REMR TECHNICAL NOTE CS-MR-7.3

RAPID-HARDENING CEMENTS AND PATCHING MATERIAL

PURPOSE: To present the types of rapid-hardening cements and patching materials available for concrete repair and describe the use, properties, and placement of these materials for repairing concrete.

BACKGROUND: Highway and airfield pavements, bridge decks, marine structures and other concrete structures occasionally require repairs in order to keep them in service. One significant problem is the length of time that the use of the structure is interrupted if conventional concrete is used in the repairs. The length of interruption can be reduced by using nonconventional, rapid-hardening cements and cementitious patching materials. Numerous packaged patching materials that develop high early strengths are available from different suppliers. These are proprietary materials which are composed of certain types of rapid-hardening cements or blends of cement which may contain accelerators, fillers, and aggregates. They are specifically intended for use in small patches. Their high unit cost, rapid setting times, and possible high heat of evolution make them poorly suited for large-scale applications. However, rapid-hardening cements can be obtained in sacks or bulk for preparing concretes for large-scale applications.

SPECIFICATIONS: Very little guidance for selection, mixing, and placement of these types of cements and patching materials is available. A specification for packaged, dry, rapid-hardening materials for concrete repair is given in ASTM C 928-89 (Ref a). This specification requires that a very rapid-hardening material have a compressive strength of 1,000 psi in 3 hr and 3,000 psi in 24 hr. Other requirements are given for length change (wet and dry), slump or flow, and freeze-thaw resistance. If one uses these materials, it is recommended that he obtain guidance from the supplier before mixing and placing them.

A report (Ref b) on high performance concretes designates three categories based on strength: (a) very early strength, (b) high early strength, and (c) very high strength. Very early strength concretes have a strength of at least 3,000 psi within 4 hr after placement. High early strength concretes have a compressive strength of at least 5,000 psi within 24 hr. Very high strength concretes have a strength of 10,000 psi within 28 days. Most rapid-hardening cements discussed in this technical note meet the requirement of the very early strength concrete, except for the high alumina cements that would require 6 hr to obtain a compressive strength of 3,000 psi.

For additional information, see CM-PC-1.31, CM-PC-2.2, CM-PC-2.3, CM-PC-2.4, and CM-PC-2.5.

TYPES OF RAPID-HARDENING CEMENTS:

a. Magnesium-Phosphate Cement. This cementitious material is a blend of magnesium oxide (MgO) and ammonium dihydrogen phosphate

($NH_4H_2PO_4$). These ingredients react with water, rapidly producing strength and heat. This type of cement can obtain several thousand psi compressive strength in 1 hr. Most of these cements are available as packaged patching material, containing the cement, aggregate, filler, and other admixtures. Two types of magnesium-phosphate cement (MPC) patching materials are produced:

(1) Two-component system in which magnesia and fillers form the powder component and a measured quantity of aqueous phosphate solution, the liquid component. These two components are mixed together prior to its application.

(2) One-component system in which all the constituents are supplied in powder form and prepacked together. This system is mixed with gauging water prior to its use.

Four of the packaged patching materials were tested by the Waterways Experiment Station (WES). Three of the patching materials were one-component systems and the other was a two-component System. All of the materials contained fine aggregates and are considered MPC mortars. These materials can be extended with a coarse aggregate. The test results for these materials are shown in Table 1.

Table 1
Results of Tests on Magnesium PhosRhate Patching Materials

Property	MPC-1	MPC-2	MPC-3	MPC-4*
Compressive strength, psi				
1 hr	4,410	600	2,890	2,320
2 hr	5,970	2,570	3,940	4,010
3 hr	6,350	3,230	4,350	4,590
28 days	9,240	6,820	6,190	8,580
Bond strength, psi	2,250	210	1,500	4,340
Freeze-thaw durability	Fair	--	Excellent	--
Flexural strength, psi 28 days	1,010	650	1,090	1,160

* Two-component system.

Because of the relatively short working time of MPC mortar or concrete (10 to 20 min), the amount mixed should be limited by the placing and finishing time. All but one of the materials tested by WES had a self-leveling consistency and did not require vibration for consolidation. A study (Ref c) performed in Great Britain on the properties of an MPC-based material reported that the material expands slightly (0.01 to 0.02 percent) during the initial stage of hardening. It was also reported that the material can be applied in cold weather (20 °F) by adding an accelerator to the mixture or using mixing water heated to 100 °F. The performance of 14 concrete pavement repairs made with the MPC material was monitored over a 6-year period. All of the repairs, except one, was reported

to have performed satisfactorily. Personnel at WES have inspected some failures of MPC mortar and concrete patches on airfield pavements and concluded that the failures were the result of the following:

(a) The MPC patching materials were not extended with coarse aggregate. Most manufacturers recommend that their materials be extended with coarse aggregate when the patch is deeper than 1-1/2 in. The coarse aggregate reduces the exotherm which helps prevent thermal cracking.

(b) Mixing water was not accurately measured.

(c) A cold-weather formulation was used at temperatures above 80 °F. One manufacturer of MPC patching materials produces a hot- and cold-weather formulation. The hot-weather formulation is recommended for temperatures above 80 °F.

b. High Alumina Cement (HAC). The main ingredient of HAC is monocalcium aluminate ($CaO\text{-}A1_20_3$). This cement develops high early strengths; the 24-hr strength is equivalent to that of portland cement in 28 days. Tests were made years ago at WES to determine early strengths of mortar prepared from HAC. Two-inch cubes had compressive strengths of 7,020 psi in 18 hr, 8,380 psi in 3 days, and 9,020 psi in 7 days.

An HAC, Fondue, manufactured by Lafarge Fondu International was tested by WES in 1990. The compressive strengths of concrete prepared from this cement are given below:

Age	Compressive Strength, Psi
6 hr	3,010
24 hr	5,780
7 days	7,480

The initial set time of Fondue is reported to be 3 hr, which is longer than that of most rapid-hardening cements. This set time is beneficial for transportation of the mixed concrete. The set-ting time of HAC can be adjusted by adding portland cement. These mixtures can be used for a wide variety of jobs that require a rapid set: quick repairs, grouting, and plugging. All mixing equipment should be cleaned of portland cement before mixing HAC to avoid low setting times. Admixtures can be added to HAC con-crete mixtures to both retard and accelerate the concrete mixture. WES tested an HAC concrete mixture in which an accelerator (lithium carbonate) was added and a compressive strength of 5,000 psi was obtained in 2 hr.

HACs are more stable at high temperatures than ordinary portland cements. Fondue reports that their cements can withstand temperatures up to 3,000 °F. In the preparation of concrete made from HAC to resist high temperatures, selection of the correct aggregates is important because of expansion during the temperature changes.

A problem that exists for HAC is the conversion of the hydrated-calcium-aluminate compounds that occur over time, resulting in

higher permeability and loss in strength. Neville (Ref d) states that "conversion" takes place when the HAC concrete is subjected to moisture and temperatures 85 °F or higher.

c. Regulated-Set Portland Cement. Compared with to conventional portland cement, regulated-set cement contains a reduced proportion of dicalcium silicate and no tricalcium aluminate. It does contain a new ternary compound called calcium fluoroaluminate to produce very high early strengths and short set times. The only known source for this cement in the United States is Ideal Cement Industries, Saratoga, Arkansas.

The initial setting time for regulated-set portland cement is approximately 15 to 20 min. Citric acid can be used as a retarder to extend the setting time by as much as 1 hr. Obviously, early strength is affected by retarder usage. Handling times for different dosage rates of citric acid at 90 °F are given below:

Dosage Rate Citric Acid % Weight of Cement	Handling Time Minutes
0.2	20
0.3	29
0.4	44
0.5	64

A concrete mixture prepared from regulated-set portland cement was tested at WES. The test results are shown in Table 2. High early strengths (indicated by the compressive strength of 3,680 psi in 4 hr), high flexural strengths, and bond strengths were obtained from this concrete. The concrete surface resisted scaling during cycles of freezing and thawing.

Table 2
Test Results for Regulated-Set Portland Cement Concrete

Property	Test Result
Compressive strength, psi	
4 hr	3,680
6 hr	4,020
24 hr	5,670
7 days	6,630
28 days	7,650
Flexural strength, psi	
1 day	830
28 days	890
Bond strength to hardened concrete, psi (slant shear)	3,900
Scaling resistance to deicing chemicals, 25 cycles	Slight scaling, rating 1

The manufacturer of the cement reports that concretes made with regulated-set portland cement show greater expansion and weight loss during storage in sulfate solutions than concrete made with a Type I portland cement. The use of this type of cement in concrete is not recommended for concrete exposed to sulfate soils or water. Adequate freeze-thaw durability can be achieved by the use of air-entraining admixtures in the same manner as for other cements.

d. GYRsum Cements. Gypsum cements are essentially gypsum semihydrate ($CaSO_4 \cdot 1/2H20$), differing in granular shape and density and in additives. Compressive strength of 3,000 psi in 30 min is not unusual for this type of cement. The time of set and strengths of four gypsum cements from the same manufacturer are listed below:

	Cement	Water	Time of Set	30-min Strengths, psi	
Gypsum Cement	lb	lb	min	Flexural	Compressive
1	100	30	12-15	700	4,000
2	100	60	3-5	580	1,800
3	100	40	5	760	3,250
4	100	45	42	—	—

For the most part, concretes made with gypsum cements are not as durable as portland-cement concretes. They abrade easily, do not withstand frost action readily, and may be affected by fuel or solvent spills.

e. Special Blended Cements. There are many different types of blended cements available that develop high early strengths. Most are packaged as patching materials. Three cements tested by WES are Pyrament Blended Cement (PBC), Pyrament Blended Cement Extended Setting Time (PBC-XT), and Rapid Set Cement.

(1) Pyrament Blended Cements are manufactured by the Pyrament Division, Lone Star Industries, and can be obtained in 50-lb bags, super sacks (3,760 lb), or in bulk. The manufacturer states that the blended cement is a complete system requiring only the addition of aggregate and water. PBC-XT is the cement used for most applications since this cement has a longer setting time and can be transported in ready-mix trucks to the jobsite. WES started testing concrete made from PBC-XT in 1990 as part of the Construction Productivity Advancement Research (CPAR) Program. Some of the test results are shown in Table 3. Other tests in progress but not shown in Table 3 are workability, cold-weather applications, and resistance to sulfate attack, scaling, alkali reactivity, and chloride permeability. Results from these tests are available from WES.

(2) Rapid-Set Cement is a hydraulic cement used to make rapid strength-gaining concrete. The manufacturer, Rapid-Set Products, states that the chemical composition of the cement is similar to a Type K Shrinkage Compensating Cement that does not shrink or expand. The manufacturer states that the concrete mixture proportions should be the same as those used for portland-cement concrete except that Rapid-Set Cement be used. The mixing water should be adjusted to

Table 3
Test Results for PBC-XT Concrete

Property	Test Result
Compressive strength, psi	
4 hr	4,110
6 hr	4,900
24 hr	6,390
7 days	9,730
28 days	10,640
Flexural strength, psi	
4 hr	545
6 hr	690
24 hr	790
7 days	940
28 days	980
Resistance to freezing and thawing, 300 cycles, ASTM C 666, durability factor	96
Bond strength to hardened concrete slant shear, psi	3,960
Drying shrinkage, 56 days, %	0.03

obtain a slump of 6 ± 1 in. The use of an air-entraining admixture is recommended for areas subject to severe freezing and thawing. Concrete made with Rapid-Set Cement is mixed, placed, and finished the same way as conventional concrete, except that the concrete should be placed within 15 min after the addition of the mixing water. Concrete made with Rapid-Set Cement was tested at WES, and the results are shown in Table 4.

Table 4
Results of Tests on Rapid-Set Cement Concrete

Property	Test Result
Compressive strength, psi	
1 hr	2,140
3 hr	3,020
24 hr	3,850
28 days	5.560
Flexural strength, psi	
24 hr	540
28 days	1,110
Bond strength to hardened concrete, slant shear, psi	
24 hr	1,900
28 days	2,680

ACCELERATING ADMIXTURES: Many chemicals and combinations of chemicals have been observed to accelerate the set of cement mixes. Principal accelerators are as follows:

a. Gypsum

b. Calcium chloride

c. Calcium nitrite

d. Sodium, potassium or lithium carbonates

e. Sodium and potassium silicates

Many commercial accelerating admixtures which may contain the chemicals above or other chemicals not mentioned are available from different suppliers. Compressive strengths of 2,000 psi and greater were obtained in 6 hr from a concrete mixture containing Type III portland cement and a commercial accelerator (Ref e).

PACKAGED PATCHING 14ATERIALS: Numerous rapid-hardening patching materials are available from different suppliers. During one of the REMR studies, WES obtained some of these materials for testing and information on others. Guidance for mixing, placing, and curing of these materials should be obtained from the manufacturer. The compressive strengths, flexural strengths, and bond strengths of 13 different patching materials are shown in Table 5. Products 1 through 8 were tested at WES. The results for the other five products were taken from Gurjar and Carter (Ref f). The results of bond strength tests are lower than those reported by WES because of different surface preparations of the test specimens. WES sandblasted the surface, and the DOT used a wire brush.

Table 5
Results of Tests on Packaged Patching Materials

	Compressive Strength, psi				Flexural Strength, psi	Bond Strength, psi
Product Name	2 hr	4 hr	24 hr	28 days	28 days	28 days
1. Bonsal Rapid Patch		5,880	7,080		840	3,080
2. Gilco Highway Patch	3,220	3,790	5,160	7,960	900	3,810
3. Five Star Structural Concrete	3,730	4,360	5,120	7,620	930	2,610
4. Nitoflor Patchroc	5,120		5,410	6,380	680	2,080
5. Pyrament 505	2,610	3,850	6,120	12,180	840	3,560
6. Pyrament SAC PAC	1,310	2,180	3,680	7,280	700	3,500

(Continued)

Table 5 (Concluded)

Table 5
Results of Tests on Packaged Patching Materials

Product Name	Compressive Strength, psi 2 hr	4 hr	24 hr	28 days	Flexural Strength, psi 28 days	Bond Strength, psi 28 days
7. RoadPatch II	1,850			5,300	770	1,220
8. Sikaset Roadway Patch	1,310		5,520	6,520	880	3,380
9. Euco-Speed		1,840	4,990	8,700		1,840
10. Quick-Set		120	1,990	3,960		380
11 Set Instant		610	3,070	5,830		1,390
12.Speed Crete		200	2,030	3,340		350
13.Target Traffic Patch		2,940	5,180	10,270		1,870

REFERENCES:

a. American Society for Testing and Materials. 1989. "Standard Specification for Packaged, Dry, Rapid-Hardening Cementitious Materials for Concrete Repairs," Designation: C 928-89, Annual Book of ASTM Standards, Philadelphia, PA.

b. Zia, P., Leming, M. L., and Ahmad, S. H. 1991. "High Performance Concretes, a State-of-the-Art Report," Report No. SHRP-C/FR-91-103, Strategic Highway Research Program, National Research Program, Washington, DC.

c. Bayhass, El-Jazairi. 1987 (Jul). "The Properties of Magnesia Phosphate Cement Based Materials for Rapid Repair of Concrete," Proceedings of 3rd International Conference on Structural Faults and Repair, London.

d. Neville, A. 1975. "High Alumina Cement Concrete," Halsted Press, a Division of John Wiley and Sons, Inc., New York.

e. Frazier, P., Jr., and Shoemaker, W. E. 1991 (Feb). "PCC Pavements Patching Materials and Procedures," Journal of Materials in Civil Engineering, Vol 3, No. 1.

f. Gurjar, S., and Carter, P. 1987 (Mar). "Alberta Concrete Patch Evaluation Program," Report No. ABTR/RD/RR-87/05, Alberta Transportation and Utilities, Edmonton, Alberta, Canada.