

CENTER FOR
**PORTLAND CEMENT CONCRETE
PAVEMENT TECHNOLOGY**

Mr. Michael Ross, Public Works Director
City of Overland Park
8500 Santa Fe Drive
Overland Park, Kansas 66212

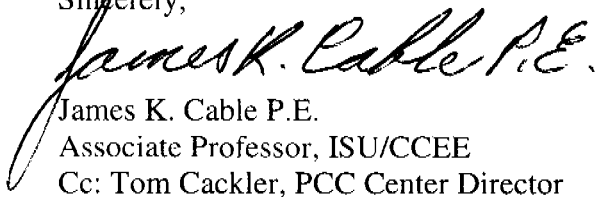
July 28, 2004

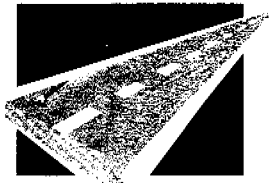
Dear Mike:

On July 14, I sent you copies of the final report for this project. In the days that followed, we received comments from the Slag industry representatives relative to certain comments that I made in the report. The enclosed original copy and seven other copies of the report on the mortar flaking represent changes made to omit some of my comments and add a section regarding the use of deicers on concrete surfaces prior to the first drying and wetting cycle of the finished concrete.

This report is being provided for information purposes. It does not change the thrust of the original report or recommendations provided in that report. Please provide one copy of the revised report to the representatives from Westwood, Merriam, Olathe, Mission, Shawnee and the Ash Grove Cement Co. One copy is reserved for you and one for the KCMMB files. Please contact Center's director, Mr. Tom Cackler (515-294-3230 or tcackler@iastate.edu) if there are questions relative to this report.

Sincerely,


James K. Cable P.E.
Associate Professor, ISU/CCEE
Cc: Tom Cackler, PCC Center Director



**Investigation of KCMMB Mortar Flaking Concerns
Research Work Final Report
Revised July 21, 2004**

Researchers' Note: All information contained in this report is being provided technical information only to the KCMMB and not for legal purposes by any of the interested parties. The opinions expressed in the report are those of the researcher in consultation with the representatives of the Portland Cement Concrete Center at Iowa State University and the American Petrographic Services Inc. through their laboratory analysis.

Introduction: The Kansas City Metro Area relies on much of its urban PCC paving to be accomplished through the use of ready-mix concrete. This concrete is produced from a very large number of producers using 25+ different paving mixes. Aggregate quality in the metro area is of a primary concern to the performance of the concrete pavements and sidewalk/curb projects. Much of the locally available limestone is susceptible to "D Cracking" and many of the sands are very finely graded and are highly ASR reactive. Local officials are working to make concrete pavements viable through resolving each problem as they are identified in terms of materials or construction. Uniformity in material specifications is one of the efforts underway at this time. Limestone has been removed from the design and replaced with granite or quartzite, shipped into the area. Slag has been added, at a replacement rate of 30-39% cement in the mixture, to mitigate the potential effect of ASR reactive sand.

PROBLEM: The efforts of the KCMMB in the areas of specification changes and material selection changes have greatly reduced or eliminated the "D cracking" problems. The current concern is the mortar flaking or scaling in a number of urban concrete surfaces placed in the last two years under the new slag addition specifications. The problem appears to be accelerated in areas of sidewalk, curb, gutters and pavements where deicing materials have been added during the first one to five winters after placement. Local government officials and construction industry personnel have asked the Portland Cement Concrete Center to look at what is causing the problem, will the observed deterioration effect the long term performance of the concrete slabs, and what changes can be made to eliminate (or minimize) it in the future construction projects.

Research Objectives: The following objectives were established for this research effort.

1. Determine the activity that is taking place in the surface of the concrete that allows for the flaking to take place.
2. Determine the expected extent of surface area and depth of paste loss that can be expected over time with the current surface activities. Will the activity stop at the first layer of coarse aggregate or continue to a greater depth over time?

3. Provide short term alternatives for local government to consider in the 2004 construction season to prevent such surface deterioration from happening with 2004 work.
4. Include this type of deterioration in the FHWA proposed Pooled Fund dealing with Ternary mix design. (Please see the note on a project change at the end of this report.)

Data Collection:

With the assistance of the various Kansas City Area city representatives, the KCMMB and a private consultant and the MoKan Chapter of ACPA, cores were obtained on April 20, 2004. MoKan chapter of ACPA coordinated the activity and directed the research team to the individual sites. The principal investigator selected the core locations and recorded the data for each specific core taken. Cores were taken from the areas adjacent to the visibly damaged concrete. This was done in an effort to determine what chemical activities are in progress. Selection of cores from damaged areas tends to miss the reason for the problem and only measure the results of the activity.

Coring was done with the use of a portable, electric powered coring machine. Four inch diameter cores were obtained for the full slab depth of each site. The original core locations were revised to meet local concern areas. Cores were obtained from the following locations/municipalities with the aid of local officials:

1. Overland Park, roundabout at 110th and Lamar
 - Core 1A obtained from the Southeast entrance ramp to the roundabout
 - Core 1B obtained from the same location
2. Mission, sidewalk at W79th and Mission Road
 - Core 2A obtained from street side of sidewalk
 - Core 2B obtained from house side of sidewalk in same general area
3. Westwood, between 50th and 51st and along Belinder
 - Core 3A obtained from sidewalk section constructed in May
 - Core 3B obtained from sidewalk section constructed in September
4. Merriam, 56th Terrace and Farley St.
 - Core 4A obtained from driveway
5. Shawnee, 5327, 5323 and a vacant lot on Woodland north of Johnson
 - Core 5A obtained from driveway apron at 5327 Woodland
 - Core 5B obtained from driveway apron at 5323 Woodland
 - Core 5C obtained from sidewalk across the street from 5323 Woodland, near vacant lot.
6. Olathe, 704 Hunter and 901 Sunset St.
 - Core 6A obtained from driveway at 704 Hunter St.
 - Core 6B obtained from driveway at 901 Sunset St.
7. Ash Grove Cement Co.
 - * Cores AG1 and AG4 were obtained from the parking lot of the corporate offices

All cores were tagged with core number only and returned to Iowa State University for analysis by the researcher. All other references in this report and the laboratory testing were made only by number to keep the testing random and unbiased.

MoKan ACPA staff, in conjunction with the construction industry and city representative provided the researcher with the available construction records regarding concrete materials sources, aggregate gradation, ASR susceptibility, cement and water chemistry for each pavement cored. This information included construction records kept by the contractor and owner, construction environmental information, time of day of placement, curing time and method, and maintenance activities after construction for the first two years.

Material Testing and Analysis:

The objective of this study was to determine the causes and potential solutions to the problem. Due to workloads at the ISU laboratory, the cores were sent to the American Petrographic Services Inc. (APS), in Saint Paul, MN. for analysis. The petrographer was asked to look in depth at the physical and chemical activity in the top one inch of each core along with comparing that to the remaining depth of the core. The petrographer was not given any information on the source of the core, its mix design or construction.

The testing procedures and results of that analysis are found in the APS report which is the appendix to this report. The test results on the general properties included the following items:

1. The coarse aggregate in the cores was comprised of ¾" to 1" maximum sized crushed quartzite and granite that was fairly well graded with fair to good overall distribution.
2. Ground granulated blast furnace slag pozzolanic admixture was observed in the concrete samples.
3. The paste color of the cores was grayish tan with the slump estimated to be medium to high (3" to 6").
4. The paste hardness of the cores was judged to be medium with paste/aggregate bond considered fair to good.
5. The depth of carbonation was up to 5/8".
6. The water/cementitious ratio in the cores was estimated at between 0.40 to 0.50 with approximately 3-10% unhydrated cement particles and a purposeful addition of ground granulated blast furnace slag.

Items 1 and 2 represent a good identification of materials in the concrete. Item 4 does not indicate a bonding problem between the materials in the mix. Items 3, 5 and 6 were the ones of interest to the researcher. The high slump, and water/cement ratio in the top of the cores was reason for concern when compared to the normal values in the remainder of each core. The amount of unhydrated cement and slag is normal for this type of analysis. The depth of carbonization is reason for concern. Pavements of 10-20 years in age often only exhibit 1/16" of carbonation. This drove the research to look at possible causes and effects of the carbonation process.

Special attention should be given by the reader when looking at the test results of each core in the areas of air content, depth of carbonation, microcracking, slump, water/cementitious material ratio and the cement hydration. One must also remember

that the conclusion for a given core of being "fair to good" would be expected in the cores that were given to the laboratory for analysis. They were selected from areas adjacent to damaged areas in the various sites.

Air void analysis is of value to the owner in the fact that it gives an indication of the durability of the concrete to resist the effect of deicers and freeze/thaw actions. In this case, core 4A was determined to contain a low entrained air content and its long-term resistance to freeze-thaw deterioration is suspect. There was variability in air content between the cores as would be expected. The hardened air contents ranged from a low of 4.6% (core 4A) to a high of 9.6% (core 5A). Eleven of the fourteen cores had hardened air contents between 5.0% and 7.6% and this was in very good agreement with the construction records from the various sites. Spacing factor and specific surface values tend to provide additional information about the ability of a concrete mixture to resist expansion and cracking related to frost damage. Current ACI guidelines for air-entrained concrete suggest that the spacing factor should be less than 0.008" (although this is often increased to 0.010" for mild climates) and the specific surface of the air bubbles typically range from about 600 in⁻¹ to 1100 in⁻¹. In this testing, cores 4A fell out of bounds on both factors. Cores AG1 and AG4 exhibited specific surface values that were lower than the ACI recommendations and AG1 had a marginally high (0.009") spacing factor. The remaining eleven cores had spacing factors and specific surface values that were considered consistent with frost-resistant concrete. However, detailed investigation of the near-surface region of the cores indicated that the top 1/32" appeared to be deficient in entrained air voids in the cores denoted as 1A and AG1.

Depth of carbonation provided the most variation between cores and appears to be abnormal in its magnitude for early age concrete. A depth of 1/32-1/16" (1-2 mm) might be expected in random samples of old age concrete but the values of up to 5/8" (15 mm) are excessive. Carbonation depths in excess of 1/8" (3 mm) were documented in eleven of the fourteen specimens.

Micro cracking in the top of some of the samples is related to the carbonation and high water/cementitious values found in some of the samples. The data also indicates that the estimated slump rose (3-6") as the water/cementitious material ratio moved above 0.45. Detailed analysis of the near-surface region (top 1/8 " or 3 mm) of the cores suggested that the water/cementitious material ratio at the top of the core was higher than that of the bulk concrete in seven out of the fourteen cores. Since some of the mixtures already had water/cementitious material ratios in the 0.45-0.50 range, any additional increase in this parameter would suggest that the durability should suffer. The exact reason for the increase in water/cementitious material ratio at the top surface of some of the concrete cores is difficult to pinpoint. However, concrete finishing and curing practices often play a significant role in these situations. Both the finishing and curing practices are highly dependent on the bleeding characteristics of the concrete mixture. In turn, the bleeding characteristics are impacted by the amount and fineness of cementitious material in the mixture, the ambient environmental conditions, the use of chemical admixtures (especially set retarders, or water reducers that delay setting time) and subbase conditions at the site.

The remaining parts of each core have been retained by the researcher and are available for viewing by the clients.

Construction Data Analysis:

A spreadsheet of construction data was developed to display each of the data items supplied to the research team from the various cities. The amount of construction data varied in quantity with the various entities. The data included construction dates, air content, air and concrete temperatures at placement, unit weight of the concrete, slump, and notes on curing materials and methods. To this data, the research team added national weather data for the appropriate areas in terms of wind speed, rainfall, and relative humidity at construction and average values for the month following construction. The date of the first freezing temperature for the construction area after construction was also recorded.

Construction was accomplished primarily in the summer months of the year (June-August). The Merriam pavement was built in November and one of the Westwood pavements was constructed in September. No noticeable difference in deterioration was noted in the field or lab results related to construction timing.

The curing records indicated a range of methods from no recorded cure to the application of white pigmented curing compound to a seven day wet cure with the addition of evaporation retarders and salt guard sealers. The primary method of cure for the sidewalks and driveway aprons cored was determined to be the addition of white pigmented curing compound.

The national weather data was used to determine the length of time in days between construction of each project and the first freezing temperatures. The Ash Grove cores were taken from areas that received freezing air temperatures 79 days after placement. In the case of the Overland Park site, freezing temperatures occurred from 84 to 128 days after placement. Concrete mixtures containing slag cements are known to gain strength slower in the first days after construction but continue to grow at a faster rate (after the initial 1-3 days) over time than traditional cement mixes. This provided time for the concrete containing slag to gain adequate strength throughout the depth of the concrete. No cracking (other than surface scaling or flaking) was noted in any of the slabs that were tested.

Recorded wind speeds for the cities involved during construction and for the first 30 days after construction ranged from 5 to 17 mph according to national weather records. With the exception of the Shawnee and Ash Grove sites, local surroundings made it very difficult to experience winds of any speed to affect the curing process to any degree.

The relative humidity recorded for the construction and month thereafter ranged from 40 to 87% overall and with variations of 20% for each of the cities within that overall range. These would be common values for the Kansas City area. The temperatures for the same period ranged from 60 to 104F during the days of construction and from 46 to 106F over

the first 30 days of the pavement lives. Essentially each of the sites saw hot, dry days and large temperature swings during the night time hours during the first month of life.

The construction records indicated slumps between 1-1/2" to 5-1/4 inches in the field. Individual days of placement had much less variation, usually within 1". The air content recorded for the concrete ranged between 5.1 and 7.8% for the concrete tested. These were acceptable field values. The average recorded air temperature at placement was 62-92F and the concrete temperatures between 68 and 91F.

Concrete mix information was also gathered where possible on the projects. The mixes in Overland Park, Shawnee and Olathe employed approximately 38-40% slag replacement. The pavement in Merriam had no slag and also had a poor air matrix. Missouri river sand was used in the Merriam, Shawnee, and Olathe projects while Kaw River sand was used in Overland Park.

Petrographic Analysis Testing Conclusions:

The conclusions reached by American Petrographic Services Inc. regarding the cores are as follows:

1. The overall quality of the concrete is fair to good to poor (core 4A). The cement paste was moderately dense and hard with carbonation up to 5/8". The crushed quartzite and granite aggregate was hard, appeared sound and durable. The concrete was placed with moderate slump.
2. The concrete in core 4A has poor durability. The concrete in core 4A contained an air void system that is not consistent with current technology for resistance to freeze-thaw deterioration. We expect deterioration to continue in the carbonated surficial paste if exposed to freezing conditions when saturated.
3. The cause of the scaling was primarily due to ineffective curing. We observed the following:
 - A. Carbonation and subvertical microcracking at the surface up to 5/8".
 - B. A soft and friable high water content paste in the top up to 1/16" indicating excess water was reworked into the surface paste (cores 2A, 2B, AG1 and AG4).

A copy of APS report is attached to this report for your information.

Project Conclusions and Recommendations:

1. The primary cause of the mortar flaking is identified from the cores as carbonation of the top 1- 15 mm (1/32 – 5/8") of the surface. The carbonation appears to be the result of excessive amounts of water being present near the surface of the concrete during finishing and prior to the application of curing materials. This also tended to increase the water/cementitious material ratio at the surface of the cores which reduced the strength and durability at this location, and allows for vertical microcracking and delamination between the paste and coarse aggregates near the surface of the concrete. The problem is exacerbated when deicing materials are placed on the pavement by choice or is contained in water from vehicles turning or parking.

2. The majority of the cores tested were found to be fair to good quality throughout the depth of the core with the deterioration limited to the first 1-15 mm at the top.
3. It is not anticipated that the carbonation will continue to any greater depths in the future in any of the pavements tested.
4. Future options for care of the existing pavements include the following suggested options:
 - a. Do nothing
 - b. Grind the surfaces to a depth of ¼" to provide a uniform texture or appearance. This should be done with caution as to not dislodge coarse aggregate particles.
 - c. Consider surface seals only if it can be demonstrated to penetrate through the carbonated layer.
 - d. Replacement should only be considered for the area of core 4A if deterioration continues. The air matrix is not adequate to resist large amounts of deicers and freeze thaw cycles. All other pavements tested are of adequate strength and air matrix to provide the design life performance.
5. Mix designs could be improved in the following manner:
 - a. Limit the use of sands for PCC work to Kaw River Sand and reduce the maximum slag replacement rate to 25% by mass as an interim measure only. The recommendation is based on a February 20, 1998 FHWA Policy Memorandum that "in the absence of mix specific data, the substitution rate of GGBF slag should be limited to 25% in concrete exposed to deicing salts and 50% in other applications". The Kaw River sand has been identified as the least reactive of the local sands. Hence, this one of the areas that is being considered for further study by the PCC Center in the Deicer Scaling Resistance Pooled Fund project. Kansas City Metro Area participation in that study can help direct some of that work to this area of concern.
 - b. Set the target water/cementitious ratio to a maximum of 0.45. The data indicates that those pavements with 0.45 or less exhibit less flaking problems.
 - c. Consider moving to a mix that is approximately 55-60% coarse aggregate. This will reduce the amount of alkali reactive sands that could be present in the mix.
6. Testing
 - a. Consider changes in your aggregate and cementitious materials testing procedures to better represent your materials and not overreact to chemical problems. One such suggestion is to consider ASTM C227 and the use of the pink quartzite and Missouri River sand as the qualifier instead of the use of Pyrex glass. This will better represent available products and may allow you to reduce the need for a given amount of slag while using available materials. This type of test will also allow you to set standards that will allow both local sands with appropriate mitigation measures.
7. Construction:
 - a. Finish only when the bleed water stops. This may be later than conventional concrete surfaces and will depend on the amount of slag in

the mixture, the ambient environmental conditions, the temperature of the concrete mixture, the presence of chemical admixtures that impact setting time and the type of subbase that is used. Information is contained in ACI publications 304 and 308 on the proper finishing of concrete in hot weather.

- b. Attention to curing material application times and rates must be emphasized for both conventional concrete and projects utilizing slag. For conventional cements, the first three days of life are critical in terms of curing and strength gain. In the case of projects utilizing slag the time of 7-10 days of cure and care is suggested. A wet cure would be preferred. If sprayed on cure is to be used, it must be applied while the surface is still moist to be of value and it must provide complete coverage of the surface.

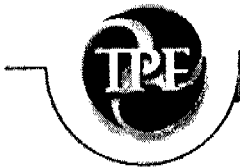
8. Operation

- a. Local government agencies should be aware of the level of aggressiveness of various deicers being applied to the street systems and the impact it may have on concrete surfaces of driveways and sidewalks. This type of information must be considered in decisions pertaining to construction and sealing of concrete surfaces prior to the application of deicers in the early life of the slabs.

Your pavements are not in danger of failing to perform in terms of service to the public. They are experiencing esthetic defects that can be corrected in existing pavements. Chances for future such problems can be greatly reduced or eliminated with sound concrete placement, finishing and curing practices. In short the solution to this problem involves not only consideration of modifications in the mix design and tighter controls on materials selection, but also more attention to construction processes and curing timing, methods and materials. The solution is available and you can achieve it with small changes in these areas.

I also encourage you to complete the negotiations with the PCC Center on participation by your organization in the "Deicer scaling Resistance of Concrete Pavements, Bridge Decks and Other Structures containing Slag Cement" Pooled Fund Study. This is different from the original "Ternary Mix Design" study we discussed. The Deicer study is currently in the advertisement and funding study phase. We should see research work begin in the next 12 months on the Deicer study. This study is related most closely to your needs in terms of timetable and problem/solutions. The Ternary Mix study has not been advertised or funded to date. Please contact Mr. Tom Cackler, Director of the PCC Center 515-294-3230 with regard to this work, estimated to cost your group \$25,000 over a three year period as was originally discussed with the other project.

If you have any questions regarding the information provided in this report or the conclusions drawn, do not hesitate to call Jim Cable 515-294-2862.



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Solicitation Number: 846
Status: Solicitation posted
Title: Deicer Scaling Resistance of Concrete Pavements, Bridge Decks and Other Structures Containing Slag Cement
Sponsoring Agency: Iowa Department of Transportation
 800 Lincoln Way
 Ames, IA
Sponsor Solicitation Contact: Sandra Larson (sandra.larson@dot.state.ia.us)
 Phone: 515-239-1205
 Fax: 515-239-1766
Technical Contact: Jim Berger (James.Berger@dot.state.ia.us)
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 Phone: 515- 239-1843
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Lead Agency: Iowa Department of Transportation
 800 Lincoln Way
 Ames, IA
FHWA Technical Liaison: Max Grogg (Max.Grogg@fhwa.dot.gov)
Partners: IA, KS
Date Posted: 03/01/2004 03:01:33 PM
Solicitation Expires: 06/30/2004
Start Year: 2004
End Year: 2007
Duration: 36 months
100% SP&R Approval: Pending Approval
Total Dollar Commitments Required: \$450,000
Commitments Received: \$50,000
Background: Concrete containing slag generally exhibits excellent long-term strength and durability. However, several authors have expressed concern about the scaling resistance of concrete containing slag, especially when the dosage of slag exceeds 50% of the total cementitious material in the mixture (1-6). Much of the concern appears to be based on the results of laboratory scaling tests (most commonly ASTM C672) (7), which tend to be in poor agreement with field observations (2-6, 8-10). Others indicate that the test performs adequately for evaluating the relative scaling resistance of concrete specimens (11). A systematic study is needed to determine why this anomalous relationship exists between the scaling of field and laboratory concrete specimens containing slag.

Ground granulated blast-furnace slag (GGBFS), referred to simply as 'slag' in this document, has a long history of use with portland cement in concrete. Generally, slag improves many properties of both plastic and hardened concrete. The Transportation Research Board (TRB) Committee

on Chemical Additions and Admixtures for Concrete summarizes the impact of slag on the properties of portland cement concrete (PCC) as listed in the table below (1). It is apparent that slag can make a significant contribution to the production of durable concrete products.

Objectives:

- Document the field performance of existing concrete pavements, bridge decks, and other structures made with slag cement that have been exposed to cyclical freeze-thaw cycles in the presence of deicing chemicals.
- Determine from the field study and construction/design records which mixtures and construction parameters have produced scale-resistant concrete containing slag.
- Determine the effectiveness of ASTM C672 in predicting the deicer scaling behavior of field concrete. If discrepancies are noted, an attempt will be made to explain why the lab tests do not adequately mimic field performance and alternative procedures will be recommended to improve the correlation between lab tests and field performance.

Scope of Work:

The proposed research project will investigate the important variables that impact the scaling resistance of concrete containing slag cement. The project will consist of a field study and a laboratory study. The field study will collect and evaluate concrete samples extracted from pavement slabs. The laboratory study will investigate how specific variables influence the deicer scaling resistance of concrete mixtures.

Comments:

10 States @ \$25,000 over three years.

State DOTs* (10 @ \$25,000) \$250,000
 Slag Cement Association* \$100,000
 Federal Highway Administration \$100,000
 Total Budget \$450,000

Documents:

<http://www.pooledfund.org/documents/solicitations/846.pdf>

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AMERICAN
PETROGRAPHIC
SERVICES, INC.

REPORT OF CONCRETE TESTING

PROJECT:

KANSAS CITY CORES

REPORTED TO:

CENTER OF TRANSPORTATION
RESEARCH & EDUCATION
2901 S. LUKE DRIVE, SUITE #3100
AMES, IOWA 50010

ATTN: TOM CACKLER

APS JOB NO: 10-03195

DATE: JUNE 18, 2004

INTRODUCTION

This report presents the results of laboratory work performed by our firm on fourteen concrete core samples submitted to us by Mr. Scott Schlorholtz of Iowa State University on April 29, 2004. We understand the concrete cores were obtained from exterior concrete sidewalks that have experienced scaling. The scope of our work was limited to performing petrographic analysis testing to document the cause of the scaling.

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 to poor (core #4A). The cement paste was moderately dense and hard with carbonation up to 5/8". The crushed quartzite and granite aggregate was hard, appeared sound, and durable. The concrete was placed with a moderate slump.
2. The concrete in core #4A has poor durability. The concrete in core #4A contained an air void system that is not consistent with current technology for resistance to freeze-thaw deterioration. We expect deterioration to continue in the carbonated surficial paste if exposed to freezing conditions when saturated.
3. The cause of the scaling was primarily due to ineffective curing. We observed the following:
 - A. Carbonation and subvertical microcracking at the surface up to 5/8".
 - B. A soft and friable high water content paste in the top up to 1/16" indicating excess water was reworked into the surface paste (Cores #2A, 2B, AG1, and AG4).

SAMPLE IDENTIFICATION

<u>Sample No.</u>	<u>Original Sample Dimensions</u>
1A	95 mm (3-3/4") diameter x 295 mm (11-5/8") long
2A	95 mm (3-3/4") diameter x 216 mm (8-1/2") long
3A	92 mm (3-5/8") diameter x 127 mm (5") long
4A	95 mm (3-3/4") diameter x 178 mm (7") long
5A	92 mm (3-5/8") diameter x 194 mm (7-5/8") long
6A	92 mm (3-5/8") diameter x 191 mm (7-1/2") long
1B	92 mm (3-5/8") diameter x 318 mm (12-1/2") long
2B	95 mm (3-3/4") diameter x 178 mm (7") long
3B	92 mm (3-5/8") diameter x 111 mm (4-3/8") long
5B	92 mm (3-5/8") diameter x 216 mm (8-1/2") long
6B	95 mm (3-3/4") diameter x 152 mm (6") long
AG1	92 mm (3-5/8") diameter x 168 mm (6-5/8") long
AG4	92 mm (3-5/8") diameter x 191 mm (7-1/2") long
5C	92 mm (3-5/8") diameter x 130 mm (5-1/8") 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 in the cores was comprised of 3/4" to 1" maximum sized crushed quartzite and granite that was fairly well graded with fair to good overall distribution.
2. Ground granulated blast furnace slag pozzolanic admixture was observed in the concrete samples.
3. The paste color of the cores was grayish tan with the slump estimated to be medium to high (3" to 6").
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 5/8".
6. The water/cementitious ratio in the cores was estimated at between 0.40 to 0.50 with approximately 3-10% unhydrated cement particles and a purposeful addition of ground granulated blast furnace slag.

Air Content Testing

See attached sheets.

TEST PROCEDURES

Laboratory testing was performed on April 29, 2004 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.

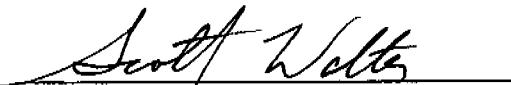
Air Content Testing

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.

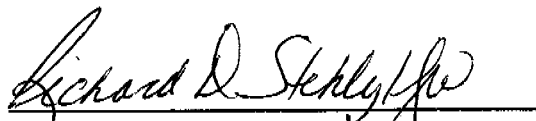
REMARKS

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.

Report Prepared By:



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

Job #: 10-03195
Sample Identification: 1A

Date: 6-10-04/6-22-04
Performed by: S. Malecha/G. Moulzolf

I. General Observations

1. Sample Dimensions: Our analysis was performed on a 295 mm (11-5/8") x 94 mm (3-11/16") x 44 mm (1-3/4") thick polished section that was cut from the original 95 mm (3-3/4") diameter x 295 mm (11-5/8") long core.
2. Surface Conditions:
Top: Rough, traffic worn surface exposing numerous fine aggregate surfaces
Bottom: Rough, irregular, formed surface placed on grade
3. Reinforcement: None observed.
4. General Physical Conditions: The top surface was traffic worn exposing numerous fine aggregate surfaces. The concrete was purposefully air entrained and overall contains a fairly distributed air void system considered freeze-thaw durable. However, a loss of some purposeful air entrainment was observed in the top approximately 1 mm (1/32") of the sample. Many subvertical drying shrinkage microcracks proceed up to 16 mm (5/8") depth from the top surface. Carbonation ranged from 2 mm (1/16") up to 4 mm (5/32") depth from the top surface. Good overall condition.

II. Aggregate

1. Coarse: 19 mm (3/4") maximum sized crushed granite. Fairly well graded with fair overall distribution.
2. Fine: Natural, quartz, feldspar, and lithic sand 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: 5.9% total, 1.4% entrapped, 4.5% entrained
2. Depth of carbonation: Ranged from 2 mm (1/16") up to 4 mm (5/32")
3. Pozzolan presence: None observed
4. Paste/aggregate bond: Good
5. Paste color: Medium tan becoming lighter in the carbonated top up to 4 mm (5/32") and dark blue gray approximately 60 mm (2-3/8") depth from the top surface.
6. Paste hardness: Medium
7. Paste proportions: 20% to 22%
8. Microcracking: Many subvertical drying shrinkage microcracks proceed up to 16 mm (5/8") depth from the top surface.
9. Secondary deposits: None observed
10. Slump: Estimated, medium (3-5")
11. Water/cementitious ratio: Estimated at between 0.40 to 0.45 with approximately 7-9% unhydrated or residual portland cement clinker particles and 6-8% unhydrated ground granulated blast furnace slag particles.
12. Cement hydration: Alites-well to fully; Belites-moderate to well; Ground granulated blast furnace slag-moderate to well

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 #: 10-03195
Sample Identification: 1B

Date: 6-9-04/6-22-04
Performed by: S. Malecha/G. Moulzolf

I. General Observations

1. **Sample Dimensions:** Our analysis was performed on a 318 mm (12-1/2") x 95 mm (3-3/4") x 46 mm (1-13/16") thick polished section that was cut from the original 95 mm (3-3/4") diameter x 318 mm (12-1/2") long core.
2. **Surface Conditions:**

Top: Rough, broomed surface with traffic wear and minor scaling
Bottom: Rough, irregular, formed surface placed on grade
3. **Reinforcement:** None observed.
4. **General Physical Conditions:** The broomed top surface was traffic worn exposing numerous fine aggregate surfaces. Also, a small amount of scaling was observed on the top surface directly over few coarse aggregate particles (mortar fines). Approximately 15% of the top surface was scaled away from the cored edges, most likely during procurement of the sample. A few subvertical drying shrinkage microcracks proceed up to 12 mm (1/2") depth from the top surface. Carbonation ranged from 1 mm (1/32") up to 12 mm (1/2") depth along subvertical microcracking. The concrete was purposefully air entrained and contains a fairly well distributed air void system considered freeze-thaw durable. The sample was fractured, in an orientation subparallel to the top surface, approximately 127 mm (5") depth from the top surface. Fair overall condition.

II. Aggregate

1. **Coarse:** 19 mm (3/4") maximum sized crushed granite. Fairly well graded with good overall uniform distribution.
2. **Fine:** Natural, quartz, feldspar, and lithic sand 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:** 8.8% total, 2.3% entrapped, 6.5% entrained
2. **Depth of carbonation:** Ranged from 1 mm (1/32") up to 12 mm (1/2") depth along subvertical microcracking
3. **Pozzolan presence:** None observed
4. **Paste/aggregate bond:** Good
5. **Paste color:** Medium tan becoming lighter in the carbonated top up to 4 mm (5/32") and dark blue gray approximately 38 mm (1-1/2") depth from the top surface.
6. **Paste hardness:** Medium
7. **Paste proportions:** 21% to 23%
8. **Microcracking:** A few subvertical drying shrinkage microcracks proceed up to 12 mm (1/2") depth from the top surface.
9. **Secondary deposits:** None observed
10. **Slump:** Estimated, medium (3-5")
11. **Water/cementitious ratio:** Estimated at between 0.40 to 0.45 with approximately 7-9% unhydrated or residual portland cement clinker particles and 6-8% unhydrated ground granulated blast furnace slag particles.
12. **Cement hydration:** Alites-well to fully; Belites-moderate to well; Ground granulated blast furnace slag-moderate to well

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 #: 10-03195
Sample Identification: 2A

Date: 6-10-04/6-22-04
Performed by: S. Malecha/G. Moulzolf

I. General Observations

1. Sample Dimensions: Our analysis was performed on a 197 mm (7-3/4") x 94 mm (3-11/16") x 44 mm (1-3/4") thick polished section that was cut from the original 95 mm (3-3/4") diameter x 216 mm (8-1/2") long core.
2. Surface Conditions:

Top: Rough, broomed surface
Bottom: Rough, irregular, formed surface placed on grade
3. Reinforcement: Poly-fiber reinforcement was observed well distributed throughout the sample.
4. General Physical Conditions: A few subvertical drying shrinkage microcracks proceed up to 6 mm (1/4") depth from the top surface. Carbonation ranged from 3 mm (1/8") up to 7 mm (9/32") depth along subvertical microcracking. The top approximately 2 mm (1/16") of the sample was characterized by a softer, lighter colored paste indicative of excessive w/c. Most coarse aggregate particles were segregated from the top surface to at least 2 mm (1/16") depth. The concrete was purposefully air entrained and contains a fairly well distributed air void system considered freeze-thaw durable. Good overall condition.

II. Aggregate

1. Coarse: 19 mm (3/4") maximum sized crushed granite. Fairly well graded with fair overall distribution.
2. Fine: Natural, quartz, feldspar, and lithic sand 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: 7.3% total, 1.2% entrapped, 6.1% entrained
2. Depth of carbonation: Ranged from 3 mm (1/8") up to 7 mm (9/32") depth along subvertical microcracking
3. Pozzolan presence: None observed
4. Paste/aggregate bond: Fair
5. Paste color: Tan becoming tannish white in the carbonated top up to 7 mm (9/32") and blue gray approximately 108 mm (4-1/4") depth from the top surface.
6. Paste hardness: Medium, soft in the top approximately 2 mm (1/16")
7. Paste proportions: 23% to 25%
8. Microcracking: A few subvertical drying shrinkage microcracks proceed up to 6 mm (1/4") depth from the top surface.
9. Secondary deposits: None observed
10. Slump: Estimated, medium (3-5")
11. Water/cementitious ratio: Estimated at between 0.43 to 0.48 with approximately 6-8% unhydrated or residual portland cement clinker particles and 3-5% unhydrated ground granulated blast furnace slag particles.
12. Cement hydration: Alites-mostly fully; Belites-moderate to fully; Ground granulated blast furnace slag-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 #: 10-03195
Sample Identification: 2B

Date: 6-14-04/6-22-04
Performed by: S. Malecha/G. Moulzolf

I. General Observations

1. **Sample Dimensions:** Our analysis was performed on a 181 mm (7-1/8") x 95 mm (3-3/4") x 48 mm (1-7/8") thick polished section that was cut from the original 95 mm (3-3/4") diameter x 178 mm (7") long core.
2. **Surface Conditions:**

Top: Rough, broomed surface with mortar erosion exposing many fine aggregate surfaces
Bottom: Rough, irregular, formed surface placed on grade
3. **Reinforcement:** Poly-fiber reinforcement was observed well distributed throughout the sample.
4. **General Physical Conditions:** The broomed top surface was mortar eroded exposing many fine aggregate surfaces. Carbonation ranged from 2 mm (1/16") up to 5 mm (3/16") depth from the top surface. The top approximately 2 mm (1/16") of the sample was characterized by a softer, lighter colored paste indicative of excessive w/c. The concrete was purposefully air entrained and contains a fairly well distributed air void system considered freeze-thaw durable. Good overall condition.

II. Aggregate

1. **Coarse:** 19 mm (3/4") maximum sized crushed granite. Fairly well graded with good overall uniform distribution.
2. **Fine:** Natural, quartz, feldspar, and lithic sand 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:** 5.1% total, 0.4% entrapped, 4.7% entrained
2. **Depth of carbonation:** Ranged from 2 mm (1/16") up to 5 mm (3/16")
3. **Pozzolan presence:** None observed
4. **Paste/aggregate bond:** Fair
5. **Paste color:** Tan becoming tannish white in the carbonated top approximately 2 mm (1/16") and blue gray approximately 89 mm (3-1/2") depth from the top surface.
6. **Paste hardness:** Medium becoming soft in the top approximately 2 mm (1/16") of the sample
7. **Paste proportions:** 22% to 24%
8. **Microcracking:** None observed
9. **Secondary deposits:** None observed
10. **Slump:** Estimated, medium (3-5")
11. **Water/cementitious ratio:** Estimated at between 0.43 to 0.48 with approximately 6-8% unhydrated or residual portland cement clinker particles and 3-5% unhydrated ground granulated blast furnace slag particles.
12. **Cement hydration:** Alites-mostly fully; Belites-moderate to well; Ground granulated blast furnace slag-moderate to well

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 #: 10-03195
Sample Identification: 3A

Date: 6-14-04/6-22-04
Performed by: S. Malecha/G. Moulzolf

I. General Observations

1. Sample Dimensions: Our analysis was performed on a 124 mm (4-7/8") x 92 mm (3-5/8") x 38 mm (1-1/2") thick polished section that was cut from the original 92 mm (3-5/8") diameter x 127 mm (5") long core.
2. Surface Conditions:

Top: Rough, broomed surface with minor scaling
Bottom: Rough, irregular, formed surface placed on grade
3. Reinforcement: None observed
4. General Physical Conditions: Scaling was observed on the top surface directly over a coarse aggregate particle (mortar flaking). A few subvertical drying shrinkage microcracks proceed up to 1 mm (1/32") depth from the top surface. Subhorizontal microcracking (popout) was observed in the top approximately 1 mm (1/32") of the sample. Carbonation ranged from negligible and intermittent up to 5 mm (3/16") depth from the top surface. The concrete was purposefully air entrained and contains a fairly well distributed air void system considered freeze-thaw durable. Fair overall condition.

II. Aggregate

1. Coarse: 19 mm (3/4") maximum sized crushed granite. Fairly well graded with good overall uniform distribution.
2. Fine: Natural, quartz, feldspar, and lithic sand 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: 6.8% total, 1.0% entrapped, 5.8% entrained
2. Depth of carbonation: Ranged from negligible and intermittent up to 6 mm (1/4")
3. Pozzolan presence: None observed
4. Paste/aggregate bond: Fair to good
5. Paste color: Tannish gray becoming blue gray approximately 102 mm (4") depth from the top surface.
6. Paste hardness: Medium
7. Paste proportions: 22% to 24%
8. Microcracking: A few subvertical drying shrinkage microcracks proceed up to 1 mm (1/32") depth from the top surface. Subhorizontal microcracking (scaling) was observed in the top approximately 1 mm (1/32") of the sample.
9. Secondary deposits: None observed
10. Slump: Estimated, medium (3-5")
11. Water/cementitious ratio: Estimated at between 0.43 to 0.48 with approximately 6-8% unhydrated or residual portland cement clinker particles and 3-5% unhydrated ground granulated blast furnace slag particles.
12. Cement hydration: Alites-well to mostly fully; Belites-low to well; Ground granulated blast furnace-low to well

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 #: 10-03195
Sample Identification: 3B

Date: 6-14-04/6-22-04
Performed by: S. Malecha/G. Moulzolf

I. General Observations

1. Sample Dimensions: Our analysis was performed on a 108 mm (4-1/4") x 95 mm (3-3/4") x 44 mm (1-3/4") thick polished section that was cut from the original 92 mm (3-5/8") diameter x 111 mm (4-3/8") long core.
2. Surface Conditions:
Top: Rough, broomed surface
Bottom: Rough, irregular, formed surface placed on grade
3. Reinforcement: Fine poly-fiber reinforcement was observed well distributed throughout the sample.
4. General Physical Conditions: A few fine subvertical drying shrinkage microcracks proceed up to 1 mm (1/32") depth from the top surface. Carbonation ranged from 1 mm (1/32") depth up to 2 mm (1/16") depth from the top surface. The concrete was purposefully air entrained and contains a fairly well distributed air void system considered freeze-thaw durable. Good overall condition.

II. Aggregate

1. Coarse: 19 mm (3/4") maximum sized crushed quartzite. Fairly well graded with good overall uniform distribution.
2. Fine: Natural, quartz, feldspar, and lithic sand 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: 7.6% total, 1.2% entrapped, 6.4% entrained
2. Depth of carbonation: Ranged from 1 mm (1/32") up to 2 mm (1/16") (3/16")
3. Pozzolan presence: None observed
4. Paste/aggregate bond: Fair
5. Paste color: Tannish gray becoming gray in the carbonated top up to 2 mm (1/16") and blue-gray approximately 76 mm (3") depth from the top surface
6. Paste hardness: Medium
7. Paste proportions: 20% to 22%
8. Microcracking: A few fine subvertical drying shrinkage microcracks proceed up to 1 mm (1/32") depth from the top surface.
9. Secondary deposits: None observed
10. Slump: Estimated, medium (3-5")
11. Water/cementitious ratio: Estimated at between 0.43 to 0.48 with approximately 5-7% unhydrated or residual portland cement clinker particles and 3-5% unhydrated ground granulated blast furnace slag particles.
12. Cement hydration: Alites-well to fully; Belites- moderate to low; Ground granulated blast furnace-low

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 #: 10-03195
Sample Identification: 4A

Date: 6-15-04/6-22-04
Performed by: S. Malecha/G. Moulzolf

I. General Observations

1. **Sample Dimensions:** Our analysis was performed on a 179 mm (7-1/16") x 95 mm (3-3/4") x 44 mm (1-3/4") thick polished section that was cut from the original 95 mm (3-3/4") diameter x 178 mm (7") long core.
2. **Surface Conditions:**
Top: Rough, broomed surface; approximately 25% scaled away and mortar erosion exposing numerous fine aggregate surface
Bottom: Rough, irregular, formed surface placed on grade
3. **Reinforcement:** 5 mm (3/16") diameter steelmesh was observed well distributed approximately 164 mm (6-7/16") depth from the top surface. No corrosion observed.
4. **General Physical Conditions:** Approximately 25% of the broomed top surface was scaled away. Also, the top surface was mortar eroded exposing numerous fine aggregate surfaces. Subhorizontal microcracking (scaling) was observed in the top approximately 11 mm (7/16") depth from the top surface. A few subvertical drying-shrinkage microcracks proceed up to 9 mm (3/8") depth from the top surface. A few fine subvertical drying shrinkage microcracks proceed up to 1 mm (1/32") depth from the top surface. Carbonation ranged from 1 mm (1/32") depth up to 7 mm (9/32") depth along subvertical microcracking. The concrete was purposefully air entrained, but does not contain an air void system considered freeze-thaw durable. Good to poor overall condition.

II. Aggregate

1. **Coarse:** 19 mm (3/4") maximum sized crushed quartzite. Fairly well graded with good overall uniform distribution.
2. **Fine:** Natural, quartz, feldspar, and lithic sand 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:** 4.6% total, 1.9% entrapped, 2.7% entrained
2. **Depth of carbonation:** Ranged from 1 mm (1/32") up to 7 mm (9/32") depth along subvertical microcracking
3. **Pozzolan presence:** None observed
4. **Paste/aggregate bond:** Fair to good
5. **Paste color:** Mottled gray and light gray becoming darker in the top approximately 2 mm (1/16") and the bottom approximately 10 mm (3/8") of the sample.
6. **Paste hardness:** Medium
7. **Paste proportions:** 26% to 28%
8. **Microcracking:** Subhorizontal microcracking (scaling) was observed in the top approximately 11 mm (7/16") depth from the top surface. A few subvertical drying shrinkage microcracks proceed up to 9 mm (3/8") depth from the top surface.
9. **Secondary deposits:** White, needly ettringite was observed lining many entrained void spaces scattered throughout the sample.
10. **Slump:** Estimated, medium (2-4")
11. **Water/cement ratio:** Estimated at between 0.40 to 0.45 with approximately 8-10% unhydrated or residual portland cement clinker particles.
12. **Cement hydration:** Alites-well to fully; Belites- well

IV. Conclusions

The general overall quality of the concrete was poor.

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

Job #: 10-03195
Sample Identification: 5A

Date: 6-15-04/6-22-04
Performed by: S. Malecha/G. Moulzolf

I. General Observations

1. **Sample Dimensions:** Our analysis was performed on a 187 mm (7-3/8") x 95 mm (3-3/4") x 44 mm (1-3/4") thick polished section that was cut from the original 92 mm (3-5/8") diameter x 194 mm (7-5/8") long core.
2. **Surface Conditions:**

Top: Rough, screeded and broomed surface with mortar erosion exposing numerous fine aggregate surfaces
Bottom: Rough, irregular, formed surface placed on grade
3. **Reinforcement:** None observed
4. **General Physical Conditions:** The screeded and broomed top surface was mortar eroded exposing numerous fine aggregate surfaces. The top up to 2 mm (1/16") of the sample was characterized by its relatively soft and light colored paste indicative of an excessive W/C. Many subvertical drying-shrinkage microcracks proceed up to 15 mm (5/8") depth from the top surface. Carbonation ranged from 2 mm (1/16") up to 15 mm (5/8") depth from the top surface. The concrete contains a significant amount of purposeful air entrainment. The core was fractured, in an orientation subparallel to the bottom surface, between 140 mm (5-1/2") and 146 mm (5-3/4") depth from the top surface. Fair to good overall condition.

II. Aggregate

1. **Coarse:** 19 mm (3/4") maximum sized crushed quartzite. Fairly well graded with good overall uniform distribution.
2. **Fine:** Natural, quartz, feldspar, and lithic sand 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:** 9.6% total, 0.7% entrapped, 8.9% entrained
2. **Depth of carbonation:** Ranged from 2 mm (1/16") up to 15 mm (5/8") along subvertical microcracking
3. **Pozzolan presence:** None observed
4. **Paste/aggregate bond:** Fair to good
5. **Paste color:** Medium tan becoming tannish white in the carbonated up to 2 mm (1/16") and dark blue gray approximately 44 mm (1-3/4") depth from the top surface
6. **Paste hardness:** Medium becoming soft and friable in the top up to 2 mm (1/16") of the sample
7. **Paste proportions:** 23% to 25%
8. **Microcracking:** Many subvertical drying-shrinkage microcracks proceed up to 15 mm (5/8") depth from the top surface.
9. **Secondary deposits:** None observed
10. **Slump:** Estimated, medium to high (4-6")
11. **Water/cementitious ratio:** Estimated at between 0.45 to 0.50 with approximately 3-5% unhydrated or residual portland cement clinker particles and 2-4% unhydrated ground granulated blast furnace slag particles.
12. **Cement hydration:** Alites-well to fully; Belites- moderately to well; ground granulated blast furnace slag - moderate to well

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 #: 10-03195
Sample Identification: 5B

Date: 6-15-04/6-22-04
Performed by: S. Malecha/G. Moulzolf

I. General Observations

1. **Sample Dimensions:** Our analysis was performed on a 210 mm (8-1/4") x 94 mm (3-11/16") x 44 mm (1-3/4") thick polished section that was cut from the original 92 mm (3-5/8") diameter x 216 mm (8-1/2") long core.
2. **Surface Conditions:**
Top: Rough, broomed surface; approximately 10% scaled away and mortar erosion exposing numerous fine aggregate surfaces
Bottom: Rough, irregular, formed surface placed on grade
3. **Reinforcement:** 5 mm (3/16") diameter steelmesh was observed approximately 187 mm (7-3/8") depth from the top surface. Minor corrosion observed.
4. **General Physical Conditions:** Approximately 10% of the broomed top surface was scaled away from the cored edges, most likely during procurement of the sample. Also, scaling was observed on the top surface directly over few coarse aggregate particles. The broomed top surface was mortar eroded exposing numerous fine aggregate surfaces. The top up to 1 mm (1/32") as characterized by its relatively soft and light colored paste indicative of an excessive W/C. A few subvertical drying shrinkage microcracks proceed up to 1 mm (1/32") depth from the top surface. Carbonation ranged from 1 mm (1/32") up to 3 mm (1/8") depth from the top surface. The concrete was purposefully air entrained and contains a fairly well distributed air void system considered freeze-thaw durable. Fair to good overall condition.

II. Aggregate

1. **Coarse:** 19 mm (3/4") maximum sized crushed quartzite. Fairly well graded with good overall uniform distribution.
2. **Fine:** Natural, quartz, feldspar, and lithic sand 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:** 7.5% total, 1.5% entrapped, 6.0% entrained
2. **Depth of carbonation:** Ranged from 1 mm (1/32") up to 3 mm (1/8")
3. **Pozzolan presence:** None observed
4. **Paste/aggregate bond:** Fair to good
5. **Paste color:** Medium tan becoming lighter in the carbonated up to 2 mm (1/16") and dark blue gray approximately 76 mm (3") depth from the top surface
6. **Paste hardness:** Medium becoming soft and friable in the top up to 1 mm (1/32") of the sample
7. **Paste proportions:** 21% to 23%
8. **Microcracking:** A few subvertical drying-shrinkage microcracks proceed up to 1 mm (1/32") depth from the top surface.
9. **Secondary deposits:** None observed
10. **Slump:** Estimated, medium to high (4-6")
11. **Water/cementitious ratio:** Estimated at between 0.45 to 0.50 with approximately 3-5% unhydrated or residual portland cement clinker particles and 2-4% unhydrated ground granulated blast furnace slag particles.
12. **Cement hydration:** Alites-well to mostly fully; Belites- well; ground granulated blast furnace slag - low to well

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 #: 10-03195
Sample Identification: 5C

Date: 6-17-04/6-22-04
Performed by: S. Malecha/G. Moulzolf

I. General Observations

1. **Sample Dimensions:** Our analysis was performed on a 127 mm (5") x 95 mm (3-3/4") x 44 mm (1-3/4") thick polished section that was cut from the original 92 mm (3-5/8") diameter x 130 mm (5-1/8") long core.
2. **Surface Conditions:**
Top: Rough, broomed surface; with mortar erosion exposing many fine aggregate surfaces
Bottom: Rough, irregular, formed surface placed on grade
3. **Reinforcement:** None observed
4. **General Physical Conditions:** The broomed top surface was mortar eroded exposing many fine aggregate surfaces. The top approximately 1 mm (1/32") of the sample was characterized by its relatively soft and light colored paste indicative of an excessive W/C. Several subvertical drying-shrinkage microcracks proceed up to 1 mm (1/32") depth from the top surface. Carbonation ranged from 2 mm (1/16") up to 5 mm (3/16") depth from the top surface. The concrete was purposefully air entrained and contains a fairly well distributed air void system considered freeze-thaw durable. Good overall condition.

II. Aggregate

1. **Coarse:** 19 mm (3/4") maximum sized crushed quartzite. Fairly well graded with good overall uniform distribution.
2. **Fine:** Natural, quartz, feldspar, and lithic sand 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, 0.5% entrapped, 5.0% entrained
2. **Depth of carbonation:** Ranged from 2 mm (1/16") up to 5 mm (3/16")
3. **Pozzolan presence:** None observed
4. **Paste/aggregate bond:** Fair to good
5. **Paste color:** Mottled gray to tannish gray becoming tannish-white in the top approximately 2 mm (1/16") and blue-gray between 70 mm (2-3/4") and 83 mm (3-1/4") depth.
6. **Paste hardness:** Medium becoming soft and friable in the top approximately 1 mm (1/32") of the sample
7. **Paste proportions:** 21% to 23%
8. **Microcracking:** Several subvertical drying-shrinkage microcracks proceed up to 1 mm (1/32") depth from the top surface.
9. **Secondary deposits:** White silica-gel was observed partially filling an entrained void space approximately 83 mm (3-1/4") depth from the top surface.
10. **Slump:** Estimated, medium (2-4")
11. **Water/cementitious ratio:** Estimated at between 0.40 to 0.45 with approximately 8-10% unhydrated or residual portland cement clinker particles and 8-10% unhydrated ground granulated blast furnace slag particles.
12. **Cement hydration:** Alites-well to fully; Belites- low to negligible; ground granulated blast furnace slag - low to negligible

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 #: 10-03195
Sample Identification: 6A

Date: 6-15-04/6-22-04
Performed by: S. Malecha/G. Moulzolf

I. General Observations

1. **Sample Dimensions:** Our analysis was performed on a 183 mm (7-3/16") x 95 mm (3-3/4") x 44 mm (1-3/4") thick polished section that was cut from the original 92 mm (3-5/8") diameter x 191 mm (7-1/2") long core.
2. **Surface Conditions:**
Top: Rough, broomed surface; approximately 5% scaled away and mortar erosion exposing many fine aggregate surfaces
Bottom: Rough, irregular, formed surface placed on grade
3. **Reinforcement:** None observed
4. **General Physical Conditions:** Approximately 5% of the broomed top surface was scaled away directly over few coarse aggregate particles. Also, the top surface was mortar eroded exposing many fine aggregate surfaces. The top up to 1 mm (1/32") was characterized by its relatively soft and light colored paste indicative of an excessive W/C. Several subvertical drying-shrinkage microcracks proceed up to 8 mm (5/16") depth from the top surface. Carbonation ranged from 1 mm (1/32") up to 3 mm (1/8") depth from the top surface. The concrete was purposefully air entrained and contains a fairly well distributed air void system considered freeze-thaw durable. Fair overall condition.

II. Aggregate

1. **Coarse:** 19 mm (3/4") maximum sized crushed quartzite. Fairly well graded with good overall uniform distribution.
2. **Fine:** Natural, quartz, feldspar, and lithic sand 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:** 5.1% total, 1.1% entrapped, 4.0% entrained
2. **Depth of carbonation:** Ranged from 1 mm (1/32") up to 3 mm (1/8")
3. **Pozzolan presence:** None observed
4. **Paste/aggregate bond:** Fair
5. **Paste color:** Tan becoming lighter in the carbonated top approximately 2 mm (1/16") and blue-gray approximately 121 mm (4-3/4") depth from the top surface.
6. **Paste hardness:** Medium becoming soft and friable in the top approximately 1 mm (1/32") of the sample
7. **Paste proportions:** 22% to 24%
8. **Microcracking:** Several subvertical drying-shrinkage microcracks proceed up to 8 mm (5/16") depth from the top surface.
9. **Secondary deposits:** None observed
10. **Slump:** Estimated, medium to high (4" to 6")
11. **Water/cementitious ratio:** Estimated at between 0.45 to 0.50 with approximately 4-6% unhydrated or residual portland cement clinker particles and 2-4% unhydrated ground granulated blast furnace slag particles.
12. **Cement hydration:** Alites- mostly fully; Belites- well; ground granulated blast furnace slag - well

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 #: 10-03195
Sample Identification: 6B

Date: 6-16-04/6-22-04
Performed by: S. Malecha/G. Moulzolf

I. General Observations

1. Sample Dimensions: Our analysis was performed on a 149 mm (5-7/8") x 95 mm (3-3/4") x 43 mm (1-11/16") thick polished section that was cut from the original 95 mm (3-3/4") diameter x 152 mm (6") long core.
2. Surface Conditions:
Top: Rough, broomed surface; approximately 5% scaled
Bottom: Rough, irregular, formed surface placed on grade
3. Reinforcement: None observed
4. General Physical Conditions: Scaling was observed on the broomed top surface directly over few coarse aggregate particles (mortar flaking). Many subvertical drying-shrinkage microcracks proceed up to 4 mm (5/32") depth from the top surface. Carbonation ranged from 1 mm (1/32") up to 7 mm (9/32") depth from the top surface. The concrete was purposefully air entrained and contains a fairly good air void system considered freeze-thaw durable. Fair overall condition.

II. Aggregate

1. Coarse: 19 mm (3/4") maximum sized crushed quartzite. Fairly well graded with good overall uniform distribution.
2. Fine: Natural, quartz, feldspar, and lithic sand 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: 6.7% total, 1.2% entrapped, 5.5% entrained
2. Depth of carbonation: Ranged from 1 mm (1/32") up to 7 mm (9/32")
3. Pozzolan presence: None observed
4. Paste/aggregate bond: Fair
5. Paste color: Medium tan becoming dark blue-gray approximately 89 mm (3-1/2") depth from the top surface
6. Paste hardness: Medium
7. Paste proportions: 20% to 22%
8. Microcracking: Many subvertical drying-shrinkage microcracks proceed up to 4 mm (5/32") depth from the top surface.
9. Secondary deposits: None observed
10. Slump: Estimated, medium to high (4" to 6")
11. Water/cementitious ratio: Estimated at between 0.45 to 0.50 with approximately 3-5% unhydrated or residual portland cement clinker particles and 1-2% unhydrated ground granulated blast furnace slag particles.
12. Cement hydration: Alites- mostly fully; Belites- well to fully; ground granulated blast furnace slag - well 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 #: 10-03195
Sample Identification: AG1

Date: 6-9-04/6-22-04
Performed by: S. Malecha/G. Moulzolf

I. General Observations

1. Sample Dimensions: Our analysis was performed on a 162 mm (6-3/8") x 90 mm (3-9/16") x 35 mm (1-3/8") thick polished section that was cut from the original 92 mm (3-5/8") diameter x 168 mm (6-5/8") long core.
2. Surface Conditions:
Top: Rough, broomed surface with mortar erosion and approximately 10% scaled away
Bottom: Rough, irregular, formed surface placed on grade
3. Reinforcement: None observed
4. General Physical Conditions: Approximately 10% of the broomed top surface was scaled away. Also, the top surface was mortar eroded exposing numerous fine aggregate surfaces. The top up to 1 mm (1/32") of the sample was characterized by its relatively soft and light colored paste indicative of an excessive W/C. The concrete was purposefully air entrained and overall contains an air void system considered freeze-thaw durable. However, a loss of purposeful air entrainment was observed in the top approximately 1 mm (1/32") of the sample. Subhorizontal microcracking (scaling) was observed in the top up to 1 mm (1/32") of the sample. A few fine subvertical drying-shrinkage microcracks proceed up to 1 mm (1/32") depth from the top surface. Carbonation proceeds up to 1 mm (1/32") depth from the top surface. Poor overall condition.

II. Aggregate

1. Coarse: 19 mm (3/4") maximum sized crushed quartzite. Fairly well graded with good overall uniform distribution.
2. Fine: Natural, quartz, feldspar, and lithic sand 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: 7.1% total, 1.8% entrapped, 5.3% entrained
2. Depth of carbonation: Up to 1 mm (1/32")
3. Pozzolan presence: None observed
4. Paste/aggregate bond: Fair
5. Paste color: Medium grayish tan becoming tannish-white in the carbonated top up to 1 mm (1/32") and blue-gray approximately 13 mm (1/2") depth from the cored edges
6. Paste hardness: Medium becoming soft and friable in the top up to 1 mm (1/32") of the sample
7. Paste proportions: 32% to 34%
8. Microcracking: Subhorizontal microcracking (scaling) was observed in the top up to 1 mm (1/32")
9. Secondary deposits: None observed
10. Slump: Estimated, medium (3-5")
11. Water/cementitious ratio: Estimated at between 0.42 to 0.47 with approximately 5-7% unhydrated or residual portland cement clinker particles and 6-8% unhydrated ground granulated blast furnace slag particles.
12. Cement hydration: Alites- well to fully; Belites- low; ground granulated blast furnace slag - negligible to low

IV. Conclusions

The general overall quality of the concrete was good.

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

Job #: 10-03195
Sample Identification: AG4

Date: 6-9-04/6-22-04
Performed by: S. Malecha/G. Moulzolf

I. General Observations

1. Sample Dimensions: Our analysis was performed on a 101 mm (4") x 102 mm (4") x 51 mm (2") thick polished section that was cut from the original 102 mm (4") diameter x 191 mm (7-1/2") long core.
2. Surface Conditions:
Top: Rough, broomed surface with mortar erosion exposing numerous fine aggregate surfaces
Bottom: Rough, irregular, formed surface placed on grade
3. Reinforcement: None observed
4. General Physical Conditions: The broomed top surface was mortar eroded exposing numerous fine aggregate surfaces. Many subvertical drying-shrinkage microcracks proceed up to 2 mm (1/16") depth from the top surface. Carbonation ranged from 1 mm (1/32") up to 2 mm (1/16") depth from the top surface. The concrete was purposefully air entrained and contains a fairly distributed air void system considered freeze-thaw durable. Fair to poor overall condition.

II. Aggregate

1. Coarse: 19 mm (3/4") maximum sized crushed quartzite. Fairly well graded with good overall uniform distribution.
2. Fine: Natural, quartz, feldspar, and lithic sand 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: 6.6% total, 1.6% entrapped, 5.6% entrained
2. Depth of carbonation: Ranged from 1 mm (1/32") up to 2 mm (1/16")
3. Pozzolan presence: None observed
4. Paste/aggregate bond: Fair
5. Paste color: Medium grayish tan becoming light gray in the carbonated top up to 2 mm (1/16") and dark blue-gray approximately 10 mm (3/8") depth from the cored edges
6. Paste hardness: Medium soft at top surface to a negligible depth
7. Paste proportions: 21% to 23%
8. Microcracking: Many subvertical drying-shrinkage microcracks proceed up to 2 mm (1/16") depth from the top surface
9. Secondary deposits: None observed
10. Slump: Estimated, medium (3-5")
11. Water/cementitious ratio: Estimated at between 0.43 to 0.48 with approximately 5-7% unhydrated or residual portland cement clinker particles and 2-4% unhydrated ground granulated blast furnace slag particles.
12. Cement hydration: Alites- well to fully; Belites- low; ground granulated blast furnace slag - low

IV. Conclusions

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



**AMERICAN
PETROGRAPHIC
SERVICES, INC.**

REPORT OF AIR VOID ANALYSIS

PROJECT:

KANSAS CITY CORES

REPORTED TO:

CENTER OF TRANSPORTATION
RESEARCH & EDUCATION
2901 S. LUKE DRIVE, SUITE #3100
AMES, IOWA 50010

ATTN: TOM CACKLER

APS JOB NO: 10-03195

DATE: JUNE 18, 2004

Sample No: 1A 2A 3A 4A
Conformance: Sample 4A contains an air void system which is not consistent with current technology for freeze-thaw resistance.

Sample Data:

Description: Hardened Concrete Core
Dimensions: 3 3/4" diameter 3 3/4" diameter 3 5/8" diameter 3 3/4" diameter
by 11 5/8" long by 8 1/8" long by 5" long by 7" long

Test Data ASTM:C457 Linear Traverse Method, APS Standard Operating Procedure 00 LAB 003

	1A	2A	3A	4A
Air Void Content, %	5.9	7.3	6.8	4.6
Entrained, % ≤ 0.040"	4.5	6.1	5.8	2.7
Entrapped, % > 0.040"	1.4	1.2	1.0	1.9
Air Voids/inch	11.07	13.39	11.58	3.76
Specific Surface, in ² /in ³	750	740	680	330
Spacing Factor, inches	0.005	0.005	0.005	0.015
Paste Content, %	22.0	25.0	24.0	26.0
Magnification	50x	50x	50x	50x
Traverse Length, inches	92"	92"	96"	92"
Test Date	6/15/04	6/15/04	6/15/04	6/17/04



**AMERICAN
PETROGRAPHIC
SERVICES, INC.**

REPORT OF AIR VOID ANALYSIS

PROJECT:

KANSAS CITY CORES

REPORTED TO:

CENTER OF TRANSPORTATION
RESEARCH & EDUCATION
2901 S. LUKE DRIVE, SUITE #3100
AMES, IOWA 50010

ATTN: TOM CACKLER

APS JOB NO: 10-03195

DATE: JUNE 18, 2004

Sample No:

5A

6A

1B

2B

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:

3⁵/₈" diameter
by 7⁵/₈" long

3⁵/₈" diameter
by 7¹/₂" long

3⁵/₈" diameter
by 12¹/₂" long

3³/₄" diameter
by 7" long

Test Data ASTM:C457 Linear Traverse Method, APS Standard Operating Procedure 00 LAB 003

	5A	6A	1B	2B
Air Void Content, %	9.6	5.1	8.8	5.1
Entrained, % ≤ 0.040"	8.9	4.0	6.5	4.7
Entrapped, % > 0.040"	0.7	1.1	2.3	0.4
Air Voids/inch	20.84	10.20	13.81	10.62
Specific Surface, in ² /in ³	870	800	630	830
Spacing Factor, inches	0.003	0.006	0.004	0.005
Paste Content, %	25.0	24.0	23.0	24.0
Magnification	50x	50x	50x	50x
Traverse Length, inches	92"	92"	90"	92"
Test Date	6/17/04	6/16/04	6/15/04	6/15/04



REPORT OF AIR VOID ANALYSIS

PROJECT:

KANSAS CITY CORES

REPORTED TO:

CENTER OF TRANSPORTATION
RESEARCH & EDUCATION
2901 S. LUKE DRIVE, SUITE #3100
AMES, IOWA 50010

ATTN: TOM CACKLER

APS JOB NO: 10-03195

DATE: JUNE 18, 2004

Sample No:	3B	5B	6B	AG1
Conformance:	The samples contain an air void system which is generally consistent with current technology for freeze-thaw resistance.			
Sample Data:				
Description:	Hardened Concrete Core			
Dimensions:	3 ⁵ / ₈ " diameter by 4 ³ / ₈ " long	3 ⁵ / ₈ " diameter by 8 ¹ / ₂ " long	3 ³ / ₄ " diameter by 6" long	3 ⁵ / ₈ " diameter by 6 ⁵ / ₈ " long
Test Data ASTM:C457 Linear Traverse Method, APS Standard Operating Procedure 00 LAB 003				
Air Void Content, %	7.6	7.5	6.7	7.1
Entrained, % ≤ 0.040"	6.4	6.0	5.5	5.3
Entrapped, % > 0.040"	1.2	1.5	1.2	1.8
Air Voids/inch	16.03	13.19	14.94	8.48
Specific Surface, in ² /in ³	850	710	890	480
Spacing Factor, inches	0.003	0.004	0.004	0.009
Paste Content, %	22.0	23.0	22.0	32.0
Magnification	50x	50x	50x	50x
Traverse Length, inches	90"	90"	92"	92"
Test Date	6/15/04	6/17/04	6/16/04	6/16/04



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REPORT OF AIR VOID ANALYSIS

PROJECT:

KANSAS CITY CORES

REPORTED TO:

CENTER OF TRANSPORTATION
RESEARCH & EDUCATION
2901 S. LUKE DRIVE, SUITE #3100
AMES, IOWA 50010

ATTN: TOM CACKLER

APS JOB NO: 10-03195

DATE: JUNE 18, 2004

Sample No:

AG4

5C

Conformance:

The samples contain an air void system which is consistent with current technology for freeze-thaw resistance.

Sample Data:

Description:

Hardened Concrete Core

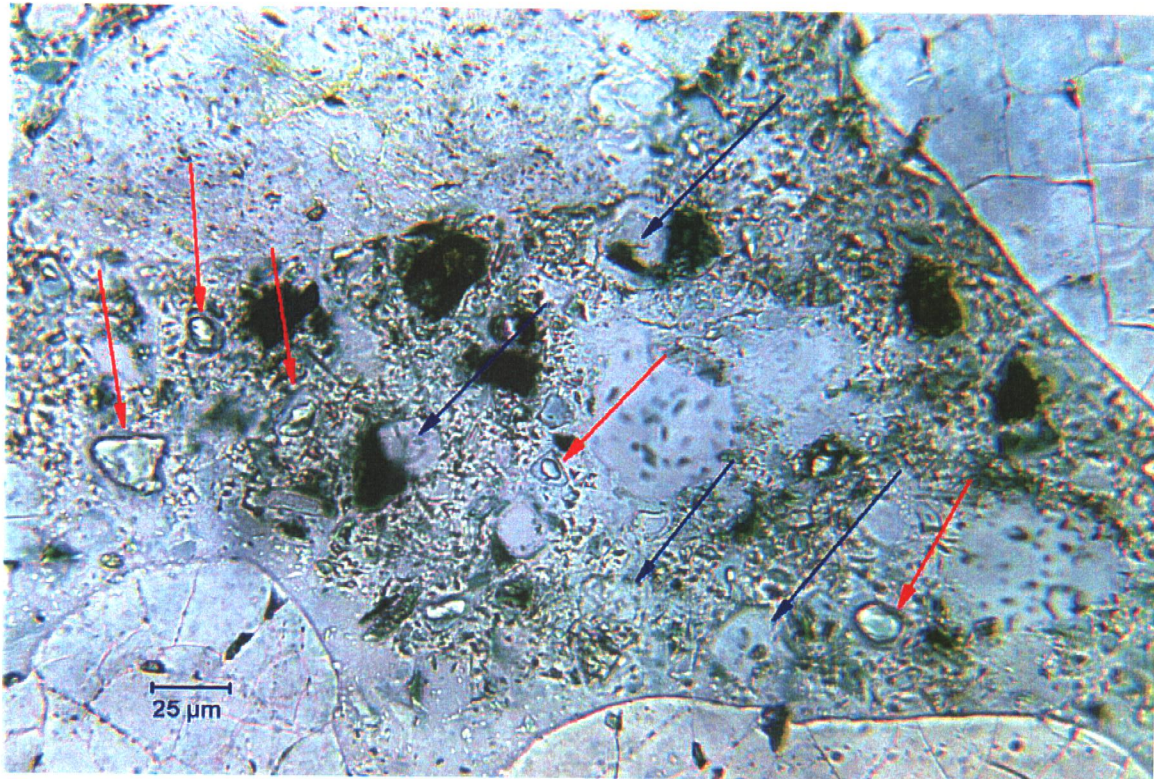
Dimensions:

3⁵/₈" diameter by
7¹/₂" long

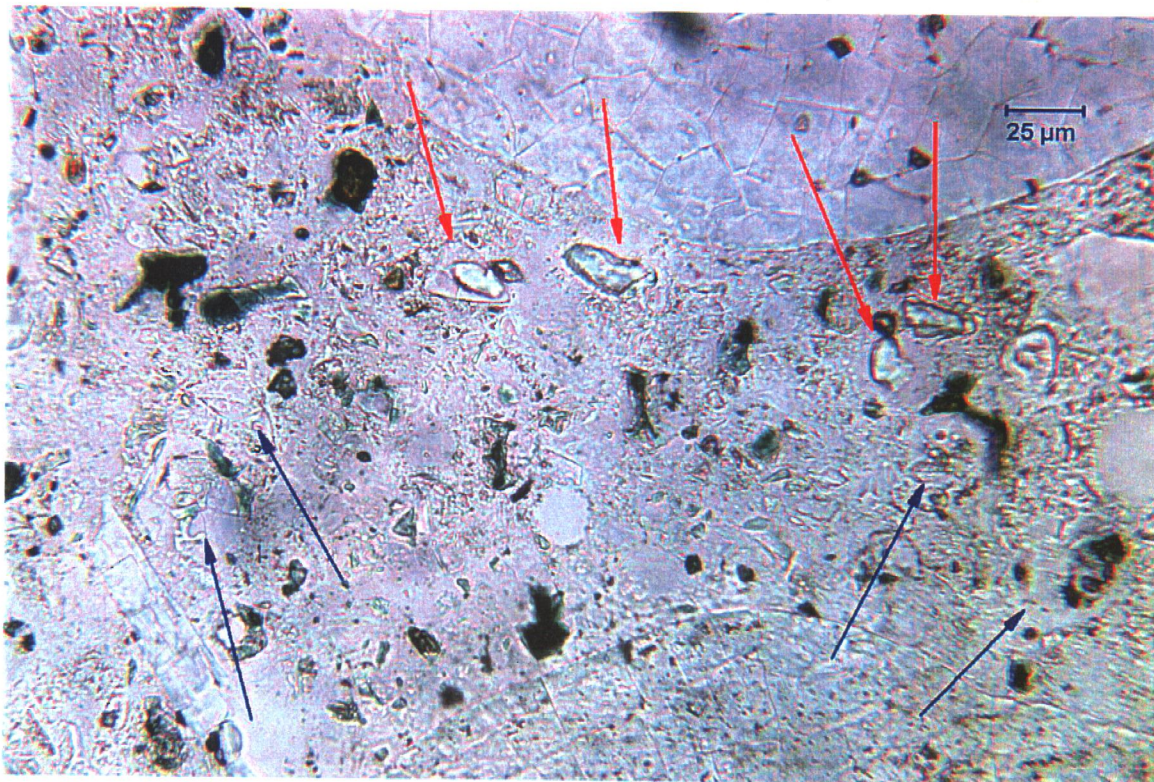
3⁵/₈" diameter by
5¹/₈" long

Test Data ASTM:C457 Linear Traverse Method, APS Standard Operating Procedure 00 LAB 003

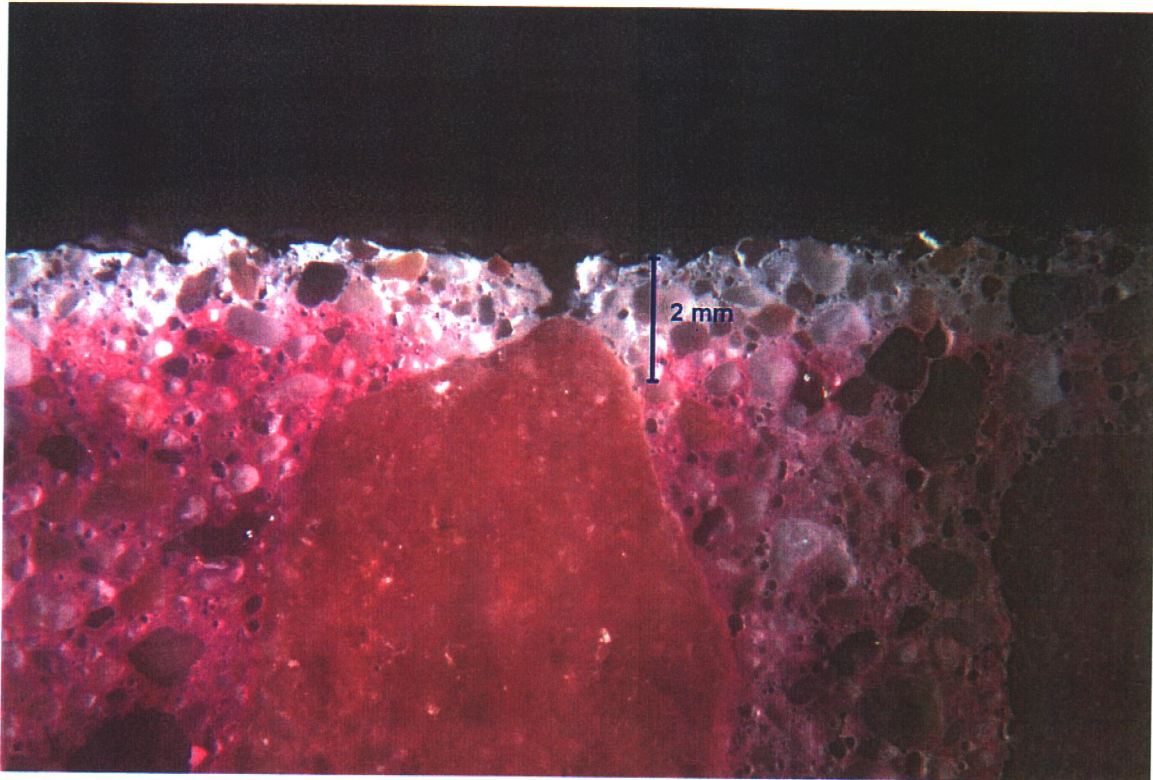
Air Void Content, %	6.6	5.5
Entrained, % \leq 0.040"	5.1	5.0
Entrapped, % $>$ 0.040"	1.5	0.5
Air Voids/inch	9.00	14.50
Specific Surface, in ² /in ³	540	1050
Spacing Factor, inches	0.006	0.004
Paste Content, %	23.0	23.0
Magnification	50x	50x
Traverse Length, inches	96"	90"
Test Date	6/16/04	6/17/04



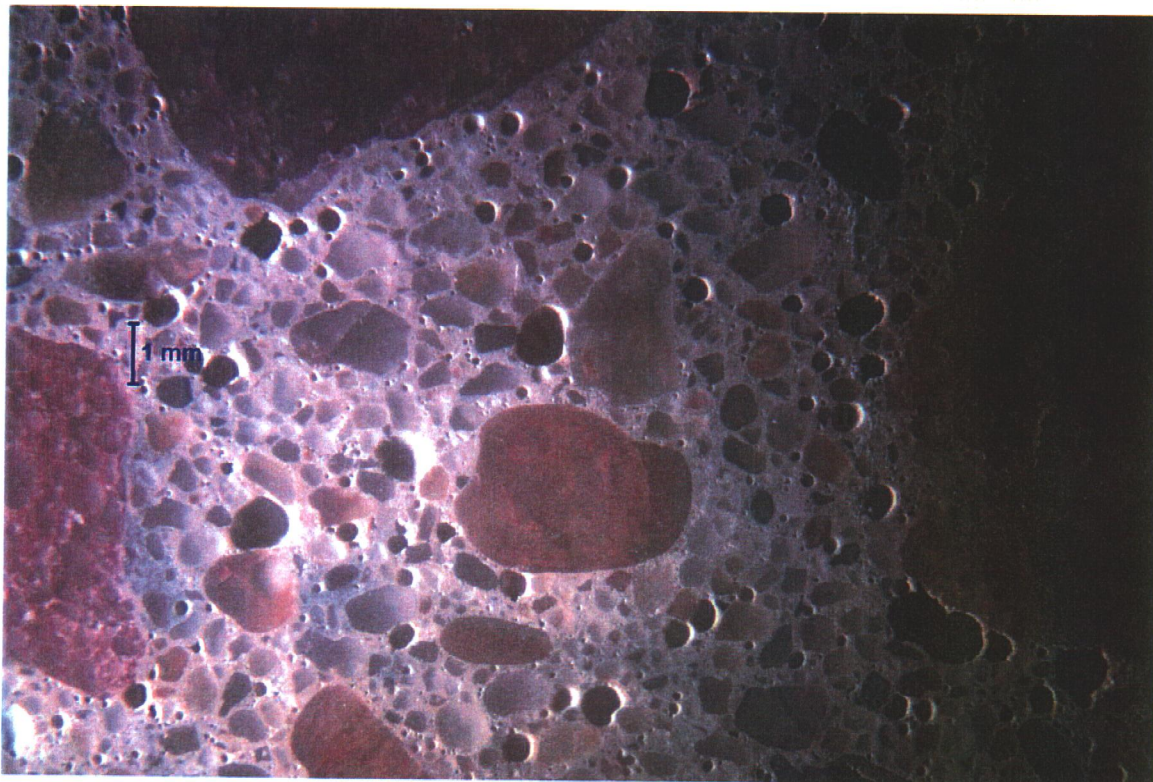
SAMPLE ID: 1A DESCRIPTION: Fully hydrated alite portland cement clinker relics (blue arrows) and unhydrated GGBFS particles (red) in thin section of paste under plane polarized light.
MAG: 400x



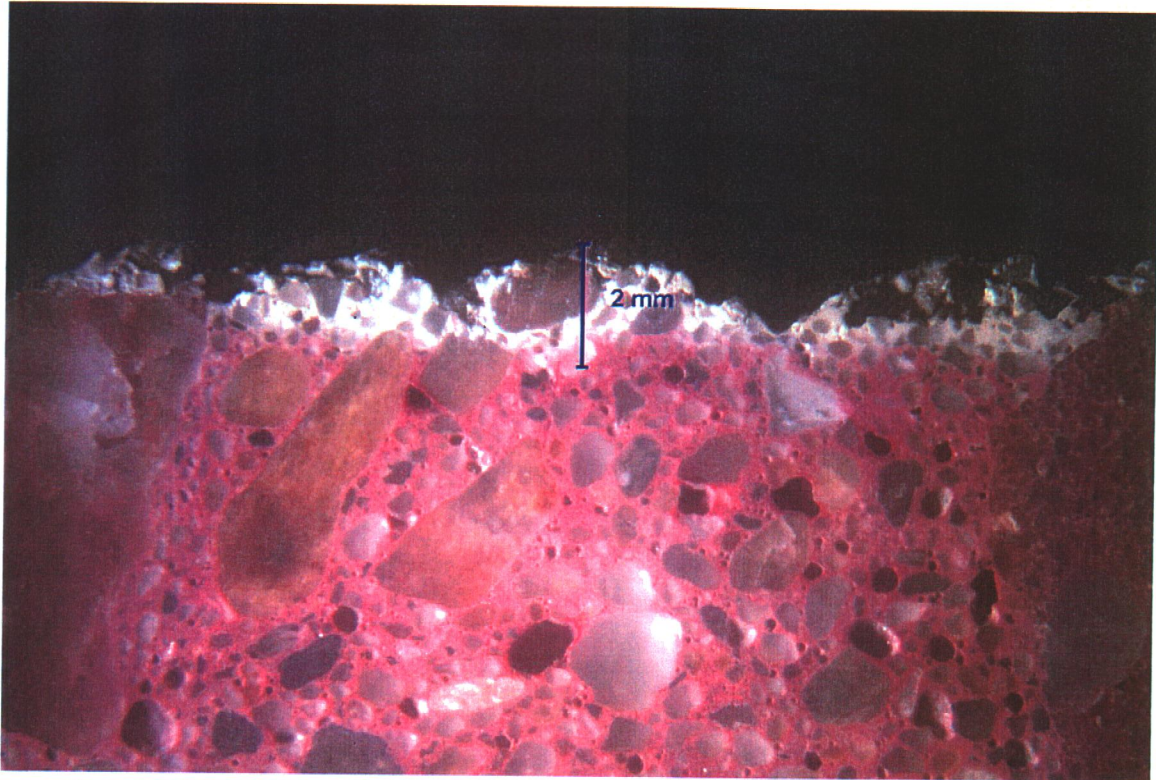
SAMPLE ID: 2B DESCRIPTION: Mostly fully hydrated alite portland cement clinker relics (blue arrows) and unhydrated GGBFS particles (red) in thin section of paste under plane polarized light.
MAG: 400x



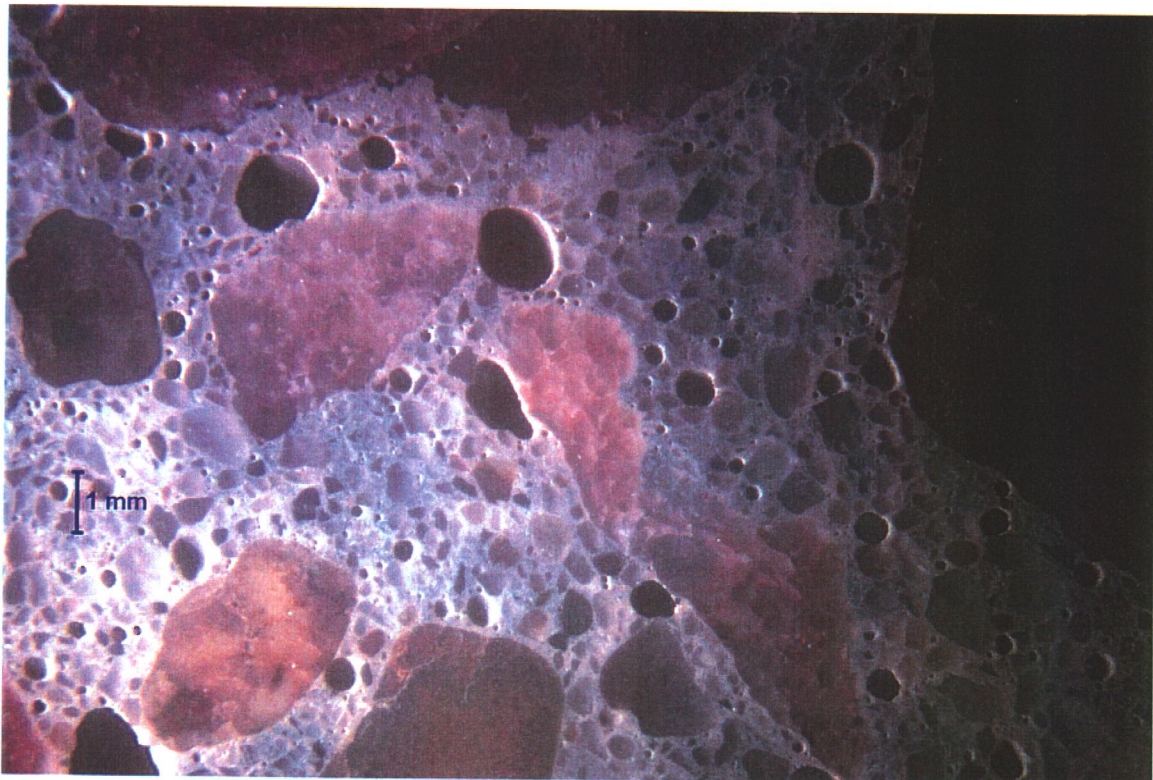
SAMPLE ID: AG-4 DESCRIPTION: Carbonation (unstained) proceeds up to 2mm depth from the top surface. Note very light colored, soft and friable surficial paste.
MAG: 10x



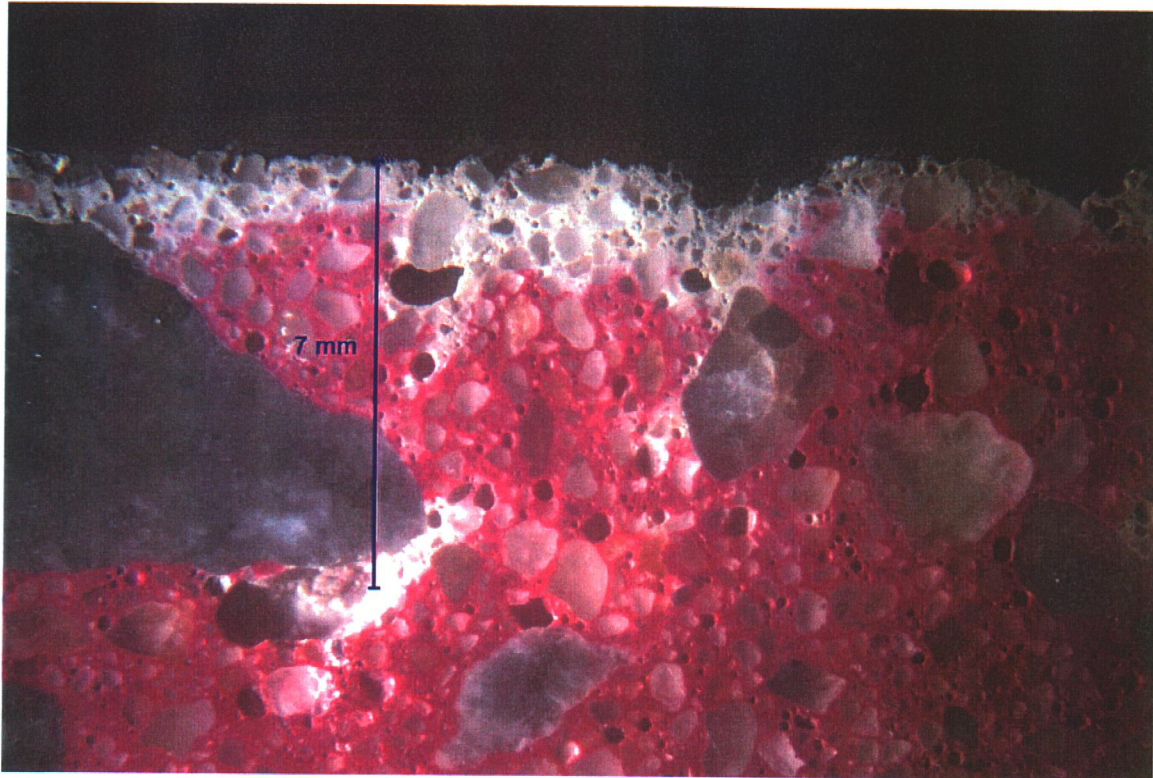
SAMPLE ID: AG-4 DESCRIPTION: Overall hardened air content, 6.6 % total.
MAG: 10x



SAMPLE ID: AG-1 DESCRIPTION: Carbonation (unstained) proceeds up to 2mm depth from the top surface. Note very light colored, soft and friable surficial paste.
MAG: 10x

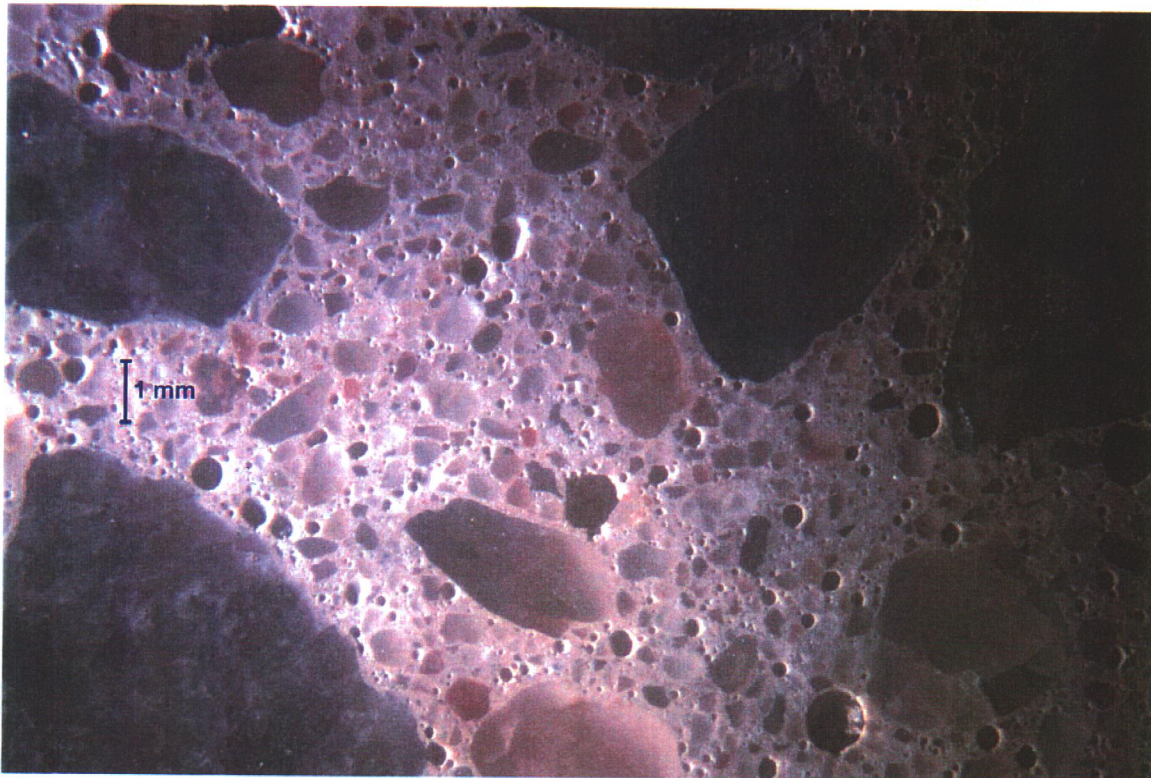


SAMPLE ID: AG-1 DESCRIPTION: Overall hardened air content, 7.1 % total.
MAG: 10x



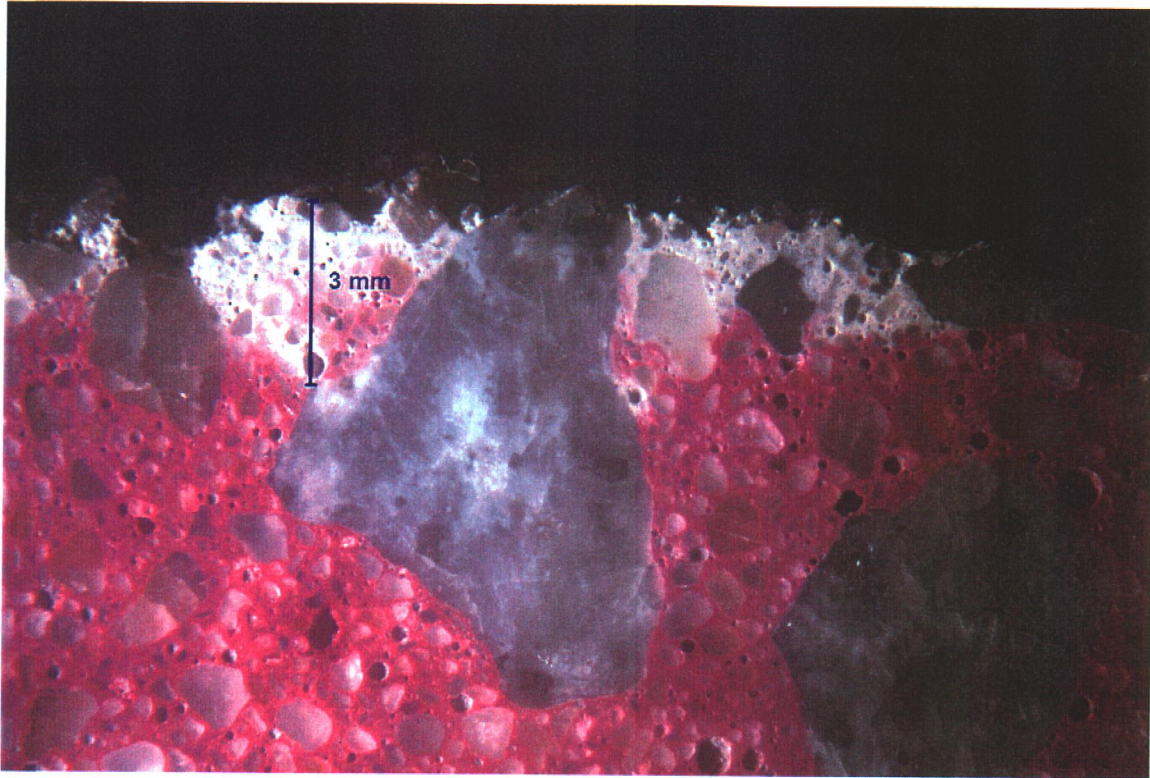
SAMPLE ID: 6B DESCRIPTION: Carbonation (unstained) proceeds intermittently up to 7mm depth from the top surface, along vertical shrinkage microcracking.

MAG: 10x



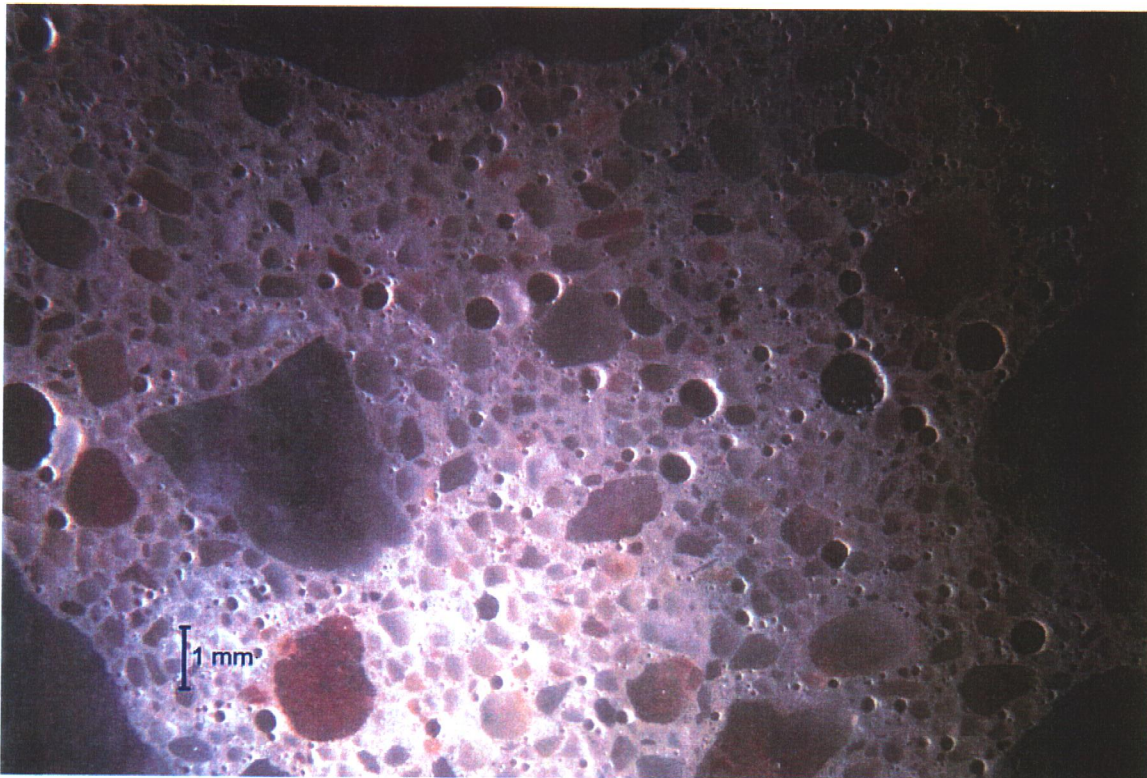
SAMPLE ID: 6B DESCRIPTION: Overall hardened air content, 6.7 % total.

MAG: 10x



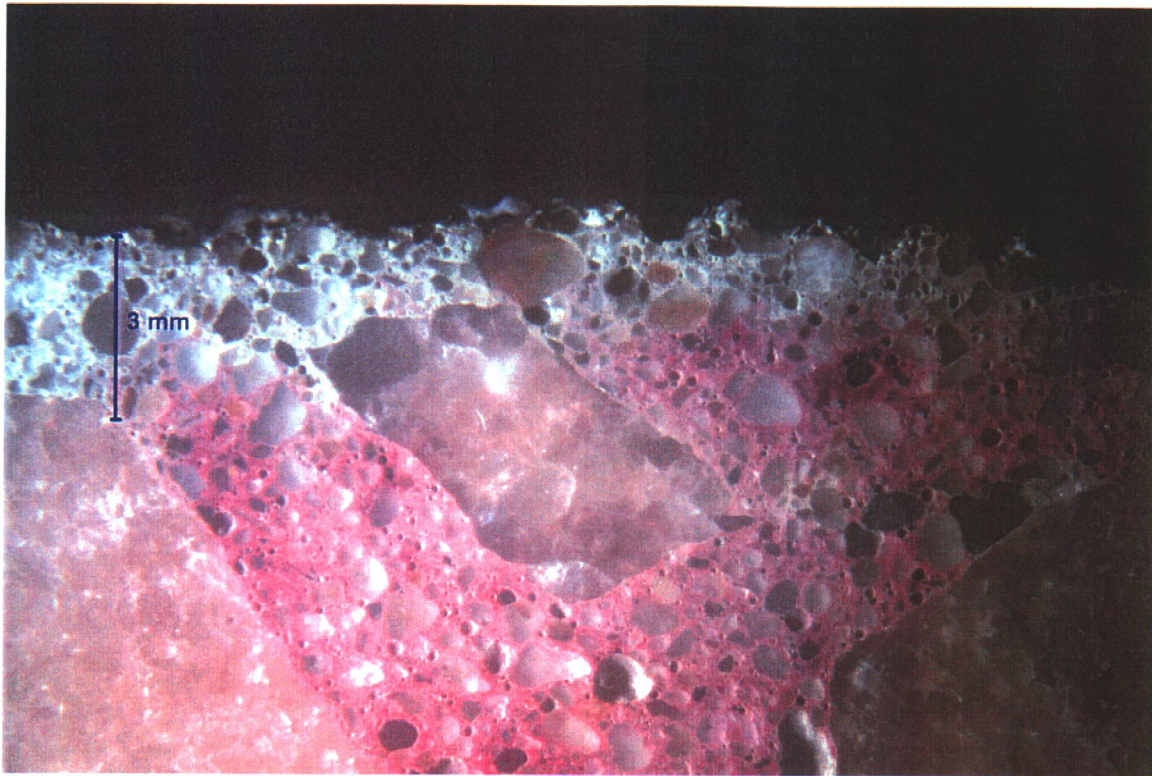
SAMPLE ID: 6A DESCRIPTION: Carbonation (unstained) proceeds up to 3mm depth from the top surface.

MAG: 10x



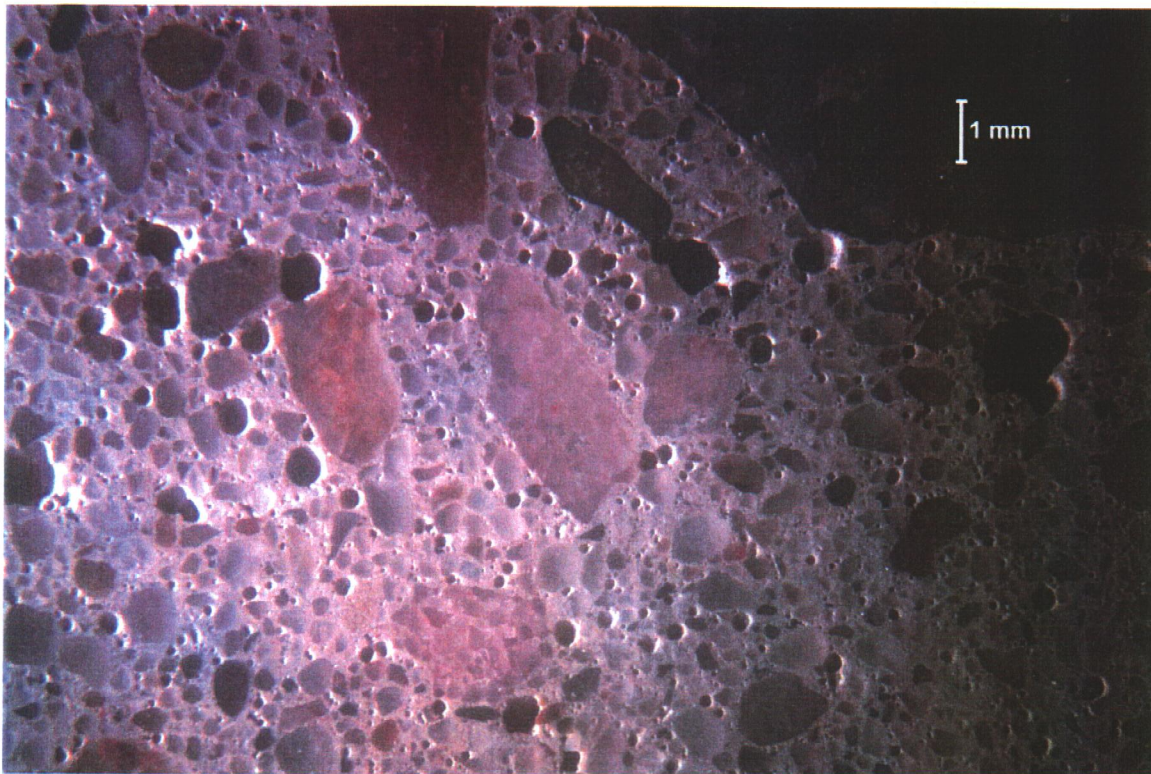
SAMPLE ID: 6A DESCRIPTION: Overall hardened air content, 5.1 % total.

MAG: 10x



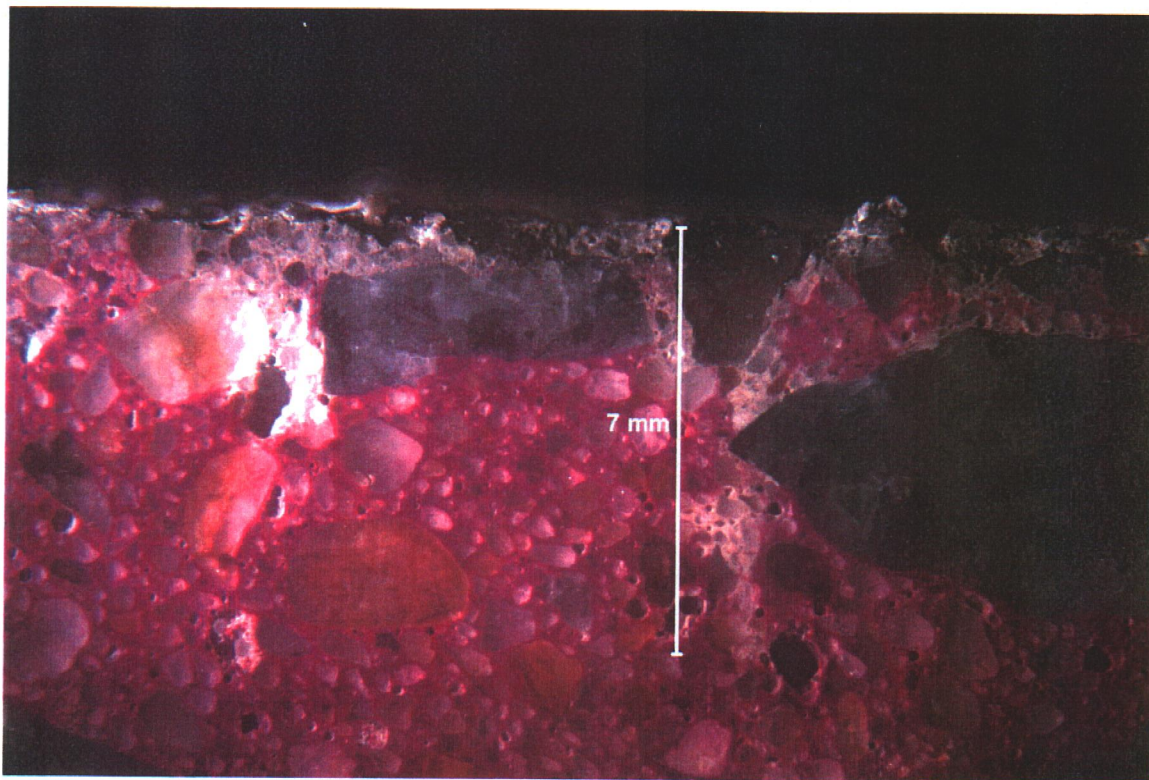
SAMPLE ID: 5B DESCRIPTION: Carbonation (unstained) proceeds up to 3mm depth from the top surface.

MAG: 10x



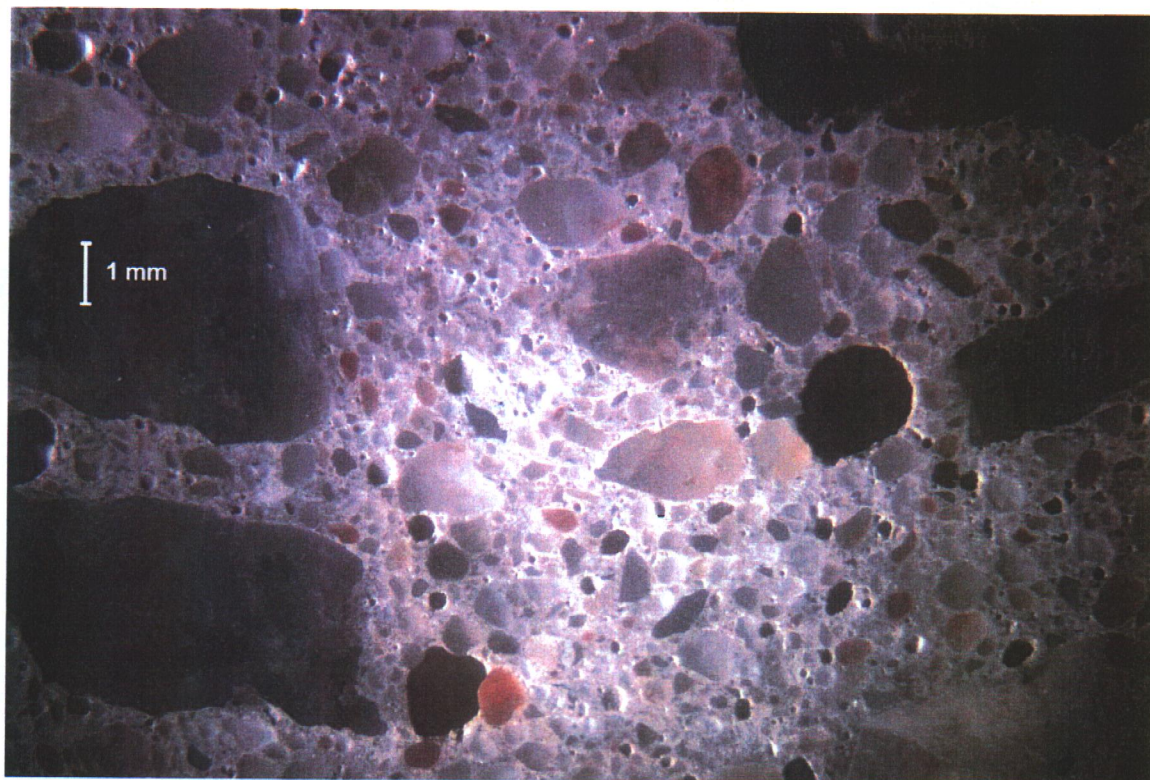
SAMPLE ID: 5B DESCRIPTION: Overall hardened air content, 7.4 % total.

MAG: 10x



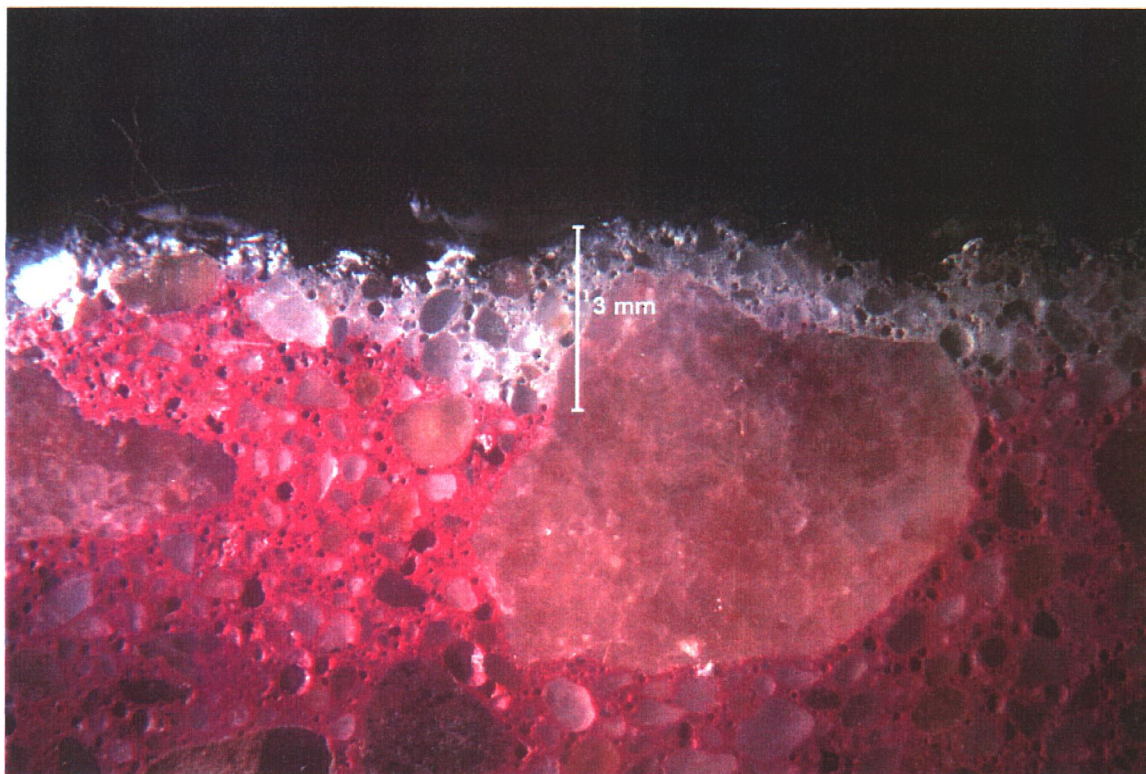
SAMPLE ID: 4A DESCRIPTION: Carbonation (unstained) proceeds up to 7mm depth from the top surface, along vertical shrinkage microcracking.

MAG: 10x



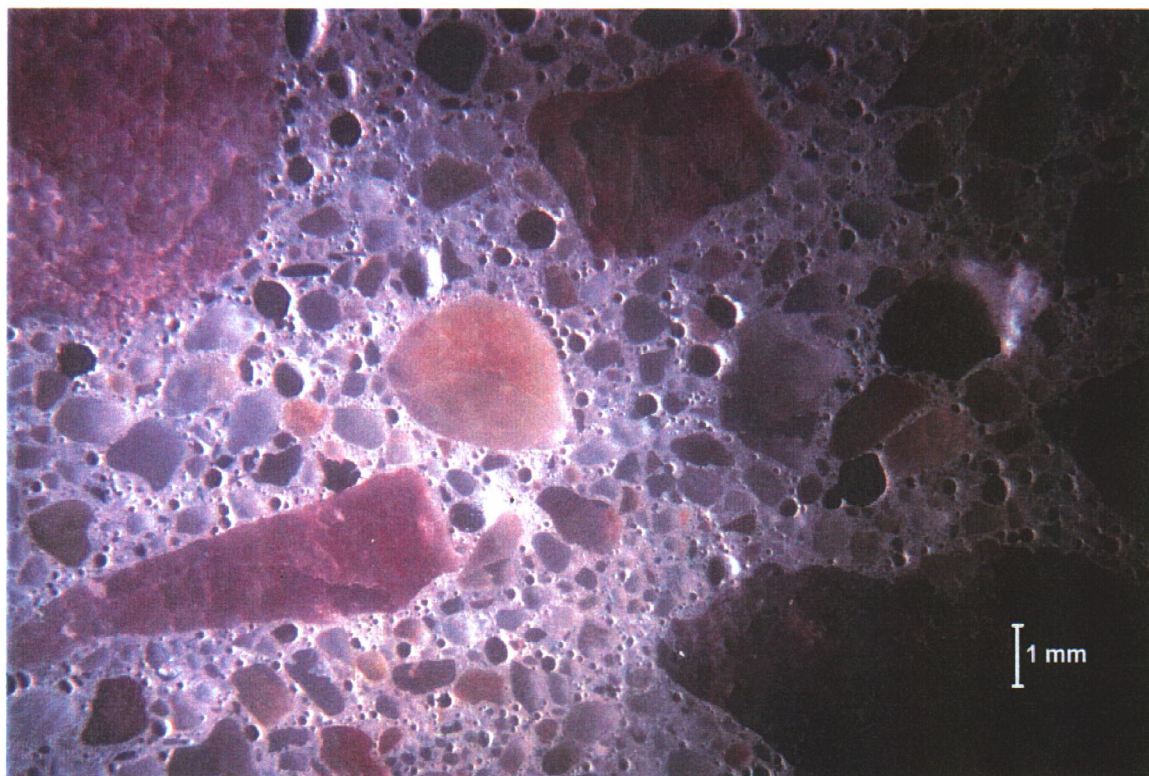
SAMPLE ID: 4A DESCRIPTION: Overall hardened air content, 4.6 % total.

MAG: 10x



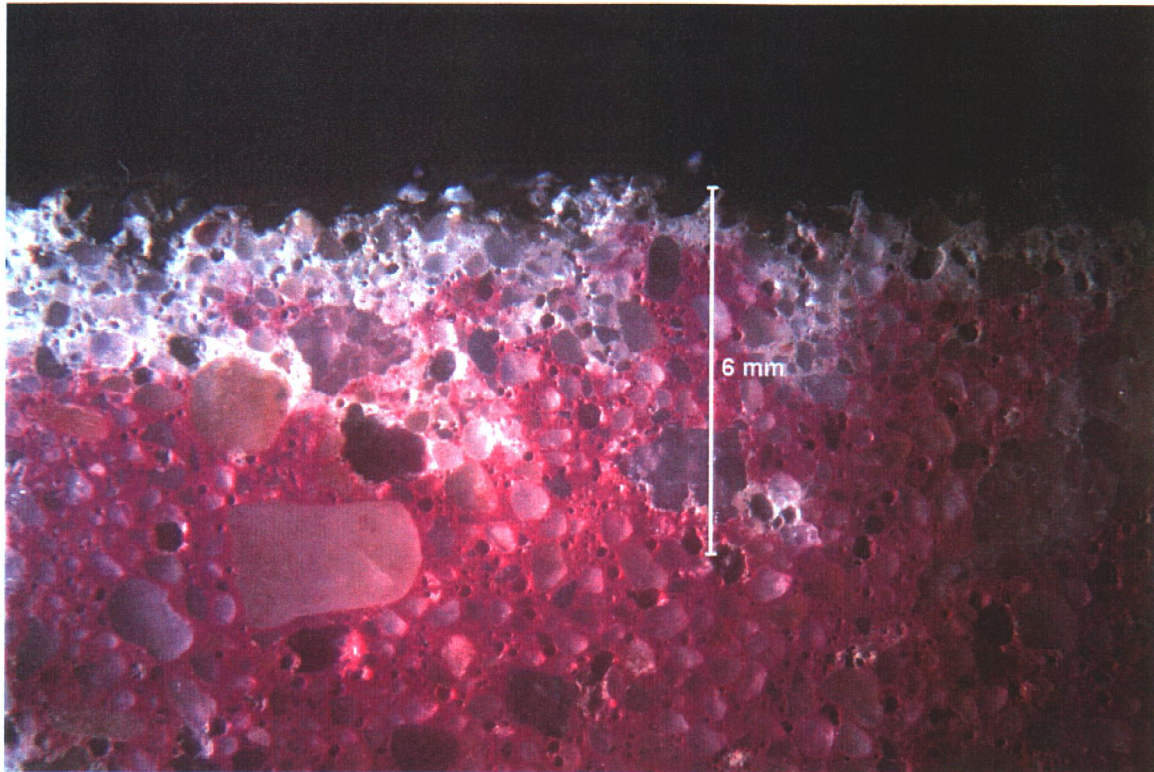
SAMPLE ID: 3B DESCRIPTION: Carbonation (unstained) proceeds up to 3mm depth from the top surface.

MAG: 10x



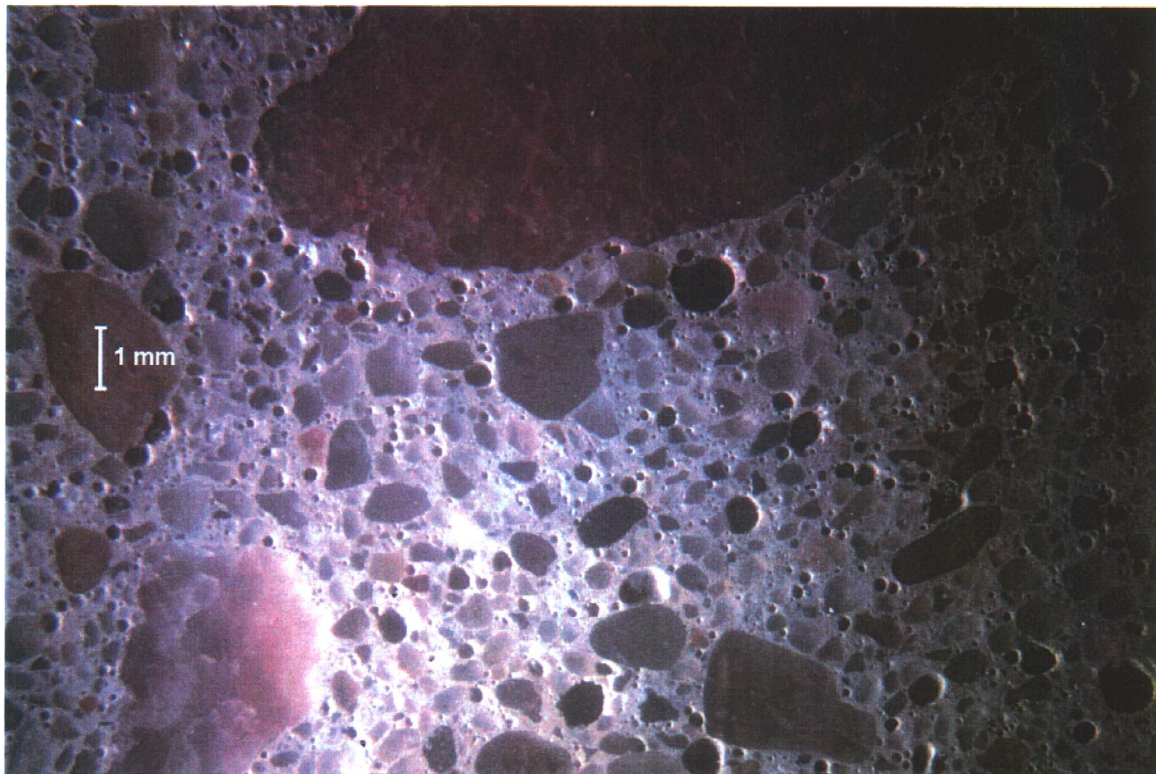
SAMPLE ID: 3B DESCRIPTION: Overall hardened air content, 7.6 % total.

MAG: 10x



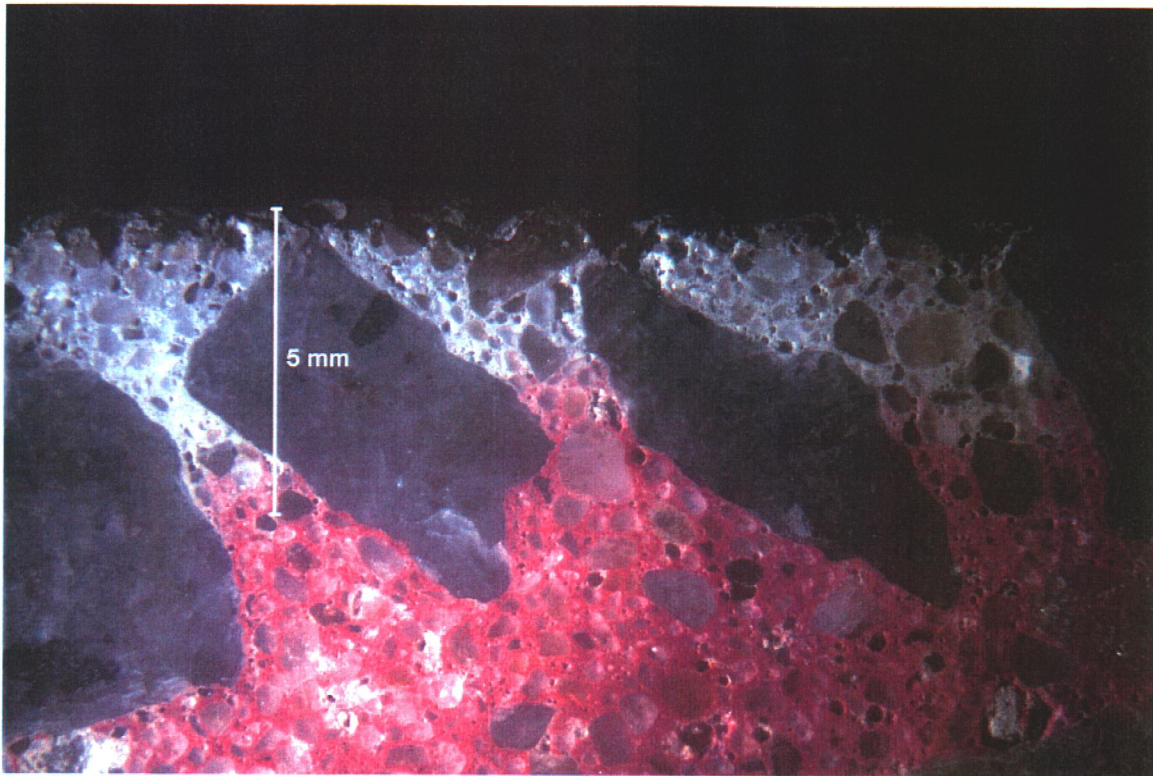
SAMPLE ID: 3A DESCRIPTION: Carbonation (unstained) proceeds intermittently up to 5mm depth from the top surface.

MAG: 10x



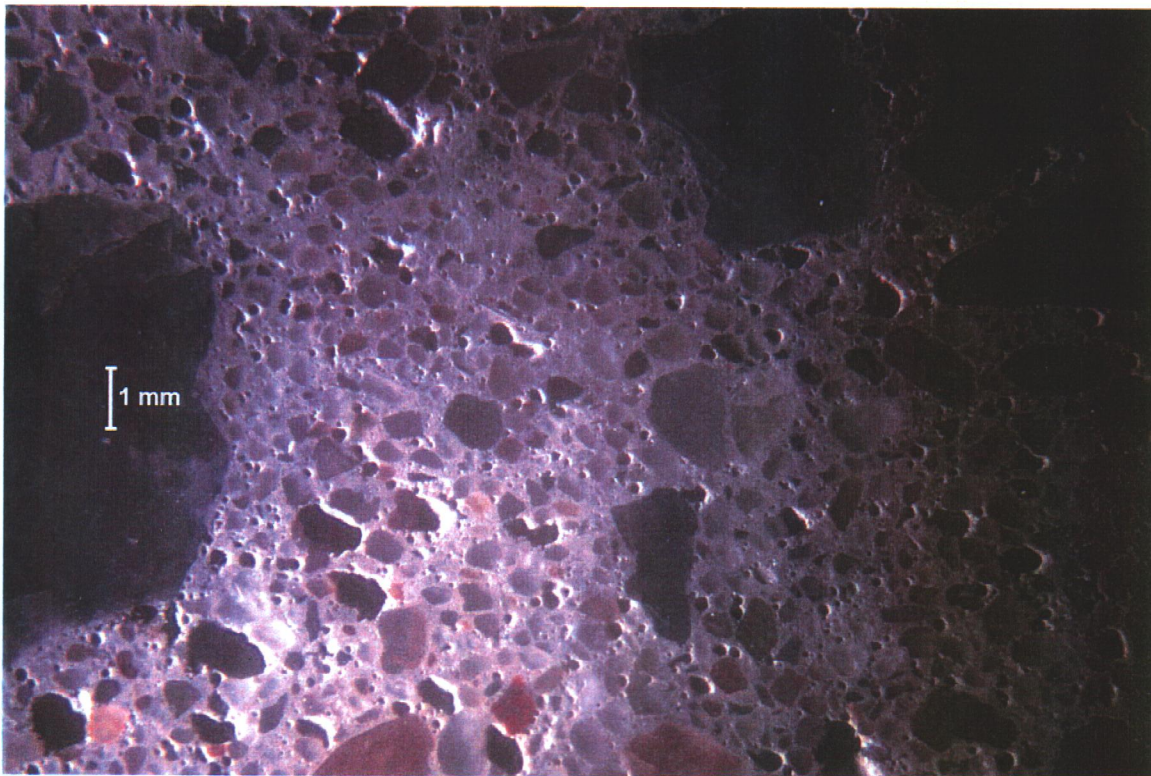
SAMPLE ID: 3A DESCRIPTION: Overall hardened air content, 6.8 % total.

MAG: 10x



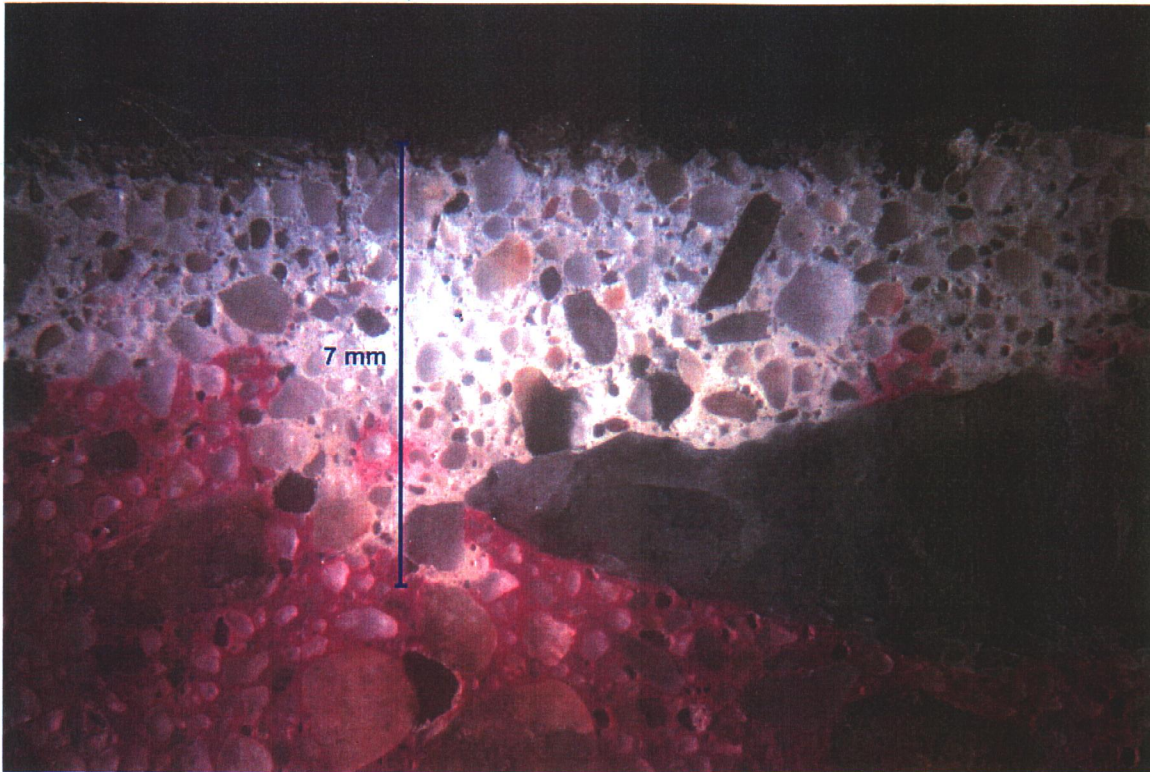
SAMPLE ID: 2B DESCRIPTION: Carbonation (unstained) proceeds up to 5mm depth from the top surface.

MAG: 10x



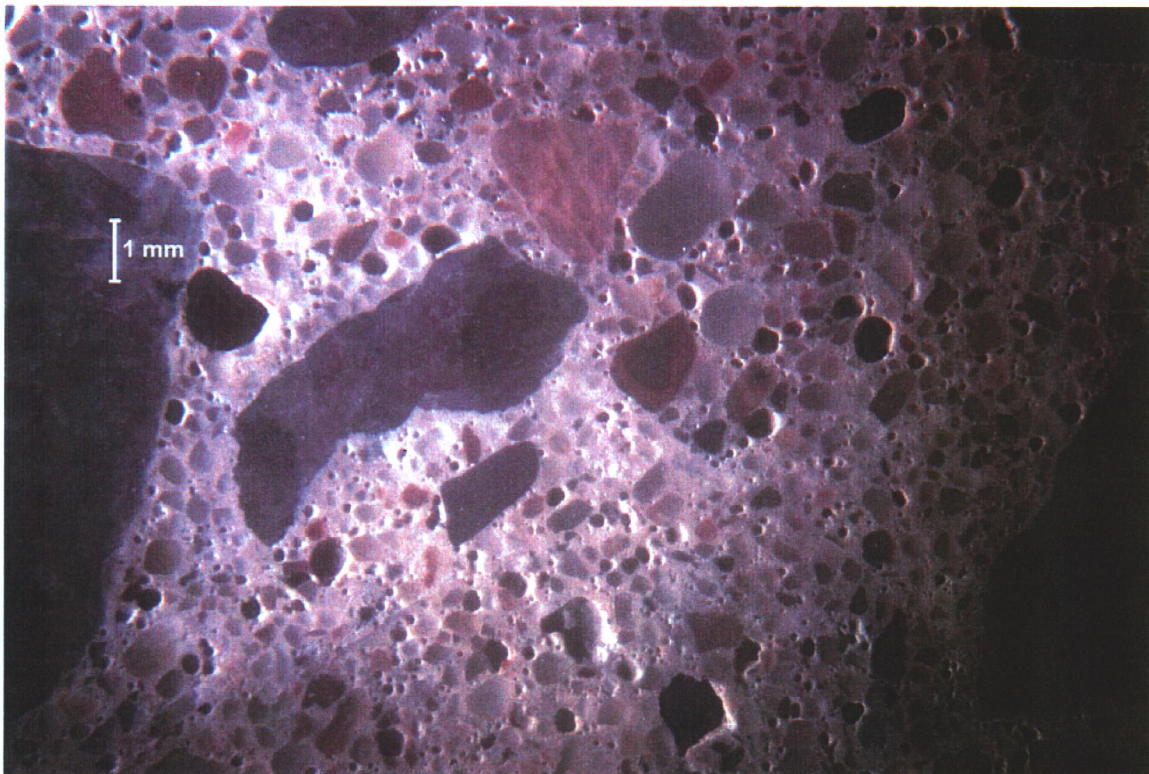
SAMPLE ID: 2B DESCRIPTION: Overall hardened air content, 5.1 % total.

MAG: 10x



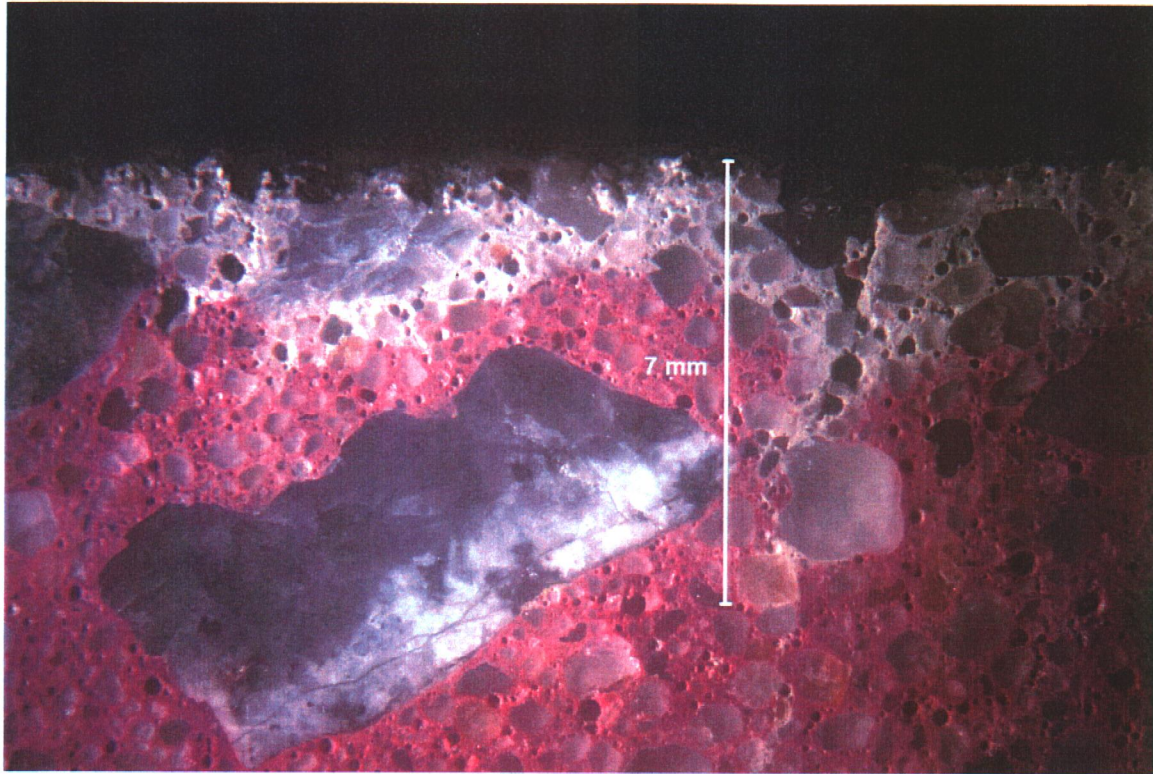
SAMPLE ID: 2A DESCRIPTION: Carbonation (unstained) proceeds up to 7mm depth from the top surface.

MAG: 10x

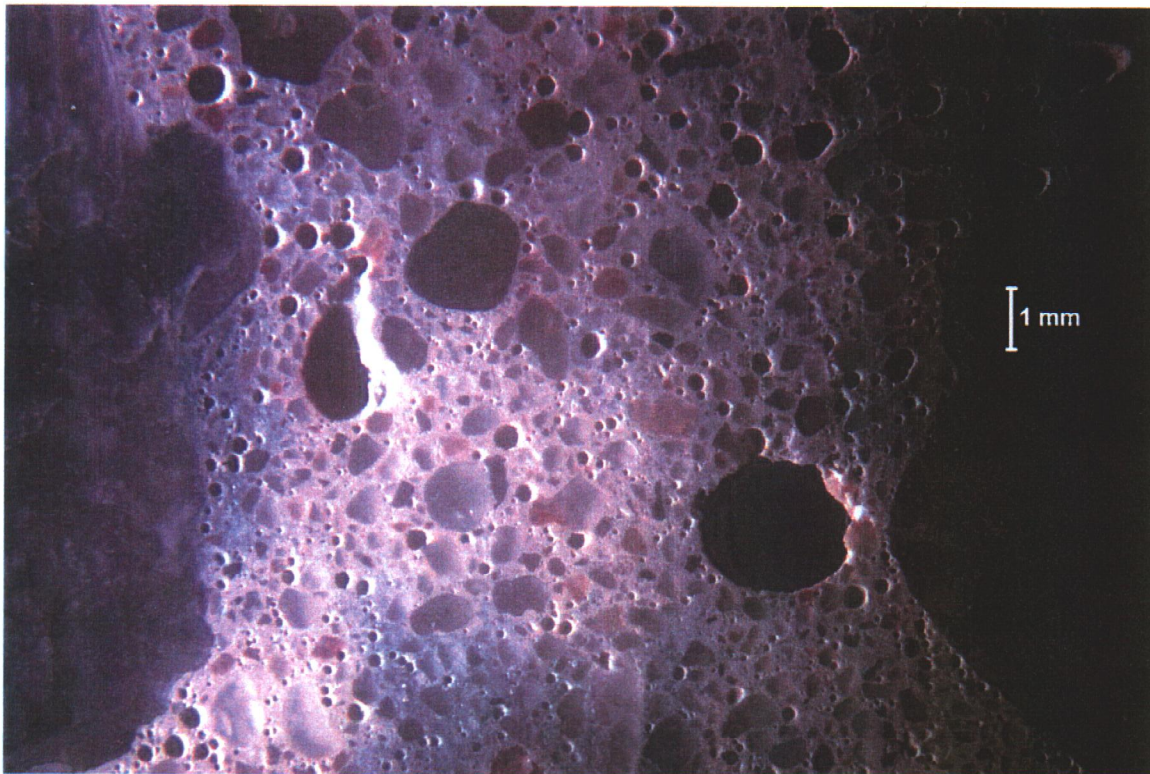


SAMPLE ID: 2A DESCRIPTION: Overall hardened air content, 7.3 % total.

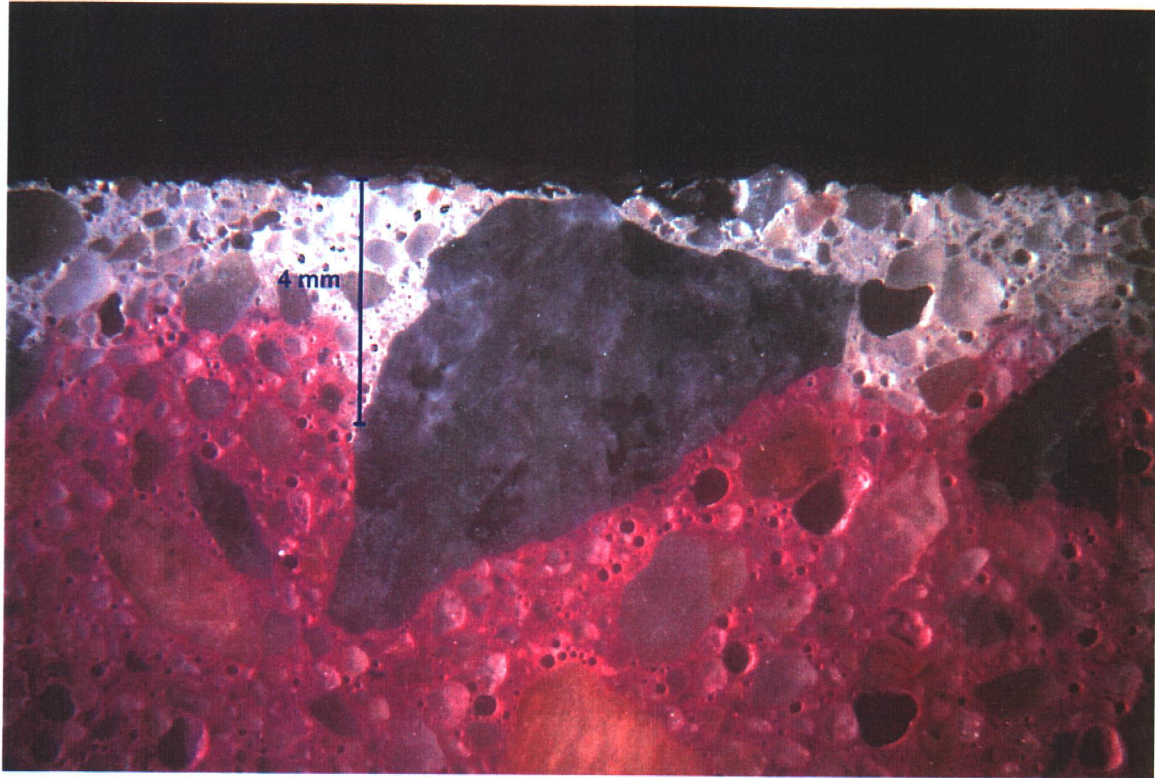
MAG: 10x



SAMPLE ID: 1B DESCRIPTION: Carbonation (unstained) proceeds up to 7mm depth from the top surface, along vertical shrinkage microcracking.
MAG: 10x

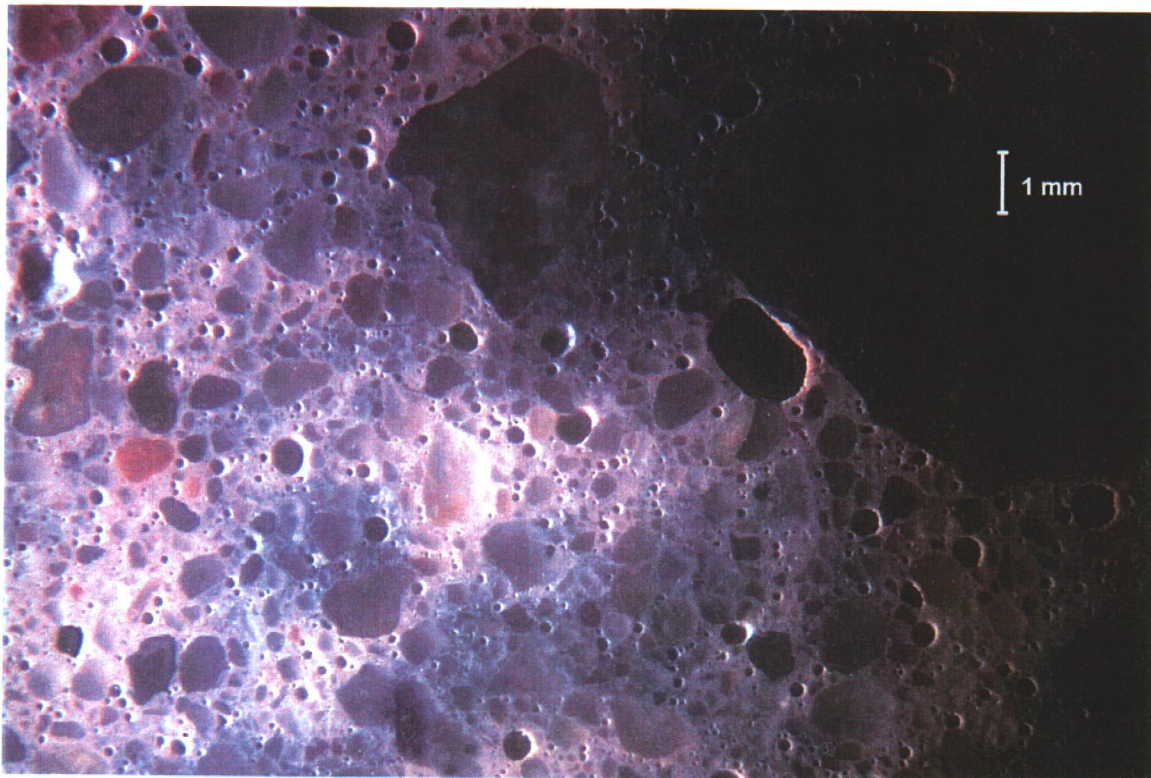


SAMPLE ID: 1B DESCRIPTION: Overall hardened air content, 8.8 % total.
MAG: 10x



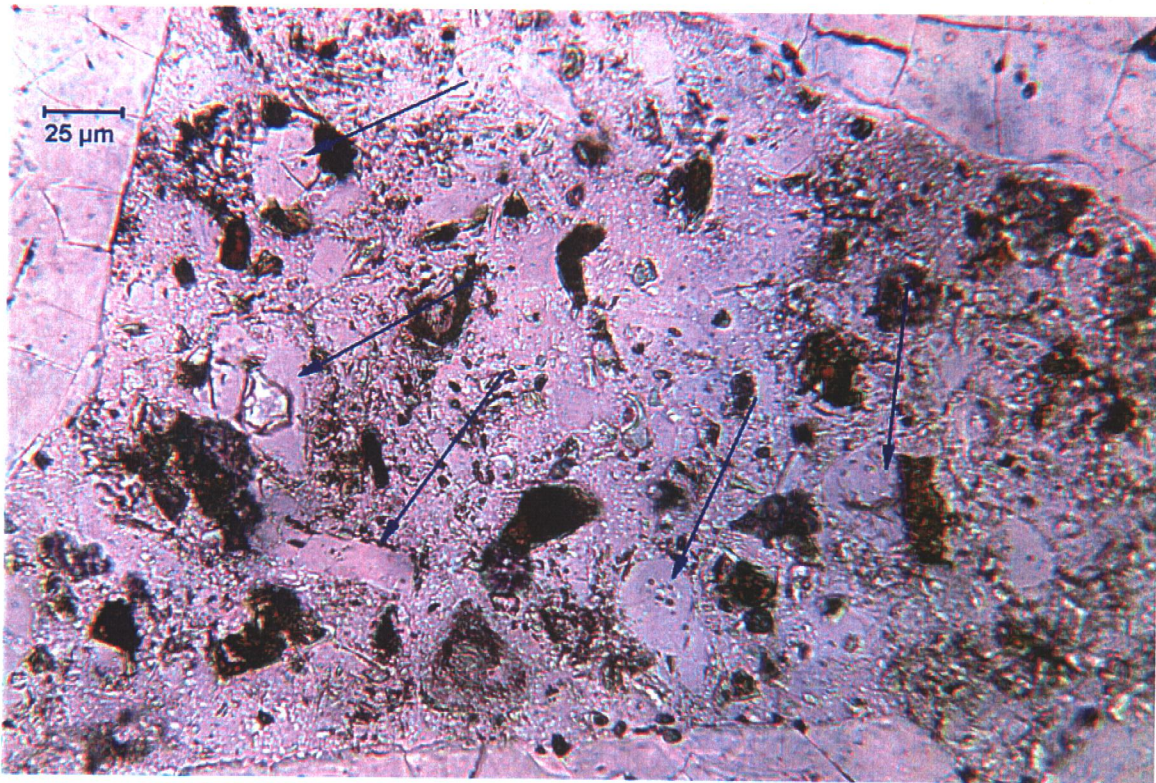
SAMPLE ID: 1A DESCRIPTION: Carbonation (unstained) proceeds up to 4mm depth from the top surface.

MAG: 10x

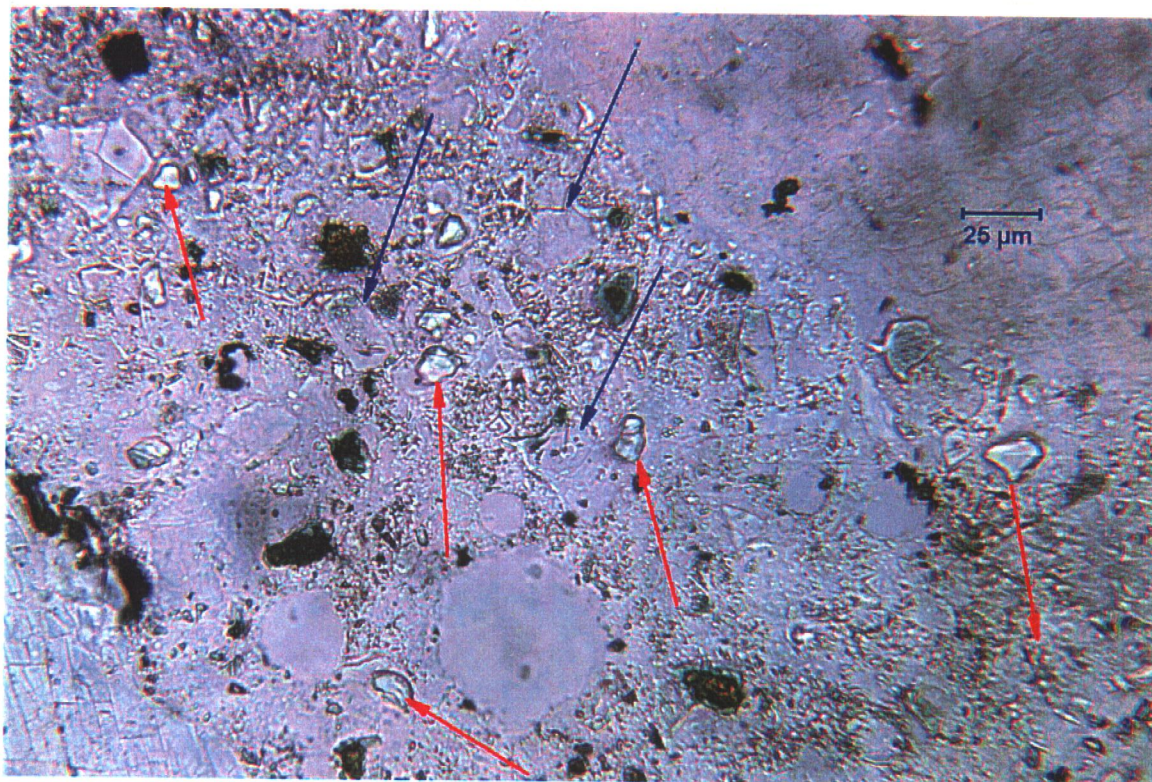


SAMPLE ID: 1A DESCRIPTION: Overall hardened air content, 5.9 % total.

MAG: 10x



SAMPLE ID: 4A DESCRIPTION: Well to fully hydrated alite portland cement clinker particles (blue arrows) in thin section of paste under plane polarized light.
MAG: 400x



SAMPLE ID: 5B DESCRIPTION: Mostly fully hydrated alite portland cement clinker relics (blue arrows) and unhydrated GGBFS particles (red) in thin section of paste under plane polarized light.
MAG: 400x