Deciphering the cause(s) of incompatibility is the best way to determine appropriate corrective measures.

Table 1. Identifying Air-Void System Incompatibilities

	Characteristic	Test
Laboratory Tests (before construction starts)	Uniformity of air-void system	Air content, unit weight, air-void analyzer
	Stability of air-void system	Foam drainage
	Hardened air	ASTM C 457
	Severity of air-void clustering	Clustering index
Field Tests (after construction begins)	Uniformity of air-void system	Air content, unit weight, air-void analyzer
	Stability of air-void system	Foam drainage
	Uniformity of fly ash	Foam index

Table 2. Identifying Stiffening and Setting Incompatibilities

	Characteristic	Test
Laboratory Tests (before construction starts)	Rate of Stiffening	Isothermal calorimetry, minislump, or rheology using paste mixtures with different dosages of admixtures and fly ash
	Cracking	Ring test
Field Tests (after construction begins)	Rate of stiffening	Slump loss, semi-adiabatic calorimetry, ultrasonic P-wave or other early stiffening test

National Concrete Pavement Technology Center

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This technical summary is based on chapter 4 of the IMCP Manual (Taylor, P.C., et al. 2006. *Integrated Materials and Construction Practices for Concrete Pavement: A State-of-the-Practice Manual*, Ames, Iowa, Iowa State University [FHWA HIF-07-004] [www.cptechcenter.org/publications/imcp/]) and was sponsored by the Federal Highway Administration. (References for any citations in this summary are at the end of the chapter.)

CP Tech Center Mission
The mission of the National Concrete Pavement Technology Center is to unite key transportation stakeholders around the central goal of advancing concrete pavement technology through research, tech transfer, and technology implementation.

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4b

A summary of chapter 4 (pages 97–104) of the *IMCP Manual* (reference information on page 4)

Materials Incompatibilities

This document is one of a set of technical summaries of chapters 1 through 10 of the *Integrated Materials and Construction Practices for Concrete Pavements: A State-of-the-Practice Manual* (IMCP manual). Together, these summaries provide a general overview of information in the manual and introduce its important concepts. To be useful as training documents, the technical summaries should be used in conjunction with the manual. This summary covers sections of chapter 4 dealing with concrete mix materials incompatibilities, why they are an issue, and how to test for for them and adjust the mixture accordingly.

What is Materials Incompatibility?

When combinations of acceptable cementitious materials and/or chemical admixtures react in undesirable or unexpected ways, the combinations are said to be incompatible.

Why is it Important?

The results of incompatible materials typically include one or more of the following:

- Air-void system problems:
  - Air voids cluster around aggregate particles (figure 1).
  - Excess air voids may weaken the system.
- Early stiffening and setting:
  - Concrete sets in the mixer or truck.
  - Concrete stiffens as it passes through paver.
  - Concrete sets before finishing.
  - Concrete cracks before saw cuts can be completed.
- Retarded stiffening/setting:
  - Plastic shrinkage cracking increases.
  - Concrete may crack before saw cuts can be completed.

How Air-void System Incompatibilities Occur

The concrete's air-void system can be compromised for a variety of reasons:

- Use of non-vinsol air-entraining admixtures.
- Addition of extra water after the initial mixing.
- Extended mixing.

How Stiffening and Setting Incompatibilities Occur

Most materials incompatibilities are manifested as problems with mix stiffening and setting. The exact cause may be one or more of the following:

- Sulfates and aluminates out of balance.
- Calcium shortage.
- Use of Type A or B water-reducers.
- High cement fineness.
- Use of fly ash with high aluminate (C_3A).
- High temperature.
- Low water-cementitious materials (w/cm) ratio.

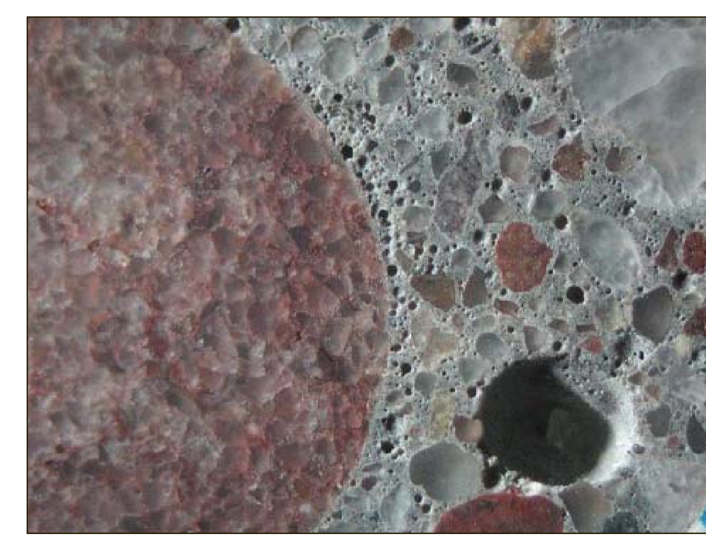

Figure 1. A typical example of air voids clustered around an aggregate particle

Why is Materials Incompatibility an Issue Now?

Materials incompatibility is a somewhat more common phenomenon today than it was 30 years ago, primarily resulting from the use of new or modified mix materials and more demanding construction requirements:

- Today's cements are designed to react faster, allowing faster placement and turnaround times.
- Supplementary cementitious materials are increasingly used to enhance certain mix characteristics cost effectively.
- Chemical admixtures are also used to enhance certain mix characteristics.
- Construction efforts are constantly being pushed to lower costs, while at the same time to deliver thinner sections, higher strengths, and fewer trials/tests with new materials combinations.

These factors increase the complexity of cement hydration, making the mix more sensitive to changes in weather or source materials. As a result, an acceptable mixture in one batch of concrete may behave in an unacceptable way in the next batch.

Although such materials incompatibilities may seem unpredictable and uncontrollable, in fact they can be predicted and prevented through an adequate mix testing routine before paving begins and during construction.

For a thorough discussion of testing, see chapter 9 and Technical Summary 9 regarding quality assurance and quality control.

Sulfates and Aluminates Out of Balance

Early cement hydration reactions (mixing stage) involve a delicate balance of aluminates (C_3A) and sulfates in solution. Aluminate reacts immediately when exposed to water, so sulfates are used to slow down and control this reaction. An imbalance between these two components will cause undesirable setting conditions.

Not enough sulfate ➔ Flash set

- Aluminate reacts too quickly with water.
- Permanent stiffening (flash set) occurs within the first 30 minutes.

Too much sulfate ➔ False set

- Excess sulfate causes solid gypsum to precipitate out of the solution.
- Temporary false set occurs.
- Continued mixing will remedy the stiffening effect as the gypsum re-dissolves.

Form of sulfate

Although the total amount of sulfate is important, it is the amount that has dissolved into solution that is critical for retaining a sulfate-aluminate balance. Sulfate in the cement mixture will be in one of three forms, which contribute sulfate to the solution in different amounts and at different rates:

- Gypsum—Dissolves slowly.
- Plaster—Dissolves fastest, so it is useful in preventing flash set; too much, however, can result in false set. Plaster becomes less soluble as the temperature increases.
- Anhydrite—Dissolves slowest, so it may provide insufficient sulfate in solution.

The different forms of sulfate must be carefully balanced to ensure the proper amount of sulfate in solution during the hydration process. Cements often contain about half plaster and half gypsum for their sulfate content.

Calcium Shortage

Most of the strength development of concrete is due to hydration of silicates (alites and belites), which begins slowly during the dormancy stage and continues through densification.

- When mixed with water, the silicates alite (C_3S) and belite (C_2S) dissolve and release calcium ions into solution.
- Alites (C_3S) and water react, causing initial set and continuing with decreasing speed for a long time.
- Belites (C_2S) react with water, causing later strength gain. Belite reactions start to be noticeable after several days and continue for a long time.

Normally, calcium dissolves until water in the mix becomes supersaturated. This generally occurs a few hours into hydration, during the dormancy stage. However, if there is not enough calcium in solution to reach supersaturation,

- Alite hydration is delayed.
- Setting may be severely delayed or prevented entirely.

A calcium shortage can be caused by uncontrolled aluminate (C_3A) reactions. It is possible for a mixture to exhibit false set as a result of sulfate-aluminate imbalance (see **Too much sulfate**, page 2) and then to experience severe retardation due to a calcium shortage.

Water Reducers

The addition of water reducers to a mixture can have unintended side effects. In particular, Types A and B admixtures may affect the aluminate-silicate balancing act in two ways:

- Accelerate aluminate reactions (increasing the risk of premature stiffening).
- Slow silicate reactions (delaying setting and slowing strength gain).
- Overdoses may prevent setting altogether.

When aluminate (C_3A) reactions are uncontrolled and workability is reduced, the addition of more water reducer will most likely exacerbate the problem. As a result, when certain water-reducing admixtures are used, mixtures may need a higher sulfate content to keep aluminate reactions under control.

High Cement Fineness

Finer cements have higher reaction rates, which increases the risk of out-of-control reactions and materials incompatibilities.

Fly Ash

Supplementary cementitious materials, especially fly ash, tend to retard the silicate hydration rate. This generally extends hydration, so that strength gain begins more slowly but continues longer. In some situations, this can be beneficial.

High-calcium fly ash may contain extra aluminate (C_3A), increasing the risk of uncontrolled stiffening and flash set. Higher total sulfate content may be required to keep the mixture in balance.

High Temperature

Temperature strongly influences the solubility and reactivity of compounds in concrete mixtures. High temperatures, for example,

- Generally decrease the rate at which calcium dissolves, reducing the amount of sulfate in solution available to control accelerated aluminate reactions (see **Not enough sulfate**, page 2).
- Accelerate all other reactions.

Low Water-to-Cementitious Materials (w/cm) Ratio

The severity of stiffening and setting irregularities is affected by the w/cm ratio.

A low w/cm ratio, for example, can contribute to early stiffening. The same mixture at a higher w/cm ratio, with greater spacing between particles, may not exhibit early stiffening.

Testing for Incompatibilities

Testing mixtures for materials compatibility may seem time consuming, but the safety issues related to handling unexpectedly stiff concrete, as well as the costs of reconstructing a failed pavement, provide incentive to include testing time in the construction schedule.

Early testing for incompatibilities can help flag potential problems when they can still be fixed, preventing the headaches caused when incompatibility failures show up during construction. Many problems will be avoided by regularly monitoring the following:

- Slump loss.
- Setting time.
- Unit weight.
- Temperature profile.
- Uniformity and stability of air-void system.

Testing should be phased (tables 1 and 2):

- Sometime before construction, lab tests must be run to prequalify the materials planned for the project.
- Trial batches should be tested very soon before construction starts, using the actual materials and under actual field conditions.
- Field batches must be regularly monitored during construction.

Use control charts to track results over time. The phased approach is important for two reasons:

- Several complex mechanisms are in play, so more than one test is often needed.
- Often there is no threshold value for a unique mixture, so variability must be tracked over time instead.

Potential Incompatibilities Solutions

If a test result jumps unexpectedly, it could be the result of the mixture itself or of the test. Interpreting the results can be complicated and may require expert input. If a mixture is deemed incompatible, several possible actions may help bring it back into balance:

- Change dosage of supplementary cementitious material(s).
- Change chemical admixture type.
- Change working temperature.
- Delay addition of admixture.
- Raise w/cm ratio (warning: adding water after initial mixing may exacerbate air-void problems).
- For finer cements, increase sulfate content and perhaps the plaster-to-gypsum ratio.
- Get expert help.

Remember, incompatibilities occur when otherwise acceptable materials react with each other in surprising ways.