NORTH DAKOTA
DEPARTMENT OF TRANSPORTATION

MATERIALS AND RESEARCH DIVISION

Experimental Study MR 97-01

Practice of Unsealed Joints in New Portland Cement Concrete Pavements

Final Evaluation Report

January 2009

Prepared by

NORTH DAKOTA DEPARTMENT OF TRANSPORTATION
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Written by

Curt Dunn/Bryon Fuchs/Kyle Evert

Disclaimer

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Practice of Unsealed Joints in New Jointed Concrete Pavements

Objective

The practice of not sealing joints in new Portland Cement Concrete (PCC) pavements is not new. Several state agencies have experimented with unsealed joints and have had positive results.

Currently, new construction of PCC pavements incorporates the use of an underlying permeable base course equipped with edge drains. The purpose of the permeable base course and edge drains is to intercept and drain unwanted moisture that has entered the base through the pavement surface. If the surface moisture has an immediate outlet there should be no need to seal the joints.

Sealing joints has not been a cost effective measure for NDDOT because the sealants have been proven to fail shortly after construction. Substantial savings can be incurred by eliminating the sealant and the second sawing process that goes with sealing.

The objective of this study is to determine if joint sealants are necessary for the performance and longevity of the pavement structure.

Scope

Since 1997, the North Dakota Department of Transportation (NDDOT) has included unsealed joint test sections on several new PCC paving projects.

NDDOT will evaluate the unsealed joint test sections every other year for approximately 10 years. Items that will be monitored and evaluated are:

- Distress at the joints.
- Ride.
- The amount of non-compressible material in the joints.

- If the incompressible material is being filtered through the joint into the drainage system.

Location

In 1997 two PCC paving projects included unsealed joint test sections. They are as follows:

- IM-6-029(027)161 - I-29 from ND 54 north to near Jct 17 (SB)
  STA 9167+20 to STA 9187+20
- IM-2-094(007)256 - I-94 near the City of Jamestown (WB)
  STA 240+00 to STA 260+00

In 1998 two other PCC paving projects included unsealed joints. They are as follows:

- IM-5-094(008)071 - I-94 from Gladstone to Taylor (EB)
  STA 4032+02 to STA 4060+37
- IM-8-029(025)053 - I-29 from the Wild Rice River to 32nd Avenue (SB)
  STA 3042+40 to STA 3062+40

Figure 1 shows the locations of the unsealed joints.

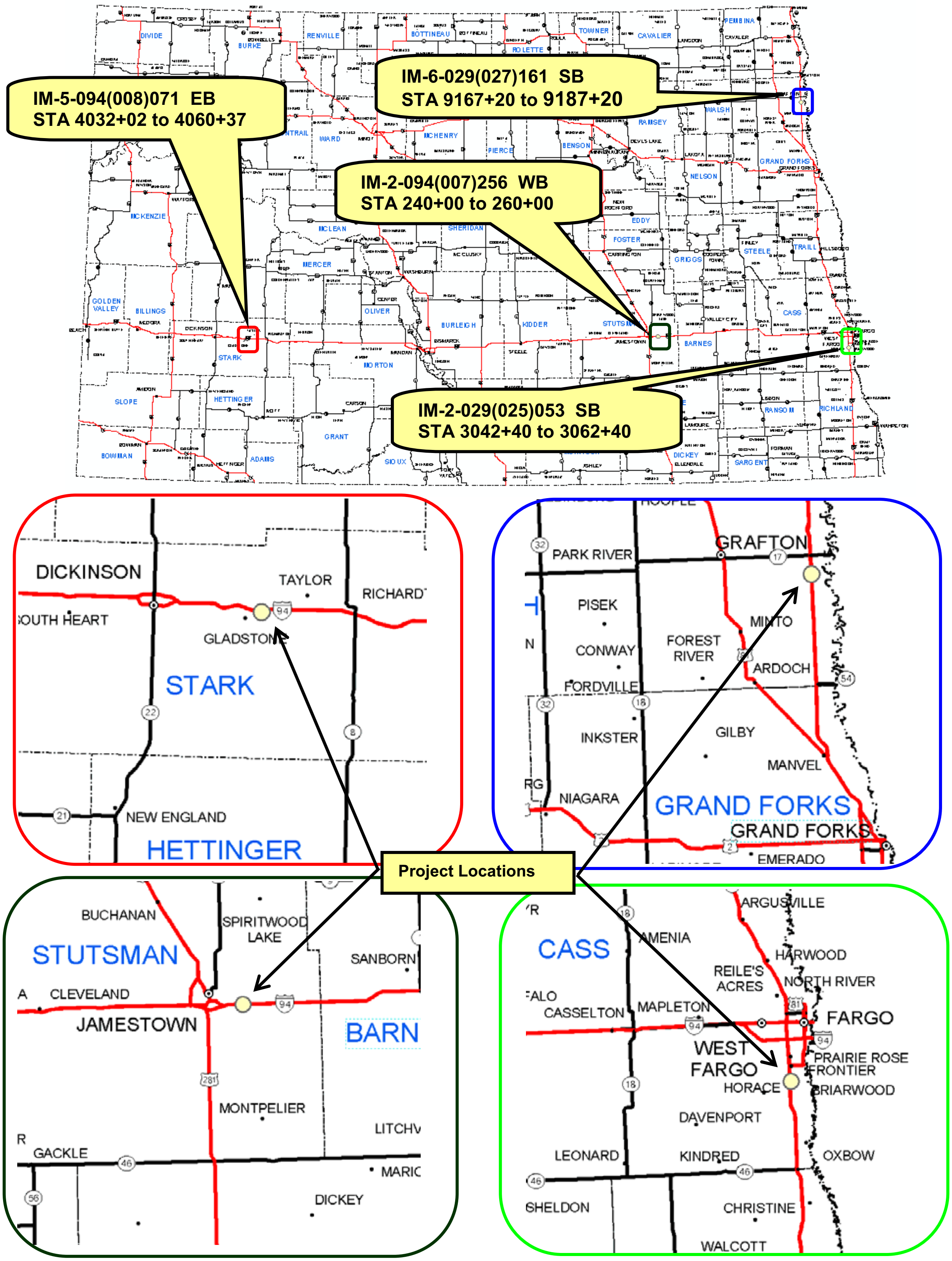

Figure 1 - Project Location.

Design

One of the design parameters is that the finished sawed joint width be 1/8 inch and the saw cut depth be 1/3 the thickness of the pavement. The test sections except one are all 2000' in length with corresponding 1000' control sections on each side. One test section, I-94 from Gladstone to Taylor is 2,835' in length with corresponding 1000' control sections on each side.

Traffic

One-way daily traffic is shown for I-29 from the Wild Rice River to 32nd Avenue (SB) in Table 1.

Year	Pass	Trucks	Total	One-way Rigid ESALs
2000	4,012	688	4,700	928
2004	4,588	713	5,300	963
2006	4,840	715	5,550	963
2008	4,599	682	5,281	966

Table 1

One-way daily traffic is shown for I-94 from Gladstone to Taylor (EB) in Table 2.

Year	Pass	Trucks	Total	One-way Rigid ESALs
2000	1,934	500	2,434	655
2004	2,060	575	2,635	748
2006	2,060	575	2,635	748
2007	2,352	760	3,112	988

Table 2

One-way daily traffic is shown for I-94 near the Jamestown (WB) in Table 3.

Year	Pass	Trucks	Total	One-way Rigid ESALs
2000	2,693	779	3,742	1,096
2004	2,605	895	3,500	1,255
2006	3,110	1060	4,170	1,560
2007	3,094	1194	4,288	1403

Table 3

One-way daily traffic is shown for I-29 from ND 54 north to near Jct 17 (SB) in Table 4.

Year	Pass	Trucks	Total	One-way Rigid ESALs
2000	1,647	700	2,347	1,008
2004	1,975	795	2,770	1,098
2006	1835	815	2645	1140
2008	2,278	819	3,097	1148

Table 4

Construction

Project IM-6-029(027)161

The following paragraphs and photos describe the construction process associated with unsealed joints in a PCC pavement.

The process is virtually the same as for sealed joints except that the widening process is omitted along with the process of installing the sealant. Photo 1 depicts a view of a typical gang sawing machine that was used on project IM-6-029(027)161 in the Grand Forks District. The gang saw shown was equipped with four individual 1/8" wide saws spaced approximately 8' apart.

Photo 1 - Typical gang sawing machine used on project IM-6-029(027)161 in the Grand Forks District.

Materials and Research visited the project site on September 5, 1997. The contractor was in the process of sawing joints in the test section. However, it became necessary for the contractor to cease operations because the PCC was still too green. This in turn was causing the PCC to spall during the sawing operation. The contractor commented that he was very concerned about the spalling since this would be the final sawing the unsealed joints would receive. The sawing machine stayed approximately 1/2 mile behind the paving machine. The contractor was able to saw a joint across the mainline in approximately 1 minute and 15 seconds.

Photo 2 depicts a view of a typical sawed joint.

Photo 2 - Typical sawed joint.

In nearly all cases the contractor managed to produce a finished saw width ranging from 1/8" to 1/4" as shown in photo 3.

The average saw depth was approximately 3-3/8” deep as shown in photo 4.

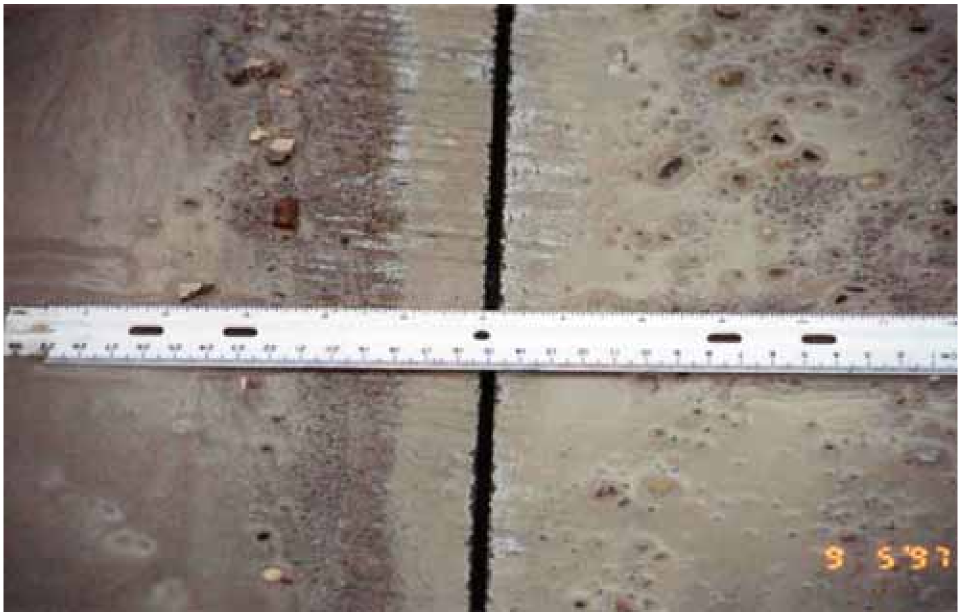

Photo 3 - Width of a typical joint.

As previously mentioned the saw depth on project IM-6-029(027)161 was T/3. The PCC pavement thickness on project IM-6-029(027)161 is 10". During the joint sawing process there were some problems that developed. Photos 5 and 6 depict the sawing process as it commences from right to left. Please note that photos 5 and 6 were taken from the same location. In photo 7, the end saw overlaps an area

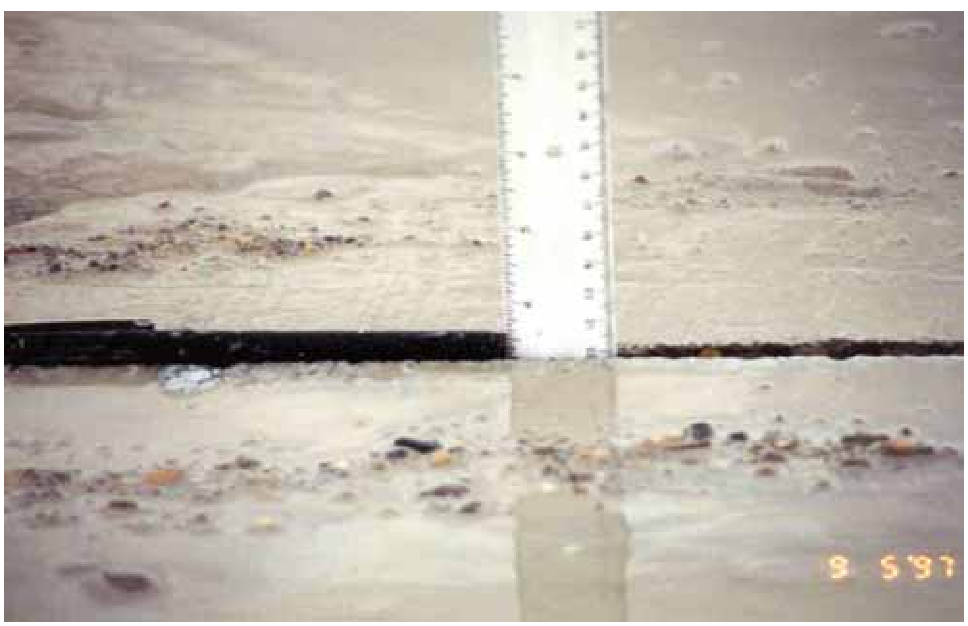

Photo 4 - Saw depth is approximately 3-3/8" deep.

previously sawed. As a result of the saws overlapping one another, a segment of approximately 1 to 2 feet in length is left with an extra wide width.

Photo 5 - Sawing process as it commences from right to left.

Photo 6 - Sawing process as it finishes from right to left.

This condition is shown in photo 7. It appears from photo 7 that the individual saws were not completely in line while overlapping one another's cutting path. Notice also in photo 7 that the overlapping is causing medium sized chips to be dug out of the

PCC. The condition depicted in photo 7 has occurred in nearly every joint sawed and is present within each joint as many as three times.

Photo 7 - Extra wide segment caused by the contractors gang saws being out of alignment.

The extra width caused by the overlapping saws has been registered as wide as 1/2", as shown in photo 8. Project engineer Morris Evens (NDDOT) brought the sawing problems to the attention of the contractor.

In projects where sealed joints are required, the extra wide areas do not appear as noticeable once the joint is widened for sealing purposes. Joints requiring sealing are generally widened to 3/8".

Making the saw cut as narrow as possible is important because there is less chance for incompressible materials to become lodged between the pavement slabs. This in turn may cause high stress locations when thermal expansion forces the pavement into compression.

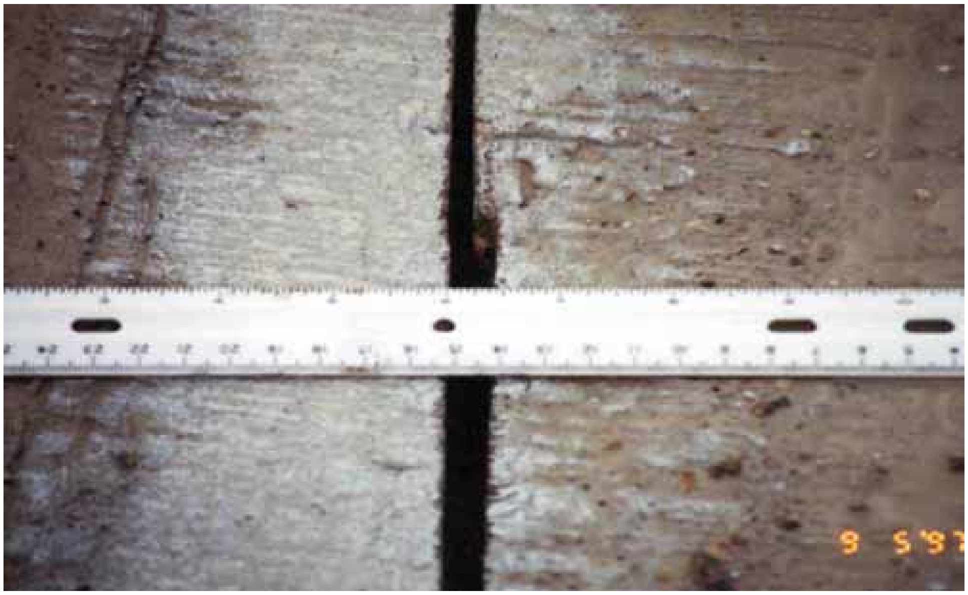

Photo 8 - Some of the widened segments are as much as 1/2" wide.

Project IM-2-094(007)256

A 2000' portion of project IM-2-094(007)256 near Jamestown was also constructed with unsealed joints. Materials and Research visited the test section just after the unsealed joints had been constructed. Photo 9 depicts a view of a typical unsealed joint.

Photo 9 - Typical unsealed joint.

Photo 9 also depicts a view of a segment of the joint that appears wider than the rest of the joint. This extra wide segment of the joint is similar to the condition present in the Grand Forks test section and is present in virtually every joint. Photo 10 depicts a close-up view of one these extra wide segments. It appears that the extra wide segments are also at least 1/2" wide.

Photo 10 - Close-up view of an extra wide segment.

During construction of the unsealed joints near Jamestown, the contractor used a walk-behind saw as opposed to gang saws. During the sawing operation it became necessary for the contractor to reposition the sawing machine in order to achieve a cut along the entire width of the PCC slab. In many cases the contractor failed to reposition the saw properly before reentering a previously sawed joint thereby creating the extra wide segments previously noted. It is also possible that the widening segments may have been caused by the contractor backing up and then preceding forward again.

Photo 11 on the next page depicts a close-up view of a portion of an unsealed joint that was sawed correctly. It appears from the measurement taken in photo 11 that the joint is approximately 1/4" in width.

Photo 11 - Close-up view of a portion of an unsealed joint that was sawed correctly.

Insufficient depths were also recorded during initial observations at the Jamestown test section. Photo 12 shows the saw depth in the joint in question to be approximately 3". As previously mentioned, the planned saw depth on project IM-2-094(007)256 was T/3. The PCC pavement thickness on project IM-2-094(007)256 is 10".

Photo 12 - Saw depth of joint in question to be approximately 3".

Projects IM-5-094(008)071 and IM-8-029(025)053

The unsealed test sections constructed during the 1998 season were included in PCC paving projects IM-5-094(008)071 and IM-8-029(025)053. Materials and Research was unable to visit these sites during construction, however, after conversing with the project engineers it appears that the construction process went well on both projects.

On project IM-5-094(008)071 a gang sawing machine was used to saw the unsealed joints. The project engineer commented that the contractor initially had problems with the joints being sawed too wide where the individual saws were overlapping. However, after some adjustments the condition appeared to be much improved.

On project IM-8-029(025)053 the project engineer commented that a self-propelled sawing machine utilizing only one blade was used. The sawing machine was similar to a walk behind sawing machine except that the worker rode instead of walking behind. The project engineer also commented that the contractor did not appear to be having the same problems encountered on other PCC projects where the saws overlapped.

Final Evaluation

The NDDOT Materials & Research Division evaluated the unsealed joint test sections for the following items:

- Distress at the joints.
- Ride.
- The amount of non-compressible material in the joints.
- If the incompressible material is being filtered through the joint into the drainage system.

The ride characteristics appear to be the same between the test sections and the control sections while driving in a vehicle. The effect of the spalled joint had on the ride is tough to measure since the initial ride was never profiled.

Project IM-6-029(027)161 - Grand Forks District

Materials and Research visited the test site on project IM-6-029(027)161 on November 25, 2008.

Spalling and corner breaks are the only distress noted at the joints in the test section as well as the control section. There was only one slab with a corner break. The severity of the spalls between the test section and control section are the same, however, the unsealed test section has many more joints with spalls. The test section has nearly all of the joints with spalls. The majority of the spalling has occurred in the wheel paths. Refer to Table 5 to compare the test section with the control section. There is a decline in the number of spalled transverse joints. This is due to the judgment of the evaluator. It appears the numbers of spalled joints for both sections are no longer increasing.

Grand Forks - IM-6-029(027)161	Number of Spalled Joints				
	2001	2003	2005	2006	2008
Test Section – Unsealed	33	94	122	112	97
	24.8%	70.7%	91.7%	84.2%	72.9%
Control Section – Sealed	18	38	49	20	27
	13.5%	28.6%	36.8%	15.0%	20.3%

Table 5

The unsealed joint section spalls tend to be more severe than the sealed joint section. Photo 13 shows a typical spalled joint in the control section. Photo 14 shows a typical spalled joint in the unsealed section and Photo 15 displays a joint with severe spalls.

Photo 13 - Typical spalled joint in the sealed (control) section.

Photo 14 - Typical spalled joint in the unsealed (test) section.

Photo 15 - Most severe spall in unsealed (test) section.

The amount of incompressible material in the unsealed joints are approximately 40-50% filled (depth) in the driving lane. The portion of the joint on the shoulder however, is full of incompressible material. The driving lanes may have remained relatively free of incompressible material due to differential air pressure caused by a vacuum created by the traffic. Photo 16 shows a comparison between the driving lane and the shoulder. This photo is from 2001 and the amount of incompressible material has not changed.

At this time, the incompressible material does not seem to be affecting the drainage system due to the absence of incompressibles in the joints.

Photo 16 - Incompressible material in shoulder versus driving lane.

Project IM-2-094(007)256 - Valley City District

Materials and Research visited the test site near Jamestown on November 25, 2008.

This test site has longitudinal joint spalling, transverse joint spalling, and mid panel cracks. There are two mid panel cracks on the control section and 7 mid panel cracks on the test section. There are five longitudinal joints with spalls in the control section and 12 longitudinal joints with spalls in the test section. The transverse joint spalling is still the most severe distress on the roadway. The test section has many more spalled transverse joints than the control section. Table 6 displays how the spalled transverse joints differ between the control section and test section. The majority of the spalling has occurred in the wheel paths.

Valley City	Number of Spalled Joints				
IM-2-094(007)256	2001	2003	2005	2006	2008
Test Section – Unsealed	29	86	111	116	96
	21.8%	64.7%	83.5%	87.2%	72.2%
Control Section – Sealed	18	57	82	68	54
	13.5%	42.9%	61.7%	51.1%	40.6%

Table 6

Photo 17 shows a typical spalled joint in the test section and Photo 18 shows a typical spalled joint in the control section. There is a decline in the number of spalled transverse joints, as per the judgment of the evaluator. It appears the numbers of spalled joints are no longer increasing.

Photo 17 - Typical spalled joint in the test section.

Photo 18 - Typical spalled joint in control section.

The joints on the shoulders are full of incompressible material. The project engineer commented that after construction of the unsealed joint section, this section was used to transport a significant amount of aggregate for other construction phases of the project. It is possible that some of the material lost from the hauling trucks may have become lodged within the unsealed joints. The amount of incompressible material in the joints may also be attributed to additional sand being placed on this segment of roadway during the winter. The additional sand is required due to an increase in snow collecting on the roadway as a result of a nearby shelter belt.

Photo 19 shows an attempt to patch a spalled area in the sealed section. There was also an area in the unsealed section that was repaired as well.

Photo 19 - Attempted spall repair in sealed control section.

Project IM-8-029(025)053 - Fargo District

Materials and Research visited the test site south of Fargo on November 25, 2008.

Transverse joint spalling, longitudinal joint spalling, and corner breaks are the only distresses noted at the joints in the test section as well as the control section. The corner breaks and longitudinal joint spalls are not very serious due to the low quantity of these types of distresses. The severity of the transverse joint spalls are the same, however the number of spalls in the unsealed test section are slightly higher than those in the control section. Refer to Table 7. The majority of the spalling has occurred in the wheel paths.

Fargo	Number of Spalled Joints				
IM-8-029(025)053	2001	2003	2005	2006	2008
Test Section – Unsealed	28	40	67	94	70
	21.1%	30.1%	50.4%	70.7%	52.6%
Control Section – Sealed	31	31	64	74	66
	23.3%	23.3%	48.1%	55.6%	49.6%

Table 7

The severity of the spalling is more severe in the unsealed joint section. There is a decline in the number of spalled transverse joints, according to the judgment of the evaluator. It appears the numbers of spalled joints are no longer increasing.

Photo 21 shows a spalled joint in the test section that was attempted to be repaired.

Photo 21 - Attempted spall repair in test section.

Photo 22 - Incompressible material in an unsealed joint at the shoulders.

Incompressible material has filled the unsealed joints on the shoulders completely. The joints in the driving lane are partially filled with incompressibles ranging from 3/8” to 1 1/8” below the concrete surface. The amount of incompressible material in the joints may be attributed to additional sand being placed on this segment of roadway during the winter. This segment of roadway is near an urban area with high traffic where greater than usual sanding is required. Photo 22 shows the amount of incompressible material in an unsealed joint.

At this time, the incompressible material does not seem to be affecting the drainage system.

Project IM-5-094(008)071 - Dickinson District

Materials and Research visited the test site near Gladstone on September 29, 2005.

This test section experienced some distresses that the other test sites didn't experience. There is map cracking on the transverse joints in the wheel paths. There is also a longitudinal crack running down the center of the roadway for the majority of the project. These distresses can be seen in Photos 23 & 24.

Photo 23 – Photo of severe map cracking next to transverse joint in "control section".

These sections of roadway were repaired in the fall of 2005. Materials and Research visited the test section when it was repaired. Sections of the roadway required a full depth repair. When the concrete was removed, cracking at the center of

Photo 24 – Photo of longitudinal joint after concrete was removed.

slab depth could be seen. This can be seen in Photo 24 and 25. Cores were taken to be tested by American Petrographic Services, Inc. Samples from these cores were taken at different depths of the concrete. Their testing reported that the cause of the deterioration appears to be due to inconsistencies in the entrained air void system throughout the concrete. They reported that in general they observed lower entrained air content volumes in the upper portions of the concrete. Note the delaminated condition of the pavement section, as depicted in photo 24 and 25. See Appendix A to review report from American Petrographic Services, Inc.

Photo 25 – Photo of crack running transversely in the center of a pavement section removed from roadway.

This site was not evaluated for transverse joint spalling or longitudinal joints spalling after the pavement was repaired in 2005, once the original joints are now gone. Table 8 displays the spall results from 2005. A photo of a repaired joint can be seen in Photo 26.

Dickinson	Number of Spalled Joints			% of Joints Spalled		
IM-5-094(008)071	2001	2003	2005	2001	2003	2005
Test Section – Unsealed	*53	*84	*84	28.2%	44.7%	44.7%
Control Section – Sealed	6	16	32	4.5%	12.0%	24.0%

***This test section was 2,835 feet long. Number of joints is 188 versus 133 in previous sections.**

Table 8

Photo 26 – Photo of repaired joint.

Summary

Every test section shows a higher number of spalled joints versus the control section as shown in Table 9.

Grand Forks IM-6-029(027)161	Number of Spalled Joints				
	2001	2003	2005	2006	2008
Test Section – Unsealed	33	94	122	112	97
	24.8%	70.7%	91.7%	84.2%	72.9%
Control Section – Sealed	18	38	49	20	27
	13.5%	28.6%	36.8%	15.0%	20.3%
Valley City IM-2-094(007)256	**Number of Spalled Joints**				
	2001	2003	2005	2006	2008
Test Section – Unsealed	29	86	111	116	96
	21.8%	64.7%	83.5%	87.2%	72.2%
Control Section – Sealed	18	57	82	68	54
	13.5%	42.9%	61.7%	51.1%	40.6%
Fargo IM-8-029(025)053	**Number of Spalled Joints**				
	2001	2003	2005	2006	2008
Test Section – Unsealed	28	40	67	94	70
	21.1%	30.1%	50.4%	70.7%	52.6%
Control Section – Sealed	31	31	64	74	66
	23.3%	23.3%	48.1%	55.6%	49.6%
Dickinson IM-5-094(008)071	**Number of Spalled Joints**				
	2001	2003	2005	2006	2008
Test Section – Unsealed	*53	*84	*84	NA	NA
	28.2%	44.7%	44.7%	-	-
Control Section – Sealed	6	16	32	-	-
	4.5%	12.0%	24.1%	-	-

***This test section was 2,835 feet long. Number of joints is 188 versus 133 in previous sections.**

Table 9

Spalls on the transverse joints are the only distresses common in all the research sections. The Dickinson section is the only section with deteriorated sections. These distresses were caused by the quality of workmanship in the construction of the pavement.

The quantities of other distresses, such as corner cracking, longitudinal and transverse cracking, that have occurred in all the test sections except Dickinson section are an acceptable amount in concrete pavements. Incompressible material was also evaluated. Incompressible material was found in the shoulders of the pavement. It appears most likely the moving traffic kept the mainline joints clear of incompressible material.

The Dickinson District test section had a problem with map cracking in the wheel paths along the transverse joint. Also there was a longitudinal crack running down the middle of the roadway. These distresses are localized in the Dickinson district. Test performed by American Petrographic Services, Inc. indicate that the cause of the deteriorated concrete was due to inconsistencies in the entrained air void system. The control and test section both had the same unique distresses. The distresses were more severe in the unsealed section. It is reasonable to believe that the unsealed joints accelerated the rate that joints became distressed, and accelerated the deterioration of the concrete pavement.

Recommendation

From the results of the test sections we would not recommend unsealed longitudinal and transverse joints. Visual observations showed a higher percentage of spalling in the sealed test section with some spall repair conducted to address the worst areas. The department has recently decided to install fewer drainable base sections which would increase the value of the sealed joints. The sealed joints would reduce the amount of water intrusion into the pavement and base section.

Appendix A

AMERICAN
PETROGRAPHIC
SERVICES, INC.

JUN 2 4 2005

REPORT OF CONCRETE TESTING

PROJECT:

SIM-5-094 (049) (076)

REPORTED TO:

NORTH DAKOTA DOT
300 AIRPORT ROAD
BISMARCK, ND 58504

ATTN: SCOTT WUTZKE

APS JOB NO: 10-03826

DATE: JUNE 17, 2005

INTRODUCTION

This report presents the results of laboratory work performed by our firm on four concrete core samples submitted to us by Mr. Scott Wutzke of North Dakota DOT on May 27, 2005. We understand the concrete cores were obtained from an exterior concrete pavement that has experienced joint deterioration. The scope of our work was limited to performing petrographic analysis testing to document the cause of the joint deterioration.

CONCLUSIONS

Based on our observations, test results, and past experience, our conclusions are as follows:

1. The overall quality of the concrete was fair to good. The cement paste was relatively dense and hard with carbonation up to 1/2". The glacial gravel aggregate was hard, sound, and durable. The concrete was placed with a low slump.

2. The concrete contained an air void system that is consistent with current technology for resistance to freeze-thaw deterioration. However, we expect deterioration to continue in the carbonated surficial paste if exposed to freezing conditions when saturated.

3. The cause of the deterioration appears to be due to inconsistencies in the entrained air void system throughout the concrete. In general, we observed lower entrained air content volumes in the upper portions of the concrete.

550 Cleveland Ave. No. • St. Paul, MN 55114 • 651-[illegible] Fax 651-647-2744 • www.ampetrographic.com

SAMPLE IDENTIFICATION

Sample Number:	1	2	3	10
Sample Type:	Hardened Concrete Core			
Original Sample Dimensions, in:	4" diameter by 8-11/16" long	4" diameter by 8-7/8" long	4" diameter by 9-1/8" long	4" diameter by 8-13/16" long

TEST RESULTS

Our complete petrographic analysis test results appear on the attached sheets entitled 00 LAB 001 "Petrographic Examination of Hardened Concrete, ASTM:C856." A brief summary of the general concrete properties is as follows:

1. The coarse aggregate of the cores was comprised of 3/4" maximum sized glacial gravel that was fairly well graded with good overall uniform distribution.

2. Fly ash pozzolanic admixture was observed in all four concrete samples.

3. The paste color of the cores was mottled gray with the slump estimated to be low (1" to 3").

4. The paste hardness of the cores was judged to be medium with the paste/aggregate bond considered fair to good.

5. The depth of carbonation was up to 1/2".

6. The water/cementitious ratio of the cores was estimated at between 0.35 to 0.41 with approximately 11-14% unhydrated cement particles and a purposeful addition of fly ash pozzolan.

Air Content Testing

Sample Identification:	1	2	3	10
Total Air Analysis -				
Air Void Content, %	6.1	5.5	4.2	4.3
Spacing Factor, in	0.006	0.007	0.006	0.007
Entrapped Air (%)	1.8	1.9	0.5	1.0
Entrained Air (%)	4.3	3.6	3.7	3.3

TEST PROCEDURES

Laboratory testing was performed on May 27, 2005, and subsequent dates. Our procedures were as follows:

Petrographic Analysis

A petrographic analysis was performed in accordance with APS Standard Operating Procedure 00 LAB 001, "Petrographic Examination of Hardened Concrete," ASTM:C856-latest revision. The petrographic analysis consisted of reviewing cement paste and aggregate qualities on a whole basis as well as on a cut/polished section. The depth of carbonation was documented using a phenolphthalein indicator solution applied on a freshly cut and polished surface of the concrete sample. The water/cement ratio of the concrete was estimated by viewing a thin section of the concrete under an Olympus BH-2 polarizing microscope at magnification up to 1000x. Thin section analysis was performed in accordance with APS Standard Operating Procedure 00 LAB 013, "Determining the Water/Cement of Portland Cement Concrete, APS Method." The samples are first highly polished, then epoxied to a glass slide. The excess sample is cut from the glass and the slide is polished until the concrete reaches 25 microns or less in thickness.

Air Content Testing

Air content testing was performed using APS Standard Operating Procedure 00 LAB 003, "Microscopical Determination of Air Void Content and Parameters of the Air Void System in Hardened Concrete, ASTM:C457-latest revision." The linear traverse method was used. The concrete cores were cut perpendicular with respect to the horizontal plane of the concrete as placed and then polished prior to testing.

REMARKS

The test samples will be retained for a period of at least thirty days from the date of this report. Unless further instructions are received by that time, the samples may be discarded. Test results relate only to the items tested.

Report Prepared By:

Scott F. Wolter, P.G.
President
MN License No. 30024

Richard D. Stehly, P.E., FACI
MN Lic. No. 12856

00 LAB 001 Petrographic Examination of Hardened Concrete
ASTM: C-856

Job #:	10-03826	Date:	6-2-05 / 6-16-05
Sample Identification:	1	Performed by:	S. Malecha/G. Moulzolf

I. General Observations

1. Sample Dimensions: Our analysis was performed on a 221 mm (8-11/16") x 102 mm (4") x 49 mm (1-15/16") thick polished section that was cut from the original 102 mm (4") diameter x 221 mm (8-11/16") long core.

2. Surface Conditions:

   Top: Rough, screeded, and tined surface was traffic worn with many fine aggregate surfaces worn smooth
   Bottom: Smooth, saw-cut surface

3. Reinforcement: None observed.

4. General Physical Conditions: The screeded and tined top surface was traffic worn with many fine aggregate surfaces worn smooth. Carbonation ranged from 1 mm (1/32"), up to 5 mm (3/16") depth from the top surface. The subvertical macrocracks/microcrack proceeds up to approximately 149 mm (5-5/8") depth from the top surface. The macro/microcracking proceeds around most coarse aggregate particles as opposed to through them. Clear to white alkali silica gel was observed partially filling the macrocracks/microcrack between approximately 76 mm (3") and 92 mm (3-5/8") depth from the top surface. The concrete was purposefully air entrained and contains a fairly well distributed air void system considered freeze-thaw durable in both the top 3" and the rest of the sample. Fair overall condition.

II. Aggregate

1. Coarse: 25 mm (1") maximum sized glacial gravel. Rock types include basalt, carbonate, quartzite, felsite, and chert. Fairly well graded with good overall uniform distribution.

2. Fine: Natural, quartz, feldspar and lithic sand with that was fairly well graded. The grains were mostly sub-rounded with many sub-angular particles. Good overall uniform distribution.

III. Cementitious Properties

1. Air Content: 6.1% total, 1.8% entrapped, 4.3% entrained
2. Depth of carbonation: Ranged from 1 mm (1/32") up to 3 mm (1/8")
3. Pozzolan presence: A purposeful addition of fly ash was observed.
4. Paste/aggregate bond: Fair
5. Paste color: Medium gray
6. Paste hardness: Medium
7. Paste proportions: 24% to 26%
8. Microcracking: A subvertical macro/microcrack proceeds up to approximately 149 mm (5-5/8") depth from the top surface. The macro/microcracking proceeds around most coarse aggregate particles as opposed to through them.
9. Secondary deposits: Clear to white alkali silica-gel was observed partially filling the subvertical microcrack between approximately 76 mm (3") and 92 mm (3-5/8") depth from the top surface.
10. Slump: Estimated, low (1-3")
11. Water/cementitious ratio: Estimated at between 0.35 to 0.40 with approximately 12-14% unhydrated or residual portland cement clinker particles and a purposeful addition of fly ash.
12. Cement hydration: Alites- well to fully; Belites- moderate to fully

IV. Conclusions

The general overall quality of the concrete was good.

00 LAB 001 Petrographic Examination of Hardened Concrete
ASTM: C-856

Job #:	10-03826	Date:	6-9-05 / 6-16-05
Sample Identification:	2	Performed by:	S. Malecha/G. Moulzolf

I. General Observations

1. Sample Dimensions: Our analysis was performed on a 225 mm (8-7/8") x 102 mm (4") x 49 mm (1-15/16") thick polished section that was cut from the original 102 mm (4") diameter x 225 mm (8-7/8") long core.

2. Surface Conditions:

   Top: Rough, screeded, and tined surface was traffic worn with many fine aggregate surfaces worn smooth
   Bottom: Smooth, saw-cut surface

3. Reinforcement: None observed.

4. General Physical Conditions: The screeded and tined top surface was traffic worn with many fine aggregate surfaces worn smooth. A subvertical drying-shrinkage microcrack proceeds up to 10 mm (3/8") depth from the top surface. Carbonation ranged from negligible up to 6 mm (1/4") depth from the top surface. The core was fractured in an orientation subparallel to the top surface approximately 102 mm (4") depth from the top surface. The fracture proceeds around most coarse aggregate particles as opposed to through them. The concrete was purposefully air entrained and contains a fairly well distributed air void system considered freeze-thaw durable only under moderate exposure conditions. Fair to good overall condition.

II. Aggregate

1. Coarse: 19 mm (3/4") maximum sized glacial gravel. Rock types include mostly granite, basalt, quartzite, sandstone, felsite, and chert with some iron oxide. Fairly well graded with good overall uniform distribution.

2. Fine: Natural, quartz, feldspar and lithic sand with that was fairly well graded. The grains were mostly sub-rounded with many sub-angular particles. Good overall uniform distribution.

III. Cementitious Properties

1. Air Content: 5.5% total, 1.9% entrapped, 3.6% entrained
2. Depth of carbonation: Ranged from negligible up to 5 mm (3/16")
3. Pozzolan presence: A purposeful addition of fly ash was observed.
4. Paste/aggregate bond: Good
5. Paste color: Medium gray
6. Paste hardness: Medium
7. Paste proportions: 25% to 27%
8. Microcracking: A subvertical drying shrinkage microcrack proceeds up to 10 mm (3/8") depth from the top surface. A microcrack, oriented subparallel to the fracture proceeds across the diameter of the core between approximately 2 and 3-1/2" depth from the top surface.
9. Secondary deposits: None observed
10. Slump: Estimated, low (1-3")
11. Water/cementitious ratio: Estimated at between 0.36 to 0.41 with approximately 11-13% unhydrated or residual portland cement clinker particles and a purposeful addition of fly ash.
12. Cement hydration: Alites- well to mostly fully; Belites- moderate to fully

IV. Conclusions

The general overall quality of the concrete was fair to good.

00 LAB 001 Petrographic Examination of Hardened Concrete
ASTM: C-856

Job #:	10-03826	Date:	6-7-05 / 6-16-05
Sample Identification:	3	Performed by:	S. Malecha/G. Moulzolf

I. General Observations

1. Sample Dimensions: Our analysis was performed on a 232 mm (9-1/8") x 102 mm (4") x 48 mm (1-7/8") thick polished section that was cut from the original 102 mm (4") diameter x 232 mm (9-1/8") long core.

2. Surface Conditions:

   Top: Rough, screeded, and tined surface was traffic worn with many fine aggregate surfaces worn smooth
   Bottom: Smooth, saw-cut surface

3. Reinforcement: None observed.

4. General Physical Conditions: The screeded and tined top surface was traffic worn with many fine aggregate surfaces worn smooth. A few subvertical drying-shrinkage microcracks proceed up to 15 mm (5/8") depth from the top surface. Carbonation ranged from negligible up to 13 mm (1/2") depth along subvertical microcracking. The core sample was fractured in an orientation subparallel to the top surface approximately 89 mm (3-1/2") depth from the top surface. The fracture proceeds around most coarse aggregate particles as opposed to through them. The concrete was purposefully air entrained and contains a fairly distributed air void system considered freeze-thaw durable only under moderate exposure conditions in top 3". The remaining bottom of the core contains a fairly well distributed air void system considered freeze-thaw durable. A cold joint was observed at approximately 225 mm (8-7/8") depth from the top surface. Fair to good overall condition.

II. Aggregate

1. Coarse: 19 mm (3/4") maximum sized glacial gravel. Rock types include mostly granite, basalt, carbonate, quartzite, sandstone, felsite, and chert with some iron oxide. Fairly well graded with good overall uniform distribution.

2. Fine: Natural, quartz, feldspar and lithic sand with that was fairly well graded. The grains were mostly sub-rounded with many sub-angular particles. Good overall uniform distribution.

III. Cementitious Properties

1. Air Content: 4.2% total, 0.5% entrapped, 3.7% entrained
2. Depth of carbonation: Ranged from negligible up to 13 mm (1/2") depth along subvertical microcracking
3. Pozzolan presence: A purposeful addition of fly ash was observed.
4. Paste/aggregate bond: Fair
5. Paste color: Gray becoming lighter at approximately 225 mm (8-7/8") depth from the top surface
6. Paste hardness: Medium
7. Paste proportions: 27% to 29%
8. Microcracking: A few subvertical drying shrinkage microcracks proceed up to 15 mm (5/8") depth from the top surface.
9. Secondary deposits: None observed
10. Slump: Estimated, low (1-3")
11. Water/cementitious ratio: Estimated at between 0.36 to 0.41 with approximately 11-13% unhydrated or residual portland cement clinker particles and a purposeful addition of fly ash.
12. Cement hydration: Alites- well to mostly fully; Belites- moderate to fully

IV. Conclusions

The general overall quality of the concrete was fair to good.

00 LAB 001 Petrographic Examination of Hardened Concrete
ASTM: C-856

Job #:	10-03826	Date:	6-14-05 / 6-16-05
Sample Identification:	10	Performed by:	S. Malecha/G. Moulzolf

I. General Observations

1. Sample Dimensions: Our analysis was performed on a 224 mm (8-13/16") X 100 mm (3-13/16") X 46 mm (1-13/16") thick polished section that was cut from the original 102 mm (4") diameter x 224 mm (8-13/16") long core.

2. Surface Conditions:

   Top: Rough, screeded, and tined surface was traffic worn with many fine aggregate surfaces worn smooth
   Bottom: Smooth, saw-cut surface

3. Reinforcement: None observed.

4. General Physical Conditions: The screeded and tined top surface worn with many fine aggregate surfaces worn smooth. A few subvertical drying-shrinkage microcracks proceed up to 30 mm (1-3/16") depth from the top surface. Carbonation ranged from negligible up to 1 mm (1/32") up to 12 mm (1/2") along subvertical microcracking. The core sample was fractured in an orientation subparallel to the top surface approximately between 54 mm (2-1/8") and 73 mm (2-7/8") depth from the top surface. The concrete was purposefully air entrained and contains an only fairly distributed air void system considered freeze-thaw durable only under moderate exposure conditions. The concrete contains several coarse aggregate sized masses of light colored air entrained concrete (recycled concrete aggregate). Fair to good overall condition.

II. Aggregate

1. Coarse: 25 mm (1") maximum sized glacial gravel. Rock types include mostly basalt, quartzite, sandstone, felsite, and chert with some iron oxide. Fairly well graded with good overall uniform distribution.

2. Fine: Natural, quartz, feldspar and lithic sand with that was fairly well graded. The grains were mostly sub-rounded with many sub-angular particles. Good overall uniform distribution.

III. Cementitious Properties

1. Air Content: 4.3% total, 1.0% entrapped, 3.3% entrained
2. Depth of carbonation: Ranged from 1 mm (1/32") up to 13 mm (1/2") depth along subvertical microcracking
3. Pozzolan presence: A purposeful addition of fly ash was observed.
4. Paste/aggregate bond: Fair
5. Paste color: Mottled medium gray with light gray
6. Paste hardness: Medium
7. Paste proportions: 27% to 29%
8. Microcracking: A few subvertical drying shrinkage microcracks proceed up to 23 mm (7/8") depth from the top surface.
9. Secondary deposits: White to clear ettringite was observed partially filling some entrained voids scattered throughout the sample.
10. Slump: Estimated, low (1-3")
11. Water/cementitious ratio: Estimated at between 0.36 to 0.41 with approximately 11-13% unhydrated or residual portland cement clinker particles and a purposeful addition of fly ash.
12. Cement hydration: Alites- well to mostly fully; Belites- moderate to fully

IV. Conclusions

The general overall quality of the concrete was fair to good.

AMERICAN
PETROGRAPHIC
SERVICES, INC.

REPORT OF AIR VOID ANALYSIS

PROJECT:

SIM-5-094 (049) (076)

REPORTED TO:

NORTH DAKOTA DOT
300 AIRPORT ROAD
BISMARCK, ND 58504

ATTN: SCOTT WUTZKE

APS JOB NO: 10-03826

DATE: JUNE 17, 2005

Sample No:	1	2	3	10
Conformance:	The samples contain an air void system which is consistent with current technology for freeze-thaw resistance.			
Sample Data:				
Description:	Hardened Concrete Core			
Dimensions:	4" diameter by 8-11/16" long	4" diameter by 8-7/8" long	4" diameter by 9-1/8" long	4" diameter by 8-13/16" long
Test Data:	ASTM:C457 Linear Traverse Method, APS Standard Operating Procedure 00 LAB 003			
Air Void Content, %	6.1	5.5	4.2	4.3
Entrained, % ≤ 0.040"	4.3	3.6	3.7	3.3
Entrapped, % > 0.040"	1.8	1.9	0.5	1.0
Air Voids/inch	10.62	9.29	9.47	8.16
Specific Surface, in^2/in^3	700	680	890	760
Spacing Factor, inches	0.006	0.007	0.006	0.007
Paste Content, %	26.0	26.0	27.0	27.0
Magnification	50x	50x	50x	50x
Traverse Length, inches	103"	103"	103"	103"
Test Date	6/14/05	6/14/05	6/14/05	6/14/05

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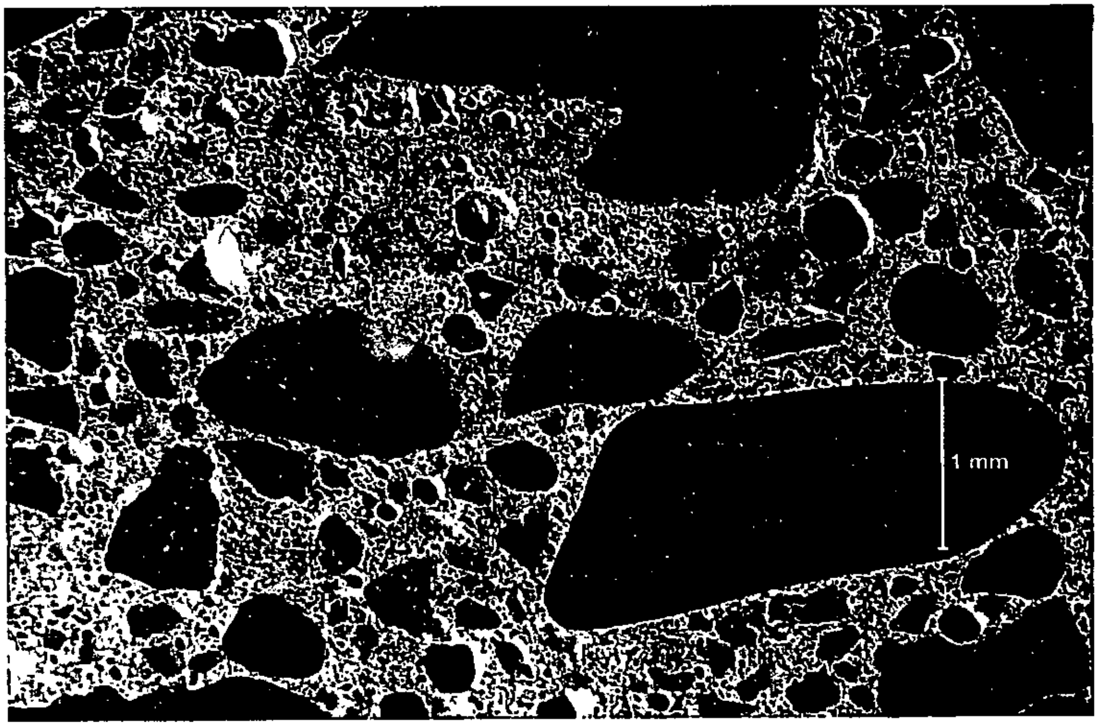
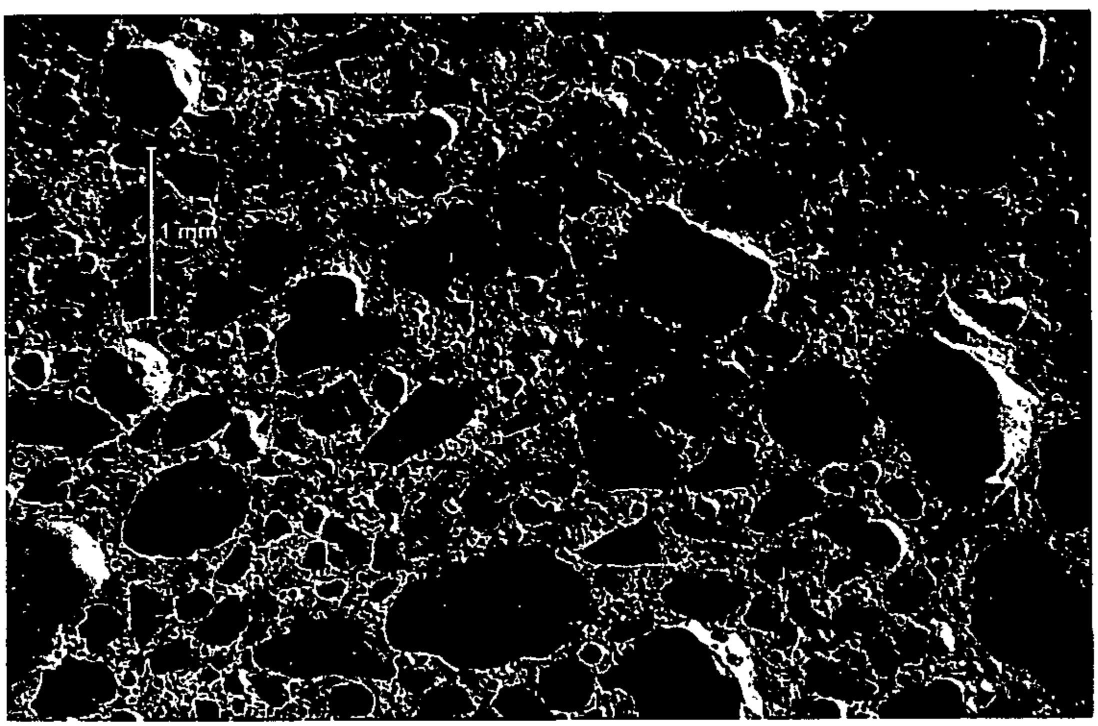


SAMPLE ID: 1 DESCRIPTION: Overall hardened air content is 4.4% in the top 3" of the sample. Image is from 0.25" depth.

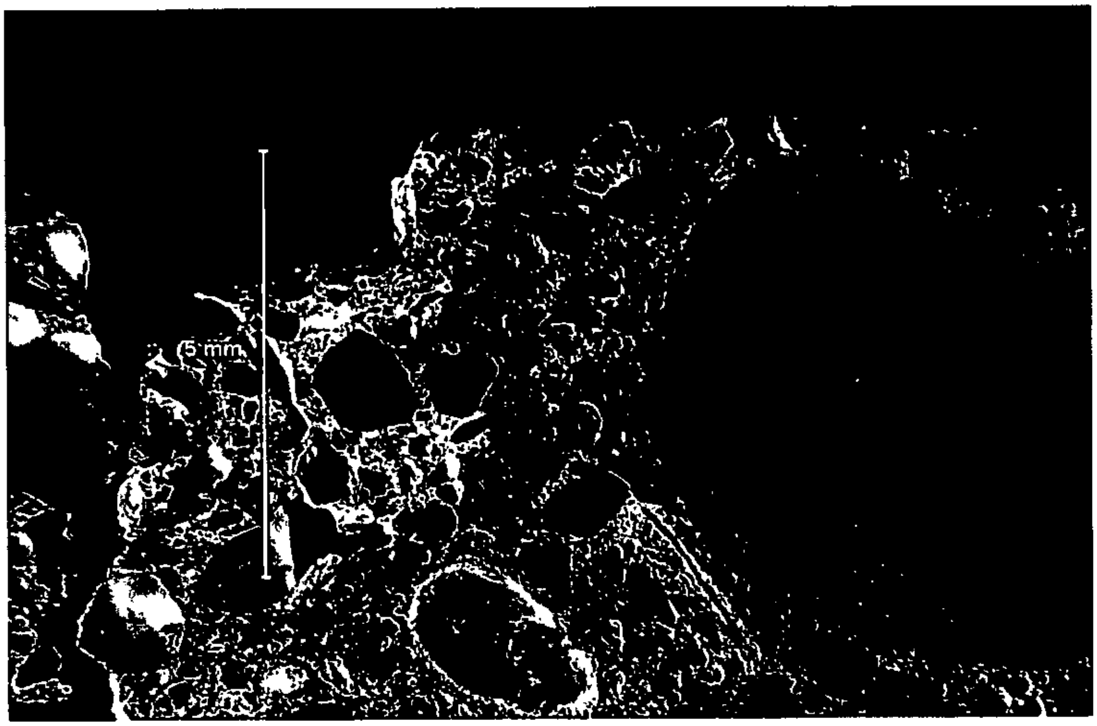
MAG: 30x



SAMPLE ID: 1 DESCRIPTION: Overall hardened air content is 7.7% below 3" depth in the sample. Image is from 3.5" depth.

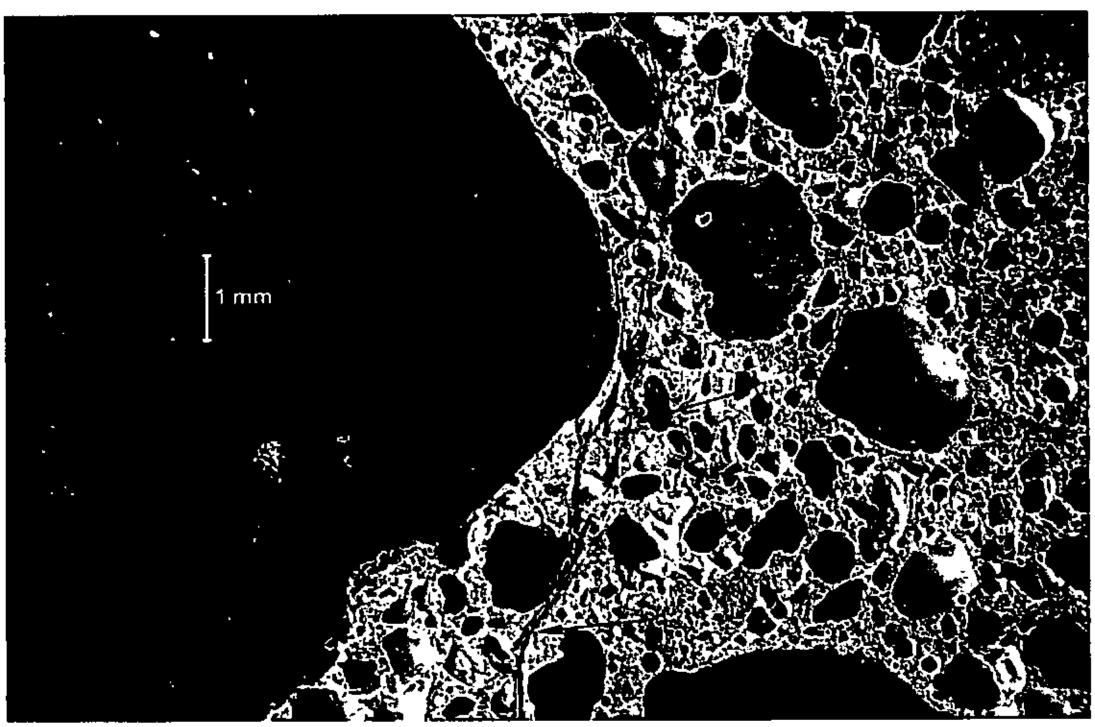
MAG: 30x

APS# 10-03826 DATE: JUNE 17, 2005
PROJECT: SIM-5-094 (049) (076)



SAMPLE ID: 1 DESCRIPTION: Carbonation (unstained) proceeds up to 5mm depth from the top surface.

MAG: 15x

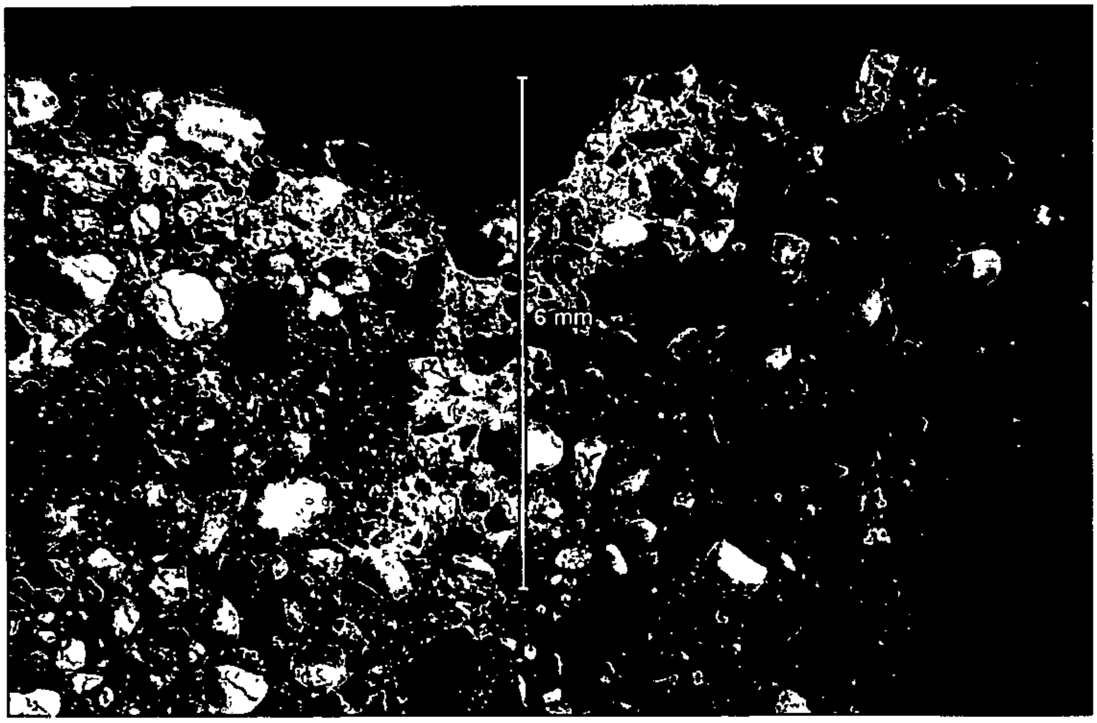


SAMPLE ID: 1 DESCRIPTION: Clear ASR gel partially fills a subvertical microcrack proceeding from the top surface.

MAG: 15x

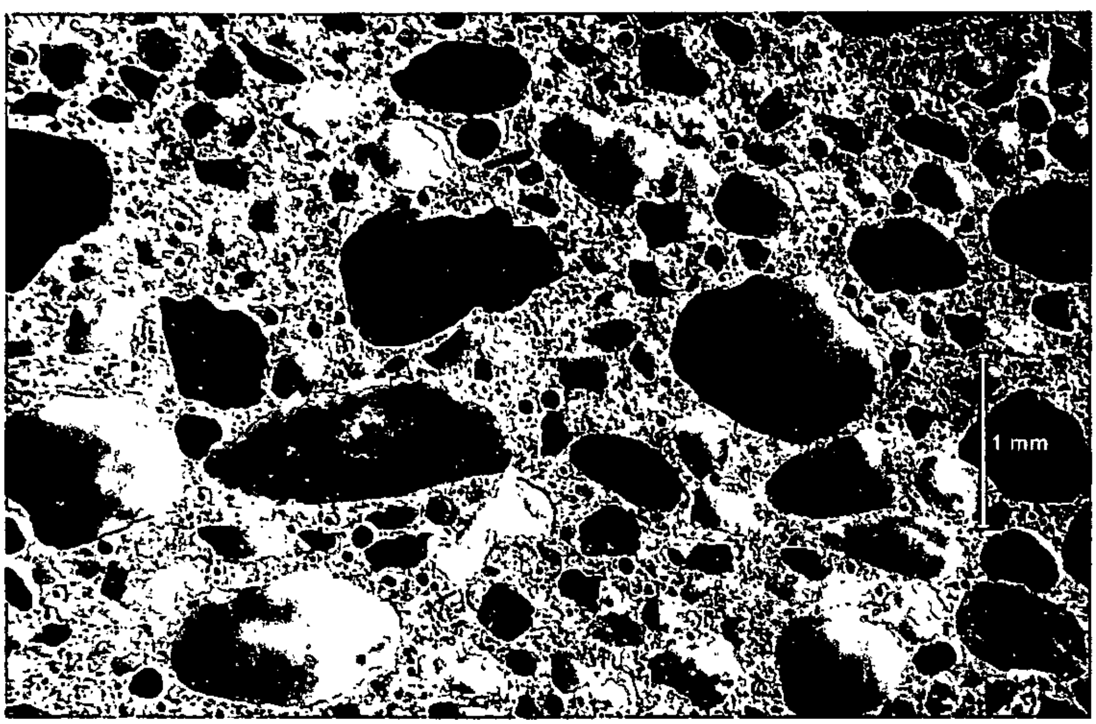
APS# 10-03826 DATE: JUNE 17, 2005

PROJECT: SIM-5-094 (049) (076)



SAMPLE ID: 2 DESCRIPTION: Carbonation (unstained) proceeds up to 5mm depth from the top surface.

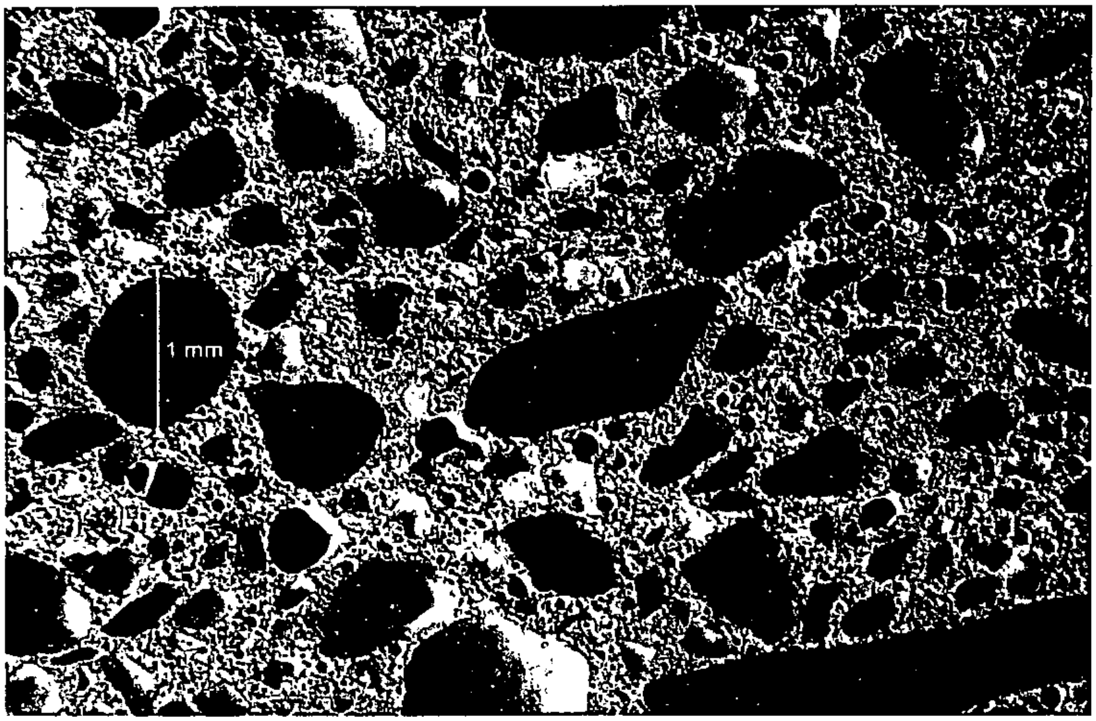
MAG: 15x



SAMPLE ID: 2 DESCRIPTION: Overall hardened air content is 5.5%.

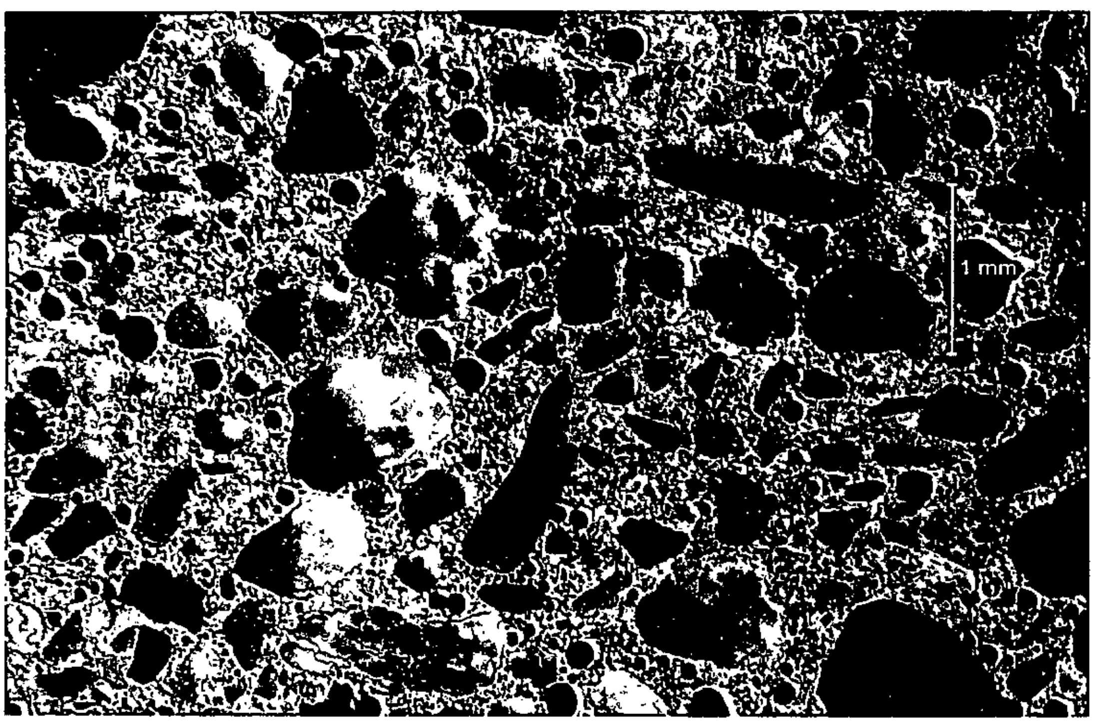
MAG: 30x

APS# 10-03826 DATE: JUNE 17, 2005
PROJECT: SIM-5-094 (049) (076)



SAMPLE ID: 3 DESCRIPTION: Overall hardened air content is 3 2% in the top 3" of the sample. Image is from 2.5" depth.

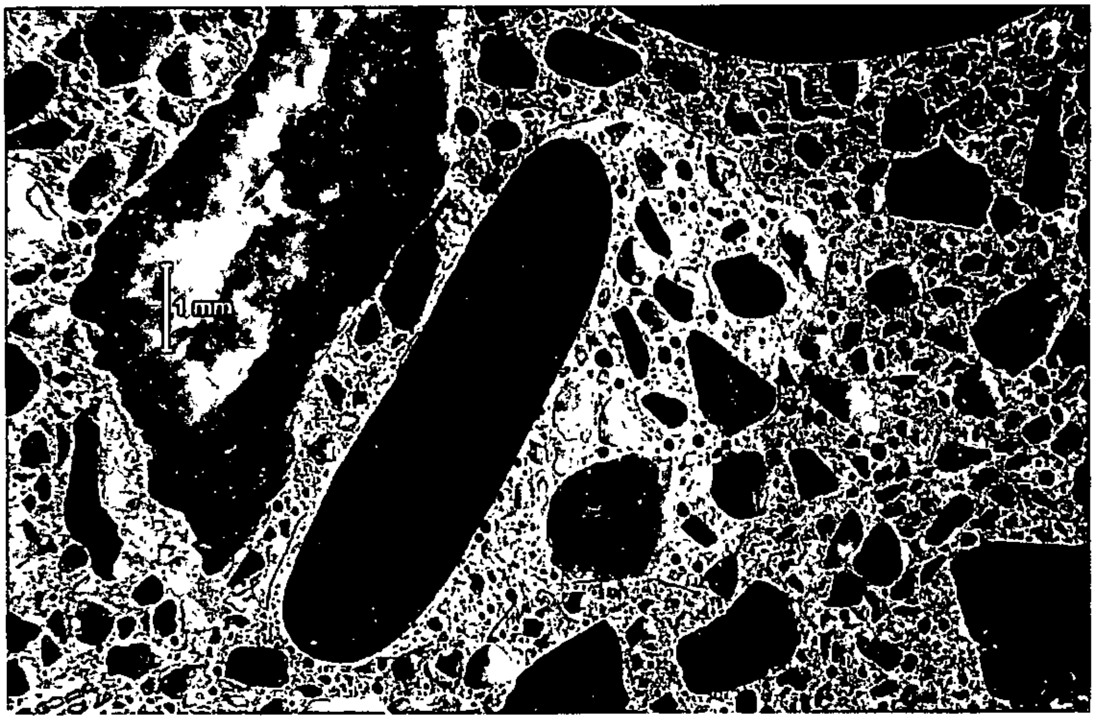
MAG: 30x



SAMPLE ID: 3 DESCRIPTION: Overall hardened air content is 5.3% below 3" depth in the sample. Image is from 6.5" depth.

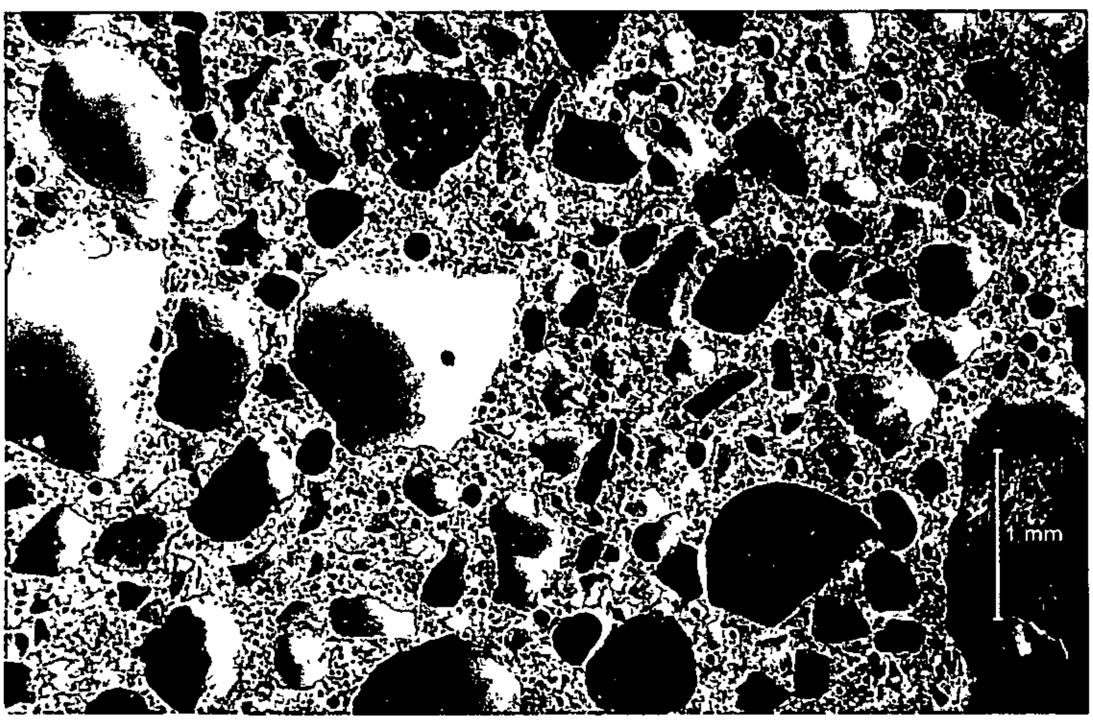
MAG: 30x

APS# 10-03826 DATE: JUNE 17, 2005
PROJECT: SIM-5-094 (049) (076)



SAMPLE ID: 10 DESCRIPTION: An apparent recycled concrete aggregate particle; oulined in red dash line.

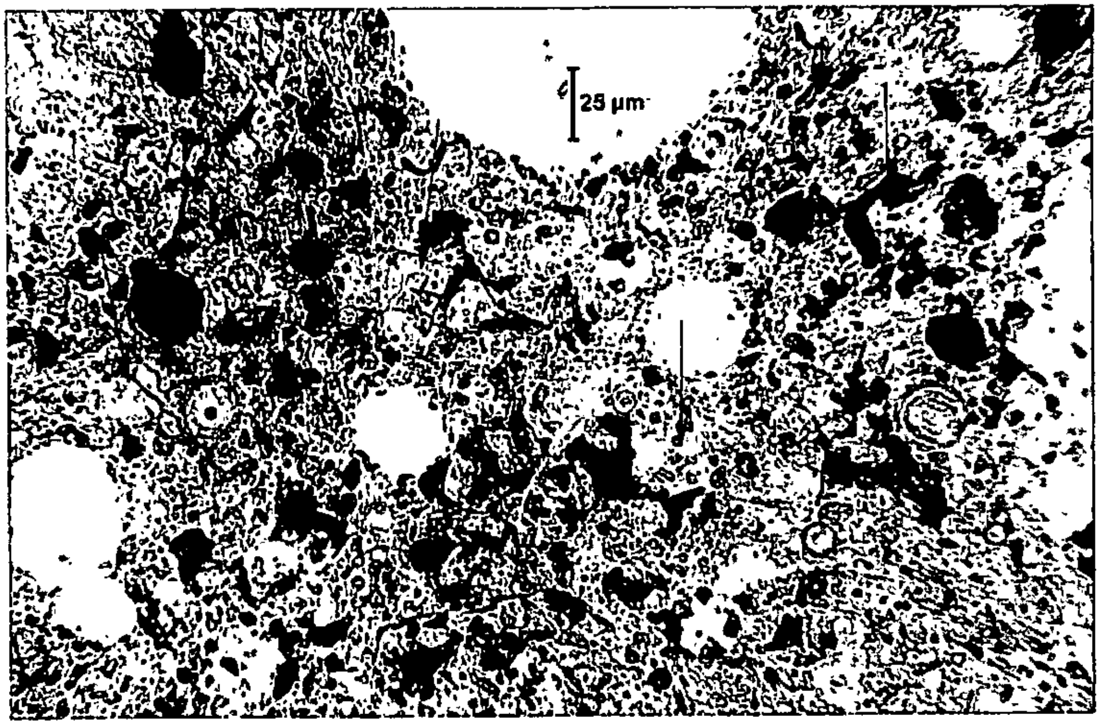
MAG: 15x



SAMPLE ID: 10 DESCRIPTION: Overall hardened air content is 4.3%.

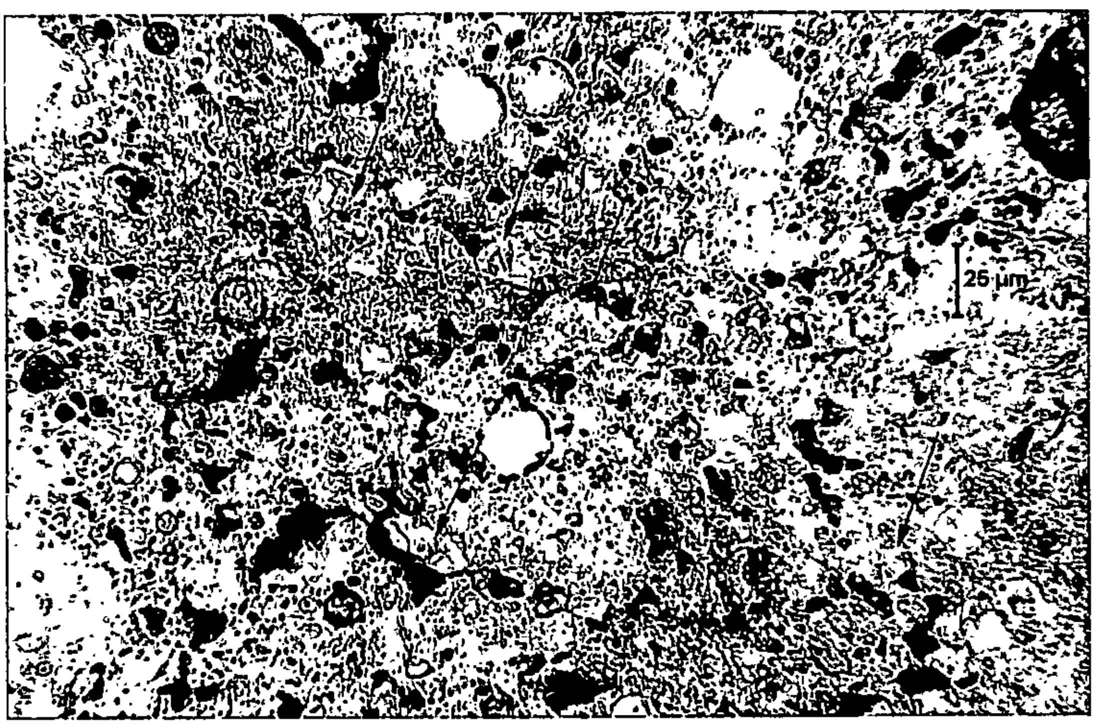
MAG: 30x

APS# 10-03826 DATE: JUNE 17, 2005
PROJECT: SIM-5-094 (049) (076)



SAMPLE ID: 1 DESCRIPTION: Fully hydrated alite portland cement clinker relics in thin section of concrete paste under plane polarized light. Note spherical flyash pozzolan particles.

MAG: 400x



SAMPLE ID: 2 DESCRIPTION: Fully hydrated alite portland cement clinker relics in thin section of concrete paste under plane polarized light. Note spherical flyash pozzolan particles.

MAG: 400x

AMERICAN PETROGRAPHIC SERVICES, INC.

6 2005

REPORT OF AIR VOID ANALYSIS

PROJECT:

SIM-5-094 (049) (076)

REPORTED TO:

NORTH DAKOTA DOT
300 AIRPORT ROAD
BISMARCK, ND 58504

ATTN: SCOTT WUTZKE

APS JOB NO: 10-03826

DATE: JUNE 30, 2005

Sample No:	2 top 3"	2 Bottom	10 Top 3"	10 Bottom
Sample Data:				
Description:	Hardened Concrete Core			
Dimensions:	4" diameter by 8-7/8" long		4" diameter by 8-13/16" long	
Test Data: ASTM:C457 Linear Traverse Method, APS Standard Operating Procedure 00 LAB 003				
Air Void Content, %	3.4	7.5	3.2	5.3
Entrained, % ≤ 0.040"	3.0	4.2	2.5	4.1
Entrapped, % > 0.040"	0.4	3.3	0.7	1.2
Air Voids/inch	7.61	10.94	8.06	8.25
Specific Surface, in^2/in^3	900	580	1000	620
Spacing Factor, inches	0.0062	0.0059	0.0059	0.0075
Paste Content, %	26.0	26.0	27.0	27.0
Magnification	50x	50x	50x	50x
Traverse Length, inches	51"	52"	51"	52"
Test Date	6/28/05	6/28/05	6/28/05	6/28/05

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