manufacturer to ensure compatibility among them.
- Do not exceed the recommended dosages.
- Ensure all cementitious materials meet project specifications and/or the requirements of appropriate ASTM standards.
- It is also advisable to have hot and cool weather mixture designs in locations where seasonal differences in temperature may be significant.

Temperature and Workability

Mixture design procedures typically do not directly address concrete workability. The contractor must recognize that in addition to designing the mixture to meet the requirements of strength, slump, and air, the mixture must be designed to assure workability for the given mixture characteristics, the project paving equipment, and expected ambient conditions at the time of paving.

Temperature can have a significant effect on workability, water demand, slump loss, air content, and setting.

- Premature transverse cracking in PCC pavements is often associated with combinations of higher temperature at the time of construction and unfavorable environmental factors. These factors can affect the rate of hydration, strength gain, and moisture loss.
- Concrete for hot weather placement should contain less cement and more supplementary cementitious materials. The opposite is true for cold weather paving.
- Laboratory mixture designs should be conducted at the temperature(s) anticipated in the field.
- Test the slump and air content every 10 to 15 minutes for a sufficient time after initial mixing to simulate the longest anticipated haul time.
- When long haul times are anticipated, the initial air content may need to be higher than required at placement to compensate for loss of air during transit.
- The mixture design should not be too sensitive to elevated placement temperatures, variations in aggregate moisture content, or slight variations in batching.

If plan mixture behavior is different than the laboratory mixture, possible reasons may include ambient temperature, mixing time, material differences (laboratory materials are cleaner, different cement characteristics), mixing process differences (drum v. laboratory mixer), aggregate moisture content, and material charging differences.

Conclusion

Contractors need to understand that because concrete mix design parameters are based on minimums and maximums criteria, the contractor has discretion on how to prepare the mix design. Because of this discretion, the contractor, not the owner, may be responsible if the concrete pavement experiences performance problems.

While we believe the owner's warranty of design places liability on them for these issues, to protect against such problems, contractors need to continue to become better educated on the selection and use of different components of the mix design.

ABOUT THE AUTHOR

Thomas Olson is the founding partner of Olson Construction Law. Tom's commitment is to provide guidance on how to resolve issues on the jobsite, not in the courtroom. Tom has worked on highway heavy projects throughout much of the United States for more than thirty years. A prolific speaker and writer as well as attorney, his expertise is in concrete and asphalt paving, utility, earthwork and bridge construction, schedule analysis, material testing, and the technical and legal obligations of both engineers and contractors.