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Accelerated Techniques for Concrete Paving

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This report covers the state of the art of accelerated-concrete paving techniques, often referred to as "fast-track" concrete paving. Accelerated-concrete paving techniques are appropriate for roadways, airfield, and other paved surfaces where quick access is required. Considerations include planning, concrete materials and properties, jointing and joint sealing, curing and temperature control, concrete strength testing, and opening-to-traffic criteria. Applications and uses of accelerated-concrete paving are discussed.

Keywords: accelerated paving; airports; admixtures; aggregates; cement; construction; concrete pavement; curing; fast-track paving; gradation; highways; intersections; joint sealing compound; jointing; nondestructive strength testing; specifications; streets; temperature; opening-to-traffic.

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CHAPTER 1—INTRODUCTION

1.1—General

Airport authorities and road agencies face major challenges from increasing traffic volumes on existing airports, roadways, and urban streets. Owners must repair or replace deteriorated pavements while maintaining traffic on these structures. Traditional pavement construction, repair, or replacement solutions may no longer be universally acceptable due to increasing public impatience with traffic interruption. Traditional solutions are especially inappropriate in urban areas where congestion is severe. Accelerated construction techniques for portland cement concrete pavement resolve these problems by providing quick public access to a high-quality, long-lasting pavement. Accelerated construction techniques are suitable for new construction, reconstruction, or resurfacing projects. Accelerated construction for concrete paving is often referred to as "fast-track" concrete paving. Accelerated paving encompasses two classes of activities: technological methods to accelerate the rate of strength gain and contractual methods to minimize the construction time.

Table 1.2—Changes to project components useful to shorten concrete pavement construction time[2]

Project Component	Possible changes
Planning	Implement partnering-based project management. Implement lane rental charges. Allow night construction. Allow contractor to use innovative equipment or procedures to expedite construction (for example, minimum-clearance machines, dowel inserters, and ultra-light saws). Specify more than one concrete mixture for varied strength development. Provide options to contractors, not step-by-step procedures. Use time-of-completion incentives and disincentives.
Concrete materials	Try different cement types (particularly Type III). Use helpful admixtures. Use a well-graded aggregate. Keep water-cementitious materials ratio (*w/cm*) below 0.43.
Jointing and sealing	Allow early-age sawing. Use dry-sawing blades. Use step-cut blades for single-pass joint sawing. Use a sealant that is unaffected by moisture or reservoir cleanliness.
Concrete curing and temperature	Suggest blanket curing to aid strength gain when beneficial. Monitor concrete temperature and understand relationship of ambient, subgrade, and mixture temperature on strength gain. Elevate concrete temperature before placement.
Strength testing	Use nondestructive methods to replace or supplement cylinders and beams for strength testing. Use concrete maturity or pulse velocity testing to predict strength.
Traffic opening criterion	Revise from a time criterion to a strength criterion. Channel early loads away from slab edges. Resist truck traffic.

Many methods exist to accelerate pavement construction.[1] Two traditional acceleration methods are time incentives and penalties for project completion. Agencies have been using these time-of-completion incentives for many years, and often contractors will meet these requirements by lengthening the work day or increasing the size of construction crews. Using accelerated paving techniques, a contractor often can complete a project without increasing crew size or changing normal labor schedules.

1.2—Changes to construction specifications and processes

To build an accelerated paving project, both the contractor and the agency must make some changes to traditional construction specifications and processes. Often, these involve high-early-strength concrete, but they also can include revising opening-to-traffic criteria, construction staging, joint construction, and worker responsibilities. Table 1.2 suggests changes to project components that can decrease construction time.

CHAPTER 2—PROJECT APPLICATIONS

2.1—General

Accelerated techniques for concrete paving allow transportation officials to consider concrete for projects that might not otherwise be feasible because of lengthy concrete curing intervals. Some specifications require cure intervals from 5 to 14 days for conventional concrete mixtures.[3] With accelerated paving techniques, concrete can meet opening strengths in less than 12 hours.[2,4,5]

2.2—Highways and tollways

Many highway agencies use accelerated techniques for concrete paving techniques to expedite construction and ease work-zone congestion. Major projects in Chicago and Denver have shown how accelerated-concrete paving can decrease construction time for urban and suburban roadways.[6,7]

Tollway authorities lose revenue as a result of lane closures because traffic delays cause many drivers to find alternative routes. Accelerated-concrete pavement minimizes revenue loss by allowing earlier access at high-congestion areas like toll booths and interchanges.

The need for accelerated techniques on rural highway or road construction is more limited. A contractor may use accelerated techniques to speed construction on portions of a project to allow construction equipment on the pavement sooner than usual. The contractor also may use accelerated-concrete paving for the last portion of a project to speed final opening to public vehicles. The Federal Highway Administration (FHWA) is encouraging all highway agencies to use accelerated techniques for concrete paving to meet special construction needs.[2]

2.3—Streets

Accelerated paving technology also provides solutions for public access on residential and urban streets. Residents along suburban streets can usually gain access to their driveways within 24 hours.

2.4—Intersections

Intersections pose major construction staging and traffic interruption challenges because they affect two or more streets. A unique project by the Iowa Department of Transportation involved the replacement of nine intersections using accelerated paving.[8,9] Using two concrete mixtures and night construction, the contractor finished each intersection without disrupting daily rush-hour traffic.[9]

Reconstructing intersections one quadrant at a time allows traffic to continue to use the roadways. With accelerated construction techniques and quadrant construction, a contractor can pave the intersection in less than one week. Where it is feasible to close the entire intersection for a short time, a contractor can use accelerated paving techniques to complete reconstruction over a weekend.

2.5—Airports

On airport aprons, runways, and taxiways, accelerated-concrete paving speeds sequential paving placements. Such pavement gains strength quickly and allows contractors to operate slipform equipment sooner on completed adjacent paving lanes. The construction schedule is reduced by shortening the wait before paving interior lanes. Accelerated paving techniques also can speed reconstruction of cross-runway intersections, runway extensions, and runway keel sections. This may be necessary to maintain traffic at commercial airports or for the national defense at military air bases. Accelerated-concrete paving reduces the time that passenger loading gates are out of service at commercial airports for apron reconstruction.

Table 3.1—Important considerations for planning accelerated-concrete paving projects

Important planning considerations
Access for local traffic
Local business disruption
Utility work
Construction equipment access and operation
Availability of suitable materials
Work-zone safety
Pavement edge drop-off requirements
Crossovers that disrupt both directions of traffic
Detour routes that can suffer damage and congestion from prolonged construction zone detours
Using fast-track concrete near the end of one day's paving can facilitate next-day startup

CHAPTER 3—PLANNING

3.1—Planning considerations

Developing a traffic-control plan before construction is essential for projects with high traffic volumes. The goal is to reduce the construction period and minimize traffic disruption. An agency will benefit because meeting this goal will reduce public complaints, business impacts, user-delay costs, and traffic-control costs. The contractor will benefit by reducing workers' exposure to accidents and reducing the time for which equipment is committed to a project.

Planners should include accelerated paving techniques when assessing project feasibility or when developing construction staging plans. Table 3.1 lists other issues that should be considered when planning an accelerated project.

One common method specifiers use to ensure project completion by a certain date is through a time-of-completion contract that offers monetary incentives and penalties to the contractor. The agency specifies the completion date and the daily incentive or penalty value. The contractor earns the incentive for completing the project before the deadline or pays the penalty for finishing late. These arrangements are easily understood and usually ensure timely construction. Certain new lane-rental contracting techniques may be more useful for accelerated-concrete pavement construction, because they encourage more contractor flexibility and innovation than a completion-time contract.

3.2—Lane rental

Lane rental is an innovative contracting practice that encourages contractors to lessen the construction impact on road users.[10,11] There are three basic lane rental methods: cost-plus-time bidding; continuous site rental; and lane-by-lane rental. For each method, the agency must determine a rental charge for use of all or part of the roadway by the contractor. The rental charge usually coincides with the user cost estimate for delays during project construction. The user costs vary for each project and, consequently, so should rental charges. Computer programs are available to determine work zone user costs.[12]

Table 3.2—Sample hourly lane-by-lane rental charges*

Closure or obstruction	Peak time periods 6 to 9 a.m. 3 to 6 p.m.	All other hours
One lane	$X	0.25 × $X
One shoulder	0.25 × $X	0.0625 × $X
One lane and shoulder	1.25 × $X	0.3125 × $X
Two lanes	2.25 × $X	0.625 × $X
Two lanes and shoulder	2.50 × $X	0.6875 × $X

*Proportional to a base amount $X for one lane during peak hours, for a given project length.[10]

Not all projects warrant lane-rental assessments. A lane-rental contract requires special contracting terms and is most suitable for large projects where construction congestion management is critical. To reduce congestion on smaller projects, an agency can modify concrete materials and construction specifications to decrease road or lane closure time. Contract management and record keeping on lane-rental projects can be difficult. Accounting for partial completion of portions of a project can be confusing. Therefore, it is important for contract language to cover these situations.

Cost-plus-time bidding (also called "A+B bidding") divides each contractor's bid into two parts: the construction cost and the time cost.[10,11] Along with construction costs, the contractor must include an estimate of the number of days necessary to complete the project in the bid. The agency multiplies the time estimate by a daily time-value charge to determine a time cost, and then adds the time cost to the construction cost to determine each contractor's total bid value. The contractor with the lowest combined cost receives the contract for construction. To encourage maximum production, cost-plus-time bidding should also include a completion-time incentive and disincentive.

With lane-by-lane rental, the contractor pays for the lanes or combination of lanes occupied by the crew during construction. The agency can vary the lane rental rates depending on the lane in use (outside, inside, shoulder) or upon the time of day or week (Table 3.2). This encourages the contractor to occupy lanes in off-peak hours and to plan construction thoughtfully. This contracting arrangement may not be suitable for certain reconstruction projects with limited staging options.

3.3—Partnering

For rapid-completion projects, the agency's goal is usually clear—perform the work with minimal traffic disruption. Many agencies and contractors are now using partnering arrangements to focus on project goals and to maintain open communication. The result is timely decision making that keeps construction moving, saves money, and reduces the chance that a problem will become a dispute.

3.4—Specifications

Small specification changes that expand the contractor's construction and equipment choices often result in significant time and cost savings while maintaining the quality of construction. Allowing the use of minimum clearance, slipform paving machines, dowel bar inserters, and early-age saws (See Section 3.5) are examples. Permitting more than one concrete mixture also will allow a contractor to meet different construction needs within a project.

End-result specifications provide the most freedom to the contractor. With end-result specifications, the contractor must provide a pavement meeting strength, slab thickness, and smoothness criteria. The agency does not closely control proportioning of the concrete mixture or the method of paving. Accelerated-concrete pavement construction automatically becomes a contractor option with end-result specifications.[13]

Providing a choice of concrete mixtures is a simple way of expanding contractor flexibility. Project specifications for accelerated-concrete paving might include a mixture for normal, moderate, and high-early-strength concrete. The contractor can choose from the different concrete mixtures to suit different construction situations and environmental conditions. For the majority of a large project, the choice would probably be the normal mixture. The contractor might decide to use high-early-strength concrete for the final batches each work day to ensure that sawing can be done before nightfall. The high-early-strength mixture also will ensure that the concrete at the construction joint (header) is strong enough for startup the following day. A mixture with a moderate rate of strength gain would be useful for areas where construction traffic enters and leaves the new slabs.

3.5—Innovative equipment

Recent improvements in paving equipment enhance their versatility in accelerated-concrete paving. Minimum-clearance slipform paving machines allow placement of concrete pavement adjacent to traffic lanes or other appurtenances. This allows single-lane reconstruction or resurfacing next to traffic on adjacent lanes or shoulders.

Baskets to support dowel bars at contraction joints are not needed when dowel bar inserters are used. The dowel insertion equipment mounts to a slipform paving machine and frees the construction lanes for concrete haul trucks and other construction vehicles. Tests of the modern dowel bar inserters show that their placement accuracy is as good as or better than that with traditional dowel baskets.[14]

Advancements in large-diameter (up to 1270 mm [50 in.]) coring equipment may reduce urban construction time. The new equipment can cut concrete around existing or planned manholes and eliminate the need to place utility boxouts before paving new streets. The coring equipment is also useful to cut around a manhole so it can be raised for an overlay.

CHAPTER 4—CONCRETE MATERIALS

4.1—Concrete mixture proportioning

One of the primary ways to decrease facility closure time is to use a concrete mixture that develops strength rapidly. Rapid strength gain is not limited to the use of special blended cements or sophisticated construction methods. It is usually possible to proportion such a mixture using locally available cements, admixtures, and aggregates.

Table 4.1—Example concrete mixture components for accelerated pavements[15]

Material	Type	Quantity
Cement	ASTM C 150 Type I	415 to 475 kg/m^3 (700 to 800 lb/yd^3)
	ASTM C 150 Type III	415 to 475 kg/m^3 (700 to 800 lb/yd^3)
Fly Ash	ASTM C 618	10 to 20% of cement by weight
Water-cementitious materials ratio		0.37 to 0.43
Air-entraining admixture	ASTM C 260	As necessary
Accelerating admixture	ASTM C 494	As necessary
Water-reducing admixture	ASTM C 494	As necessary

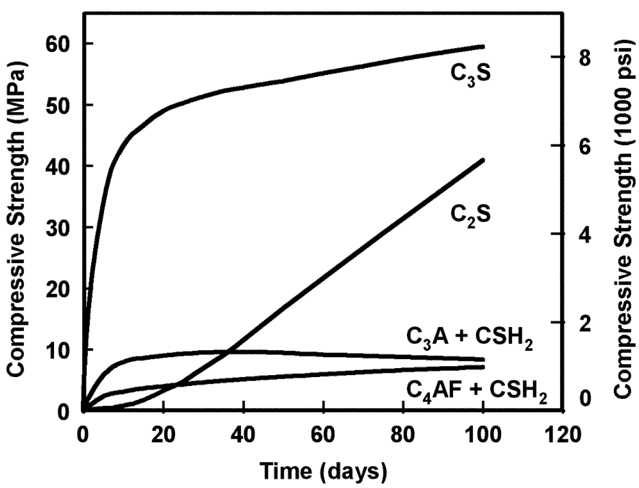

Fig. 4.1—Contribution of cement compounds to strength development.[18]

When proportioning concrete mixtures for accelerated paving, concrete technologists also should be aware of the additional influences of heat of hydration, aggregate size distribution, entrained air, concrete temperature, curing provisions, and ambient and subbase temperature. These factors may influence early and long-term concrete strength. Many different combinations of materials will result in rapid strength gain. Table 4.1 shows acceptable materials and proportions to achieve rapid early strength gain. A complete list and discussion of admixtures is provided in ASTM C 494.

A thorough laboratory investigation is important before specifying an accelerated paving mixture. The lab work should determine plastic and hardened concrete properties using project materials and should verify the compatibility of all chemically active ingredients in the mixture. Table 4.2 shows some factors that influence mixture properties and may aid mixture proportioning.

Generally, accelerated-concrete pavement will provide good durability. Most accelerated paving mixtures have entrained air and a relatively low water content that improves strength and decreases chloride permeability.[3] Freeze-thaw deterioration can occur if water freezes and expands within a concrete binder with a poor air-void distribution or if the concrete contains poor-quality aggregates. Properly cured concrete with an adequate air-void distribution resists water penetration and relieves pressures that develop in the binder.[3] Air-entrained concrete pavement is resistant to freeze-thaw deterioration even in the presence of deicing chemicals.

Table 4.2—Some factors that influence fresh and hardened mixture properties[3,16]

Fresh or hardened mixture property	Mixture proportioning or placement factor
Long-term strength	• Low water-cementitious materials ratio • Cement (composition and fineness) • Aggregate type • Entrained air content • Presence and type of admixtures • Concrete temperature • Curing method and duration
Early strength gain rate	• Cement type (Type III, etc.) • Water-cementitious materials ratio • Concrete temperature • Mixture materials temperature • Presence and type of admixtures • Curing method
Freeze-thaw durability	• Aggregate quality and grading • Entrained air (bubble size and spacing) • Water-cementitious materials ratio • Curing method and duration
Workability	• Aggregate particle shape • Combined aggregate grading • Total water content • Entrained air content • Presence and type of admixtures • Presence of pozzolans
Abrasion resistance	• Aggregate hardness • Compressive strength • Curing method and duration

4.2—Cement

ASTM C 150 Types I, II, or III portland cement can produce successful accelerated paving mixtures.[17] Certain ASTM C 595 portland/pozzolan cements and several proprietary cements that develop high early strengths may also be useful for accelerated paving applications.[4] Not every portland cement will gain strength rapidly, however, and testing is necessary to confirm the applicability of each cement.[18,19]

The speed of strength development is a result of the hydration and heat-generation characteristics of a particular combination of cement, pozzolan, and admixtures. Cements play a major role in both strength and heat development, and these properties depend on the interaction of the individual compounds that constitute the cement. High levels of tricalcium silicate (C_3S) and finely ground cement particles will usually result in rapid strength gain.[18] Tricalcium aluminate (C_3A) also can be a catalyst to enhance the rate of hydration of C_3S by releasing heat early during cement hydration. C_3A does not contribute much to long-term strength, and in general, C_3S is the major chemical contributor to both early and long-term strengths (Fig. 4.1).[18,19]

Finely ground cement increases surface area and allows more cement contact with mixing water and, consequently, the cement hydrates faster. Type III cement, which is much finer than other types of portland cement, usually develops strength quickly. Blaine fineness values for Type III cement range from about 500 to 600 m^2/kg. Blaine fineness values for Type I cement usually do not exceed 300 to 400 m^2/kg.[3,18]

Although the greater fineness of Type III cement provides a much greater surface area for the hydration reaction, it also may require more water to coat the particles. Because Type III cement is ground finer than other cements, however, there is more potential for problems that may result from overheating the cement during the grinding phase of manufacture, including false set. False set is a rapid stiffening of the concrete shortly after mixing. This is not a major problem, and it is possible to restore workability without damaging the normal set of the concrete through further mixing in a transit mixer.[18] The materials engineer and contractor should be aware of these phenomena when testing mixtures and trial batches. Tests should be conducted using the same cement that the contractor will use in construction.

A low water-cementitious material ratio (*w*/*cm*) contributes to low permeability and good durability.[18] A *w*/*cm* between 0.40 and 0.50 provides moderate chloride permeability for concrete made from conventional materials. A *w*/*cm* below 0.40 typically provides low chloride permeability.[20] Some accelerated-paving mixtures have a ratio less than 0.43 and, consequently, provide moderate to low permeability.

It is important to remember that durability is not a function of early strength but is a function of long-term strength, *w/cm* permeability, a proper air void system, and aggregate quality. Mixtures using these materials may appear to meet the quick strength development necessary for accelerated-concrete paving but may not provide adequate durability. Because of this inconsistency, a mixture should be evaluated at various ages to ensure it meets both early strength and long-term durability requirements.

Type III cement has been primarily used for the manufacture of precast concrete products. Before using a specific Type III cement in paving, it may be advisable for agency and contractor material technologists to confer with the cement supplier or local precast concrete manufacturers that are experienced with the cement. At least one state uses a minimum specimen strength for mortar cubes (ASTM C 109) to test Type III cement.[5] The cement must reach 9.0 MPa (1300 psi) in 12 hours to qualify for use in accelerated-concrete paving.

With proper proportioning, concretes using Type I and Type II portland cement also can produce adequate characteristics for accelerated-concrete paving. To develop adequate early strength, concrete made from these cements will usually require chemical admixtures.

4.3—Supplementary cementitious materials

4.3.1 *General*—It is possible to use fly ash or ground granulated blast-furnace slag in addition to portland cement in accelerated-concrete pavements. During cement hydration, these supplementary cementitious materials react with the chemical products of portland cement to extend strength gain. They also act as fine particle fillers in the binder to aid concrete workability and finishability.[3]

4.3.2 *Fly ash*—Two fly ash classifications, ASTM C 618 Class C and Class F, have been used in accelerated-concrete pavements. Class C fly ash has some cementitious properties that allow it to hydrate like cement. When compatible with portland cement, fly ash will also lower water demand, improve workability, and increase long-term strength.[3]

Although concrete employing Class C fly ash has been used on most accelerated paving projects, Class F also may produce acceptable results. Class F fly ash is generally not cementitious and can only react with the chemical products of portland cement hydration. Therefore, Class F fly ashes do not contribute much to the early strength of concrete. Class F fly ash can extend long-term strength, reduce permeability, and combat the deleterious effects of sulfates or alkalis.[3]

Evaluating accelerated-concrete pavement mixtures containing fly ash is important. The total weight of the fly ash and cement is used to determine the *w/cm* for mixture proportioning.[21] Strength tests should be made through a range of probable mixture temperatures to indicate how temperature influences rate of hydration. Knowledge of this temperature sensitivity will be useful to the inspector and contractor during construction under field conditions, particularly in the spring and fall. Accelerating admixtures will probably be necessary should the laboratory study show unacceptable strength gain with fly ash.

4.3.3 *Ground granulated blast-furnace slag*—Ground granulated blast-furnace slag is another cementitious material that might be acceptable in accelerated-concrete paving (ASTM C 989). In concrete, ground granulated blast-furnace slag can increase long-term strength and improve finishability.[3] Because its effects are temperature sensitive, however, laboratory studies are necessary to determine the optimal dosage rate and the effects of temperature on strength development. Strength development should be similar to normal concrete at temperatures around 21 C (70 F).[3] For cooler temperatures, it may be necessary to extend the curing and insulating period, or impose temperature and seasonal limitations.

4.4—Air-entraining admixtures

Air-entraining admixtures meeting ASTM C 260 requirements are used to entrain microscopic air bubbles in concrete. Entrained air improves concrete durability by reducing the adverse effects of freezing and thawing.[3,18,19] The volume of entrained air necessary for good durability varies according to the severity of the environment and the concrete's maximum aggregate size. Mixtures with larger coarse aggregates usually have less mortar and require less air than those with smaller maximum aggregate sizes. Typically, concrete mixtures have 4.5 to 7.5% total air content.

Air entrainment is as necessary for accelerated-concrete mixtures as for normal-setting mixtures in freeze-thaw environments. During field mixing, it is important to use the appropriate air-entraining admixture dosage rate so that the air content is adequate after placement. Higher percentages of entrained air can reduce the early and long-term strength of the mixture, while lower percentages may reduce the concrete durability. Therefore, close control of air content is necessary for successful projects.

Table 4.3—Water-reducing admixtures specified in ASTM C 494

Type and classification	Effect
Water reducer (Type A)	Reduces water demand by at least 5% Increases early- and later-age strength
Water reducer and retarder (Type D)	Reduces water demand by at least 5% Retards set Reduces early-age (12 h) strength Increases later-age strength
Water reducer and accelerator (Type E)	Reduces water demand by at least 5% Accelerates set Increases early- and later-age strengths
High-range water reducer (Type F)	Reduces water demand by at least 12% Increases early- and later-age strengths
High-range water reducer and retarder (Type G)	Reduces water demand by at least 12% Retards set Reduces early-age (12 h) strength Increases later-age strength

4.5—Water-reducing admixtures

Water-reducing admixtures reduce the quantity of water necessary in a concrete mixture or improve workability at a given water content.[3] Water-reducing admixtures increase early strength in accelerated-concrete paving mixtures by lowering the quantity of water required for appropriate concrete placement and finishing techniques. Water reducers disperse the cement, reducing the number of cement agglomerations.[18,19] More efficient and effective cement hydration occurs, thus increasing strength at all ages. Water reducers can be used to increase early concrete strength with any cement but are especially useful when using Type I cement in an accelerated-concrete paving mixture.

Table 4.3 lists five water-reducing admixtures covered by ASTM C 494. Water-reducing admixtures (Types A, E, and F) generally provide the necessary properties for accelerated-concrete paving. ASTM C 1017 also classifies certain high-range water-reducing admixtures as superplasticizers. Many available high-range water-reducing admixtures meet both ASTM C 494 and ASTM C 1017 requirements. While most water-reducing admixtures will work well with different portland cements, laboratory testing is essential to determine if a concrete containing the admixture will develop the desired properties. Excessive dosage of high-range water-reducing admixtures may lead to retardation of setting.

ASTM C 494 Type A admixtures are common in accelerated-concrete paving. Generally, a concrete containing a Type A water-reducing admixture will require from 5 to 10% less water than a similar mixture without the admixture. A Type D water-reducing, set-retarding admixture may be desirable when very high mixture temperatures induce an early set that preempts placing and finishing operations. Type D water reducers slightly retard the initial set to extend the period of good workability for placing and finishing. This retardation can also affect early strength gain, particularly during the first 12 hours. After 12 hours, the strength gain is similar to concrete containing a Type A water reducer. Concrete made with Type E, F, or G admixtures requires thorough laboratory evaluation to determine if the concrete properties are acceptable for anticipated environmental conditions and placement methods. Types F and G admixtures may be more appropriate for high-slump mixtures or when a lower *w/cm* is desired.

4.6—Accelerating admixtures

Accelerating admixtures aid strength development and reduce initial setting times by increasing the reaction rate of C_3A. Accelerating admixtures generally consist of soluble inorganic salts or soluble organic compounds and should meet requirements of ASTM C 494, Type C or Type E.

A common accelerator is calcium chloride ($CaCl_2$). Many agencies use $CaCl_2$ for full-depth and partial-depth concrete pavement patching when quick curing and opening to traffic is needed. The optimum dose is about 2% by weight of cement. This dose will approximately double the one-day strength of normal concrete.[5] It is very important to test both fresh and hardened concrete properties before specifying a mixture containing an accelerating admixture. With some aggregates, concrete will be susceptible to early freeze-thaw damage and scaling in the presence of $CaCl_2$. Another drawback of $CaCl_2$ is its corrosive effects on reinforcing steel. If the pavement requires any steel, it is advisable to select a nonchloride accelerator or an alternative method of achieving early strength.

4.7—Aggregate

Aggregates that comply with ASTM C 33 specifications are acceptable for use in accelerated-concrete pavements. Existing accelerated-paving projects made with concrete containing these aggregates have met their early-strength requirements and are providing good service. Further consideration of grading and aggregate particle shape may optimize early and long-term concrete strength. These factors also can have a significant influence on the plastic and hardened mixture properties and may warrant consideration for accelerated-concrete pavements.

Typical procedures consider the proportions of coarse and fine aggregates without specifying the combined or total grading. Consequently, concrete producers draw aggregate from two stockpiles at the plant site, one for coarse and one for fine material. To improve aggregate grading, additional intermediate sizes of material (blend sizes) at the plant site during project construction may be required.

4.7.1 *Grading*—Grading data indicate the relative composition of aggregate by particle size. Sieve analyses of source stockpiles are necessary to characterize the materials. The best use of such data is to calculate the individual proportions of each aggregate stockpile in the mixture to obtain the designed combined-aggregate grading. Well-graded mixtures generally have a uniform distribution of aggregates on each sieve. Gap-graded mixtures have a deficiency of aggregates retained on the 2.36 mm through 600 µm (No. 8 through 30) sieves.

An optimum combined-aggregate grading efficiently uses locally available materials to fill the major voids in the concrete to reduce the need for mortar. Particle shape and texture are important to the response of the concrete to vibration, especially in the intermediate sizes. A well-consolidated concrete mix-

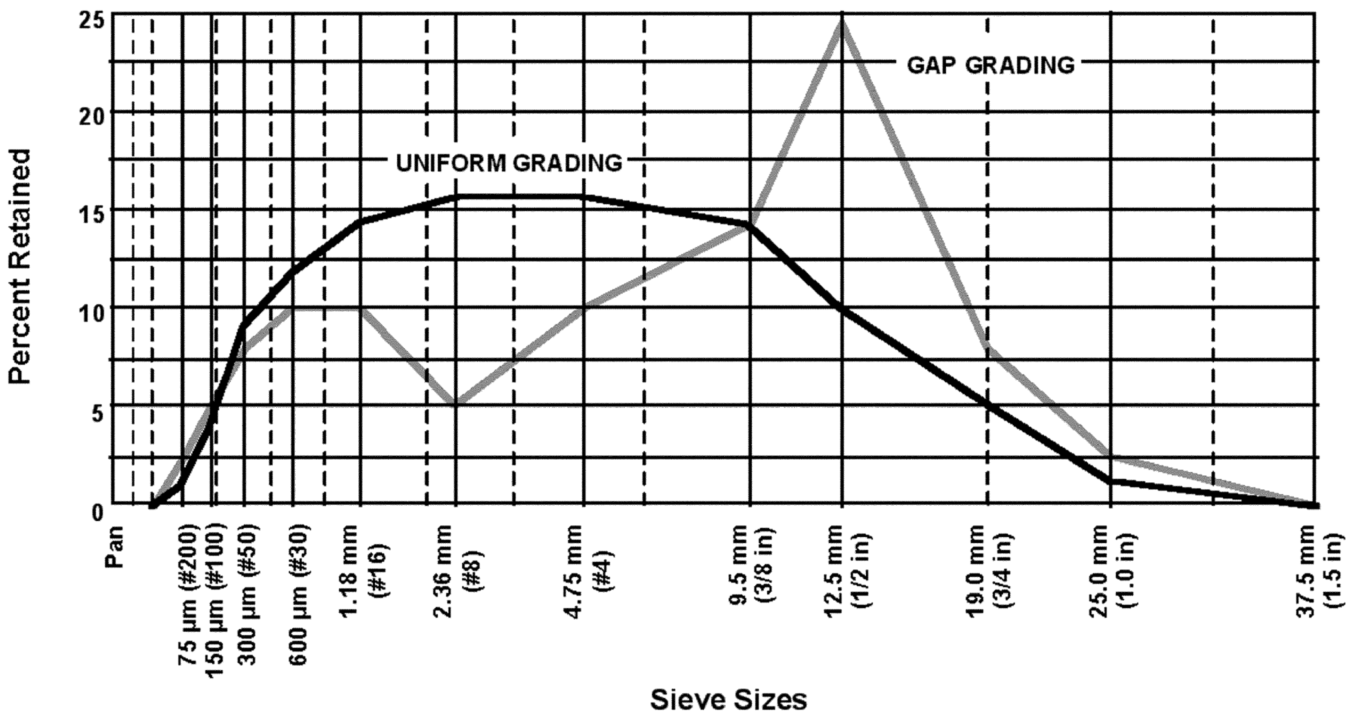

Fig. 4.2—Grading plot showing gap-graded mixture and mixture with adequate intermediate particles.

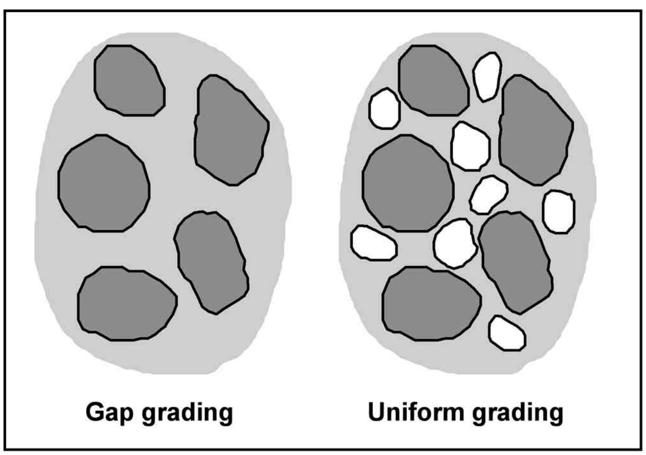

Fig. 4.3—Diagram showing how intermediate blend size aggregates fill spaces between larger, coarse aggregates.

ture with an optimum aggregate grading will produce dense and durable concrete without edge slump.

One approach to evaluate the combined-aggregate grading is to assess the percentage of aggregates retained on each sieve.[22] A grading that approaches the shape of a bell curve on a standard grading chart indicates an optimal distribution (Fig. 4.2). Blends that leave a deficiency in the 2.36 mm through 600 µm (No. 8 through No. 30) sieves are partially gap graded.

There is a definite relationship between aggregate grading and concrete strength, workability, and long-term durability.[3,14,22,23] Intermediate-size aggregates fill voids typically occupied by less dense cement paste and thereby optimize concrete density (Fig. 4.3). Increasing concrete density in this manner will result in:

- Reduced mixing water demand and improved strength because less mortar is necessary to fill space between aggregates;
- Increased durability through reduced avenues for water penetration in the hardened concrete;
- Better workability and mobility because large aggregate particles do not bind in contact with other large particles under the dynamics of finishing and vibration; and
- Less edge slump because of increased particle-to-particle contact.

Well-graded aggregates also influence workability and ease the placing, consolidating, and finishing of concrete. While engineers traditionally look at the slump test as a measure of workability, it does not necessarily reflect that characteristic of concrete. Slump evaluates only the fluidity of a single concrete batch and provides a relative measure of fluidity between separate concrete batches of the same mixture proportions.[3]

Concrete with a well-graded aggregate often will be much more workable at a low slump than a gap-graded mixture at a higher slump. A well-graded aggregate may change concrete slump by 90 mm (3-1/2 in.) over a similar gap-graded mixture. This is because approximately 320 to 385 kg/m^3 (540 to 650 lb/yd^3) less water is necessary to maintain mixture consistency than is necessary with gap grading.[21]

4.7.2 *Particle shape and texture*—The shape and texture of aggregate particles impact concrete properties.[3] Sharp and rough particles generally produce less-workable mixtures than rounded and smooth particles at the same *w/cm*.[3,21] The bond strength between aggregate and cement mortar improves as aggregate texture becomes rougher. The improved bond will improve concrete flexural strength.[3]

Natural coarse aggregates and natural sands are very mobile under vibration. Cube-shaped crushed aggregate is also more mobile under vibration than flat or elongated aggregate. The good mobility allows concrete to flow easily around the baskets, chairs, and reinforcing bars, and is ideal for pavements.

Flat or elongated intermediate and large aggregates can cause mixture problems.[3,14] These shapes generally require more mixing water or fine aggregate for workability and, consequently, result in a lower concrete flexural strength (unless more cementitious materials are added). Allowing no more than 15% flat or elongated aggregate by weight of the total aggregate[3] is advisable. Use ASTM D 4791 to determine the quantity of flat or elongated particles.

4.8—Water

The sooner the temperature of a mixture rises, the faster the mixture will develop strength. One way to raise the temperature of plastic concrete is to heat the mixing water; however, this is more practical for small projects that do not require a large quantity of concrete, such as intersection reconstruction.

Several factors influence the water temperature needed to produce a desirable mixture temperature at placement. The critical factors are ambient air temperature, aggregate temperatures, and aggregate free moisture content. When necessary, ready-mixed concrete producers heat water to 60 to 66 C (140 to 150 F) to elevate mixture temperature sufficiently for cool-weather construction. In such conditions, the use of blanket insulation is advised. To avoid a flash set of the cement, the hot water and aggregates should be combined before adding the cement when mixing batches.[3] See ACI 306R for additional guidance on controlling the initial concrete temperature.

Hot water only facilitates early hydration, and its benefits are generally short-lived. Several hours of heat containment through insulation may be necessary for rapid strength gain to continue, particularly when cool conditions prevail.

CHAPTER 5—CONSTRUCTION

5.1—General

No special equipment is necessary for a contractor to place accelerated-concrete pavement. Because the time for placement can be shorter than with conventional paving, however, accelerated paving requires well-planned construction sequencing. Contractors and specifying agencies should be aware that operation adjustments will be necessary while the paving crew becomes accustomed to mixture characteristics. It will take time for workers to become comfortable with accelerating their duties. Constructing test slabs will familiarize an inexperienced crew with the plastic properties of the accelerated-concrete before starting full-scale operations.

Contractors have built successful accelerated-concrete pavements using both slipform and fixed-form construction techniques. There are no reports indicating unusual problems with mixing, placing, and finishing accelerated-concrete paving. The contractor and agency should carefully consider concrete haul distances on large projects.

The adjustments that accompany construction start-up on accelerated projects for concrete pavement normally will not interfere with the ride quality. Contractors have built accelerated-paving projects to meet conventional ride specifications, and agencies should not modify their smoothness specifications for accelerated-concrete pavements.

5.2—Curing and temperature management

5.2.1 *Importance of curing*—Curing provisions are necessary to maintain a satisfactory moisture and temperature condition in concrete for a sufficient time to ensure proper hydration.[3] Internal concrete temperature and moisture directly influence both early and ultimate concrete properties. Therefore, applying curing provisions immediately after placing and finishing activities[3,24] is important. Even more so than with standard concrete, curing is necessary to retain the moisture and heat necessary for hydration during the early strength gain of accelerated-concrete pavement. Accelerated pavements require especially thorough curing protection in environmental conditions of high temperature, low humidity, high winds, or combinations of these.

Air temperature, wind, relative humidity, and sunlight influence concrete hydration and shrinkage. These factors may heat or cool concrete or draw moisture from exposed concrete surfaces. The subbase can be a heat sink that draws energy from the concrete in cold weather or a heat source that adds heat to the bottom of the slab during hot, sunny weather.

Monitoring heat development in the concrete enables the contractor to adjust curing measures to influence the rate of strength development, the window for sawing (see Section 5.3.1), and the potential for uncontrolled cracking. Monitoring temperature when environmental or curing conditions are unusual or weather changes are imminent is particularly important.[23] Maturity testing allows field measurement of concrete temperature and correlation to concrete strength. Chapter 6 describes maturity testing in more detail.

5.2.2 *Curing compounds*—Liquid membrane-forming curing compounds should meet ASTM C 309 material requirements. Typically, white-pigmented compound (Type 2, Class A) is applied to the surface and exposed edges of the concrete pavement. The materials create a seal that limits evaporation of mixing water and contributes to thorough cement hydration. The white color also reflects solar radiation during bright days to prevent excessive heat build up in the concrete surface. Class A liquid curing compounds are sufficient for accelerated-concrete paving under normal placement conditions when the application rate is sufficient.

Agencies that build concrete pavements in mountainous and arid climates often specify a slightly heavier dosage rate of resin-based curing compound meeting ASTM C 309, Type 2, Class B requirements. The harsher climate causes dramatic daily temperature changes, often at low humidity levels. As a result, the concrete is often more susceptible to plastic-shrinkage cracking and has a shorter window for joint sawing.

Most conventional paving specifications require an application rate around 5.0 m^2/L (200 ft^2/gal.). Accelerated-concrete pavement mixtures rapidly use mixing water during early hydration and this may lead to a larger potential for plastic shrinkage at the surface. Therefore, increasing the application of curing compound for accelerated paving

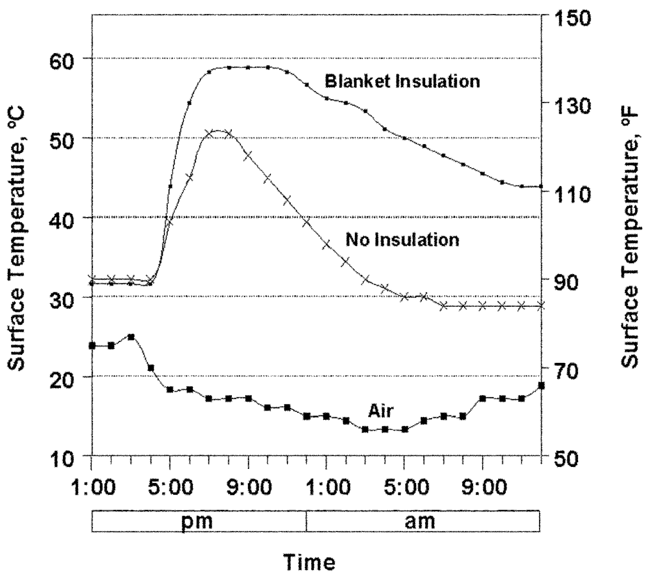

Fig. 5.1—Effectiveness of insulating blankets.

Table 5.1—Blanket use recommendations[24]

Minimum ambient air temperature in period	Opening time, h				
	8	16	24	36	48
<10 C (<50 F)	Yes	Yes	Yes	Yes	No
10 to 18 C (50 to 65 F)	Yes	Yes	Yes	No	No
18 to 27 C (65 to 80 F)	Yes	No	No	No	No
>27 C (>80 C)	No	No	No	No	No

projects to about 3.75 m^2/L (150 ft^2/gal.) is advisable. Because deep tining increases surface area, the higher application rate also is important where surface texture tine depth exceeds about 3 mm (1/8 in.). Bonded overlays less than 150 mm (6 in.) thick require an application rate of 2.5 m^2/L (100 ft^2/gal.). The thin overlay slabs have a large ratio of surface area to concrete volume so evaporation consumes proportionately more mixing water than with typical slabs.[25]

The first few hours, while the concrete is still semiplastic, are the most critical for good curing. Therefore, the contractor should apply the curing compound as soon as possible after final finishing. Construction and public vehicle tires may wear some of the compound off of the surface after opening, but this does not pose a problem because the concrete should have reasonable strength and durability by that time. Curing compound should be applied in two passes at 90 degrees to each other. This will ensure complete coverage and offset wind effects, especially for tined surfaces.

5.2.3 *Blanket insulation*—Insulating blankets provide a uniform temperature environment for the concrete. Insulating blankets reduce heat loss and dampen the effect of both air temperature and solar radiation on the pavement, but do not negate the need for a curing compound.[5] The purpose of blanket insulation is to aid early strength gain in cool ambient temperatures. Table 5.1 indicates when insulation is recommended.[24]

Care should be taken not to place blankets too soon after applying a curing compound. In warm conditions, waiting several hours and placing the blankets as the joint sawing

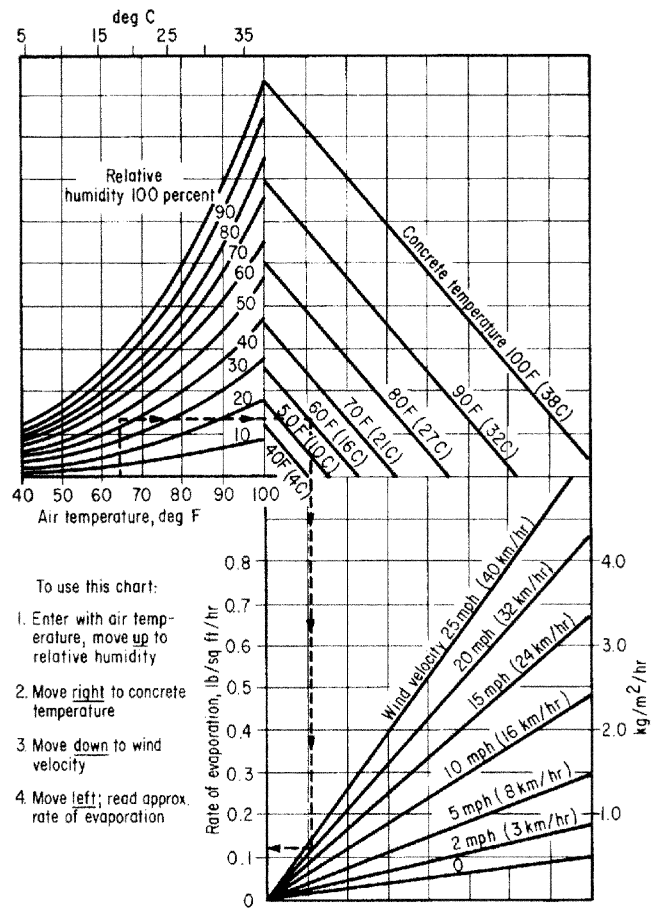

Fig. 5.2—Chart to calculate evaporation rate under prevailing environmental and concrete temperature conditions.[3]

progresses may be acceptable. In any case, it is inadvisable to wait until after finishing all joint sawing to start placing insulating blankets. Figure 5.1 shows how effective insulating blankets are in maintaining the temperature of concrete compared to an exposed surface of the same mixture.

Experience indicates that an insulating blanket with a minimum thermal resistance (R) rating of 0.035 $m^2 \cdot K/W$ (0.5 $h \cdot ft^2 \cdot F/Btu$) is adequate for most conditions.[5,21,24-27] The blanket should consist of a layer of closed-cell polystyrene foam with another protective layer of plastic film. Additional blankets may be necessary for temperatures below about 4 C (40 F).

5.2.4 *Plastic shrinkage*—The temperatures of accelerated-paving mixtures often exceed air temperature and require special attention to avoid plastic-shrinkage cracking. Plastic-shrinkage cracks can form during and after concrete placement when certain prevailing environmental conditions exist. The principal cause of plastic-shrinkage cracking is rapid evaporation of water from the slab surface.[3] When this occurs while concrete is in a plastic or semiplastic state, it will result in shrinkage at the surface. Air temperature, relative humidity, wind velocity, and concrete temperature influence the rate of evaporation. The tendency for rapid evaporation increases when concrete temperature exceeds air temperature.[24] Additional guidance on controlling plastic-shrinkage cracking is given in ACI 305R.