Evaluation of Concrete Pavement on US Route 113, Delaware

Field Site and Petrographic Evaluation

ASR Development and Deployment Program
Field Application and Demonstration Projects

U.S. Department of Transportation
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16. Abstract

This report presents the findings of an evaluation of an approximately 1-mile section of concrete pavement on U.S. Route 113 in Delaware. The section evaluated is the northbound lane starting at East Redden Road just north of the town of Georgetown, DE. The purpose of the current investigation is to confirm the presence of ASR and that ASR is the predominant cause of deterioration of the concrete pavement, and to determine whether the pavement is a suitable candidate for inclusion in the FHWA program as a demonstration project.

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Alkali-silica reactivity, reactive aggregates, petrography, evaluation, DRI, concrete, cores, micrograph, deterioration, ettringite

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Evaluation of Concrete Pavement on US Route 113, Delaware

Introduction

This report presents the findings of an evaluation of an approximately 1-mile section of concrete pavement on U.S. Route 113 in Delaware. The section evaluated is the northbound lane starting at East Redden Road just north of the town of Georgetown, DE. The evaluation consisted of a visual examination of the pavement and the extraction and testing of cores; testing at this stage has been limited to petrographic assessment and stiffness damaging testing. According to the construction documents made available at the time of writing this report, the pavement was constructed in 1993 and the concrete contained 5 sacks of cement (Blue Circle – Atlantic) and no supplementary cementing materials.

Delaware Department of Transportation (DelDOT) is of the opinion that the pavement is suffering from alkali-silica reaction (ASR) and the presence of ASR of low “intensity level” has been confirmed by a petrographic analysis performed by Dr. Donald Campbell (report dated September 11, 2008). DelDOT have requested that the pavement be treated topically with lithium nitrate and that the treatment be conducted as one of the “Field Application and Demonstration Projects” under the FHWA’s “ASR Development and Deployment Program”. The purpose of the current investigation is to confirm the presence of ASR and that ASR is the predominant cause of deterioration of the concrete pavement, and to determine whether the pavement is a suitable candidate for inclusion in the FHWA program as a demonstration project.

Visual Investigation

Dr. Michael Thomas of C&CS Atlantic Inc. visited the pavement on November 10, 2008, in the company of Mr. James Pappas and other representatives of DelDOT, and Mr. David Stokes of the FMC Corp. Approximately 0.5 miles of the right-hand lane of the northbound lanes was examined; photographs are shown in Appendix A). Visible cracking was not present for much of the pavement and the “damage” was restricted to dark stained lines in the vicinity of transverse and longitudinal joints (see Fig. A1). Hairline cracks (with < 0.015 in) were visible on close inspection in some of these locations (Fig. A2). A small number of panels did show visible cracking with cracks (widths 0.020 – 0.60 in) generally oriented in the longitudinal direction (Figs. A3 and A4).

Extraction of Cores

Seven 4-in diameter cores were cut to the full depth of the pavement (approximately 11 in). Photographs of the cores are presented in Appendix B. Only cores #5 and #6 were extracted from panels that showed visible cracking.

Laboratory Testing of Cores

Concrete cores were sent to Dr. Benoit Fournier of the University of Laval. To date, 2 cores have been examined by petrography to determine the damage index rating (DRI) and 3 cores have been evaluated using the stiffness damage test (SDT). Photographs of the two polished sections of cores used for the DRI are shown in Appendix C. Details of the procedures and the results for the DRI and SDT are given in Appendices D and E, respectively.

Summary of Findings

The extent of ASR and ASR damage in the concrete ranges from very low to moderate and there is clear significant variation in the damage from one location to another. Much of the concrete shows no visible cracking or hairline cracking and this is consistent with the low DRI values for cores taken from these locations. In the two or three panels that show visible cracks, the DRI is significantly higher. The results from the SDT are generally inconclusive with the core from the cracked panel showing a similar rating as those from the uncracked concrete.

Overall the condition of the concrete and the extent of ASR, though variable, render the concrete pavement a suitable candidate for treatment under the FHWA "ASR Development and Deployment Program". It is understood that DelDOT plan to treat this section with a topical application of lithium nitrate. Our previous experience with such topical lithium treatments do not lend support to this type of treatment as we have, generally, observed little penetration of lithium when it is applied topically to concrete structures. However, some level of success (and penetration) was achieved with previous topical treatments to concrete pavements in Delaware. On this basis, another trial seems warranted provided appropriate monitoring is employed to determine the efficacy of the treatment.

Sincerely

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Appendix A – Photographs of Concrete Pavement on Delaware Route 113

Figure A1 Staining around pavement joints

Figure A2 Hairline cracking (< 0.015-in) in panel where Core #3 is located

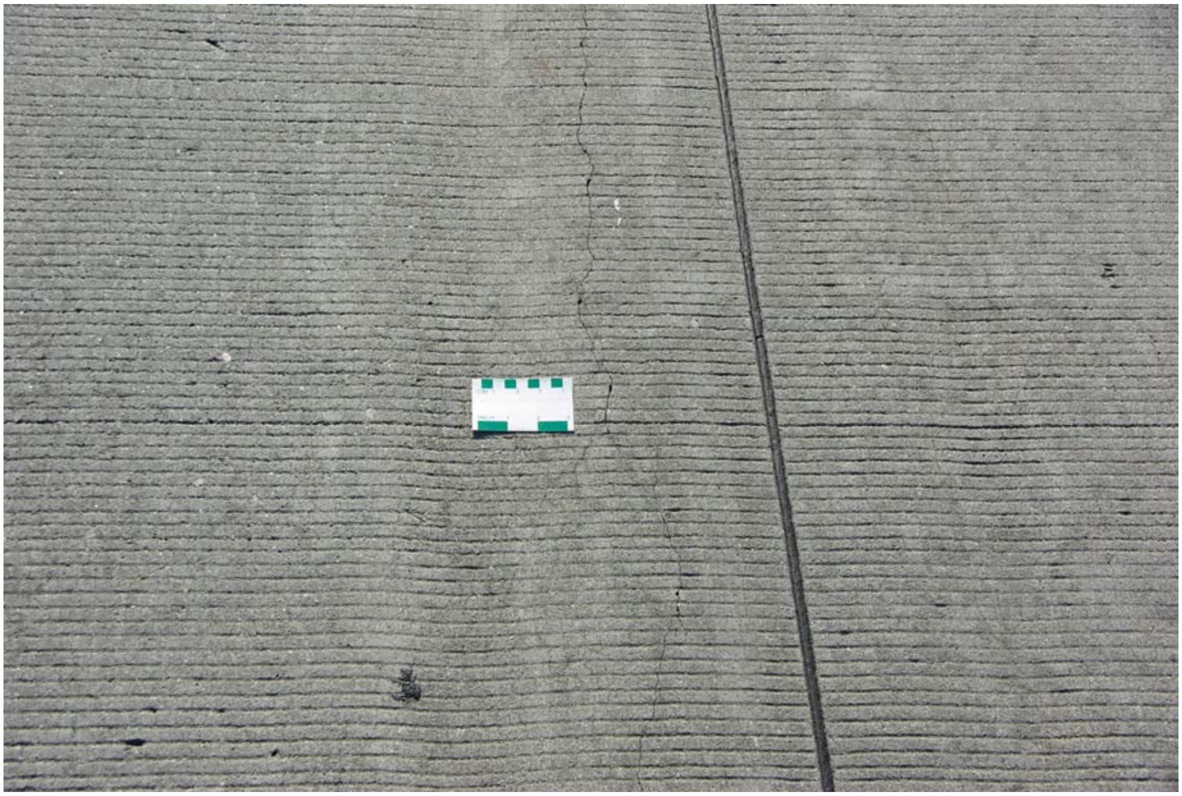


Figure A3 Cracking (0.03 – 0.06-in.) in panels where Cores #5 & #6 are located

Figure A4 Close-up of Cracking (0.03 – 0.06-in.) in panels where Cores #5 & #6 are located

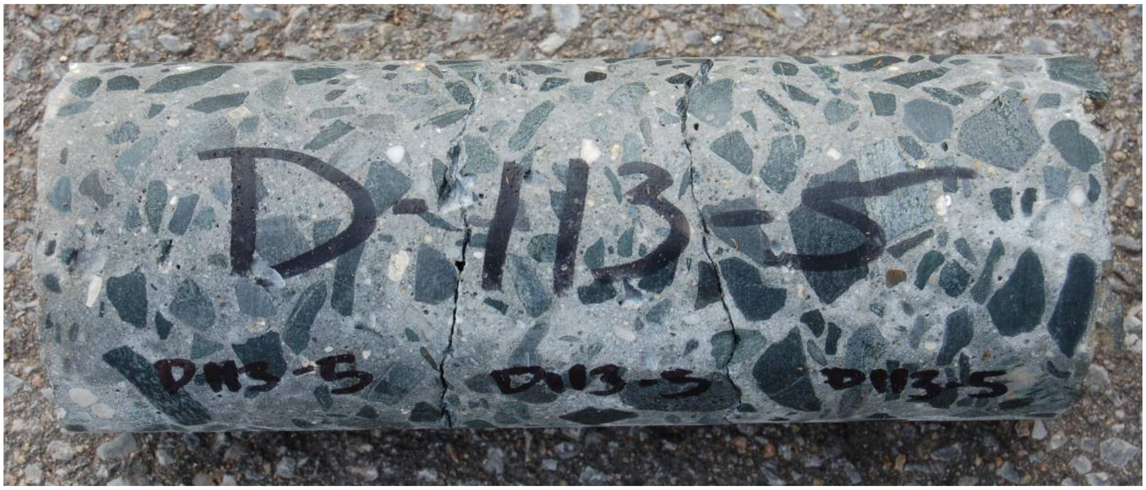
Appendix B - Photographs of Cores from Delaware Route 113

Core D113-1

Core D113-2

Core D113-3

Core D113-4

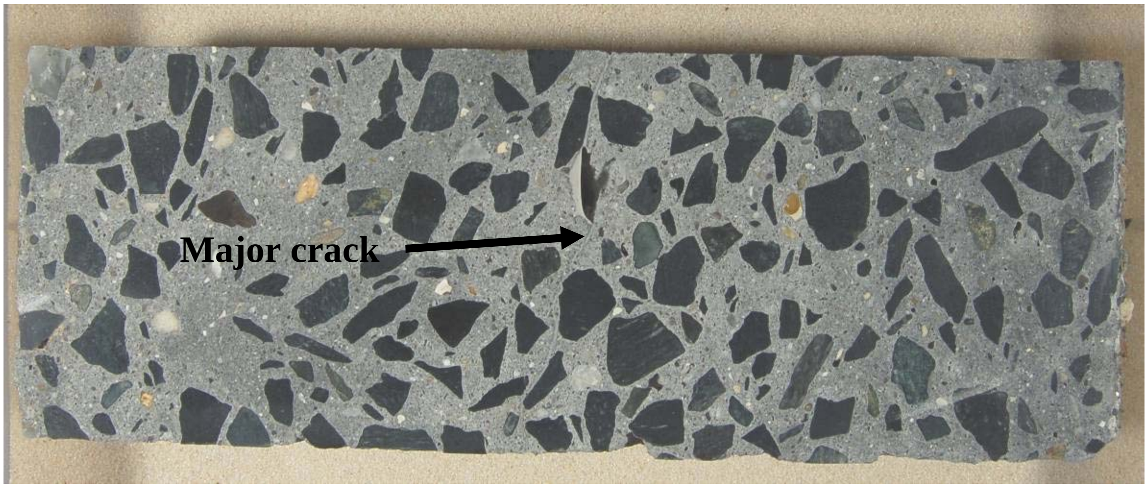


Core D113-5

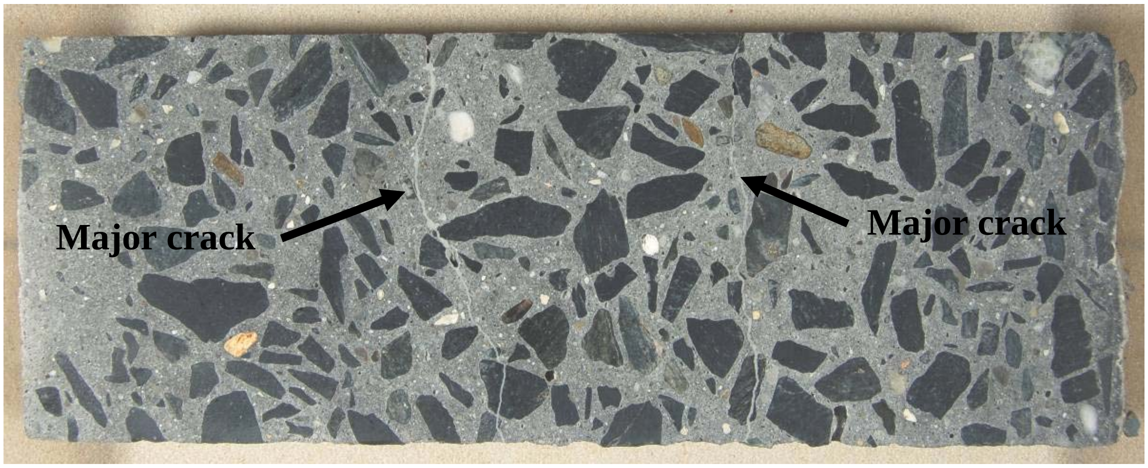
Core D113-6

Core D113-7

Appendix C - Photographs of the Polished Sections



Section 113-07
The core was in two pieces that were glued together.
The location of the major crack is identified on the picture.



Section 113-05
The cores was in three pieces that were glued together.
The location of the major cracks is identified on the picture.

Appendix D - Damage Rating Index

Grattan-Bellew (1992) and Dunbar and Grattan-Bellew (1995) described a method to evaluate the condition of concrete by counting the number of typical petrographic features of ASR on polished concrete sections (18x magnification)(Figure 1). A grid is drawn on the polished concrete section, which includes a minimum of 200 grid squares, 1 cm by 1 cm (0.4 by 0.4 in) in size. The *Damage Rating Index* represents the normalized value (to 100 cm^2) (16 in^2) of the presence of these features after the count of their abundance over the surface examined has been multiplied by weighing factors representing their relative importance in the overall deterioration process.

Petrographic feature	**Abbreviation**	**Weighing factor**
Coarse aggregate with cracks	CCA	x 0.25
Coarse aggregate with cracks and gel	C + GCA	x 2.0
Coarse aggregate debonded	CAD	x 3.0
Reaction rims around aggregate	RR	x 0.5
Cement paste with cracks	CCP	x 2.0
Cement paste with cracks and gel	C+GCP	x 4.0
Air voids lined or filled with gel	GAV	x 0.50

Figure 1: Petrographic features and Weighing Factors for the Damage Rating Index

The results of the DRI for the two cores examined (113-5 and 113-7) are illustrated in Figures 2 and 3. There is currently no “absolute” number for the DRI that indicates whether a concrete is not affected, or mildly, moderately or severely deteriorated due to ASR. However, values below 50 to 100 are generally indicative of a low degree of reaction / deterioration. Also, the method is under review to try improving the process and thus reduce the variability between the operators.

The two cores examined show fairly different degrees of deterioration, as illustrated by the DRI values of 395 and 65.

- <u>Core 113-5 - Petrographic features for the section 113-5 are illustrated in Figure 4.</u>
  - The sample shows significant signs of ASR both in the coarse and the fine aggregates. The main signs of reactivity are cracking both in the coarse aggregate particles and in the cement paste. In many cases, alkali-silica gel is observed in the cracks (both in the paste and the aggregates).
  - The degree of cracking is not that evident at the “macroscale” (i.e. visible with naked eye) but can be observed more easily under the stereobinocular microscope as used for the DRI.
  - Several particles of chert in the fine aggregate are observed that show significant signs of reactivity and associated cracking in the surrounding cement paste. Gel impregnation is also often observed by the darkening of the paste surrounding several of the reacted chert particles. A new petrographic feature was added to account for the reactivity observed in the chert particles; the feature is called “reacted particles (RP)” and a weighing factor of 0.50 was associated to it. This new feature has contributed a value of 44 to the DRI number of 395 obtained for this sample.
  - Only a few air voids contain deposits of alkali-silica gel.
  - Deposits of ettringite were found lining a large proportion of the air voids in the concrete (e.g. Figure 4F). The deposits form a sort of dense layer of compacted needles as illustrated in Figure 6.

- Core 113-7 - Petrographic features for the section 113-7 are illustrated in Figure 5.
  - The sample shows only low degree of ASR. Cracking is observed in some coarse aggregate particles but there is very limited cracking observable (at least at the magnification of 18x) in the cement paste. Petrographic features for the section 113-7 are illustrated in Figure 5. Chert particles are also in the fine aggregate fraction; however, in general, they show evidence of reactivity at a significantly lower degree than in the core 113-05. The "reacted particles (RP)" feature has contributed a value of 16 to the DRI number of 65 obtained for this sample.
  - A large proportion of the air voids in the cement paste, especially in the bottom portion of the core, are lined with secondary deposits of ettringite forming a relatively dense layer of compacted needle-type crystals. The nature of the above product was confirmed under the Scanning Electron Microscope on a sample taken from the core submitted to the SDT testing (D113-1) (Figure 6).

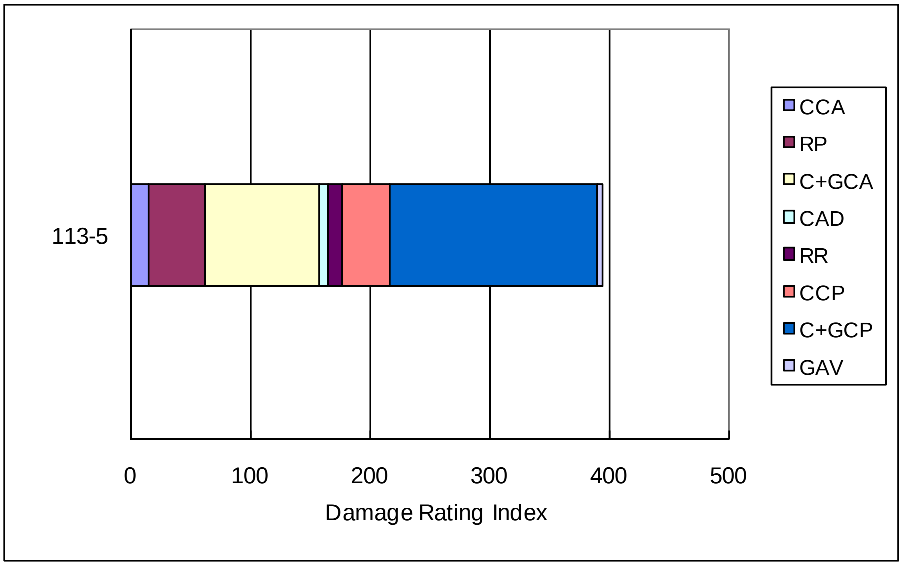


Figure 2 : Results of the Damage Rating Index for the core 113-5. The DRI for this core is 395.

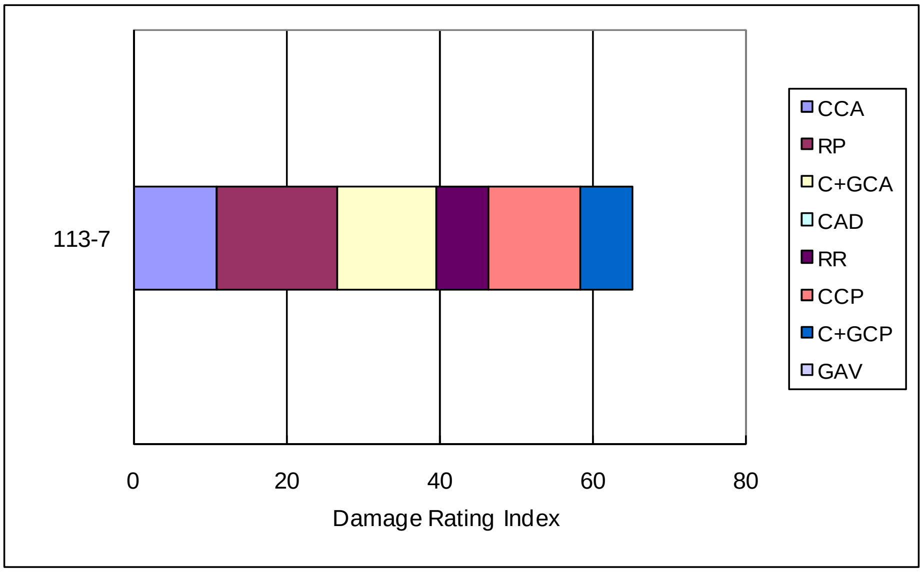


Figure 3 : Results of the Damage Rating Index for the core 113-7. The DRI for this core is 65.

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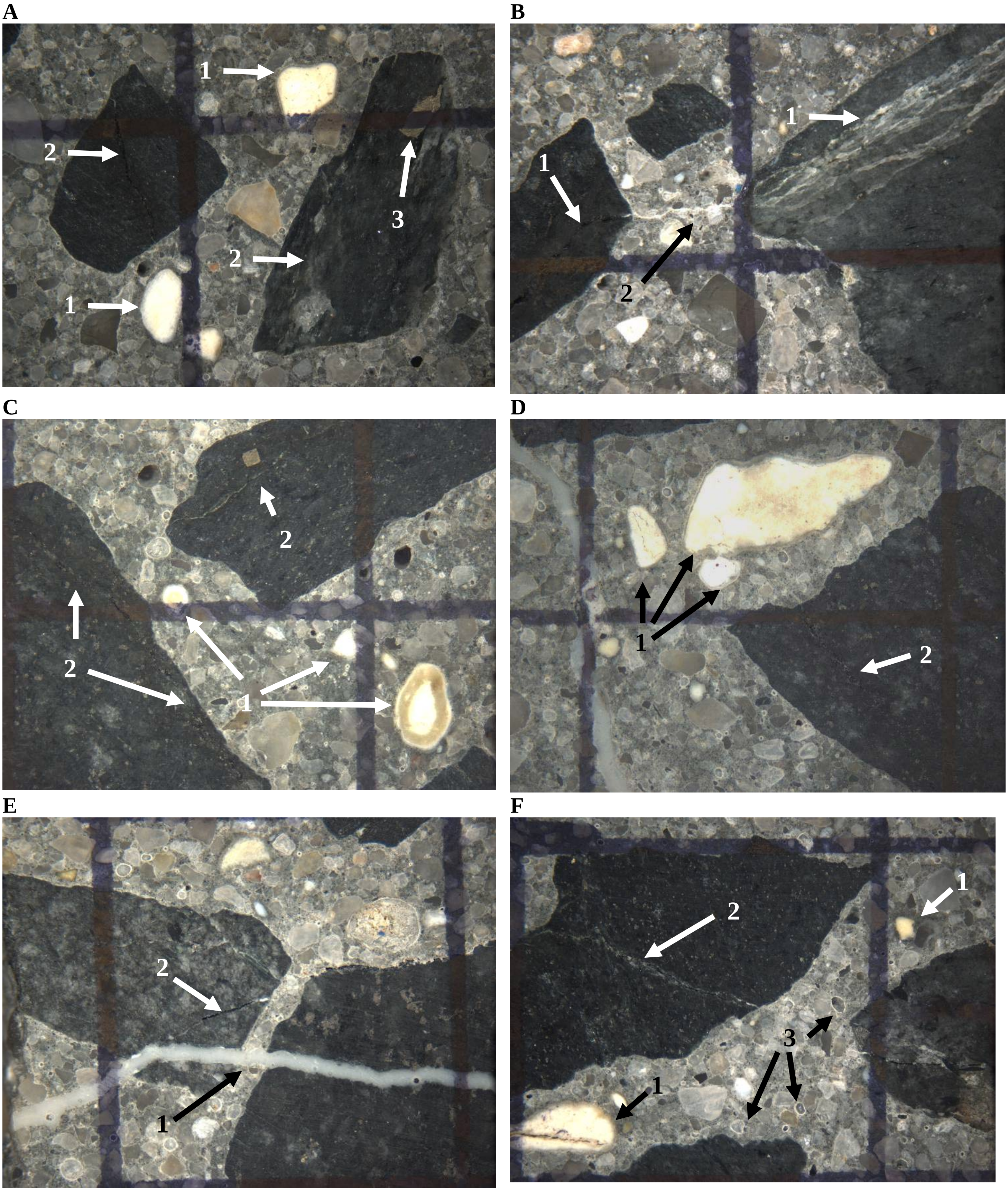

Figure 4: Micrographs of the Polished Section 113-05

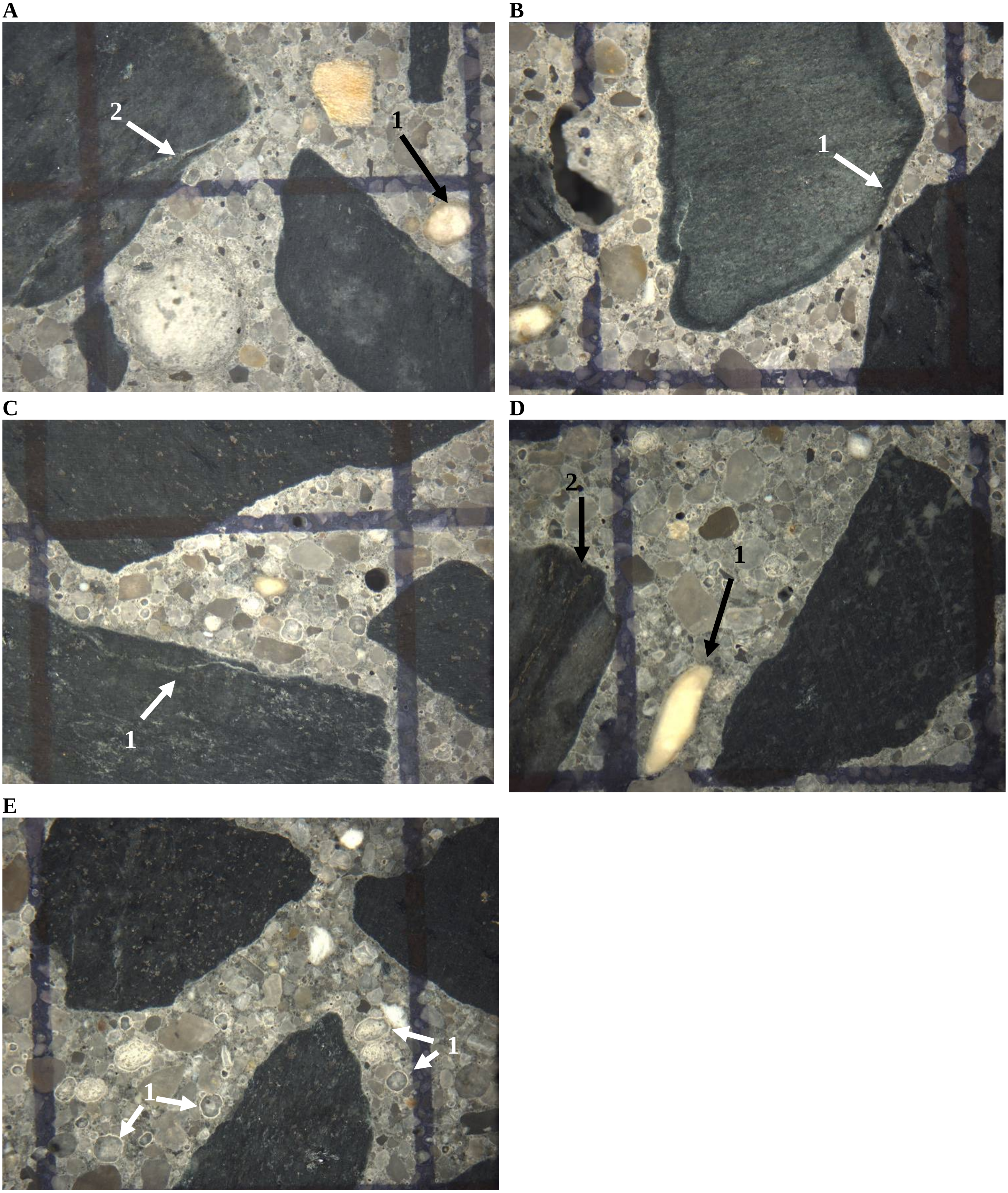

Figure 5: Micrographs of the Polished Section 113-07

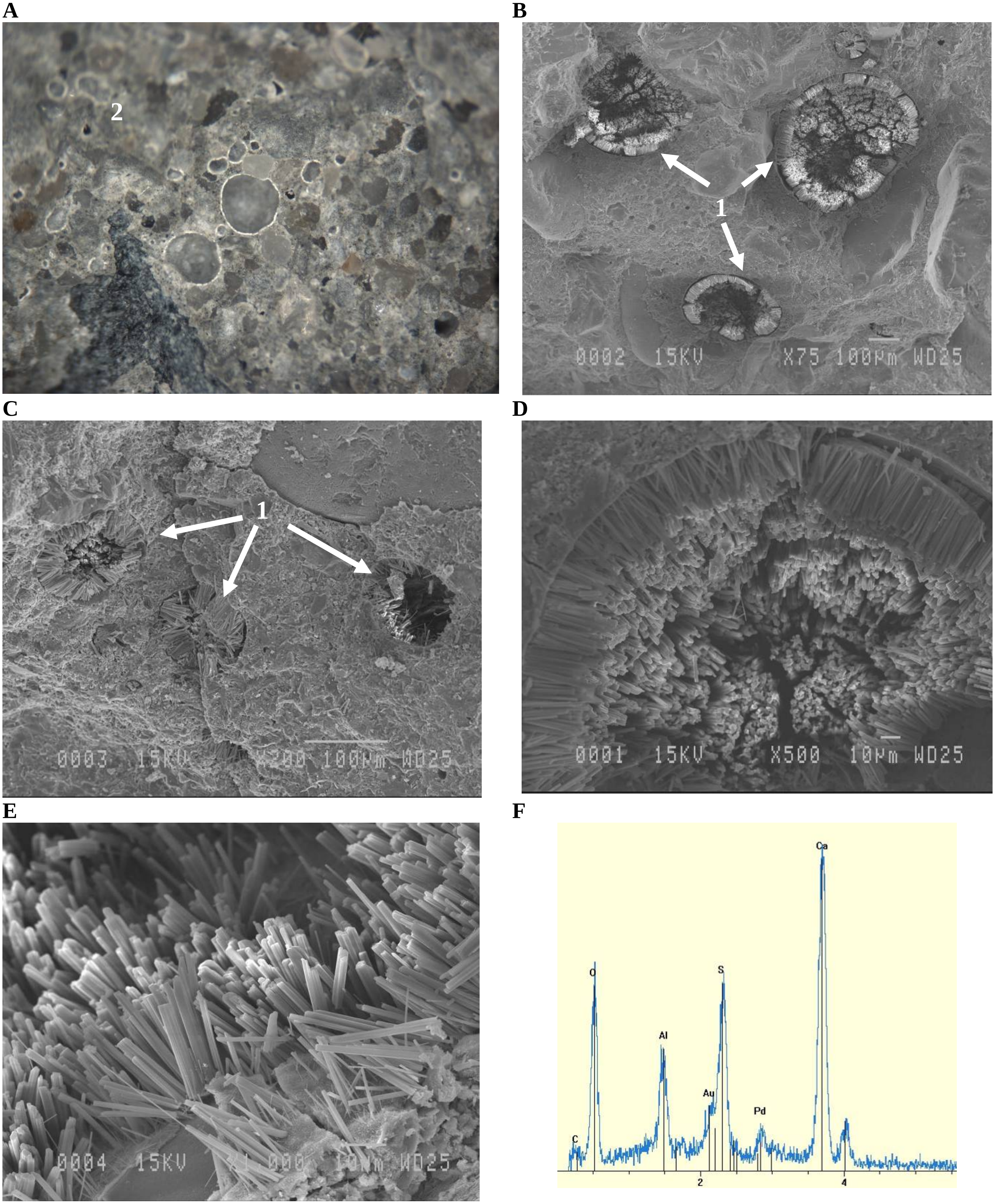

Figure 6: SEM Micrographs of the concrete core 113-1

Captions for Figure no. 4: Section 113-5

A. Reacted chert particles (1) of the fine aggregate and cracking in the coarse aggregate (2). We can observe gel impregnation (darkening) of the cement paste around several reacted chert particles. Several coarse aggregate particles include dissiminated iron sulfides (3).
B. Cracking in the cement paste (2) connecting two cracked coarse aggregate particles (1). Gel can be observed filled the cracks both in the cement paste and aggregate particles.
C. Reacted chert particles (1) of the fine aggregate and cracking in the coarse aggregate (2). The reacted chert particles often show a reaction rim, internal cracking which sometimes extends into the cement paste and partial desintegration.
D. Reacted chert particles (1) of the fine aggregate and cracking in the coarse aggregate (2). Cracks in the aggregate particles are often filled, at least partially, by alkali-silica gel.
E. Major crack in the concrete core (1) that was glued with epoxy cement and crack partially filled with alkali-silica gel in the coarse aggregate particle (2).
F. Reacted chert particles (1) of the fine aggregate and cracking in the coarse aggregate (2). We can observe gel impregnation (darkening) of the cement paste around several reacted chert particles. Several voids of the cement paste are lined with secondary deposits of ettringite (3).

Captions for Figure no. 5: Section 113-7

A. "Partially" reacted chert particles (1) of the fine aggregate and cracking (partially filled with alkali-silica gel) in the coarse aggregate (2). In general, the chert particles in the core 113-7 show a lesser degree of reaction than those in the section 113-5.
B. Dark reaction rim around a coarse aggregate particle. This is not a very common feature in the concrete examined.
C. Cracking (partially filled with alkali-silica gel) in the coarse aggregate (1). Voids are often lined with a layer of secondary products which would need further identification under the scanning electron microscope.
D. "Partially" reacted chert particles (1) of the fine aggregate; présence of iron sulfides in the corase aggregate particles (2).
E. Typically, coarse aggregate particles show limited internal cracking (compared to sefction 113-5), as shown on this micrograph. Several voids are lined with secondary deposits of ettringite (1).

Captions for Figure no. 6: Core 113-1

A. Sterobinocular micrograph showing voids lined with deposits of ettringite.
B. SEM micrograph showing voids lined with deposits of ettringite.
C. SEM micrograph showing voids lined and even filled with deposits of ettringite.
D. SEM micrograph showing a void lined with a densely packed layer of ettringite needles.
E. SEM micrograph showing ettringite needles in an air void.
F. Typical composition (EDS) of the ettringite needles (calcium sulfoaluminate).

Appendix E - Stiffness Damage Test (SDT) (see Fournier et al. 2008 for more detailed information on the method)

The Stiffness Damage Test (SDT) was originally proposed by Chrisp et al. (1989, 1993) and adopted by the Institution of Structural Engineers in the early 1990's (ISE 1992). It is based on the cyclic uniaxial compressive loading of concrete core samples (5 cycles) between 0 and 5.5 MPa (800 psi). The reduction in the Young's elastic modulus, the energy dissipated during the load-unload cycles, which corresponds to the surface area of the hysteresis loops, and the accumulated plastic strain after these cycles, are associated with the closure of the existing cracks and to a slip mechanism, and thus represent a measure of the damage in the specimen (microcracking) in the direction of the applied stress. Smaoui et al. (2004a, 2004b, 2004c) and Bérubé et al. (2005a) found that the test gave better results when applying a maximum load of 10 MPa (1450 psi) during the 5 load/unload cycles (rather than 5.5 MPa (800 psi) in the original method). This modified SDT can thus supply useful information about the internal damage (microcracking) of the concrete under study.

The results of the SDT obtained on three cores (113-1, 113-2 and 113-6) are given in Table 1 and illustrated in Figure 7. There is currently no "absolute" number for the SDT that indicates that a concrete is not affected, or mildly, moderately or severely deteriorated due to ASR. Smaoui et al. (2004a) tested a number of different aggregates subjected to the Concrete Prism Test (ASTM C 1293) and carried out the SDT at different concrete prism expansion levels. The results of Samoui et al. (2004a) are illustrated in Figure 8.

The results in Figure 8 show that the results of the SDT can be significantly affected by the type of reactive aggregate. For this reason, the curves proposed in Figure 8 are not directly applicable to the testing carried out on the cores tested in this study. However, Figure 8 provide an "order of magnitude" of the results obtained in the SDT for a number of reactive aggregates. Based on Figure 8, the results of the SDT obtained on the cores 113-01, 113-02 and 113-06 (from Delaware) "could" correspond to a concrete that would have suffered from a relatively low to moderate expansion/deterioration. Once again, this is an approximation; confirmation of the correspondance between the internal damage due to ASR and the SDT values would be best obtained by establishing a calibration curve with the aggregate used in the Delaware structure. This would be obtained by performing expansion testing under controlled conditions in the laboratory and mechanical testing of specimens obtained from the deteriorating concrete at specific expansion levels (or internal degrees of deterioration).

Table 1: Results of the Stiffness Damage test.

Sample	Dissipated Energy (J/m^3)
113-01	0.62×10^3
113-02	0.64×10^3
113-06	0.65×10^3

The concrete cores were tested under compression after the completion of the SDT; the compressive strength of the cores ranged from 7000 to 8500 psi. The visual examination of fragments of the concrete cores submitted to the SDT/compression testing revealed the presence of reacted chert particles; however in relatively small quantities (~ < 1% of the sand fraction). Also, secondary products of ettringite were found lining quite a few voids of the cement paste.

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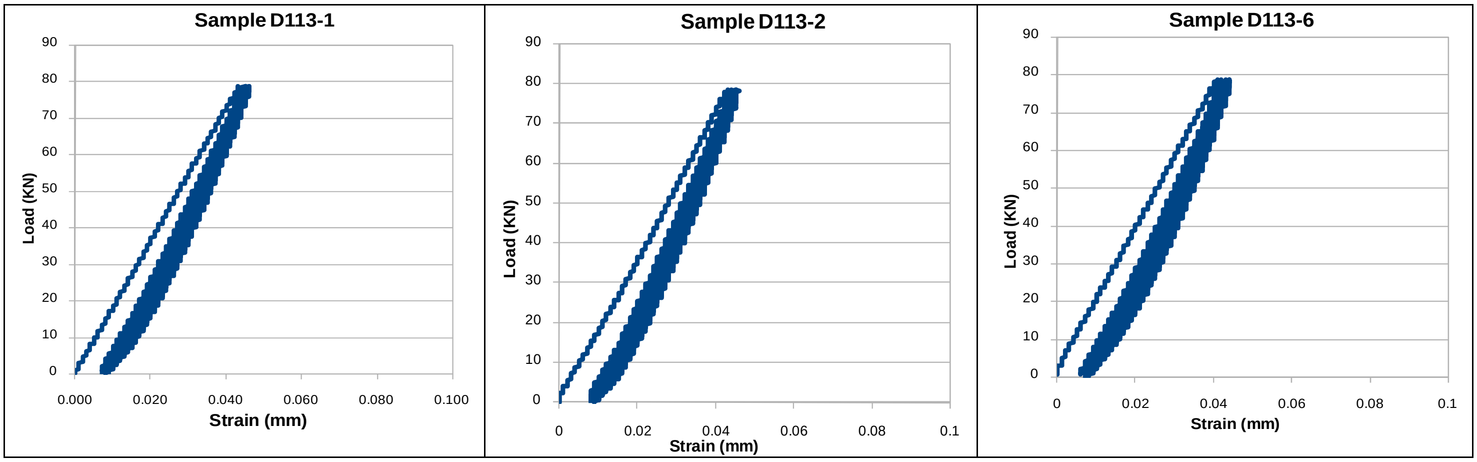

Figure 7: Results of the Stiffness Damage test for the cores D113-1, 113-2 and 113-6.

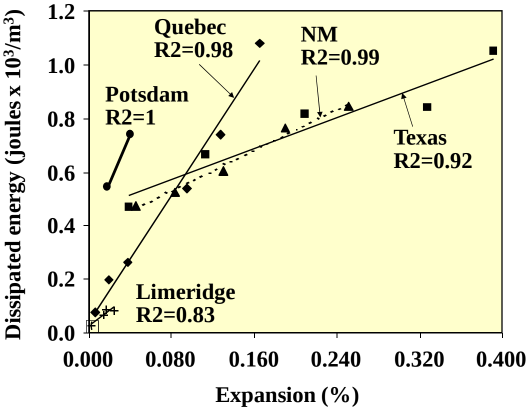

Figure 8 : Relationship between the Dissipated Energy (areas under the first hysteresis) and the expansion of concrete dues to ASR (Samoui et al. 2004).

Benoit Fournier, Ph.D.
Laval University, November 24 2008.