WHAT is Scaling

Scaling is local flaking or peeling of a finished surface of hardened concrete as a result of exposure to freezing and thawing. Generally, it starts as localized small patches which later may merge and extend to expose large areas. Light scaling does not expose the coarse aggregate. Moderate scaling exposes the aggregate and may involve loss of up to 1/8 to 3/8 inch [3 to 10 mm] of the surface mortar. In severe scaling more surface has been lost and the aggregate is clearly exposed and stands out.

Note—Occasionally concrete peels or scales in the absence of freezing and thawing. This type of scaling is not covered in this CIP. Often this is due to the early use of a steel trowel, over-finishing or finishing while bleed water is on the surface. (see CIP 20 on Delaminations)

WHY Do Concrete Surfaces Scale

Concrete slabs exposed to freezing and thawing in the presence of moisture and/or deicing salts are susceptible to scaling. Most scaling is caused by:

a. The use of non-air-entrained concrete or too little entrained air. Adequate air entrainment is required for protection against freezing and thawing damage. However, even air-entrained concrete will scale if other precautions, as listed below, are not observed.

b. Application of excessive amounts of calcium or sodium chloride deicing salts on concrete with inadequate strength, air entrainment, or curing. Chemicals such as ammonium sulfate or ammonium nitrate, which are components of most fertilizers, can cause scaling as well as induce severe chemical attack on the concrete surface.

c. Any finishing operation performed while bleed water is on the surface. If bleed water is worked back into the top surface of the slab, a high water-cement ratio and, therefore, a low-strength surface layer is produced. Overworking the surface during finishing will reduce the air content in the surface layer, making it susceptible to scaling in freezing conditions.

d. Insufficient curing. This omission often results in a weak surface skin, which will scale if it is exposed to freezing and thawing in the presence of moisture and deicing salts.

HOW to Prevent Scaling

a. Concrete exposed to freezing and thawing cycles must be air-entrained. Severe exposures require air contents of 6 to 7 percent in freshly mixed concrete made with 3/4-inch [19 mm] or 1-inch [25-mm] aggregate. In moderate exposures, where deicing salts will not be used, 4 to 6 percent air will be sufficient. Air-entrained concrete of moderate slump (up to 5 inches [125 mm]) and adequate quality should be used. In general, concrete strength of 3500 psi [24 MPa] for freezing and thawing exposure and 4000 psi [28 MPa] when deicers are used should be adequate to prevent scaling.

b. DO NOT use deicing salts, such as calcium or sodium chloride, in the first year after placing the concrete. Use clean sand for traction. When conditions permit, hose off accumulation of salt deposited by cars on newly placed driveways and garage slabs. Subsequently, use salt sparingly. Never use ammo-
nium sulfate or ammonium nitrate as a deicer; these are chemically aggressive and destroy concrete surfaces. Poor drainage, which permits water or salt and water to stand on the surface for extended periods of time, greatly increases the severity of the exposure and may cause scaling. (This is often noticed in gutters and sidewalks where the snow from plowing keeps the surface wet for long periods of time.)

c. Provide proper curing by using liquid membrane curing compound or by covering the surface of newly placed slab with wet burlap. Curing ensures the proper reaction of cement with water, known as hydration, which allows the concrete to achieve its highest potential strength.

d. DO NOT perform any finishing operations with water present on the surface. Bull floating must promptly follow initial screeding. Delay finishing operations until all the bleed water has risen to and disappeared from the surface. This is critical with air-entrained concrete in dry and windy conditions where concrete that is continuing to bleed may appear dry on the surface.

e. Do not use a jitterbug or vibrating screed with high slump concrete, as it tends to form a weak layer of mortar on the surface.

f. Protect concrete from the harsh winter environment. It is important to prevent the newly placed concrete from becoming saturated with water prior to freeze and thaw cycles during winter months. Apply a commercially available silane or siloxane-based breathable concrete sealer or water repellent specifically designed for use on concrete slabs. Follow the manufacturer’s recommendations for application procedures and frequency. Another option is a 1:1 mixture of boiled linseed oil and mineral spirits applied in two layers. The concrete should be reasonably dry prior to the application of a sealer. Late summer is the ideal time for surface treatment. The sealer can be sprayed, brushed, or rolled on the surface of the concrete. CAUTION: Linseed oil will darken the color of the concrete and care should be taken to apply it uniformly.

HOW to Prevent Scaled Surfaces

The repaired surface will only be as strong as the base surface to which it is bonded. Therefore, the surface to be repaired should be free of dirt, oil or paint and, most importantly, it must be sound. To accomplish this, use a hammer and chisel, sandblasting, high-pressure washer, or jack hammer to remove all weak or unsound material. The clean, rough, textured surface is then ready for a thin bonded resurfacing such as:

a. Portland cement concrete resurfacing
b. Latex modified concrete resurfacing
c. Polymer-modified cementitious-based repair mortar

References

1. Guide to Durable Concrete, ACI 201.2R, American Concrete Institute, Farmington Hills, MI.
2. Scale-Resistant Concrete Pavements, IS117.02P, Portland Cement Association, Skokie, IL.
3. Protective Coatings to Prevent Deterioration of Concrete by Deicing Chemicals, National Cooperative Highway Research Program Report No. 16.
4. Guide for Concrete Floor and Slab Construction, ACI 302.1R, American Concrete Institute, Farmington Hills, MI.
5. Residential Concrete, National Association of Home Builders, Washington, DC.
6. Slabs on Grade, Concrete Craftsman Series CCS-1, American Concrete Institute, Farmington Hills, MI.

Follow These Rules to Prevent Scaling

1. For moderate to severe exposures, use air-entrained concrete of medium slump (3-5 in. [75-125 mm]) and cure properly.
2. Do not use deicers in the first winter.
3. Seal the surface with a commercial sealer or a mixture of boiled linseed oil and mineral spirits.
4. Use correct timing for all finishing operations and avoid the use of steel trowels for exterior concrete slabs.
5. Specify air-entrained concrete. In cold weather, concrete temperature should be at least 50°F [10°C], contain an accelerating admixture, and be placed at a lower slump.

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Crazing is the development of a network of fine random cracks or fissures on the surface of concrete or mortar caused by shrinkage of the surface layer. These cracks are rarely more than $\frac{1}{8}$ inch [3 mm] deep and are more noticeable on steel-troweled surfaces. The irregular hexagonal areas enclosed by the cracks are typically no more than $1\frac{1}{2}$ inch [40 mm] across and may be as small as $\frac{1}{4}$ or $\frac{3}{8}$ inch [12 or 20 mm] in unusual instances. Generally, craze cracks develop at an early age and are apparent the day after placement or at least by the end of the first week. Often they are not readily visible until the surface has been wetted and it is beginning to dry out.

Crazing cracks are sometimes referred to as shallow map or pattern cracking. They do not affect the structural integrity of concrete and rarely do they affect durability or wear resistance. However, crazed surfaces can be unsightly. They are particularly conspicuous and unsightly when concrete contains calcium chloride, a commonly used accelerating admixture.

Concrete surface crazing usually occurs because one or more of the rules of “good concrete practices” were not followed. The most frequent violations are:

- Poor or inadequate curing. Environmental conditions conducive to high evaporation rates, such as low humidity, high temperature, direct sunlight, and drying winds on a concrete surface when the concrete is just beginning to gain strength, cause rapid surface drying resulting in craze cracking. Avoid the delayed application of curing or even intermittent wet curing and drying after the concrete has been finished.
- Too wet a mix, excessive floating, the use of a jitterbug or any other procedures that will depress the coarse aggregate and produce an excessive concentration of cement paste and fines at the surface.
- Finishing while there is bleed water on the surface or the use of a steel trowel at a time when the smooth surface of the trowel brings up too much water and cement fines. Use of a bull float or darby with water on the surface or while the concrete continues to bleed will produce a high water-cement ratio, weak surface layer which will be susceptible to crazing, dusting and other surface defects.
- Sprinkling cement on the surface to dry up the bleed water is a frequent cause of crazing. This concentrates fines on the surface. Spraying water on the concrete surface during finishing operations will result in a weak surface susceptible to crazing or dusting.
- Occasionally carbonation of the surface results in crazing as it causes shrinkage of the surface layer. Carbonation is a chemical reaction between cement and carbon dioxide or carbon monoxide from unvented heaters. In such instances the surface will be soft and will dust as well.
HOW to Prevent Crazing?

a. To prevent crazing, start curing the concrete as soon as possible. Keep the surface wet by either flooding with water, covering it with damp burlap and keeping it continuously moist for a minimum of 3 days, or spraying the surface with a liquid-membrane curing compound. Avoid alternate wetting and drying of concrete surfaces at an early age. Curing retains the moisture required for proper reaction of cement with water, called hydration.

b. Use moderate slump (3 to 5 inches [75 to 125 mm]) concrete. Higher slump (up to 6 or 7 inches [150 to 175 mm]) can be used provided the mixture is designed to produce the required strength without excessive bleeding and/or segregation. This is generally accomplished by using water-reducing admixtures.

c. NEVER sprinkle or trowel dry cement or a mixture of cement and fine sand on the surface of the plastic concrete to absorb bleed water. DO NOT sprinkle water on the slab to facilitate finishing. Remove bleed water by dragging a garden hose across the surface. DO NOT perform any finishing operation while bleed water is present on the surface or before the bleeding process is completed. DO NOT overwork or over-finish the surface.

d. When high evaporation rates are possible, lightly dampen the subgrade prior to concrete placement to prevent it absorbing too much water from the concrete. If a vapor retarder is required on the subgrade, cover it with 3 to 4 inches of a compactible, granular fill, such as a crusher-run material to reduce bleeding.

References

1. Guide for Concrete Floor and Slab Construction, ACI 302.1R, American Concrete Institute, Farmington Hills, MI.
2. Concrete Slab Surface Defects: Causes, Prevention, Repair, IS 177T, Portland Cement Association, Skokie, IL.
4. Ralph Spannenberg, Use the Right Tool at the Right Time, Concrete Construction, May 1996.

Follow These Rules to Prevent Crazing

1. Use moderate slump (3-5 inches) concrete with reduced bleeding characteristics.
2. Follow recommended practices and timing, based on concrete setting characteristics, for placing and finishing operations:
   a. Avoid excessive manipulation of the surface, which can depress the coarse aggregate, increase the cement paste at the surface, or increase the water-cement ratio at the surface.
   b. DO NOT finish concrete before the concrete has completed bleeding. DO NOT dust any cement onto the surface to absorb bleed water. DO NOT sprinkle water on the surface while finishing concrete.
   c. When steel troweling is required, delay it until the water sheen has disappeared from the surface.
3. Cure properly as soon as finishing has been completed.
Plastic shrinkage cracks appear in the surface of fresh concrete soon after it is placed and while it is still plastic. These cracks appear mostly on horizontal surfaces. They are usually parallel to each other on the order of 1 to 3 feet apart, relatively shallow, and generally do not intersect the perimeter of the slab. Plastic shrinkage cracking is highly likely to occur when high evaporation rates cause the concrete surface to dry out before it has set.

Plastic shrinkage cracks are unsightly but rarely impair the strength or durability of concrete floors and pavements. The development of these cracks can be minimized if appropriate measures are taken prior to and during placing and finishing concrete.

(Note: Plastic shrinkage cracks should be distinguished from other early or prehardening cracks caused by settlement of the concrete around reinforcing bars, formwork movement, early age thermal cracking, or differential settlement at a change from a thin to a deep section of concrete.)

Plastic Shrinkage Cracks

Plastic shrinkage cracks are caused by a rapid loss of water from the surface of concrete before it has set. The critical condition exists when the rate of evaporation of surface moisture exceeds the rate at which rising bleed water can replace it. Water receding below the concrete surface forms menisci between the fine particles of cement and aggregate causing a tensile force to develop in the surface layers. If the concrete surface has started to set and has developed sufficient tensile strength to resist the tensile forces, cracks do not form. If the surface dries very rapidly, the concrete may still be plastic, and cracks do not develop at that time; but plastic cracks will surely form as soon as the concrete stiffens a little more. Synthetic fiber reinforcement incorporated in the concrete mixture can help resist the tension when concrete is very weak.

Why Do Plastic Shrinkage Cracks Occur?

Small changes in any one of these factors can significantly change the rate of evaporation. ACI 305 provides a chart to estimate the rate of evaporation and indicates when special precautions might be required. However, the chart isn’t infallible because many factors other than rate of evaporation are involved.

Concrete mixtures with an inherent reduced rate of bleeding or quantity of bleed water are susceptible to plastic shrinkage cracking even when evaporation rates are low. Factors that reduce the rate or quantity of bleeding include high cementitious materials content, high fines content, reduced water content, entrained air, high concrete temperature, and thinner sections. Concrete containing silica fume requires particular attention to avoid surface drying during placement.

Any factor that delays setting increases the possibility of plastic shrinkage cracking. Delayed setting can result from a combination of one or more of the following: cool weather, cool subgrades, high water contents,
Follow These Rules to Minimize Plastic Shrinkage Cracking

1. Dampen the subgrade and forms when conditions for high evaporation rates exist.
2. Prevent excessive surface moisture evaporation by providing fog sprays and erecting windbreaks.
3. Cover concrete with wet burlap or polyethylene sheets between finishing operations.
4. Use cooler concrete in hot weather and avoid excessively high concrete temperatures in cold weather.
5. Cure properly as soon as finishing has been completed.

HOW to Minimize Plastic Shrinkage Cracking?

Attempts to eliminate plastic shrinkage cracking by modifying the composition to affect bleeding characteristics of a concrete mixture have not been found to be consistently effective. To reduce the potential for plastic shrinkage cracking, it is important to recognize ahead of time, before placement, when weather conditions conducive to plastic shrinkage cracking will exist. Precautions can then be taken to minimize its occurrence.

a. When adverse conditions exist, erect temporary windbreaks to reduce the wind velocity over the surface of the concrete and, if possible, provide sunshades to control the surface temperature of the slab. If conditions are critical, schedule placement to begin in the later afternoon or early evening. However, in very hot conditions, early morning placement can afford better control on concrete temperatures.

b. In the very hot and dry periods, use fog sprays to discharge a fine mist upwind and into the air above the concrete. Fog sprays reduce the rate of evaporation from the concrete surface and should be continued until suitable curing materials can be applied.

c. If concrete is to be placed on a dry absorptive subgrade in hot and dry weather, dampen the subgrade but not to a point that there is freestanding water prior to placement. The formwork and reinforcement should also be dampened.

d. The use of vapor retarders under a slab on grade greatly increases the risk of plastic shrinkage cracking. If a vapor retarder is required, cover it with a 3 to 4 inch lightly dampened layer of a trimable, compactible granular fill, such as a crusher-run material.

e. Have proper manpower, equipment, and supplies on hand so that the concrete can be placed and finished promptly. If delays occur, cover the concrete with moisture-retaining coverings, such as wet burlap, polyethylene sheeting or building paper, between finishing operations. Some contractors find that plastic shrinkage cracks can be prevented in hot dry climates by spraying an evaporation retardant on the surface behind the screeding operation and following floating or troweling, as needed, until curing is started.

f. Start curing the concrete as soon as possible. Spray the surface with liquid membrane curing compound or cover the surface with wet burlap and keep it continuously moist for a minimum of 3 days.

g. Consider using synthetic fibers (ASTM C 1116) to resist plastic shrinkage cracking.

h. Accelerate the setting time of concrete and avoid large temperature differences between concrete and air temperatures.

If plastic shrinkage cracks should appear during final finishing, the finisher may be able to close them by refinishing. However, when this occurs precautions, as discussed above, should be taken to avoid further cracking.

References

1. Hot Weather Concreting, ACI 305R, American Concrete Institute, Farmington Hills, MI.
2. Guide for Concrete Floor and Slab Construction, ACI 302.1R, American Concrete Institute, Farmington Hills, MI.
3. Standard Practice for Curing Concrete, ACI 308, American Concrete Institute, Farmington Hills, MI.
4. Concrete Slab Surface Defects: Causes, Prevention, Repair, IS177, Portland Cement Association, Skokie, IL.
5. Bruce A. Suprenant, Curing During the Pour, Concrete Construction, June 1997.
Concrete expands and shrinks with changes in moisture and temperature. The overall tendency is to shrink and this can cause cracking at an early age. Irregular cracks are unsightly and difficult to maintain but generally do not affect the integrity of concrete. Joints are simply pre-planned cracks. Joints in concrete slabs can be created by forming, tooling, sawing, and placement of joint formers.

Some forms of joints are:

a. Contraction joints – are intended to create weakened planes in the concrete and regulate the location where cracks, resulting from dimensional changes, will occur.

b. Isolation or expansion joints – separate or isolate slabs from other parts of the structure, such as walls, footings, or columns; and driveways and patios from sidewalks, garage slabs, stairs, lightpoles and other points of restraint. They permit independent vertical and horizontal movement between adjoining parts of the structure and help minimize cracking when such movements are restrained.

c. Construction joints – are surfaces where two successive placements of concrete meet. They are typically placed at the end of a day’s work but may be required when concrete placement is stopped for longer than the initial setting time of concrete. In slabs they may be designed to permit movement and/or to transfer load. The location of construction joints should be planned. It may be desirable to achieve bond and continue reinforcement through a construction joint.

Cracks in concrete cannot be prevented entirely, but they can be controlled and minimized by properly designed joints. Concrete cracks because:

a. Concrete is weak in tension and, therefore, if its natural tendency to shrink is restrained, tensile stresses that exceed its tensile strength can develop, resulting in cracking.

b. At early ages, before the concrete dries out, most cracking is caused by temperature changes or by the slight contraction that takes place as the concrete sets and hardens. Later, as the concrete dries, it will shrink further and either additional cracks may form or preexisting cracks may become wider.

Joints provide relief from the tensile stresses, are easy to maintain and are less objectionable than uncontrolled or irregular cracks.

How to Construct Joints?

Joints must be carefully designed and properly constructed if uncontrolled cracking of concrete flatwork is to be avoided. The following recommended practices should be observed:

a. The maximum joint spacing should be 24 to 36 times the thickness of the slab. For example, in a 4-inch [100 mm] thick slab the joint spacing should be about
Follow These Rules for Proper Jointing

1. Plan exact location of all joints, including timing of contraction joint sawing before construction.
2. Provide isolation joints between slabs and columns, walls and footings, and at junctions of driveways with walks, curbs or other obstructions.
3. Provide contraction joints and joint filling materials as outlined in specifications.

References

1. Joints in Concrete Construction, ACI 224.3R, American Concrete Institute, Farmington Hills, MI.
2. Guide for Concrete Floor and Slab Construction, ACI 302.1R, American Concrete Institute, Farmington Hills, MI.
3. Slabs on Grade, ACI Concrete Craftsman Series CCS-1, American Concrete Institute, Farmington Hills, MI.
Curing is the maintaining of an adequate **moisture** content and **temperature** in concrete at early ages so that it can develop properties the mixture was designed to achieve. Curing begins immediately after placement and finishing so that the concrete may develop the desired strength and durability.

Without an adequate supply of moisture, the cementitious materials in concrete cannot react to form a quality product. Drying may remove the water needed for this chemical reaction called **hydration** and the concrete will not achieve its potential properties.

Temperature is an important factor in proper curing, since the rate of hydration, and therefore, strength development, is faster at higher temperatures. Generally, concrete temperature should be maintained above 50°F (10°C) for an adequate rate of strength development. Further, a uniform temperature should be maintained through the concrete section while it is gaining strength to avoid thermal cracking.

For exposed concrete, relative humidity and wind conditions are also important; they contribute to the rate of moisture loss from the concrete and could result in cracking, poor surface quality and durability. Protective measures to control evaporation of moisture from concrete surfaces before it sets are essential to prevent plastic shrinkage cracking (See CIP 5).

### WHY Cure?

Several important reasons are:

a. **Predictable strength gain.** Laboratory tests show that concrete in a dry environment can lose as much as 50 percent of its potential strength compared to similar concrete that is moist cured. Concrete placed under high temperature conditions will gain early strength quickly but later strengths may be reduced. Concrete placed in cold weather will take longer to gain strength, delaying form removal and subsequent construction.

b. **Improved durability.** Well-cured concrete has better surface hardness and will better withstand surface wear and abrasion. Curing also makes concrete more watertight, which prevents moisture and water-borne chemicals from entering into the concrete, thereby increasing durability and service life.

c. **Better serviceability and appearance.** A concrete slab that has been allowed to dry out too early will have a soft surface with poor resistance to wear and abrasion. Proper curing reduces crazing, dusting and scaling.

### HOW to Cure?

**Moisture Requirements for Curing:**

Concrete should be protected from losing moisture until final finishing using suitable methods like wind breaks, fogger sprays or misters to avoid plastic shrinkage cracking. After final finishing the concrete surface must be kept continuously wet or sealed to prevent evaporation for a period of at least several days after finishing. See the table for examples.
Systems to keep concrete wet include:

a. Burlap or cotton mats and rugs used with a soaker hose or sprinkler. Care must be taken not to let the coverings dry out and absorb water from the concrete. The edges should be lapped and the materials weighted down so they are not blown away.

b. Straw that is sprinkled with water regularly. Straw can easily blow away and, if it dries, can catch fire. The layer of straw should be 6 inches thick, and should be covered with a tarp.

c. Damp earth, sand, or sawdust can be used to cure flatwork, especially floors. There should be no organic or iron-staining contaminants in the materials used.

d. Sprinkling on a continuous basis is suitable provided the air temperature is well above freezing. The concrete should not be allowed to dry out between soakings, since alternate wetting and drying is not an acceptable curing practice.

e. Ponding of water on a slab is an excellent method of curing. The water should not be more than 20°F (11°C) cooler than the concrete and the dike around the pond must be secure against leaks.

Moisture retaining materials include:

a. Liquid membrane-forming curing compounds must conform to ASTM C 309. Apply to the concrete surface about one hour after finishing. Do not apply to concrete that is still bleeding or has a visible water sheen on the surface. While a clear liquid may be used, a white pigment will provide reflective properties and allow for a visual inspection of coverage. A single coat may be adequate, but where possible a second coat, applied at right angles to the first, is desirable for even coverage. If the concrete will be painted, or covered with vinyl or ceramic tile, then a liquid compound that is non-reactive with the paint or adhesives must be used, or use a compound that is easily brushed or washed off. On floors, the surface should be protected from the other trades with scuff-proof paper after the application of the curing compound.

b. Plastic sheets - either clear, white (reflective) or pigmented. Plastic should conform to ASTM C 171, be at least 4 mils thick, and preferably reinforced with glass fibers. Dark colored sheets are recommended when ambient temperatures are below 60°F (15°C) and reflective sheets should be used when temperatures exceed 85°F (30°C). The plastic should be laid in direct contact with the concrete surface as soon as possible without marring the surface. The edges of the sheets should overlap and be fastened with waterproof tape and then weighted down to prevent the wind from getting under the plastic. Plastic can make dark streaks wherever a wrinkle touches the concrete, so plastic should not be used on concretes where appearance is important. Plastic is sometimes used over wet burlap to retain moisture.

c. Waterproof paper - used like plastic sheeting, but does not mar the surface. This paper generally consists of two layers of kraft paper cemented together and reinforced with fiber. The paper should conform to ASTM C 171.

Note that products sold as evaporation retardants are used to reduce the rate of evaporation from fresh concrete surfaces before it sets to prevent plastic shrinkage cracking. These materials should not be used for final curing.

Control of temperature:

In cold weather do not allow concrete to cool faster than a rate of 5°F (3°C) per hour for the first 24 hours. Concrete should be protected from freezing until it reaches a compressive strength of at least 500 psi (3.5 MPa) using insulating materials. Curing methods that retain moisture, rather than wet curing, should be used when freezing temperatures are anticipated. Guard against rapid temperature changes after removing protective measures. Guidelines are provided in Reference 7.

In hot weather, higher initial curing temperature will result in rapid strength gain and lower ultimate strengths. Water curing and sprinkling can be used to achieve lower curing temperatures in summer. Day and night temperature extremes that allow cooling faster than 5°F (3°C) per hour during the first 24 hours should be protected against.

References

1. Effect of Curing Condition on Compressive Strength of Concrete Test Specimens, NRMCA Publication No. 53, National Ready Mixed Concrete Association, Silver Spring, MD.
2. How to Eliminate Scaling, Concrete International, February 1980. American Concrete Institute, Farmington Hills, MI.
5. Standard Practice for Curing Concrete, ACI 308, American Concrete Institute, Farmington Hills, MI.
6. Standard Specification for Curing Concrete, ACI 308.1, American Concrete Institute, Farmington Hills, MI.
7. Cold Weather Concreting, ACI 306R, American Concrete Institute, Farmington Hills, MI.


Example Minimum Curing Period to Achieve 50% of Specified Strength*

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<tr>
<th>Type</th>
<th>Temperature</th>
<th>6 days</th>
<th>9 days</th>
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<tr>
<td>II</td>
<td>70°F (21°C)</td>
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<td></td>
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</tr>
<tr>
<td>III</td>
<td></td>
<td></td>
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</tbody>
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*Values are approximate and based on cylinder strength tests. Specific values can be established for specific materials and mixtures. From Ref. 7.
**WHAT is Hot Weather?**

Hot weather may be defined as any period of high temperature in which special precautions need to be taken to ensure proper handling, placing, finishing and curing of concrete. Hot weather problems are most frequently encountered in the summer, but the associated climatic factors of high winds, low relative humidity and solar radiation can occur at any time, especially in arid or tropical climates. Hot weather conditions can produce a rapid rate of evaporation of moisture from the surface of the concrete and accelerated setting time, among other problems. Generally, high relative humidity tends to reduce the effects of high temperature.

**WHY Consider Hot Weather?**

It is important that hot weather be taken into account when planning concrete projects because of the potential effects on fresh and recently placed concrete. High temperatures alone cause increased water demand, which, in turn, will raise the water-cement ratio and result in lower potential strength. Higher temperatures tend to accelerate slump loss and can cause loss of entrained air. Temperature also has a major effect on the setting time of concrete: concrete placed under high temperatures will set quicker and can, therefore, require more rapid finishing. Concrete that is cured at high temperatures at an early age will not be as strong at 28 days as the same concrete cured at temperatures in the range of 70°F (20°C).

High temperatures, high wind velocity, and low relative humidity can affect fresh concrete in two important ways: the high rate of evaporation may induce early plastic shrinkage or drying shrinkage cracking, and the evaporation rate can remove surface water necessary for hydration unless proper curing methods are employed. Thermal cracking may result from rapid drops in the temperature of the concrete, such as when concrete stabs or walls are placed on a hot day followed by a cool night. High temperature also accelerates cement hydration and contributes to the potential for thermal cracking in massive concrete structures.

**HOW to Concrete in Hot Weather?**

The key to successful hot weather concreting is:
1. recognition of the factors that affect concrete; and
2. planning to minimize their effects.

Use proven local recommendations for adjusting concrete proportions, such as the use of water reducing...
and set retarding admixtures. Modifying the mixture to reduce the heat generated by cement hydration, such as the use of an ASTM Type II moderate heat cement and the use of pozzolans and slag can reduce potential problems with high concrete temperature. Advance timing and scheduling to avoid delays in delivery, placing and finishing is essential. Trucks should be able to discharge immediately and adequate personnel should be available to place and handle the concrete. When possible, deliveries should be scheduled to avoid the hottest part of the day. Limits on maximum concrete temperature may be waived by the purchaser if the concrete consistency is adequate for the placement and excessive water addition is not required.

In the case of extreme temperature conditions or with mass concrete, the concrete temperature can be lowered by using chilled water or ice as part of the mixing water. The ready mixed concrete producer uses other measures, such as sprinkling and shading the aggregate prior to mixing, to help lower the temperature of the concrete.

If low humidity and high winds are predicted, windbreaks, sunscreens, mist fogging, or evaporation retardants may be needed to avoid plastic shrinkage cracking in slabs.

Follow These Rules for Hot Weather Concrete

1. Modify concrete mix designs as appropriate. Retarders, moderate heat of hydration cement, pozzolanic materials, slag, or other proven local solutions may be used. Reduce the cement content of the mixture as much as possible, while ensuring the concrete strength will be attained.

2. Have adequate manpower to quickly place, finish and cure the concrete.

3. Limit the addition of water at the job site—add water only on arrival at the job site to adjust the slump. Water addition should not exceed about 2 to 2 1/2 gallons per cubic yard (10 to 12 L/m³). Adding water to concrete that is more than 1 1/2 hours old should be avoided.

4. Slabs on grade should not be placed directly on polyethylene sheeting or other vapor retarders. Cover the vapor retarder with a minimum 4-inch (100 mm) layer of compactible, easy-to-trim, granular fill material.

5. On dry and/or hot days, when conditions are conducive for plastic shrinkage cracking, dampen the subgrade, forms and reinforcement prior to placing concrete, but do not allow excessive water to pond.

6. Begin final finishing operations as soon as the water sheen has left the surface; start curing as soon as finishing is completed. Continue curing for at least 3 days; cover the concrete with wet burlap and plastic sheeting to prevent evaporation or use a liquid membrane curing compound, or cure slabs with water (See CIP 11). Using white pigmented membrane curing compounds will help by indicating proper coverage and reflecting heat away from the concrete surface.

7. Protect test cylinders at the jobsite by shading and preventing evaporation. Field curing boxes with ice or refrigeration may be used to ensure maintaining the required 60 to 80°F (17 to 27°C) for initial curing of cylinders. (See CIP 9)

8. Do not use accelerators unless it is common practice to avoid plastic shrinkage cracking and expedite finishing operations.

References

1. *Hot Weather Concreting*, ACI 305R, American Concrete Institute, Farmington Hills, MI.

2. *Cooling Ready Mixed Concrete*, NRMCA Publication No. 106, NRMCA, Silver Spring, MD.


**WHAT are Blisters?**

Blisters are hollow, low-profile bumps on the concrete surface, typically from the size of a dime up to 1 inch (25 mm), but occasionally even 2 or 3 inches (50 – 75 mm) in diameter. A dense troweled skin of mortar about 1/8 in. (3 mm) thick covers an underlying void that moves around under the surface during troweling. Blisters may occur shortly after the completion of finishing operation. In poorly lighted areas, small blisters may be difficult to see during finishing and may not be detected until they break under traffic.

**WHY do Blisters Form?**

Blisters may form on the surface of fresh concrete when either bubbles of entrapped air or bleed water migrate through the concrete and become trapped under the surface, which has been sealed prematurely during the finishing operations. These defects are not easily repaired after concrete hardens.

Blisters are more likely to form if:

1. Insufficient or excessive vibration is employed. Insufficient vibration prevents the entrapped air from being released and excessive use of vibrating screeds works up a thick mortar layer on the surface.
2. An improper tool is used for floating the surface or it is used improperly. The surface should be tested to determine which tool, whether it be wood or magnesium bull float, does not seal the surface. The floating tool should be kept as flat as possible.
3. Excessive evaporation of bleed water occurs and the concrete appears ready for final finishing operations (premature finishing), when, in fact, the underlying concrete is still releasing bleed water and entrapped air. High rate of bleed water evaporation is especially a problem during periods of high ambient temperatures, high winds and/or low humidity.
4. Entrained air is used or is higher than normal. Rate of bleeding and quantity of bleed water is greatly reduced in air-entrained concrete giving the appearance that the concrete is ready to float and further finish causing premature finishing.
5. The subgrade is cooler than concrete. The top surface sets faster than the concrete in the bottom and the surface appears ready to be floated and further finished.
6. The slab is thick and it takes a longer time for the entrapped air and bleed water to rise to the surface.
7. The concrete is cohesive or sticky from higher content of cementitious materials or excessive fines in the sand. These mixtures also bleed less and at a slower rate. Concrete mixtures with lower contents of cementitious materials bleed rapidly for a
shorter period, have higher total bleeding and tend to delay finishing.

8. A dry shake is prematurely applied, particularly over air-entrained concrete.

9. The slab is placed directly on top of a vapor retarder or an impervious base, preventing bleed water from being absorbed by the subgrade.

**HOW To Prevent Blisters?**

The finisher should be wary of a concrete surface that appears to be ready for final finishing before it would normally be expected. Emphasis in finishing operations should be on placing, striking off and bull floating the concrete as rapidly as possible and without working up a layer of mortar on the surface. After these operations are completed, further finishing should be delayed as long as possible and the surface covered with polyethylene or otherwise protected from evaporation. If conditions for high evaporation rates exist, place a cover on a small portion of the slab to judge if the concrete is still bleeding. In initial floating, the float blades should be flat to avoid densifying the surface too early. Use of an accelerating admixture or heated concrete often prevents blisters in cool weather. It is recommended that non-air entrained concrete be used in interior slabs and that air entrained concrete not be steel troweled.

If blisters are forming, try to either flatten the trowel blades or tear the surface with a wood float and delay finishing as long as possible. Under conditions causing rapid evaporation, slow evaporation by using wind breaks, water misting of the surface, evaporation retarders, or a cover (polyethylene film or wet burlap) between finishing operations. Further recommendations are given in ACI 302.1R and ACI 305.

**Follow These Rules to Avoid Blisters**

1. Do not seal surface before air or bleed water from below have had a chance to escape.

2. Avoid dry shakes on air-entrained concrete.

3. Use heated or accelerated concrete to promote even setting throughout the depth of the slab in cooler weather.

4. Do not place slabs directly on vapor retarders. If vapor retarders are essential (CIP 28) take steps to avoid premature finishing.

5. Protect surface from premature drying and evaporation.

6. Do not use a jitterbug or excessive vibration such as a vibratory screed on slumps over 5 inches (125 mm).

7. Air entrained concrete should not be steel troweled. If required by specifications, extreme caution should be exercised when timing the finishing operation.

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**References**

1. *Guide for Concrete Floor and Slab Construction*, ACI 302.1R, American Concrete Institute, Farmington Hills, MI. [www.concrete.org](http://www.concrete.org)

2. *Slabs on Grade*, ACI Concrete Craftsman Series, CCS 1, American Concrete Institute, Farmington Hills, MI.

3. *Hot weather Concreting*, ACI 305R, American Concrete Institute, Farmington Hills, MI.

4. *Concrete Slab Surface Defects: Causes, Prevention, Repair*, IS 177, Portland Cement Association, Skokie, IL. [www.cement.org](http://www.cement.org)


WHAT is Curling?
Curling is the distortion of a slab into a curved shape by upward or downward bending of the edges. The occurrence is primarily due to differences in moisture and/or temperature between the top and bottom surfaces of a concrete slab. The distortion can lift the edges or the middle of the slab from the base, leaving an unsupported portion. The slab section can crack when loads exceeding its capacity are applied. Slab edges might chip off or spall due to traffic when the slab section curls upwards at its edges. In most cases, curling is evident at an early age. Slabs may, however, curl over an extended period.

WHY do Concrete Slabs Curl?
Changes in slab dimensions that lead to curling are most often related to moisture and temperature gradients in the slab. When one surface of the slab changes size relative to the other, the slab will warp at its edges in the direction of relative shortening. This curling is most noticeable at the sides and corners. One primary characteristic of concrete that affects curling is drying shrinkage. Anything that increases drying shrinkage of concrete will tend to increase curling.

The most common occurrence of curling is when the top surface of the slab dries and shrinks with respect to the bottom. This causes an upward curling of the edges of a slab (Figure 1A). Curling of a slab soon after placement is most likely related to poor curing and rapid surface drying. In slabs, excessive bleeding due to high water content in the concrete or water sprayed on the surface; or a lack of surface moisture due to poor or inadequate curing can create increased surface drying shrinkage relative to the bottom of the slab. Bleeding is accentuated in slabs placed directly on a vapor retarder (polyethylene sheeting) or when topping mixtures are placed on concrete slabs. Shrinkage differences from top to bottom in these cases are larger than for slabs on an absorptive subgrade.

Thin slabs and long joint spacing tend to increase curling. For this reason, thin unbonded toppings need to have a fairly close joint spacing.

In industrial floors, close joint spacing may be undesirable because of the increased number of joints and increased joint maintenance problems. However, this must be balanced against the probability of intermediate random cracks and increased curling at the joints.

The other factor that can cause curling is temperature differences between the top and bottom of the slab. The top part of the slab exposed to the sun will expand relative to the cooler bottom causing a downward curling of the edges (Figure 1B). Alternately, during a cold night when the top surface cools and contracts relative to the bottom surface in contact with a warmer subgrade, the curling due to this temperature differential will add to the upward curling caused by moisture differentials.
HOW to Minimize Slab Curling?

The primary factors controlling dimensional changes of concrete that lead to curling are drying shrinkage, construction practices, moist or wet subgrades, and day-night temperature cycles. The following practices will help to minimize the potential for curling:

1. Use the lowest practical water content in the concrete.
2. Use the largest practical maximum size aggregate and/or the highest practical coarse aggregate content to minimize drying shrinkage.
3. Take precautions to avoid excessive bleeding. In dry conditions place concrete on a damp, but absorptive, subgrade so that all the bleed water is not forced to the top of the slab. This may not be appropriate for interior slabs on which a moisture sensitive floor covering would be placed.
4. Avoid using polyethylene vapor retarders unless covered with at least four inches (100 mm) of a trimable, compactible granular fill (not sand). If a moisture-sensitive floor covering will be placed on interior slabs, the concrete will generally be placed directly on a vapor retarder (see CIP29) and other procedures may be necessary.
5. Avoid a higher than necessary cement content. Use of pozzolan or slag is preferable to very high cement content.
6. Cure the concrete thoroughly, including joints and edges. If membrane-curing compounds are used, apply at twice the recommended rate in two applications at right angles to each other.
7. When minimizing curling is critical, use a joint spacing not exceeding 24 times the thickness of the slab.
8. For thin toppings, clean the base slab to ensure bond and consider use of studs and wire around the edges and particularly in the slab corners.
9. Use a thicker slab, or increase the thickness of the slab at edges.
10. The use of properly designed and placed slab reinforcement may help reduce or eliminate curling. Load transfer devices that minimize vertical movement should be used across construction joints.
11. Certain types of breathable sealers or coatings on slabs can work to minimize moisture differentials and reduce curling.

When curling in a concrete slab application cannot be tolerated alternate options include the use of shrinkage reducing admixtures, shrinkage-compensating concrete, post tensioned slab construction or vacuum dewatering. These options should be decided before the construction and could increase the initial cost of the project.

Some methods of remedying slab curling include ponding the slab to reduce curl followed by sawing additional contraction joints, grinding slab joints where curling has occurred to restore serviceability and injecting a grout to fill voids under the slab to restore support and prevent break-off of uplifted edges.

References

1. Guide for Concrete Floor and Slab Construction, ACI 302.1R American Concrete Institute, Farmington Hills, MI www.concrete.org
2. Slabs on Grade, ACI Concrete Craftsman Series, CCS-1 American Concrete Institute, Farmington Hills, MI.
3. Shrinkage and Curling of Slabs on Grade, Series in three parts, R. F. Ytterberg, ACI Concrete International, April, May and June 1987, American Concrete Institute.
4. Concrete Slab Surface Defects: Causes, Prevention, Repair, IS177, Portland Cement Association, Skokie, IL, www.cement.org
7. Where to Place the Vapor Retarder, B. Suprenant and W. Malishc, Concrete Construction, May 1998.
WHAT are Delaminations?

In most delaminated concrete slab surfaces, the top 1/8 to ¼ inch (3 to 6 mm) is densified, primarily due to premature and improper finishing, and separated from the base slab by a thin layer of air or water. The delaminations on the surface of a slab may range in size from several square inches to many square feet. The concrete slab surface may exhibit cracking and color differences because of rapid drying of the thin surface during curing. Traffic or freezing may break away the surface in large sheets. Delaminations are similar to blisters, but much larger (see CIP 13).

Delaminations form during final troweling. They are more frequent in early spring and late fall when concrete is placed on a cool subgrade with rising daytime temperatures, but they can occur at anytime depending on the concrete characteristics and the finishing practices used.

Corrosion of reinforcing steel near the concrete surface or poor bond between two-course placements may also cause delaminations (or spalling). The resulting delaminations are generally thicker than those caused by improper finishing.

Delaminations are difficult to detect during finishing but become evident after the concrete surface has set and dried. Delaminations can be detected by a hollow sound when tapped with a hammer or with a heavy chain drag. A procedure is described in ASTM D 4580, Standard Practice for Measuring Delaminations in Concrete Bridge Decks by Sounding. More sophisticated techniques include acoustic impact echo and ground-penetrating radar.

WHY does Delamination Occur?

Bleeding is the upward flow of mixing water in plastic concrete as a result of the settlement of the solids. Delamination occurs when the fresh concrete surface is sealed or densified by troweling while the underlying concrete is still plastic and continues to bleed and/or to release air. Delaminations form fairly late in the finishing process after floating and after the first troweling pass. They can, however, form during the floating operation if the surface is overworked and densified. The chances for delaminations are greatly increased when conditions promote rapid drying of the surface (wind, sun, or low humidity). Drying and higher temperature at the slab surface makes it appear ready to trowel while the underlying concrete is plastic and can still bleed or release air. Vapor retarders placed directly under slabs force bleed water to rise and compound the problem.

Factors that delay initial set of the concrete and reduce the rate of bleeding will increase the chances for delaminations. Entrained air in concrete reduces the rate of bleeding and promotes early finishing that will produce a dense impermeable surface layer. A cool subgrade delays set in the bottom relative to the top layer.

Delamination is more likely to form if:

1. The underlying concrete sets slowly because of a cool subgrade.
2. The setting of the concrete is retarded due to con-
Concrete temperature or mixture ingredients.
3. The concrete has entrained air or the air content is higher than desirable for the application.
4. The concrete mixture is sticky from higher cementitious material or sand-fines content.
5. Environmental conditions during placement are conducive to rapid drying causing the surface to “crust” and appear ready to finish.
6. Concrete is excessively consolidated, such as the use of a jitterbug or vibrating screed that brings too much mortar to the surface.
7. A dry shake is used, particularly with air-entrained concrete.
8. The slab is thick.
9. The slab is placed directly on a vapor retarder.

Corrosion-related delaminations are formed when the upper layer of reinforcing steel rusts thereby breaking the bond between the steel and the surrounding concrete. Corrosion of steel occurs with reduced concrete cover and when the concrete is relatively more permeable causing chlorides to penetrate to the layer of the steel (See CIP 25).

**References**

1. *Guide for Concrete Floor and Slab Construction*, ACI 302.1R American Concrete Institute, Farmington Hills, MI www.concrete.org
2. *Slabs on Grade*, ACI Concrete Craftsman Series, American Concrete Institute, Farmington Hills, MI.
3. *Concrete Slab Surface Defects: Causes, Prevention, Repair*, IS177, Portland Cement Association, Skokie, IL, www.cement.org

**Follow These Rules to Avoid Delamination**

1. Do not seal surface early—before air or bleed water from below have escaped.
2. Avoid dry shakes on air-entrained concrete.
3. Use heated or accelerated concrete to promote even setting throughout slab depth.
4. Avoid placing concrete directly on vapor retarders, if the application allows.
5. Do not use air-entrained concrete for interior slabs that will receive a trowel finish.
6. Avoid placing concrete on substrate with a temperature of less than 40° F (4° C).
CIP 27 - Cold Weather Concreting

**WHAT** is Cold Weather?
Cold weather is defined as a period when the average daily temperature falls below 40°F [4°C] for more than three successive days. These conditions warrant special precautions when placing, finishing, curing and protecting concrete against the effects of cold weather. Since weather conditions can change rapidly in the winter months, good concrete practices and proper planning are critical.

**WHY** Consider Cold Weather?
Successful cold-weather concreting requires an understanding of the various factors that affect concrete properties.

In its plastic state, concrete will freeze if its temperature falls below about 25°F [-4°C]. If plastic concrete freezes, its potential strength can be reduced by more than 50% and its durability will be adversely affected. Concrete should be protected from freezing until it attains a minimum compressive strength of 500 psi [3.5 MPa], which is about two days after placement for most concrete maintained at 50°F [10°C].

Low concrete temperature has a major effect on the rate of cement hydration, which results in slower setting and rate of strength gain. A good rule of thumb is that a drop in concrete temperature by 20°F [10°C] will approximately double the setting time. The slower rate of setting and strength gain should be accounted for when scheduling construction operations, such as form removal.

Concrete in contact with water and exposed to cycles of freezing and thawing, even if only during construction, should be air-entrained. Newly placed concrete is saturated with water and should be protected from cycles of freezing and thawing until it has attained a compressive strength of at least 3500 psi [24.0 MPa].

Cement hydration is a chemical reaction that generates heat. Newly placed concrete should be adequately insulated to retain this heat and thereby maintain favorable curing temperatures. Large temperature differences between the surface and the interior of the concrete mass should be prevented as cracking may result when this difference exceeds about 35°F [20°C]. Insulation or protective measures should be gradually removed to avoid thermal shock.

**HOW** to Place Concrete in Cold Weather?
Recommended concrete temperatures at the time of placement are shown below. The ready mixed concrete producer can control concrete temperature by heating the mixing water and/or the aggregates and furnish concrete in accordance with the guidelines in ASTM C 94.

<table>
<thead>
<tr>
<th>Section Size, minimum dimension, inch [mm]</th>
<th>Concrete temperature as placed</th>
</tr>
</thead>
<tbody>
<tr>
<td>less than 12 [300]</td>
<td>55°F [13°C]</td>
</tr>
<tr>
<td>12 - 36 [300 - 900]</td>
<td>50°F [10°C]</td>
</tr>
<tr>
<td>36 - 72 [900 - 1800]</td>
<td>45°F [7°C]</td>
</tr>
</tbody>
</table>

Cold weather concrete temperature should not exceed these recommended temperatures by more than 20°F [10°C]. Concrete at a higher temperature requires more mixing water, has a higher rate of slump loss, and is more susceptible to cracking. Placing concrete in cold weather provides the opportunity for better quality, as cooler initial concrete temperature will typically result in higher ultimate strength.

Slower setting time and strength gain of concrete during cold weather typically delays finishing operations and
Cold Weather Concreting Guidelines

1. Use air-entrained concrete when exposure to moisture and freezing and thawing conditions are expected.
2. Keep surfaces in contact with concrete free of ice and snow and at a temperature above freezing prior to placement.
3. Place and maintain concrete at the recommended temperature.
4. Place concrete at the lowest practical slump.
5. Protect plastic concrete from freezing or drying.
6. Protect concrete from early-age freezing and thawing cycles until it has attained adequate strength.
7. Limit rapid temperature changes when protective measures are removed.

References

1. Cold Weather Concreting, ACI 306R, American Concrete Institute, Farmington Hills, MI.
2. Design and Control of Concrete Mixtures, Portland Cement Association, Skokie, IL.
4. ASTM C 31 Making and Curing Concrete Test Specimens in the Field, ASTM, West Conshohocken, PA.
5. Cold Weather Ready Mixed Concrete, NRMCA Pub 130, NRMCA, Silver Spring, MD.
6. Cold-Weather Finishing, Concrete Construction, November 1993
A “popout” is a small, generally cone-shaped cavity in a horizontal concrete surface left after a near-surface aggregate particle has expanded and fractured. Generally, part of the fractured aggregate particle will be found at the bottom of the cavity with the other part of the aggregate still adhering to the point of the popout cone. The cavity can range from ¼ in. (6 mm) to few inches in diameter.

The aggregate particle expands and fractures as a result of a physical action or a chemical reaction:

**Physical**
The origin of a physical popout usually is a near-surface aggregate particle having a high absorption and relatively low relative density (specific gravity). As that particle absorbs moisture; or if freezing occurs under moist conditions, its swelling creates internal pressures sufficient to rupture the particle and the overlying concrete surface. The top portion of the fractured aggregate particle separates from the concrete surface taking a portion of the surface mortar with it. In some cases the aggregate forces water into the surrounding mortar as it freezes thus causing the surface mortar to pop off, exposing an intact aggregate particle. Clay balls, coal, wood or other contaminants can uptake water and swell even without freezing, but the resulting pressure rarely is great enough to cause popouts. Also, there are reported cases of grain (soybeans, corn) contamination of aggregate shipments that have resulted in surface popouts. Such occurrences are not within the scope of this document.

Popouts as a result of physical action are typically only a problem with exterior flatwork in climates subject to freezing and thawing under moist conditions and resulting expansion. Even aggregates which meet the requirements of ASTM C 33 Class 5S, for architectural concrete in severe exposure, allow several types of particles which may cause popouts when exposed to freezing and thawing in the saturated condition. The most common type of particles resulting in popouts are low density chert in natural aggregate deposits.

Crushed aggregates are less likely to contain lightweight, absorptive particles which are more susceptible to popouts.

**Chemical**
The cause of a popout due to a chemical reaction is often related to alkali-silica reaction (ASR). Alkalis from cement or other source cause an environment of high pH (high concentrations of OH ions) causing the breakdown of silica and formation of an ASR gel, which absorbs water and expands, removing a small portion of the surface mortar with it. These are called ASR Popouts. They are typically small and are often accompanied by a small spot that is discolored and/or appears to be damp. The aggregate particle does not often fracture and split as is the case of popouts from physical action. However, the ASR phenomenon can result in micro-fractures within the aggregate particles. Some alkali-silica reaction popouts can occur within a few days after the concrete is placed.
**HOW to Avoid Concrete Popouts?**

Most popouts are aesthetic defects that do not impact the structural performance of the concrete members. A large number of popouts however make it easier for water and other harmful chemicals to enter the concrete, which can ultimately lead to other forms of deterioration such as corrosion of steel reinforcement. The following steps can be taken to avoid concrete popouts.

**Physical Popouts**

1. Avoid using aggregates which contain particles which may cause popouts, or that have a history of popouts. However, in some parts of the United States, the available natural gravels contain some particles that are likely to result in surface popouts. Due to the unavailability of economical alternate aggregates, the occurrence of popouts on sidewalks and pavements is an accepted, albeit undesirable, likelihood in those locations.

2. If popouts are unacceptable, an alternate source of aggregates must be located. If appropriate, two-course construction can be used, whereby the popout susceptible aggregate is used for the lower course and the pop-out free aggregate that is likely to be more expensive is used for the surface course.

3. Aggregates can be beneficiated to remove lightweight materials, but the added cost of beneficiation can be prohibitive for most uses.

4. Reduce the water to cementitious materials ratio of the concrete, as this will reduce the likelihood of saturation and will increase the resistance to swelling forces. Provide proper curing for exterior flatwork, as this results in improved strength of the cementitious materials, especially on the surface. This will reduce permeability thereby lowering the amount of water migrating to coarse aggregate particles. These steps can reduce the frequency, but will not necessarily, eliminate popouts.

5. Reduce the maximum aggregate size, as smaller aggregates will develop lower stresses due to freezing, and fewer popouts will occur. Those that do will be smaller and less objectionable.

**Chemical Popouts**

1. Use a low-alkali cement or a non-reactive aggregate. This is often not a practical option in many regions.

2. Flush the surfaces with water after the concrete has hardened and before applying the final curing. This will remove the alkalis that may have accumulated at the surface as a result of evaporation of bleed water.

3. Permit the use of Class F fly ash or slag cement as a partial cement substitute to reduce the permeability of the paste and mitigate deleterious reactions due to ASR.

**HOW to Repair Concrete Popouts?**

Prior to undertaking a repair program, it is advisable to confirm the cause of the popouts by obtaining core samples containing one or more typical popouts and having them studied by a qualified petrographer.

Popouts can be repaired by chipping out the remaining portion of the aggregate particle in the surface cavity, cleaning the resulting void, and by filling the void with a proprietary repair material such as a dry pack mortar, epoxy mortar, or other appropriate material following procedures recommended by the manufacturer. It will be difficult to match the color of the existing concrete. If the popouts in a surface are too numerous to patch individually, a thin bonded concrete overlay may be used to restore a uniform surface appearance. Specific recommendations for such overlays are beyond the scope of this publication.

**References**