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Porous portland cement concrete as an airport runway overlay
A laboratory evaluation

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A company recently introduced a special mixing method for producing stronger porous portland cement concrete than that made using standard mixing techniques. The process, which includes no admixtures, relies on a patented high-speed mixer to achieve the claimed results. The material, as designed by the company, was evaluated under laboratory conditions to determine its suitability for use as an overlay on concrete runways in the cold regions. Evaluations included strength, permeability and freeze–thaw tests. Concrete strength was improved whenever the high-speed mixer was used. However, the improvements were erratic, ranging from 2 to 37% stronger than the same concrete mixed using the standard technique. The mix design used by the company was fairly permeable to water but was not resistant to freezing and thawing when water was ponded on it. Further improvements are needed in both the consistency of strength and the resistance to frost of this material before it can be considered for cold regions applications.

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CONVERSION FACTORS: U.S. CUSTOMARY TO METRIC (SI) UNITS OF MEASURE

These conversion factors include all the significant digits given in the conversion tables in the ASTM *Metric Practice Guide* (E 380), which has been approved for use by the Department of Defense. Converted values should be rounded to have the same precision as the original (see E 380).

Multiply	by	To obtain
inch	25.4	millimeter
foot	0.3048	meter
foot^2	0.09290304	meter^2
foot^3	0.02831685	meter^3
pound (mass)	0.4535924	kilogram
pound force/inch^2	6894.757	pascal
ounce (U.S. fluid)	0.00002957353	meter^3
yard^3	0.7645549	meter^3
degrees Fahrenheit	$t_{°C} = (t_{°F}-32)/1.8$	degrees Celsius

Porous Portland Cement Concrete as an Airport Runway Overlay
A Laboratory Evaluation

CHARLES J. KORHONEN AND JOHN J. BAYER

INTRODUCTION

The loss of traction between tires and wet pavement poses serious problems at airports worldwide. For asphalt runways, grooving and porous overlays are two ways of improving traction to minimize hydroplaning. Regularly spaced grooves of sufficient depth allow water to escape laterally from beneath a tire, while porous overlays permit water to escape laterally and vertically from a tire. The main drawback to both methods is the tendency of asphalt to compact under repeated wheel loadings and to clog with debris, which gradually reintroduces the likelihood of hydroplaning.

For concrete runways, grooving has been the accepted means of reducing hydroplaning and improving the skid resistance for many years (Narrow 1970). Little consideration has been given to using Porous Portland Cement Concrete (PPCC) overlays primarily because they have not been thought of as being able to withstand airport traffic or wintertime conditions. However, even though newly grooved concrete effectively reduces hydroplaning, the grooves eventually wear down. Thus, as with asphalt runways, the need for periodic maintenance adds expense, inconvenience and a certain amount of uncertainty to managing airports.

Recently, CTC* introduced a patented mixing process that reportedly improves the properties of PPCC beyond that previously thought possible. CTC claims that the new process improves

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* Concrete Technology Corporation, 3916 State Street, Suite 300, Santa Barbara, California 93105. Formerly, Triad America Services Corporation, Salt Lake City, Utah, and before that Transaqua, Inc., Provo, Utah.

strengths economically enough to where PPCC could be used as an overlay for runways. Further, the material is supposed to bond very tightly to existing concrete without bonding agents, can be placed in as thin as 1-in. layers and has a high permeability. CTC believes that its PPCC can be used in all types of paving construction, including airport runways, making it an attractive alternative to grooving.

CRREL was asked by the Federal Aviation Administration (FAA) to investigate the feasibility of using this material as an overlay for concrete runways in the cold regions. Since CTC had done the initial mix design and strength tests, we decided to concentrate on determining the ability of this material to withstand winter conditions. It was acknowledged that a comprehensive evaluation should include both laboratory and field exposure tests. This report describes laboratory freeze–thaw durability, strength and permeability tests of this specially mixed concrete.

BACKGROUND

Prior to conducting the laboratory tests, CTC engineers were interviewed to learn of the advances that they had made with this product (Korhonen 1985).

The interesting aspect of this new process is that no admixtures are used to develop the reported strength gains. The company's PPCC is a no-fines concrete composed of type I cement, 3/8-in. aggregate and water (Fig. 1). The elimination of sand is supposed to yield up to a 20% savings in material and handling costs. Mix proportions were developed by CTC to achieve a

a. 3/8-in. aggregate.

b. End view of PPCC.

Figure 1. Porous Portland Cement Concrete (PPCC) consists of cement, aggregate and water.

full covering of the aggregate with cement paste, without the paste falling off the aggregate during handling and placement. The small, single-sized aggregate was choosen to produce a concrete with a relatively smooth surface and a high drainage rate.

The answer to the strength increase is said to be in the manner with which the concrete is mixed. Mixing is accomplished in two stages. First, the water and cement are mixed at high speeds, much like in a food processor, and then combined with the aggregate in a standard ro-

a. Batch plant produces about 35 yd³/hr.

tary drum mixer. The result is a no-slump concrete. A prototype batch plant, consisting of the two mixers and a conveyor belt to transfer fresh concrete to a waiting truck, is shown in Figure 2. The plant was reported to be capable of producing 1 yd³ of concrete in 1 minute, 45 seconds. Larger plants could be built if needed, according to CTC.

Because the batch plant produces a very stiff concrete, something other than standard concrete placing techniques needed to be developed. As was true with the high-speed mixer, patented equipment was fabricated to handle the paving. The company modified a slip form paver to do this. It consists of a conveyor belt to feed material from a dump truck to a screw auger within a collection hopper. The hopper is mechanically elevated and dropped repeatedly to place and consolidate the concrete as the paver moves forward. A vibrating plate is then dragged across the concrete to further consolidate it and to smooth the surface (Fig. 3). In 1985, a 12- by 10-ft by 5-in. pavement section was placed in 1 minute, 40 seconds. The company estimated then that 40,000 ft² of paving was possible in one day.

Although the PPCC strengths reported for this mixing process appeared impressive, CTC

b. Discharge conveyor belt.

Figure 2. Batch plant. It consists of a high-speed mixer, rotary drum mixer and discharge conveyor belt.

a. Truck feeds front of paver.
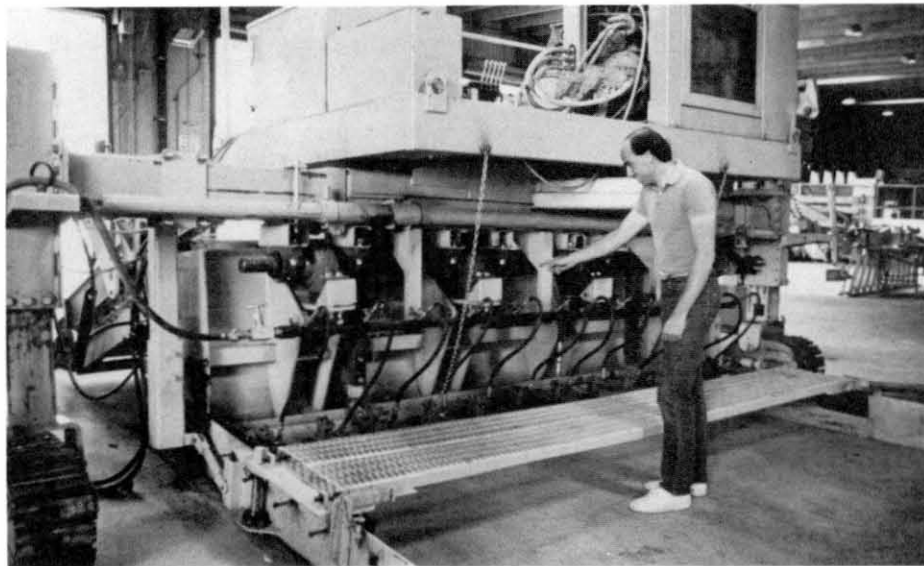
b. Air pressure runs vibrating plate at rear of paver.

Figure 3. Modified slip-form paver.

had no direct strength comparisions at the time of the interview to show the strength improvements with the high-speed mixer. (Strength comparisions were made in subsequent years.) In 1985, CTC reported compressive strengths of 3700 lb/in.^{2} at a water–cement ratio (W/C) of 0.4 for its PPCC. That has been increased to strengths in excess of 4000 lb/in.^{2} by lowering the W/C to 0.3 and by making other unspecified mix process-design refinements. When compared to PPCC strengths produced by others, CTC's results look good. Monahan (1981) reports that for aggregate similarly sized to that used by CTC and with a 0.3 W/C ratio, strengths slightly

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in excess of 2000 lb/in.[2] were possible for PPCC mixed by conventional means. By way of another comparison, CTC found that dense concrete, when produced with the high-speed mixer, had 20–37% more strength than conventionally mixed dense concrete of the same mix design. Both of these comparisons point to high-speed mixing as having a positive effect on strengths.

Up to 1985 most of the work by CTC was confined to the laboratory. Their main effort was directed toward developing mix designs that optimize strength and permeability parameters. Little cold regions field experience was available other than with a few 1-year-old test sections on a parking lot in Utah. Some laboratory freeze–thaw tests were initiated in 1985 but were delayed indefinitely because of equipment failure. Other investigations, some using electron microscopes, were also just beginning at that time.

The parking lot sections, although small, provided an indication of this material's potential cold weather use. The fact that the sections survived one winter without deterioration was encouraging (freeze–thaw cycles were not recorded). Also, despite being in an extremely dusty area, the 1-year-old sections drained freely when a pail of water was poured on them. This speaks well of PPCC's chance of remaining unclogged over time when used on runways, which normally are not so dusty. It is expected that the touch-down area would still get clogged from tire rubber as it does on runways made of other materials. No experience or testing was available to indicate how well PPCC would withstand contaminants such as fuel and de-icers.

CRREL TEST PROGRAM

Our main objective was to test the resistance of the PPCC mixed at high speed to repeated cycles of freezing and thawing. The American Society for Testing and Materials (ASTM 1984) recommends that concrete be subjected to 300 rapid freeze–thaw cycles unless there are reasons for other limits. We felt that, because the open structure of the PPCC would allow free ingress of water into a sample, deterioration would occur rapidly if it occurred at all. Thus, we decided that the concrete would be subjected to 100 freeze–thaw cycles in a damp condition as a minimum measure of frost resistance, rather than the 300 freeze–thaw cycles recommended by ASTM. The time to conduct an individual freeze–thaw cycle

also differed. Home-type chest freezers were the most convenient method to handle the many samples that needed testing, so, because of their minimal cooling capacity, the resulting freeze–thaw cycles were not rapid. This was not considered to be a problem in the validity of the results but only to be an inconvenience in that the tests would require additional time to conduct. We felt that the best way to evaluate frost resistance would be to compare test results of the porous concrete to that of air-entrained dense concrete. We were also interested in strength comparisons between porous and dense concrete made with each mixing technique, and in the porous concrete drainage rates.

To fabricate the high-speed samples for testing, two engineers from CTC traveled to CRREL with a portable high-speed mixer. CRREL provided a 4-ft^3 rotary drum mixer to combine the aggregate and the paste from the high-speed mixer to make both porous and dense samples. The drum mixer was used to make dense concrete as control samples for comparison to the high-speed samples. The two mixers are shown in Figure 4.

Materials

Type I portland cement was purchased in 94-lb bags and used for all the samples tested in this investigation. The fine aggregate and the other aggregate were obtained from a source near CRREL. It had a saturated surface dry (ssd) specific gravity of 2.68 and a water absorption of 1.0%. The coarse aggregate had a specific gravity of 2.90 (ssd) and a water absorption of 2.0%. The 3/8-in. aggregate had a specific gravity of 1.65 (ssd) and a water absorption of 1.8%. Typical sieve analysis results of these aggregates are presented Table 1. The mixing water was obtained from CRREL's water lines.

Mixing process

As mentioned above, both porous and dense concrete samples were made for testing.

The mixing process for the Conventional (drum-mixed) Dense (CD) samples followed standard laboratory procedures. The coarse and fine aggregate plus about two-thirds of the water were mixed for approximately 1 minute in the drum mixer before the cement, remaining water and admixtures were added. The mixing continued for about 3 minutes, stopped for 3 minutes and then continued for an additional 2 minutes before samples were cast.

Figure 4. High-speed mixer (left) and drum mixer. Arrow shows where the mixed water and cement are drawn off.

Table 1. Sieve analyses.

Sieve opening (mm)	Sieve no.	Percent retained	Percent passing
a. Fine aggregate			
2.00	10	12.1	87.9
0.84	20	36.6	51.2
0.42	40	31.5	19.8
0.177	80	16.3	3.5
0.074	200	2.7	0.8
b. Coarse aggregate			
19.1	3/4	10.0	90.0
12.7	1/2	64.8	25.2
9.52	3/8	17.9	7.4
6.35	3	6.7	0.7
4.76	4	0.4	0.2
c. 3/8-in. aggregate.			
6.35	3	30.2	69.8
4.76	4	31.8	38.0
2.00	10	36.2	1.9
0.84	20	0.4	1.5
0.42	40	0.1	1.4
0.149	80	0.2	1.2
0.074	200	0.4	0.8

The Conventional dense samples with Air-entrainment (CA) followed the CD procedure after an Air-Entraining Admixture (AEA) was added to the mix water.

For the High-speed Dense (HD) samples, batching procedures differed somewhat. Water and admixtures were added into the top of the high-speed mixer (Fig. 5) and spun while the cement was being added. After a few minutes, the water–cement slurry was drawn off the bottom and added to the drum mixer, which was already loaded with the fine and coarse aggregate. Mixing then continued for about 3 minutes more. Air was not added to this mix.

The High-speed Porous (HP) concrete was batched similarly to the HD concrete described above. Water and cement were mixed in the high-speed mixer and then combined with the 3/8-in. aggregate in the drum mixer.

The Conventional Porous (CP) concrete was made by mixing the 3/8-in. aggregate and two-thirds of the water in the drum mixer. Then the cement and the rest of the water were added. Mixing times followed those for the CD samples.

Mix design and samples
The mix designs were patterned after a standard mix from a ready-mix plant near CRREL.
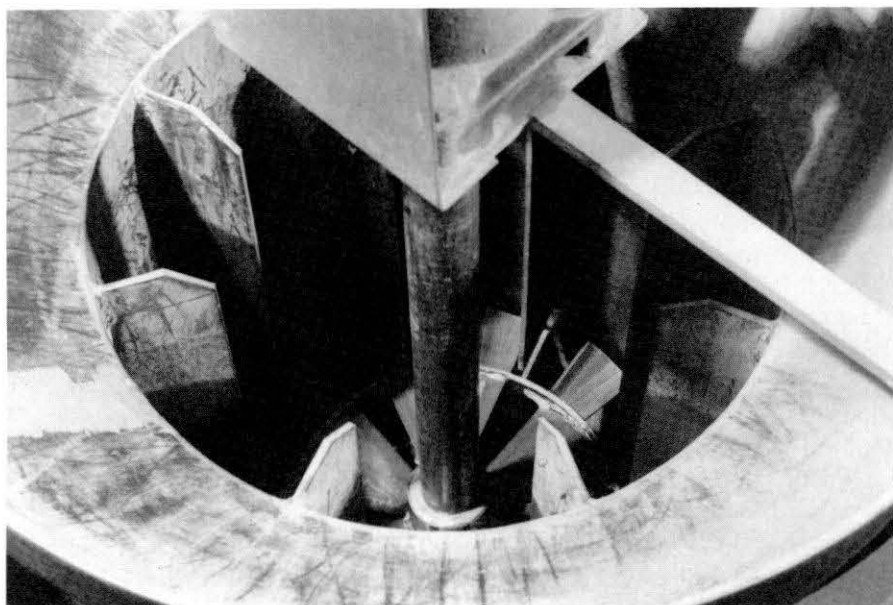
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Figure 5. High-speed mixing process. Water and cement are placed into the top of the high-speed mixer and drawn off from the bottom (see arrow in Fig. 4).

Table 2. Mix proportions.

Ingredient	Unit	Ready-mix plant	HP[a]	HD[b]	CP[c]	CD[d]	CA[e]
				Concrete type			
Cement	lb	611	48.00	38.50	21.0	38.50	45.25
Water	lb	299	13.35	18.50	5.87	19.25	21.25
W/C		0.49	0.28	0.48	0.28	0.50	0.47
Fine aggregate	lb	1440	—	84.75	—	83.75	99.75
Coarse aggregate	lb	1800	—	110.75	—	111.00	130.75
3/8-in. aggregate	lb	—	239.75	—	104.25	—	—
WRDA[f]	oz	18.5	—	1.15	—	1.15	1.36
AEA[g]	oz	1.0	—	—	—	—	0.076
Yield	ft^3	27.5	2.3	1.7	1.0	1.70	2.0

a - High-speed mixed porous concrete.
b - High-speed mixed dense concrete.
c - Conventional drum-mixed porous concrete.
d - Conventional drum-mixed dense concrete.
e - Conventional drum-mixed dense concrete with AEA.
f - Water reducing agent, oz/100 lb cement.
g - Air-entraining agent, oz/100 lb cement.

Table 2 presents the ready-mix design as well as the mixes used for this study.

Samples of two different sizes were fabricated for testing. Prisms of 3 by 3 by 15 in. were made using steel molds, while cylinders of 4 by 8 in. were cast in plastic molds. The PPCC was consolidated in three layers in the molds by tamping with a 2 by 2-in. blunt-ended tool rather than the standard 5/8-in.-diameter, rounded-end rod used for dense concrete. After casting, the samples were stored at room temperature in their molds and covered with plastic for 24 hours. Then they were removed from the molds and stored in a 80°F room with 50% relative humidi-

ty for 45 days and further cured in a 80°F saturated-lime water bath (ASTM 1981) for 7 days. The exceptions to this were the compression samples, which were broken at 7, 14 and 28 days.

Test methods

The prism and cylinder samples were subjected to three types of freeze–thaw conditions:
1. Freeze in air and thaw in air (air–air).
2. Freeze in air and thaw in water (air–water).
3. Freeze in water and thaw in water (water–water).

In each condition the core temperature of each sample was alternately lowered from 40 to 0°F and raised from 0 to 40°F to complete one freeze–thaw cycle. Figure 6 shows a typical temperature history for each test condition based on thermocouple measurements of control samples.

The air–air test was chosen to determine if the discontinuous structure of the PPCC might be affected by repeated expansion and contraction cy-

Figure 6. Freeze–thaw cycle times.

cles caused by freezing and thawing in a dry state. In this test the samples were placed in a chest-type, 21-ft^3 freezer and allowed to freeze (the same type of freezer was used for all freeze–thaw tests). The samples were thawed by manually turning off the freezer and opening its lid to expose them to room air. No water was introduced during either the freezing or the thawing cycle. It took about 24 hours to complete one air–air freeze–thaw cycle.

The air–water test simulated the condition of freezing following a heavy rain on a well-crowned runway. This test was conducted in the same manner as the air–air test, except that 45°F tap water flooded the freezing chamber during the thaw cycle. Warmer water was added to maintain a 30–40°F temperature difference between the core and exterior surface of each sample.

Because of water absorbed by the concrete, about 46 hours were required to complete one cycle of this test.

The water–water test, considered to be the most severe test, simulated a runway covered by ponded water. In this test the samples were placed into water-filled plastic containers that were a few inches larger than the samples themselves. The containers were placed in a freezer and conditions followed those of the air–water test. The free water in the containers increased cycle times to about 196 hours.

We tested for frost damage by periodically measuring pulse velocities through the prism samples, by compressively loading the cylindrical samples to failure and by recording weight changes of the prisms. Pulse velocity tests were chosen because they can be very effective at detecting internal cracks in concrete. The principle upon which they operate is quite simple. A pulse of vibrations is transmitted into one side of a concrete sample and is received at the opposite side. The time required for each pulse to travel a known distance yields the velocity. Compared to concrete, air is a very poor transmitter of these vibrations. Therefore, any air-filled crack or void should cause the pulse velocity time to increase. Moisture can cause pulse times to decrease by allowing vibrations to more freely propagate through cracks and voids. Thus, cracks caused by freezing and thawing should decrease pulse velocities, provided moisture contents remain stable.

The instrument used for the velocity tests was the V-meter made by James Electronic, Inc., Chi-
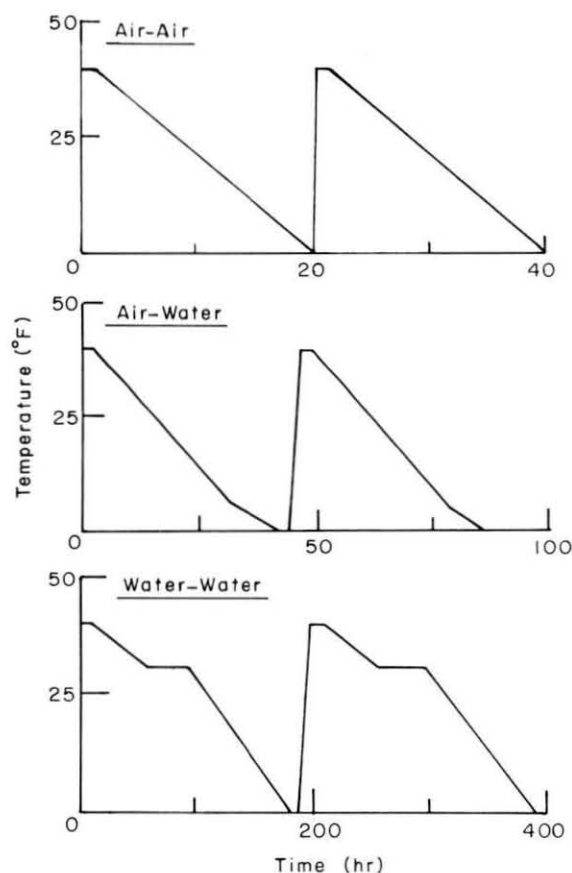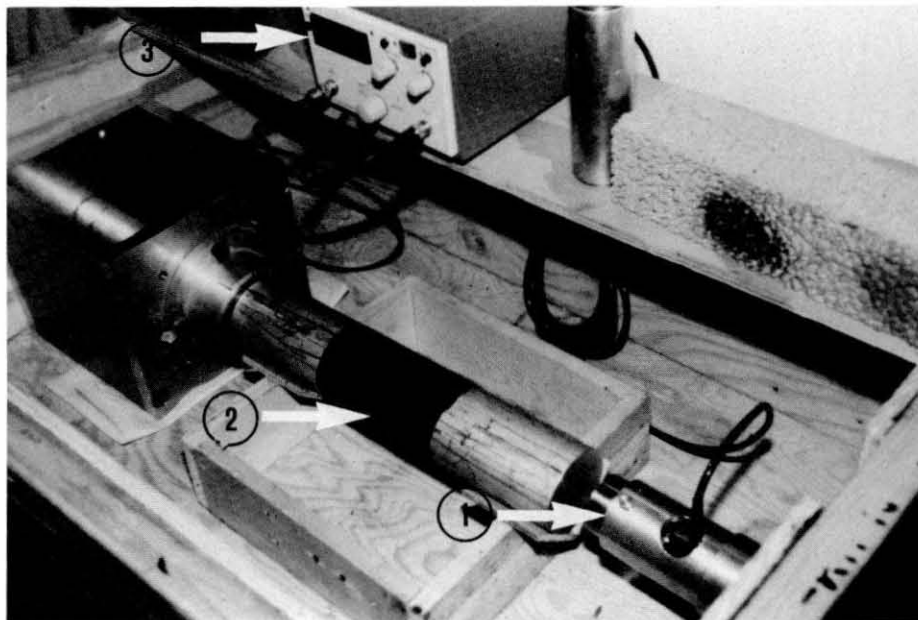
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Figure 7. Holding device for velocity tests (1 - transducer, 2 - sample, 3 - readout).

cago, Illinois. It consists of two transducers, one for transmitting and the other for receiving, each 1.97 in. in diameter by 1.65 in. long, with a resonant frequency of 54,000 cycles per second. In order for results to be reproducible, the manufacturer recommends that the transducers be placed in the same acoustical contact with a given sample time after time. To accomplish this, we devised a stand to hold the sample and the transducers in the same position for each round of tests. An air-driven piston applied a 20-lb load to the transducers to assure proper contact each time readings were taken (Fig. 7).

Weight changes in the prisms and compressive strengths of the cylinders were the two other methods of monitoring frost damage. Any significant loss of either one could be an indication of frost damage. Of course, small weight increases can occur because of absorption of water into newly formed cracks.

Other tests were conducted to better define some of the properties of high-speed mixed concrete. One test's purpose was to determine the effect that the high-speed mixer has on concrete strengths and why. For this test several cylinders of each type of concrete was mixed and tested for compressive strength at various ages. A scanning electron microscope* was then used to examine pieces of concrete from each mix process to see if there were any differences between their microstructures. In another test, permeabilities were measured to determine the drainage rates of PPCC. And finally, where applicable, freshly mixed concrete was tested for slump and air content (Table 3).

RESULTS AND DISCUSSION

Air–air frost resistance

The pulse velocities, compressive strengths and weight changes for all test conditions are shown in Figures 8–10. Figure 8 represents samples subjected to freezing and thawing in air. As can be seen, the recorded values were stable throughout the testing period, ending at essentially the same value at the 138th freeze–thaw cy-

Table 3. Properties of fresh concrete.

Concrete	Slump (in.)	Percent air
HD	6	4.4
CD	8	4.9
CA	8-1/4	5.6

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* Personal communication with Susan Taylor, CRREL, 1987.

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a. Compressive strength.

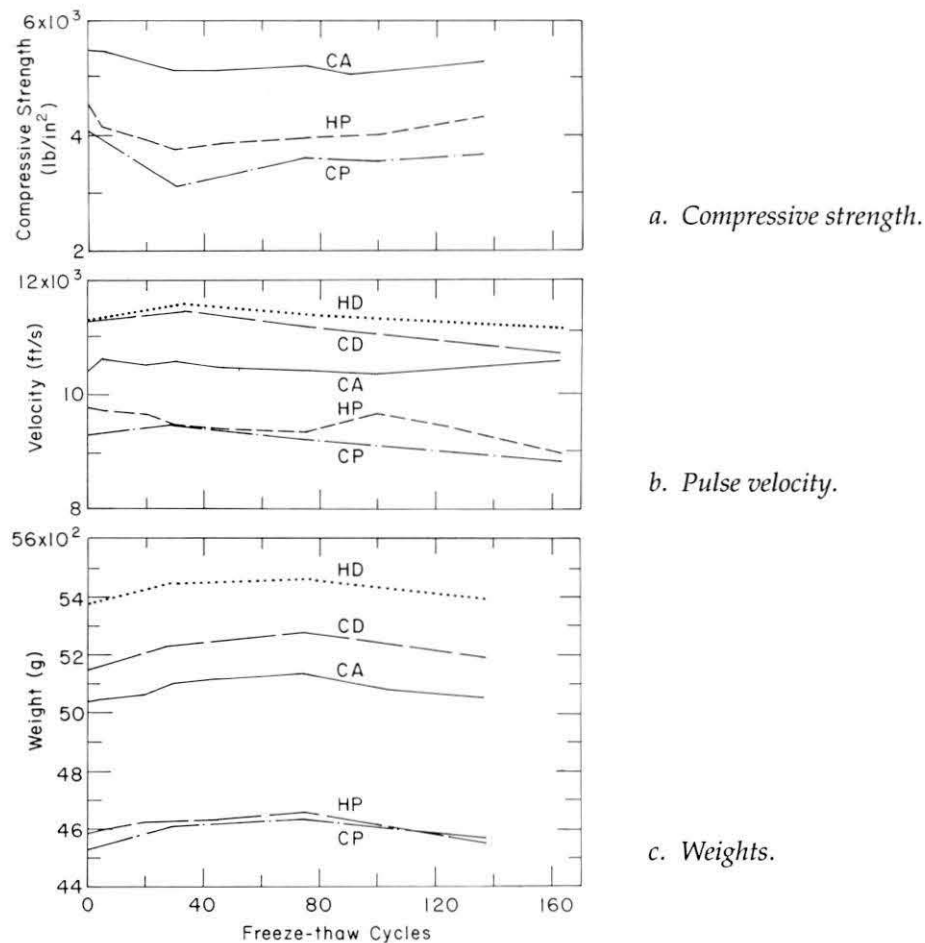*b. Pulse velocity.*

c. Weights.

Figure 8. Air–air freeze–thaw test results.

cle (163 for velocity samples) as that at the beginning. Therefore, none of the concrete appears to be affected by mere changes in temperature, which is not surprising.

The important thing demonstrated here was that our test setup for pulse velocity readings was reproducible. The velocity transducers and test samples were held in the same relation to each other and did not affect test readings.

Air–water frost resistance

The results for samples subjected to 163 cycles of freezing in air and thawing in water are presented in Figure 9. The pulse velocity results varied considerably more than did the strengths or weights. The reason for this is thought to be slight variations in moisture content of the samples. Although we exercised care to test each

sample at precisely the same time after it was removed from the thaw water, that was not always possible. As a result, we believe that moisture contents varied enough, particularly at the velocity transducer/sample interface, to affect the readings. The one consistency among the velocity results was a decrease in pulse velocity near the end of the test. This trend, however, is not considered to be an indication of frost damage because the CA samples, which are frost durable, behaved in the same manner. Thus, based on our earlier criteria of surviving 100 freeze–thaw cycles, all samples passed the minimum test for frost resistance in a damp condition. Thought was given to extending this test but the poor results of the water–water test (discussed next) convinced us otherwise.
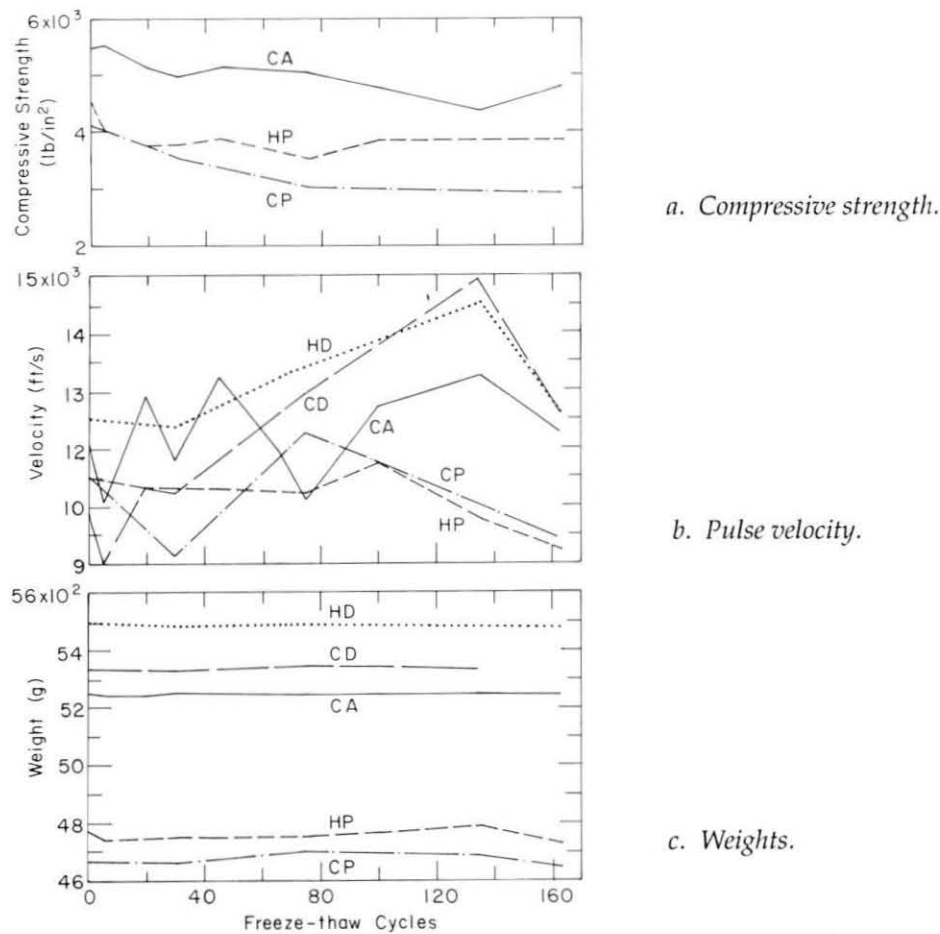
10

a. Compressive strength.

b. Pulse velocity.

c. Weights.

Figure 9. Air–water freeze–thaw test results.

Water–water frost resistance

Figure 10 presents the results for samples frozen and thawed 80 times in water-filled containers. In this test both the CP and HP failed quickly. Failure was clearly evident at the 45th cycle by the manner in which the samples broke when squeezed in compression. Prior to this test sequence, all samples broke into a few large pieces. But, at the 45th cycle, the porous samples broke into many small pieces and by the 80th cycle the porous samples literally crumbled (Fig. 11). What's interesting is that none of the samples showed visible signs of deterioration before load testing. Figure 10a shows that the CP and HP concretes lost 11 and 21%, respectively, of their strength by the 45th freeze–thaw cycle and about 37 and 38% of their strength by the end of the test. In comparison, the CA concrete lost only 7% of its strength over the 80 freeze–thaw cycles.

Also, no changes were noticeable in the manner with which the CA samples broke in compression. The weight results (Fig. 10c) remained stable for all samples, which confirms the lack of physical signs of deterioration just mentioned. The velocity readings (Fig. 10b) increased for all except the CP samples, which dropped sharply. It is not clear why the HP samples did not exhibit a similar loss in velocity as they failed in the same manner as the CP samples. The dramatic loss in velocity readings for the CP concrete indicates the presence of internal cracks.

From this test it can be concluded that CP and HP concrete are not resistant to slow freezing and thawing cycles in a saturated condition.

Strength gain

Since determining strengths was not of primary concern, we relied on CTC test results and

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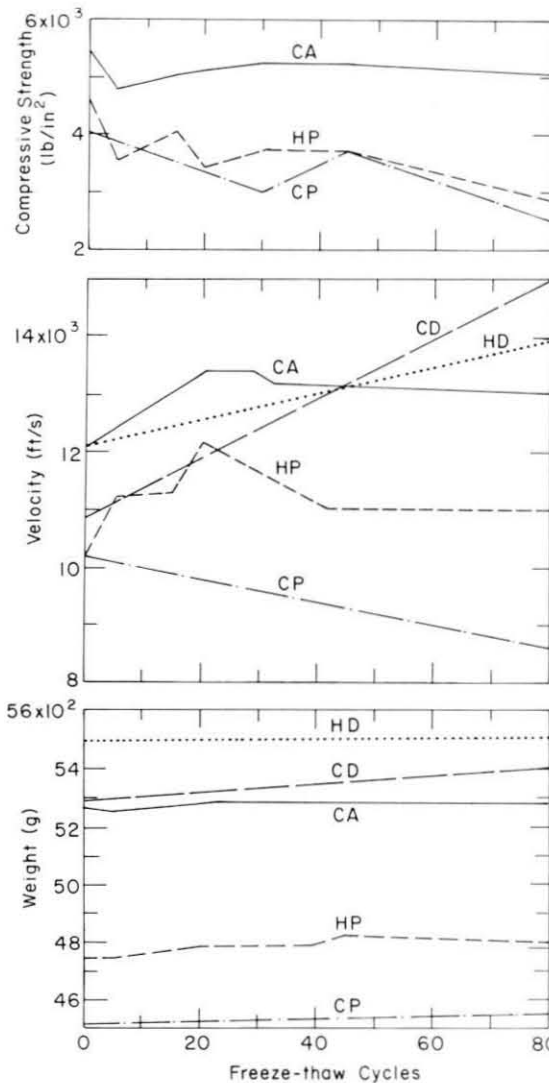
a. *Compressive strength.*

b. *Pulse velocity.*

c. *Weights.*

Figure 10. Water–water freeze–thaw test results.

provided only a few check comparisons of our own. The strengths of primary concern when designing runways are compressive and flexural strengths.

CTC tests indicate that the high-speed mixer has produced dense concrete up to 37% stronger than conventionally mixed dense concrete. More recent studies by Harding (1986) show that strengths with the high-speed mixer are not always that much higher. In one test he showed only a 7% strength increase for high-speed mixed versus conventionally mixed dense concrete. Similar results were also reported for porous concretes. He showed that the high-speed mixer improved the strengths of porous concrete 13 to 37%.

Our tests also showed some variability. In one instance HD concrete was only 2% stronger than CD (Fig. 12). We are not entirely sure why this happened but, as discussed below, variations in mixing times may have been one cause. The unexpected results give a sense of unpredictability. The majority of our tests (Table 4), however, agree with those of CTC in that the concrete mixed at high speed can be stronger. Table 4 shows that high-speed mixing increased strengths of both porous and dense concrete by 11%.
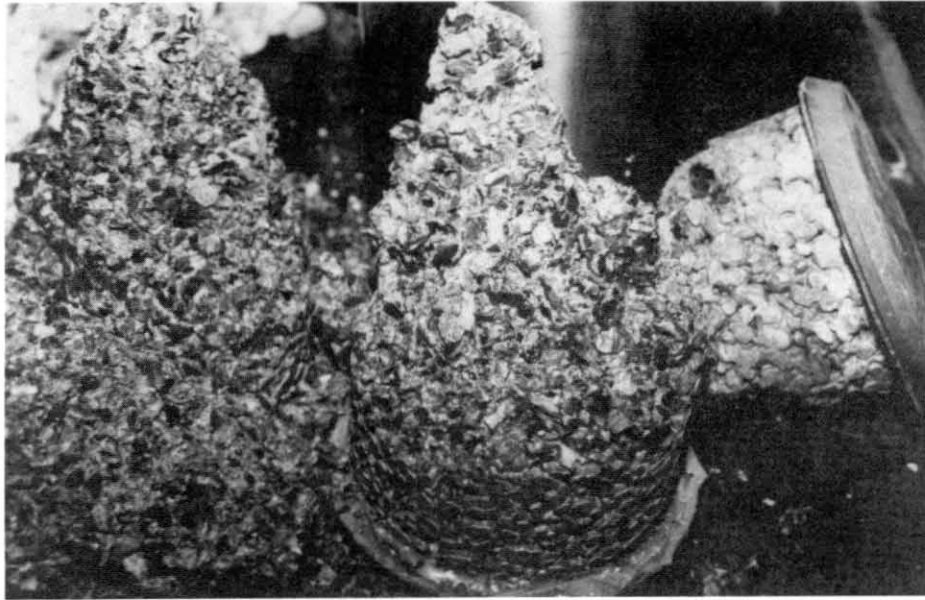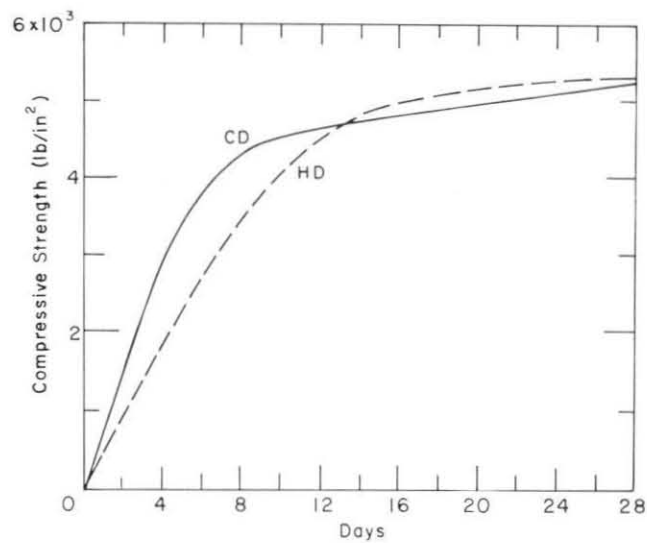
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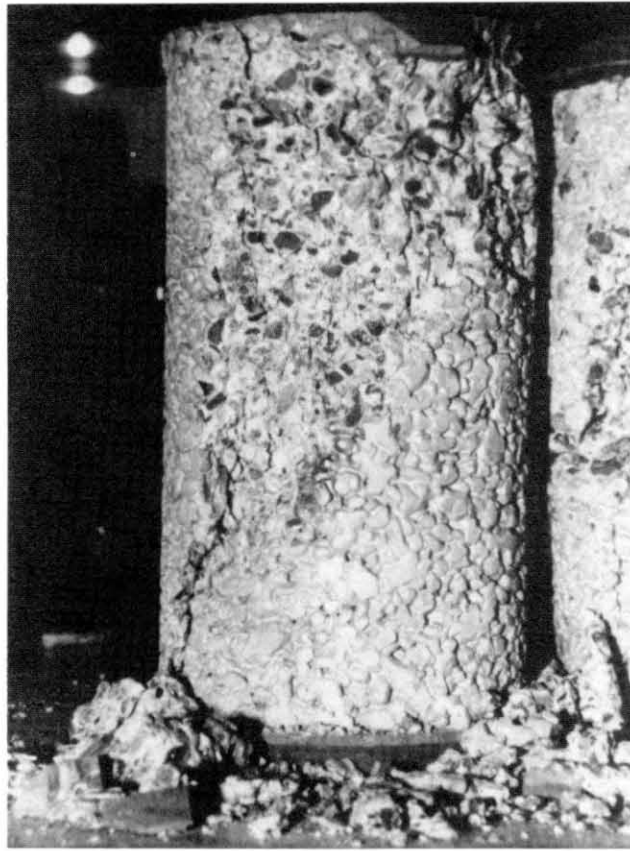
a. 10 freeze–thaw cycles.
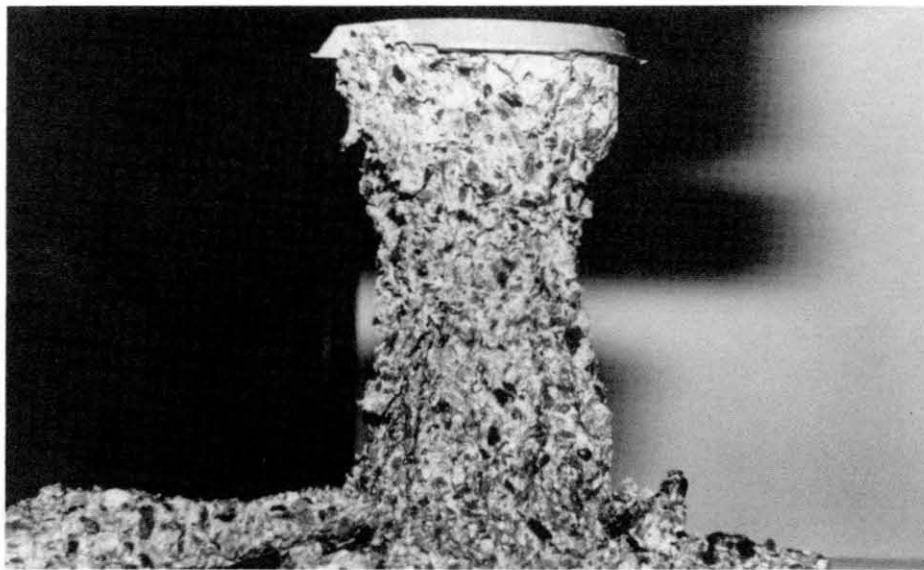
b. 45 freeze–thaw cycles.

Figure 11. Freeze–thaw damage. It became evident at the 45th freeze–thaw cycle when the porous samples crumbled in compression.

c. 80 freeze–thaw cycles.

Figure 11 (cont'd). Freeze–thaw damage. It became evident at the 45th freeze–thaw cycle when the porous samples crumbled in compression.

Figure 12. Comparison of strength gain for high-speed and drum-mixed dense concrete.

Table 4. Strengths of dense and porous concrete made with high-speed and conventional mixes.

| Type	Strength (lb/in.²)	Age (day)	Percent increase
HD	6040	28	11.0
CD	5443	28	—
HP	4570	56	11.0
CP	4117	56	—

Flexural strength tests done by CTC indicate that their PPCC is reasonably strong. Mass (1987) reports flexural strengths for two 6- by 6- by 21-in. beams in third-point loading to be 417 and 574 lb/in.² at 7 and 28 days of age respectively. The compressive strengths of cylinders for the same mix were 3699 and 4232 lb/in.²; according to the American Concrete Institute (ACI 1985), flexural strengths of 456 and 487 lb/in.² can be expected in conventional dense concrete with the same compressive strengths. Thus, the flexural strengths for the porous concrete shown above compare favorably with dense concrete. We did not conduct flexural tests of our own.

Microstructure

Pieces of CD and HD concrete were examined under a scanning electron microscope, at 300x magnification, to determine if there was a difference between the two hardened cement pastes. We did this because CTC showed in their work that there can be a big difference between the two concretes.

Sadowski (1986) shows that the air voids of a HD concrete were loaded with plate-like crystals, while the air voids of a CD concrete had fewer and smaller crystals in them (Fig. 13). This difference in crystal structure is thought to be an indication of the relative degree of hydration that has taken place in each concrete. Normally, cement does not fully hydrate because of a coating (gel) that forms around each cement particle during hydration. Unless these coatings are broken up, water cannot always reach the center of the cement particles and hydration is inhibited. The separate mixing of cement and water in the high-speed mixer is said to result in a more complete wetting of the cement, which in turn
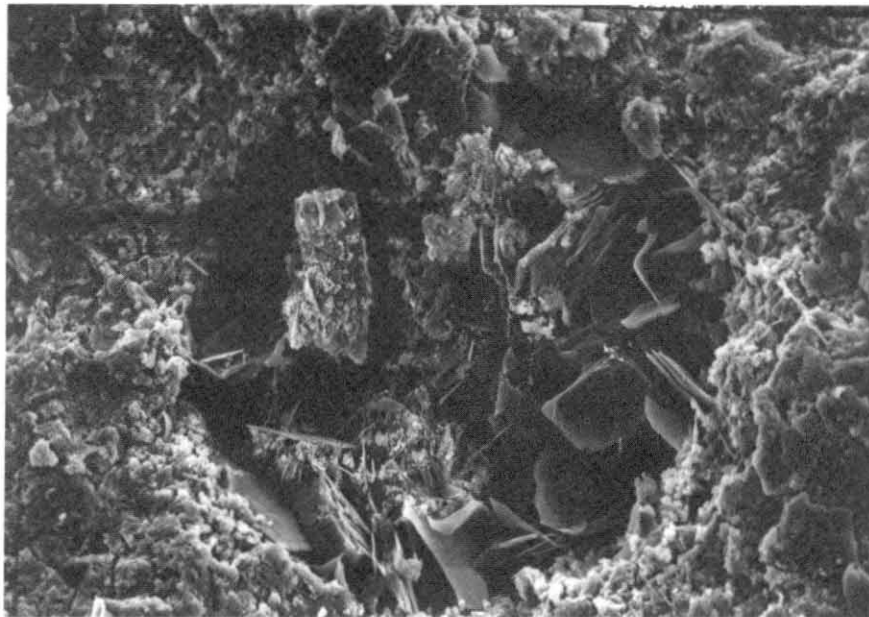
a. HD concrete, x450 magnification. Note the platy structure.

Figure 13. Microstructure of high-speed and conventionally mixed concrete by CTC (photos courtesy of S. Sadowski, CTC Corp.).
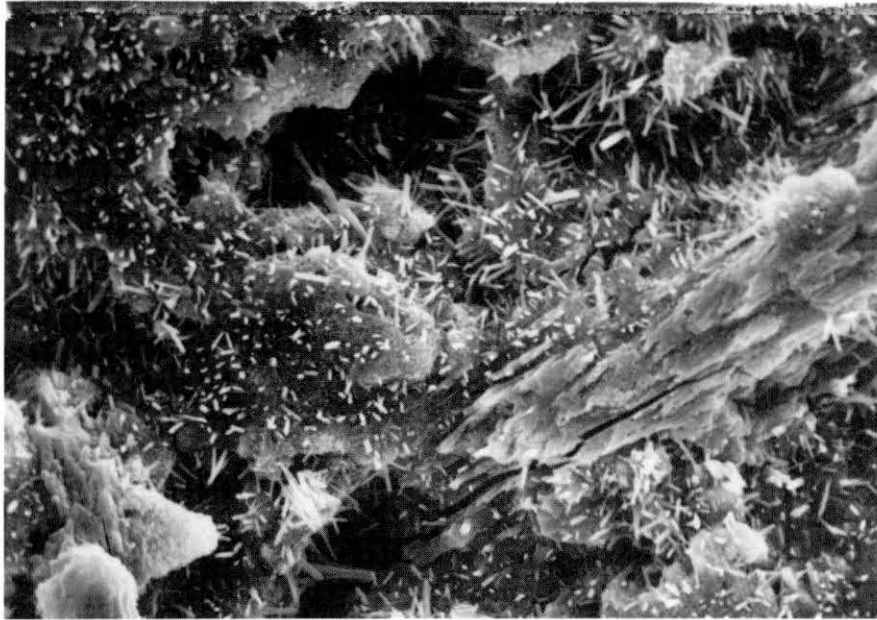
b. CD concrete, x2000 magnification. Note the small fibrous structure.

Figure 13 (cont'd). Microstructure of high-speed and conventionally mixed concrete by CTC (photos courtesy of S. Sadowski, CTC Corp.).

allows a more complete hydration (better crystal growth) and a stronger concrete.

Our examination did not show such a marked difference between the two concretes made at CRREL. In fact, crystal growth was just barely noticeable in the HD concrete and essentially nonexistant in the CD concrete (Fig. 14). Based on the above explanation of crystal growth, the absense of well-defined crystals in our concrete suggests that cement hydration was not as complete here as it was for Sadowski. This is somewhat confirmed by strength tests, as our HD concrete was only 11% stronger than the CD concrete, whereas CTC has reported up to a 37% improvement. It could be that mixing was not as complete at CRREL. Mixing times did not appear to be well controlled. For the CRREL samples, the only control on mixing time was to manually turn off the high-speed mixer after an estimated amount of time. Better control over mix times should yield more consistant results.

The scanning electron microscope also showed that the HD concrete had fewer air voids than the CD concrete (CTC also notes this). This is confirmed by the lower air content and slump measurements for HD concrete in Table 3 (slumps are lower because there is less air to act as a lubricant). Concrete strength is related only to the solid part of the paste; air voids have no strength. Thus, by producing denser concrete, the high-speed mixer promotes strength by entrapping less air in addition to improving the cement's hydration. The effect that this loss of air has on durability is not clear at this time.
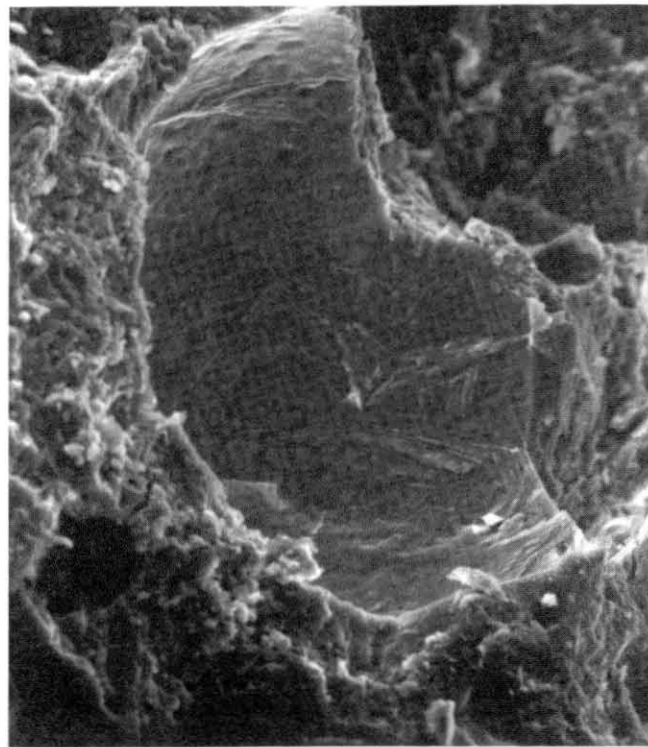
Permeability

The ability of water to quickly flow through this material (Fig. 15) is an important factor in preventing hydroplaning. Flow rates are usually determined in situ by measuring the flow of water into a pavement over a period of time. White (1976) indicates that the minimum desired flow rate for porous pavements is about 19 in./min. We determined the flow rate of water through a sample of PPCC by using a device similar to the one described by White (Fig. 16). The time for a 10-in. head of water to fall 5 in. yielded a permeability ranging from 8 to 11 in./min. Based on White's criteria, the HP mix design is not permeable enough.

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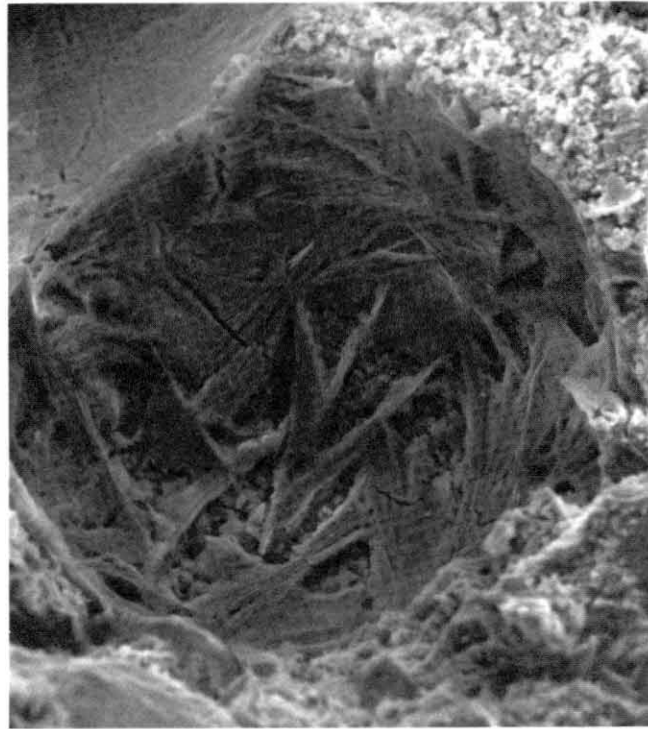
a. HD concrete, x300 magnification. Some crystal growth.

b. CD concrete, x300 magnification. Very little crystal growth.

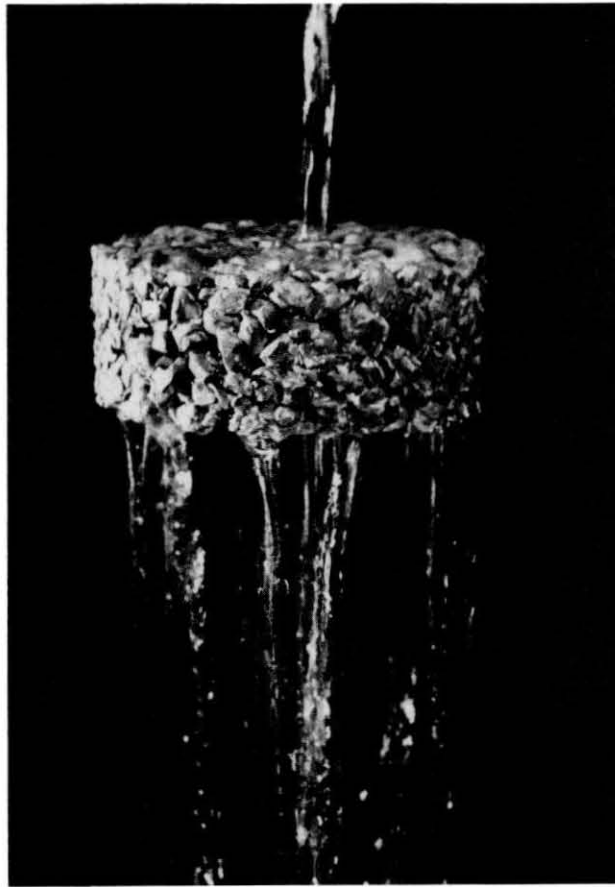*Figure 14. Microstructure of two CRREL samples.*

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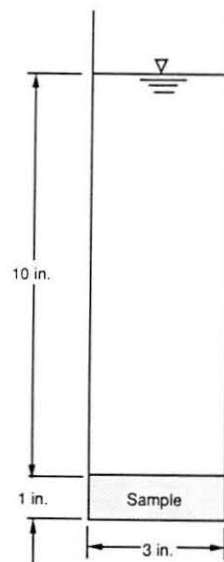*Figure 15. Free-draining nature of PPCC.*

Figure 16. Permeability device.

CONCLUSIONS

Concrete strengths can be improved by using the new high-speed mixer. The mixer appears to do this in two ways: 1) by achieving a more complete wetting, and thus better hydration, of the cement and 2) by increasing the density of the concrete by entrapping less air. Although the high-speed mixer has been documented in its ability to produce higher strengths, such improvements are not always the case. Strength improvements with the high-speed mixer have varied from 2 to 37%. With a relatively strong mix, tests show PPCC to be essentially as strong as conventional dense concrete when loaded in bending. If high strengths can be reliably produced, then PPCC might become an economical alternative to grooving concrete. However, additional work is needed to assure more reliable strength results and to define economic advantages.

For use as an overlay in the cold regions, freeze–thaw durability is a major concern. CRREL tests show that both the conventional and the high-speed mixed porous concretes are somewhat resistant to freezing and thawing in a damp condition but not in a ponded condition. The PPCC survived over 160 freeze–thaw cycles while being damp, but it failed within 45 freeze–thaw cycles while submerged in water. Because melting snow is likely to pond, this material, as currently designed, is not considered to be durable enough for use in the cold regions.

As an overlay in any climate, it is important that the PPCC be relatively free-draining to minimize hydroplaning. The drainage rate of the HP concrete was measured to be about 8–11 in./min. Compared to the reported minimum value of 19 in./min, this material is unsatisfactory in that respect.

NEEDED RESEARCH

More work is needed to improve the frost durability and permeability of this PPCC before we undertake cold regions field tests. These laboratory tests point to high-speed mixed PPCC as a possible cold regions airport runway overlay only *if* improvements can be made. Work must be done to:

1. Develop a method or procedure to produce-high speed PPCC with repeatable high-strength results.

2. Improve the freeze–thaw durability of the PPCC. Experiment with air-entraining agents and other techniques to improve freeze–thaw durability, particularly under conditions where water ponds.

3. Explore technologies, other than the patented process studied here, to improve porous concrete's cold regions performance. For example, experiment with conventionally mixed porous concrete. In our tests its strength was close to that of the high-speed porous concrete. Perhaps small amounts of sand or other aggregate sizes may prove useful. Roller-compacted concrete technology may provide another method of placing PPCC.

4. Develop a cold regions demonstration site to determine how well the PPCC stands up to wheel loadings, snow removal operations and deicers and other contaminants on a long term basis, after items 1–3 are satisfied.

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