Predicting Future Expansion of the Oyster River Durham Falls Dam

Final Report

to

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EXECUTIVE SUMMARY

Earlier studies on the Oyster River Dam's concrete suggested that a chemical reaction in the concrete's matrix known as Alkali Silica Reaction (ASR) along with other environmental factors may be degrading the concrete's long term structural integrity. This study supplemented the earlier work and was conducted to determine what the remaining ASR expansion potential, the affect of the ASR and freeze/thaw distress on the useful serviceability of the Oyster River Dam's spillway and if the distress is expected to continue in the future. This study focused on the dam's spillway because the previous work already determined the gate structure was deteriorated beyond repair and will require complete replacement within 5 to 10 years.

Laboratory tests were conducted on 10 cores extracted from the Oyster River Dam's concrete spillway to determine if ASR has significant potential to cause continued expansion in the spillway's concrete. Core samples were dimensionally measured before and after being exposed to high humidity for up to six months in an electrically charged field at elevated temperature to accelerate the reaction and its affects. These samples were compared with other samples that were immersed for a similar duration in plain water and a solution of sodium hydroxide.

The tests results suggest that ASR is not continuing to a significant degree and that the potential for ASR to cause continued concrete expansion of the spillway concrete is limited. However, there are other mechanisms at work (i.e. freeze and thaw, and mineralization of other compounds) that compromise the long term serviceability of the spillway. Because of the extensive micro-cracking observed throughout the existing concrete and the other factors contributing to concrete expansion, there is still potential for the concrete to continue to expand albeit at a slower rate than if ASR was ongoing. Areas of the spillway also exhibit non-structural near surface degradation as evident by localized concrete spalling and erosion which has locally expose steel reinforcement. The existing microcracking combined with factors involving freezing, thawing, and mineralization all contribute to a gradual degradation of the concrete's strength characteristics. The combination of these factors compromises successful bonding between new concrete and old concrete, and therefore making it difficult to rely upon such a bond for long term structural strength.

Based on the results of this and previous studies, the spillway is likely to maintain sufficient structurally integrity for possibly the next 10 to 20 years. It would however be prudent to develop a plan in the near future to address the affects of ongoing gradual degradation of the dam's spillway. The non-structure surface degradation will require attention sooner than 5 to 10 years. Future structural repairs would have better chances of success if they were designed to not depend on a structural bond between old and new concrete.

INTRODUCTION

Recent studies of the Oyster River Dam concrete[1,2] showed the concrete has deteriorated from environmental and material related distresses including Alkali Silica Reaction (ASR) and freezing and thawing. It was suggested in the earlier studies that these distresses caused extensive microcracking which decreased the concrete's tensile and elastic properties. ASR is a chemical reaction between the alkali minerals in the concrete's cement and the silica in the concrete's aggregate. This is a very slow reaction that occurs over a period of many decades and causes concrete to expand. The expansion results in a gradual degradation of the concrete's long term structural integrity and reducing the confidence with which new concrete might bond to the old concrete during a repair. What was not determined with the initial studies was to what degree ASR is still ongoing, and the affect of the ASR and freeze/thaw distress on the useful serviceability of the Oyster River Durham Falls Dam's spillway and if the distress scan be expected to continue in the future. It was decided to conduct this additional work to supplement the initial studies and specifically assess the ASR related distress.

The scope of this study was to determine if ASR is continuing and to what degree there is a remaining potential to cause continued expansion in the concrete of the spillway of Oyster River Dam by conducting a series of laboratory tests on concrete cores extracted from the dam's spillway. This study focused on the concrete of the dam's spillway because results from the previous work revealed that the concrete of the gate structure exhibited such severe deteriorated it was not possible to obtain usable concrete cores for testing.

LABORATORY TESTING PROTOCOL

Ten (10) concrete cores were obtained in July 2010 from the vertical foundation ribs between cells 7/8 and 8/9 below the dam spillway as shown on Figure 1. The core sample identification and testing information is shown in Table 1. The laboratory evaluation of the cores consisted of performing modified American Society for Testing of Materials (ASTM) tests to evaluate the concrete for potential expansion in the future from ASR.

Modified ASTM C 1260

ASTM C 1260, Standard Test Method for Potential Alkali Reactivity of Aggregates (Mortar-Bar Method) is a test method to determine the potential alkali reactivity of aggregates. Small 1"x1"x11" samples with studs in their ends are made with the aggregate in question. These samples are submerged in one normal sodium hydroxide solution held at 180 ^{o}C and the resulting expansions are monitored for 16 days and sometimes for up to 28 days. If the expansion exceeds 0.1 percent the aggregate is considered reactive and it must be mitigated when used in portland cement concrete. The modified version of this test, as used in this study, consisted of subjecting 5" cores to the test conditions after stainless steel studs were inserted in the ends. Under such conditions a concrete that contains reactive aggregates would be expected to expand very quickly, well in excess of the 0.1 percent criteria.

Modified ASTM C 1293

ASTM C 1293, Standard Test Method for Determination of Length Change of Concrete Due to Alkali-Silica Reaction is a test method highly accepted as being the most desirable test to evaluate the potential reactivity of an aggregate because it has been correlated with actual field performance of reactive concrete. The test consists of testing a concrete beam 3”x3”x11” with studs suspended over water in a sealed container held at 100 ^{o}F for one year. If the expansion exceeds 0.04 percent the aggregate must be mitigated to prevent ASR if it is used to make portland cement concrete. The down side to the test is the extremely long testing period. The test was modified by testing 5” studded cores instead of concrete beams.

Accelerated ASTM C1293

The accelerated ASTM C 1293 is also a modified version of the basic test C 1293 test. The major complaint of the standard ASTM C 1293 is the long duration of time required to complete the test. Research at the University of New Hampshire led to the development of a unique method to accelerate the standard test. ASR is pH motivated in that when the pH increases to about 12.3 within the concrete ASR becomes activated. So the probability of reaction becomes a function of the interaction of hydroxyl OH^{-1} ions and the reactive silica in the aggregate, usually high energy amorphous silica. Both ends of the cores were painted with a special carbon paint to make them conductive. A constant current circuit delivering 1 milliamp was applied on the two ends through the studs. The electrical current forces the hydroxyl ions to migrate from one end to the other and if they encounter reactive silica along the way expansion would be expected to occur, thus accelerating the standard test. A general rule of thumb is that the acceleration that occurs within 60 days is equivalent to one year of standard tsting.

Modified ASTM C 1293 Water Test

A modified version of the of the ASTM C 1293 test was performed on one of the cores after it had failed to significantly expand when submerged in the sodium hydroxide solution at 180 ^{o}F. The core was submerged in tap water and placed in the precision oven and held at 100 ^{o}F just like in the ASTM C 1293 test. The core was placed in a sufficient amount of water so the sodium hydroxide remaining within the core could be neutralized and the only effect of the test would be the core stored in water at 100 ^{o}F. Length change was monitored as a function of time as in the other expansion tests.

LABORATORY TESTING RESULTS

Studs were mounted in the ends of the cores and those selected for ASTM 1293 testing were weighed and approximately 5 percent of their weight was placed in a plastic sleeve with one sealed end. The sleeve was evacuated and sealed such that the surface of the plastic uniformly exposed the core to a thin layer of moisture. Occasionally the sleeves were opened and the cores weighed then re-evacuated and sealed with the original water so as to not lose any alkali that was initially present in the cores. This process was continued until moisture equilibrium was achieved as defined through no additional moisture weight gain. The cores were then placed in the appropriate testing environment as defined by the individual modified ASTM C 1293 test procedure discussed above. The ASTM C 1260 testing was initiated without the cores obtaining moisture equilibrium.

Modified ASTM C 1260

Figure 4 and 5 show the expansion results of the modified ASTM C 1260 testing. The results show that both cores 3-2 and 3-5 achieved approximately 0.01 percent expansion within the normal 16/28 day testing time period. As discussed above a concrete that contains reactive aggregates would be expected to expand very quickly, well in excess of the 0.1 percent criteria within the normal testing time period of 16/28 days. The core samples were left in the test solution well in excess of the normal time frame (120 days) just to make sure the expansions were not significant. Lack of significant expansion was expected result since the earlier petrographic study showed the Dam’s concrete to have undergone some obvious expansion. The conclusions drawn from this test suggest that the Oyster River Dam’s concrete has insignificant remaining ASR expansion potential. The samples were then removed from the 1 normal sodium hydroxide solution at 180 ^oF and placed in containers of tap water and held at 100 ^oF as discussed in the modified version of the of the ASTM C 1293 water test.

Modified ASTM C 1293

The modified ASTM C 1293 expansion results of samples 3-3 and 2-4 are presented in Figure 6. The expansions suggest that if the test was allowed to continue for the year test period that the 0.04 percent level would be obtained. Such would deem the aggregate ASR reactive which is just opposite of the conclusions drawn from the modified ASTM C 1260 test. These data show that expansion is continuing however as will be discussed later, the expansions are not related to ASR.

Accelerated ASTM C1293

The accelerated ASTM C 1293 test data are presented in figure 7. These data show the accelerated results at approximately 60 days to be in the order of 0.04 percent which again like the non-accelerated test suggest the aggregate is to be deemed reactive and its use would require some form of mitigation when used to make portland cement concrete. Again these data are not consistent with what the ASTM C 1260 test results showed. These unusual data suggested something else was involved with the expansion of the cores. In that the core expansions occurred by adding only water without chemicals led to the testing of the ASTM C 1260 cores in only water held at 100 ^oF.

Modified ASTM C 1293 Water Test

A modified version of the of the ASTM C 1293 test was performed on core 3-2 after it failed to significantly expand when submerged in the extremely aggressive 1 normal sodium hydroxide solution at 180 °F while the cores stored above water in the ASTM C 1293 test were expanding. The expansion in water, shown in Figure 8, continued to expand at about the same rate it did in the ASTM C 1260 test. The time scale on the x axis of Figure 8 is actually day 43 at day 0 and the last date shown at day 79 was actually day 122. The hump in the data at day17 is most likely an erroneous measurement. A composite figure showing expansions from all the tests as a function of continuous time is presented in Figure 9. This shows without doubt the expansion is a function of the presence of water and not sodium hydroxide. There is only one possibility that explains these extremely unusual results and that is the formation of Ettringite which is a calcium sulfoaaluminate hydrate.

Previous Work

The first phase of this work resulted in a possible conclusion that the Oyster River Dam had ASR and/or freeze thaw damage.[1] This appears to be true with this study, however the potential for ASR expansion is likely not as significant as originally thought most likely due to the lack of alkali and reactive silica in the remaining concrete. There is however a reaction occurring but at a relatively slow rate.

Figures 31 through 45 taken from the earlier Oyster River Durham Falls Dam report[1] follows Figure 9. These are photographs of the thin sections made during the petrographic study. Although Ettringite was noted it was not felt that it had any significance relative to ASR expansion. Close observation of these thin section photographs shows there are two types of Ettringite, one which is common to all concrete and a special version referred to as Delayed Ettringite Formation (DEF). The DEF version can be very detrimental to the integrity of concrete caused by expansion when it is formed. The presence of DEF is apparent in Figures 35, 37, 38, 40 and 41. Conventional Ettringite is shown in Figures 36, 39, 40, and 43. The formation of the DEF causes expansion due to the increased volume of outside water migrating into the concrete to combine with the sulfur and alumina within the concrete matrix (from the original Rosendale Cement). The DEF deposits act like a wedge and push the components apart. This appears to explain the expansion observed in this laboratory study when the samples expanded when placed in nothing but water held at 100 °F.

DISCUSSION

There is no question about the expansion of the concrete continuing in the future. Excessive expansion of the concrete will increase microcracking and macrocracking, lower concrete strength, accelerate delaminating and increase surface erosion. The rate of deterioration will increase due to the compounding effect of opening the system to moisture which is required for both the freeze thaw and ASR mechanism to occur. However, having stated this, it is important to address the expected rate of expansion. The Oyster River Dam is approaching its 100 anniversary and it has only been rehabilitated once. Considering it's age, this is a significant record. DEF formation is a thermally activated process and the difference in the rate of reaction going from an average temperature of the Oyster River Dam of around 50 ^{o}F to the 100 ^{o}F oven testing temperature would be expected to result in laboratory expansions in the order of 30 times faster than in the field. Typical thermally activated reaction rates double with a 10 degree temperature increase. The expansions found in the high temperature laboratory testing were low and not significant leading to the conclusion that the ongoing expansion in the field with an average temperature of around 50 ^{o}F is quantity wise insignificant. This along with the relatively high strength and elastic modulus determined in the earlier study[1] suggest the Oyster River Dam is not likely to see any significant deterioration from expansion in the near future. One area of interest that was not investigated was the affect of submersion by the twice daily high tide. It is also possible that the submersion of the lower portion of the spillway by brackish tidal water could be enhancing the expansion as evident by the relatively higher rate of expansion observed in sample #2-1 which was extracted near the high tide line (see Figure 7).

CONCLUSIONS

The Oyster River Dam has shown itself to be stable during recent flooding. It is true that the dam has concrete degradation issues as well documented in the Stephens Associates report[2], however it is not anticipated that the current condition of the Oyster River Dam's spillway will drastically change in the short term. Ultimately, like everything else constructed and exposed to the outdoors, the dam's spillway will likely need major renovation within the 10 to 20 years. As noted in the Stephens Associates report[2], the right abutment and gate structure is severely deteriorate and will likely require major renovation or replacement within the next 5 years. The scope of the testing and results described herein were not intended to address the conditional issues associated with the gate structure and right abutment.

In that the underlying concrete is expanding, it is suggested that if a renovation design is elected for the spillway over a total replacement that the new repair concrete be independent of the Oyster River Dam and no major bonding be attempted to gain structural capacity. The current areas that are delaminated are most likely the result of volumetric incompatibility at the interface of the new and old concrete as a direct result of past expansion of the original concrete.

Based on the relatively slow expansions it seems reasonable if a repair design similar to the repair that was implemented in the 1970s is repeated then the life expectancy should be similar to what was previously achieved (20-30 years). On the other hand if the repair is designed to be structurally independent (bond wise) of the current structure then a longer life may possibly be expected.

References

1. "Evaluation of the Concrete of the Oyster River Durham Falls Dam Concrete", Final Report, by Dr. David Gress Ph.d, P.E. March 25, 2010.
2. Concrete Evaluation Report, Oyster River (aka Mill Pond) Dam #071.03, by Stephens Associates Consulting Engineers, LLC. March 31, 2010.

Table 1 Durham Dam Core location and tests performed.

Core Identification	Location	Test
2-1	Rib 2 position 1	Accelerated ASTM C 1293
2-2	Rib 2 position 2	Not tested
2-3	Rib 2 position 3	Accelerated ASTM C 1293
2-4	Rib 2 position 4	Modified ASTM C 1293
2-5	Rib 2 position 5	Accelerated ASTM C 1293
3-1	Rib 3 position 1	Not tested
3-2	Rib 3 position 2	ASTM C 1260 and Water Expansion
3-3	Rib 3 position 3	Modified ASTM C 1293
3-4	Rib 3 position 4	Not tested
3-5	Rib 3 position 5	ASTM C 1260

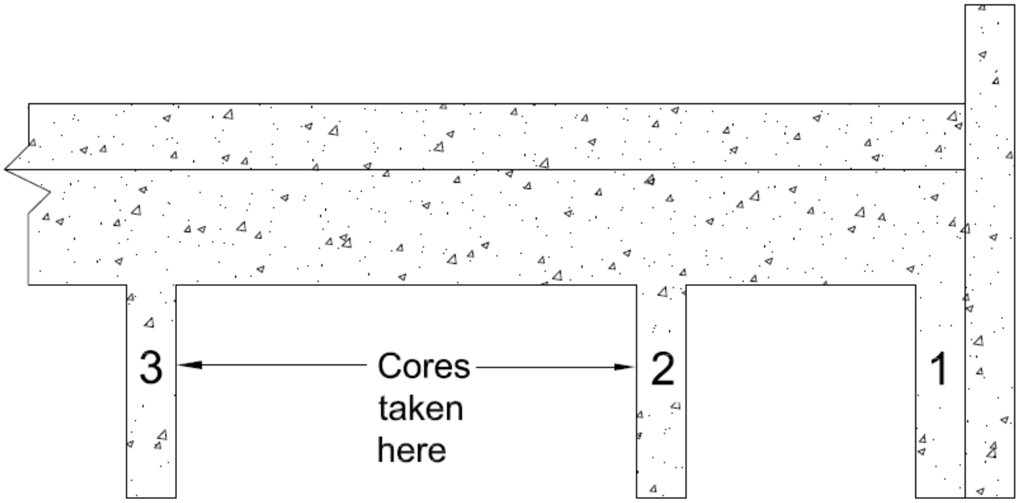

Figure 1 Section of dam section looking upstream where cores were taken.

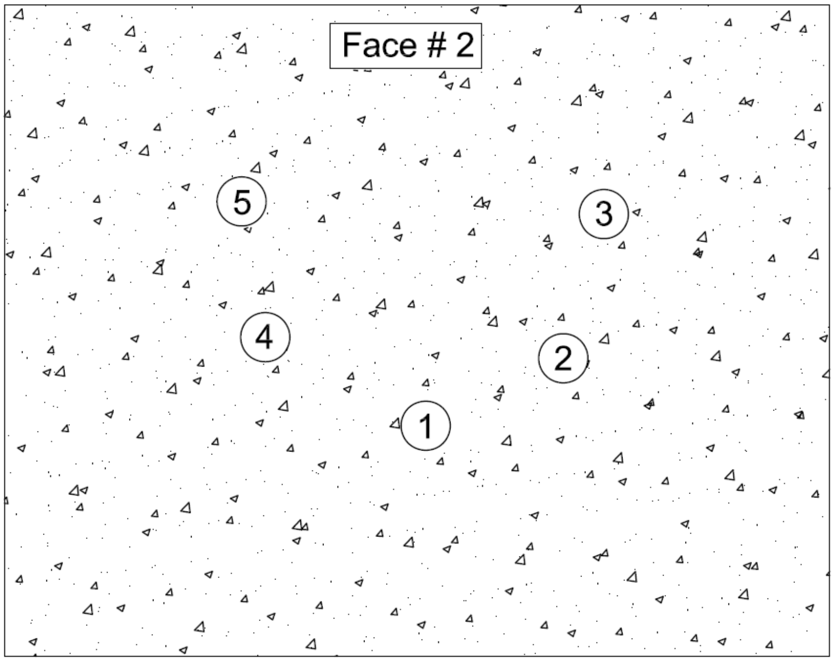

Figure 2 Face #2 showing core positions 1 through 5

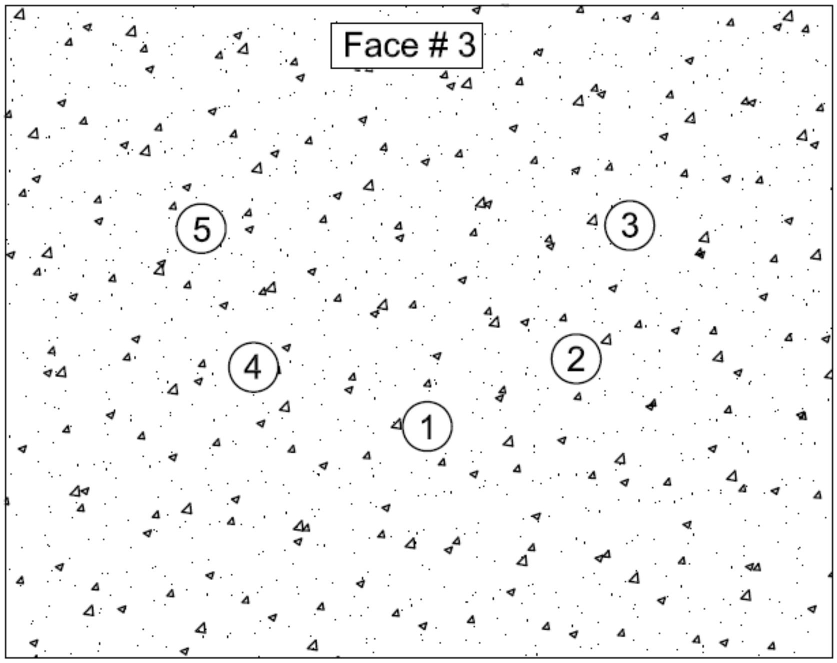

Figure 3 Face #3 showing core positions 1 through 5

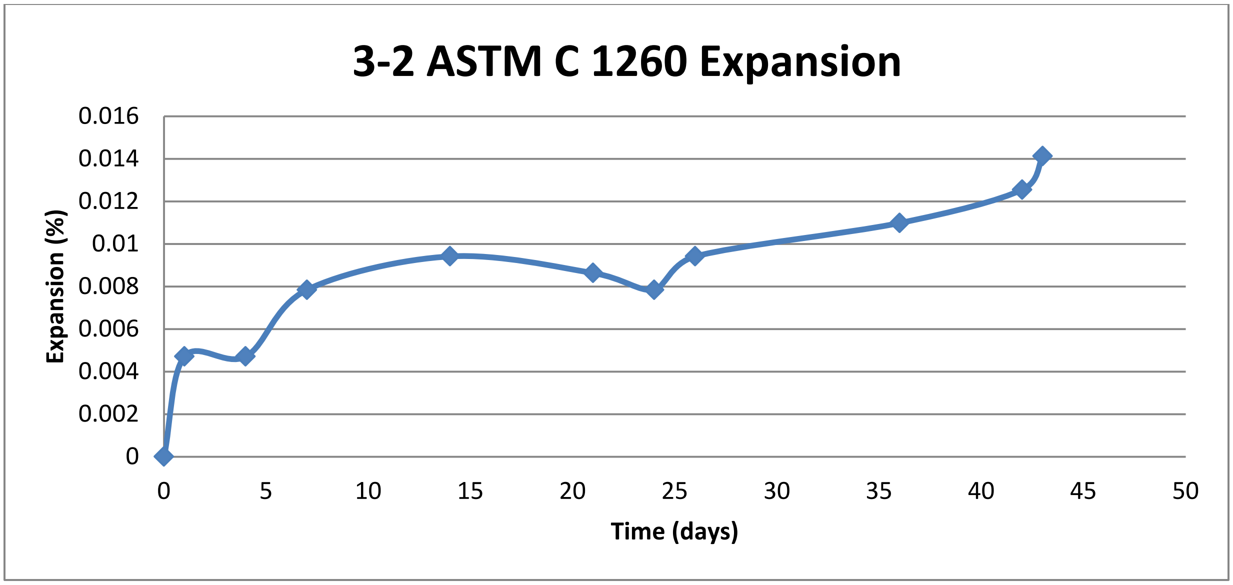

Figure 4 ASTM Core 3-2 subjected to C 1260 testing conditions

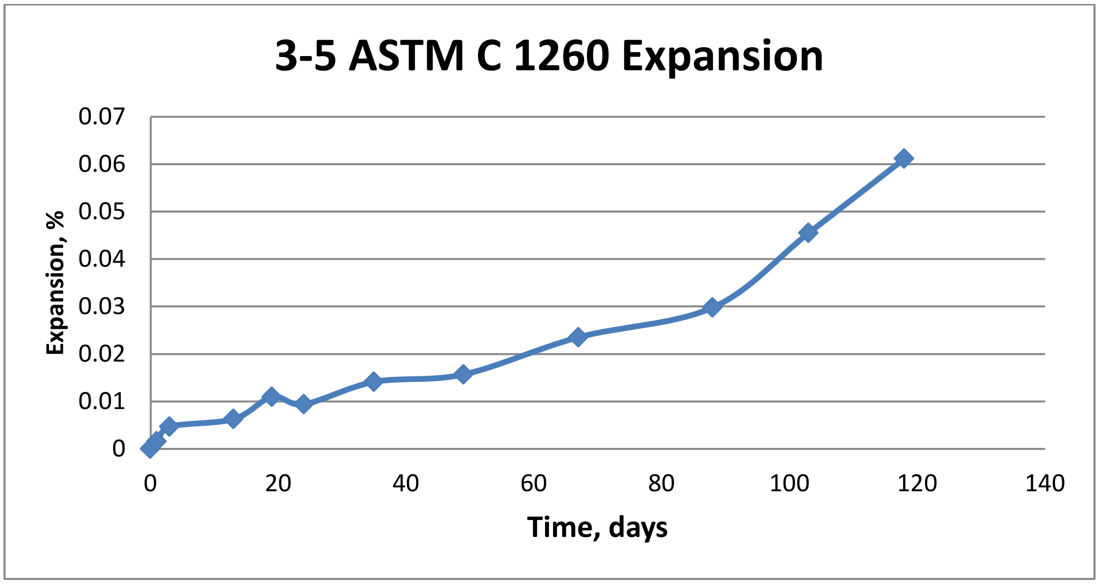

Figure 5 Core 3-5 subjected to C 1260 testing conditions

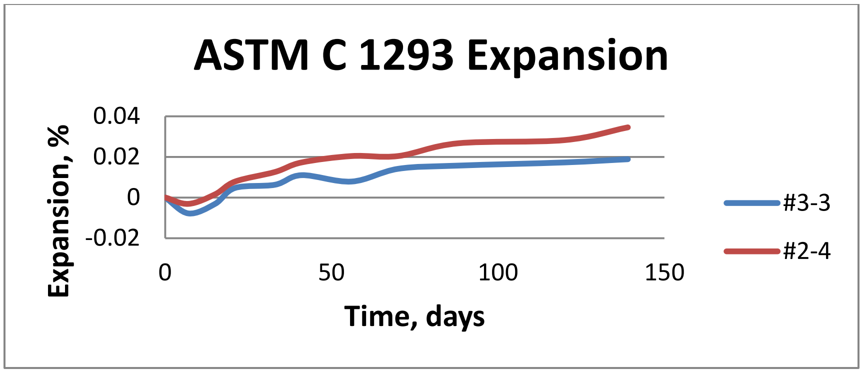

Figure 6 ASTM C 1293 results for Cores 3-3 and 2-4

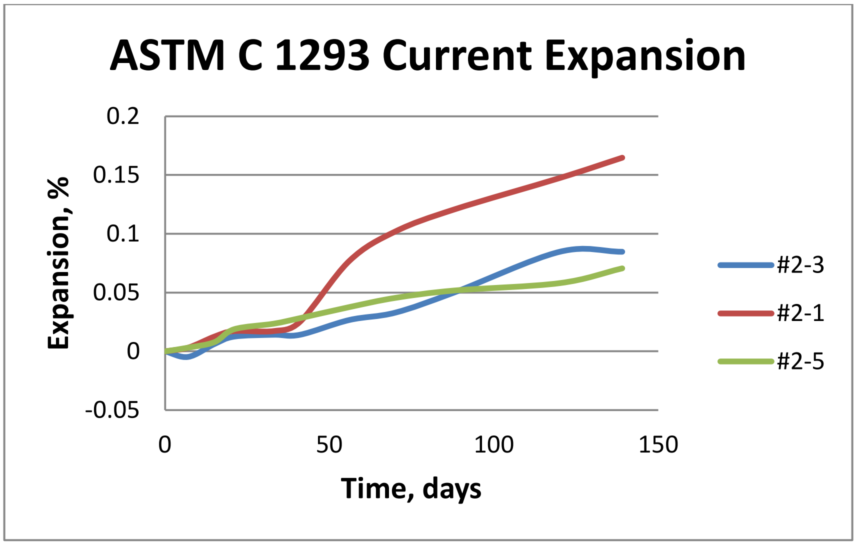

Figure 7 ASTM C 1293 with current results for Cores 2-3, 2-1, and 2-5

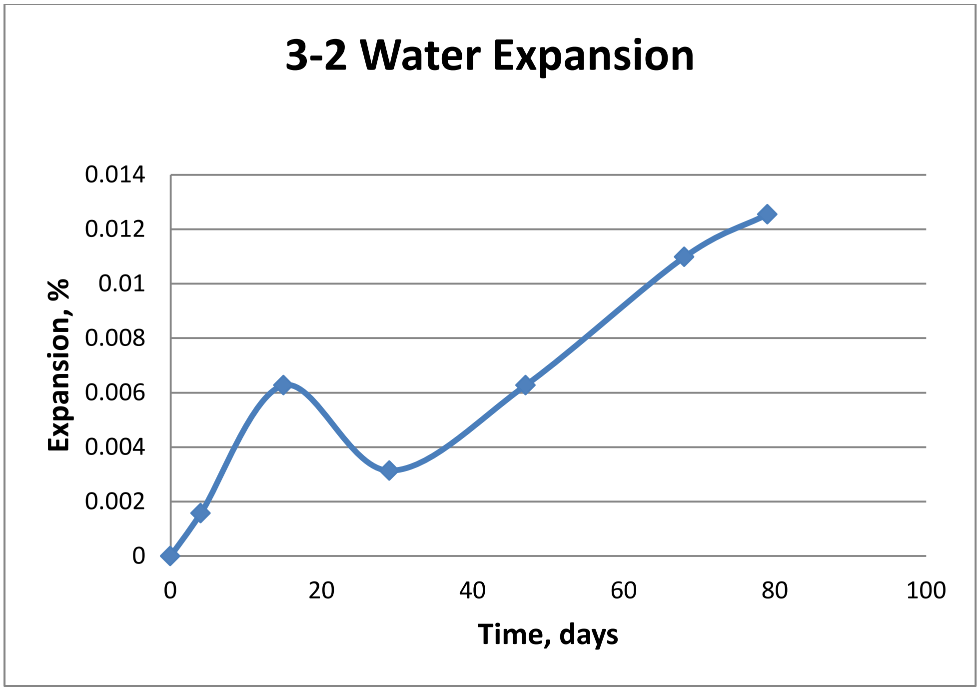

Figure 8 Expansion in 100 °F water day 0 = 43 to day 79 = 122

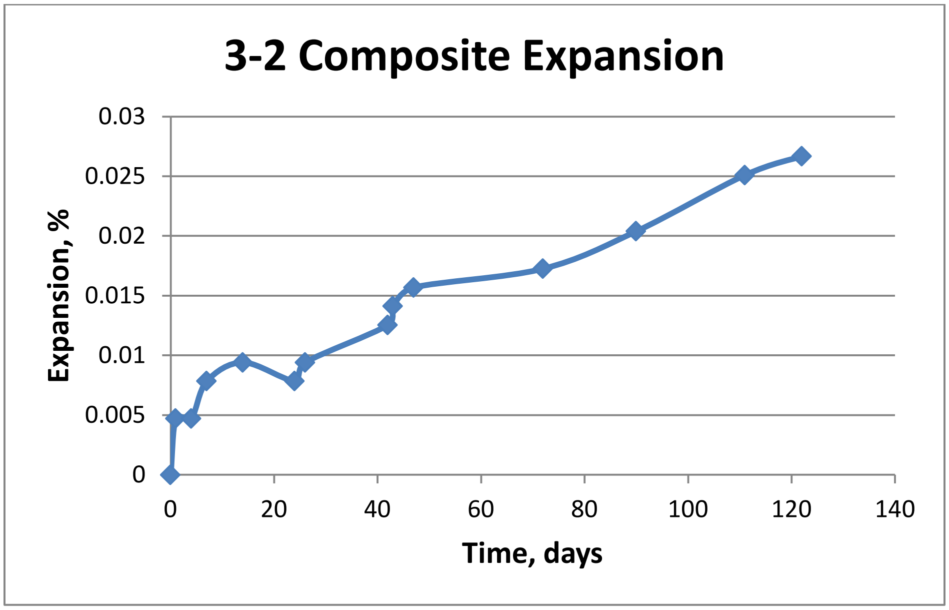

Figure 9 Continued expansion of Core 3-2 in 100 °F water starting at 43 days

The following figures are from the March 2010 Report entitled "Evaluation of the Concrete of the Oyster River Durham Falls Dam Concrete" and pertain to a series of concrete core samples collected in 2009.

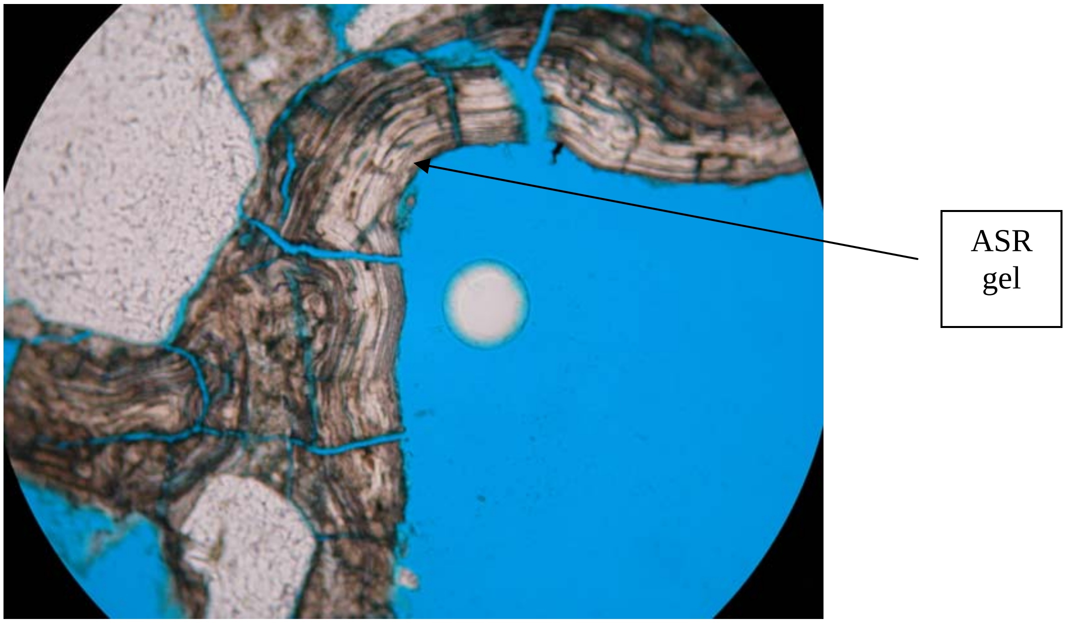

Figure 31 Core 13 vertical section showing layered ASR gel at the edges of a crack

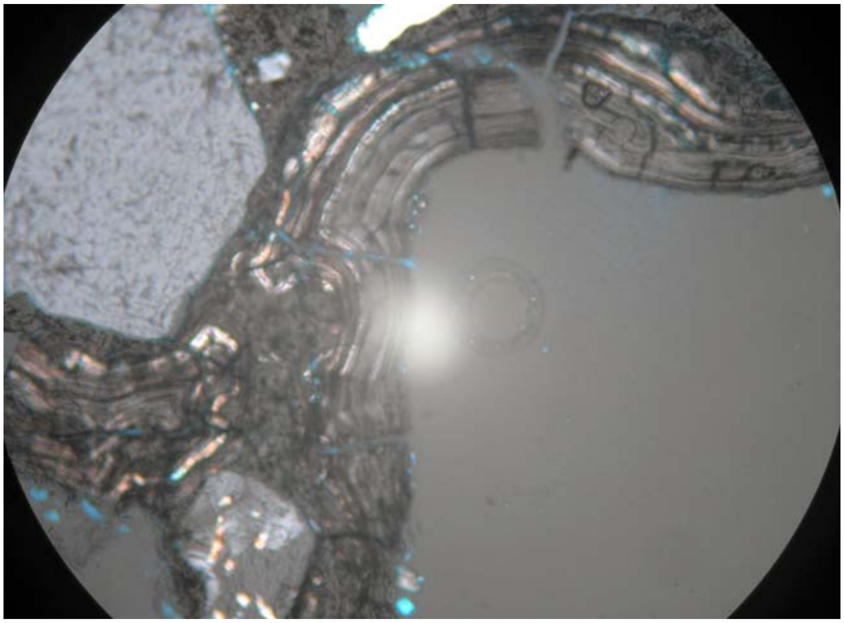

Figure 32 Core 13 vertical section showing the alternate layers of crystalline (colored portion) and non-crystalline gel (dark colored) under crossed polarized light (see Figure 31)

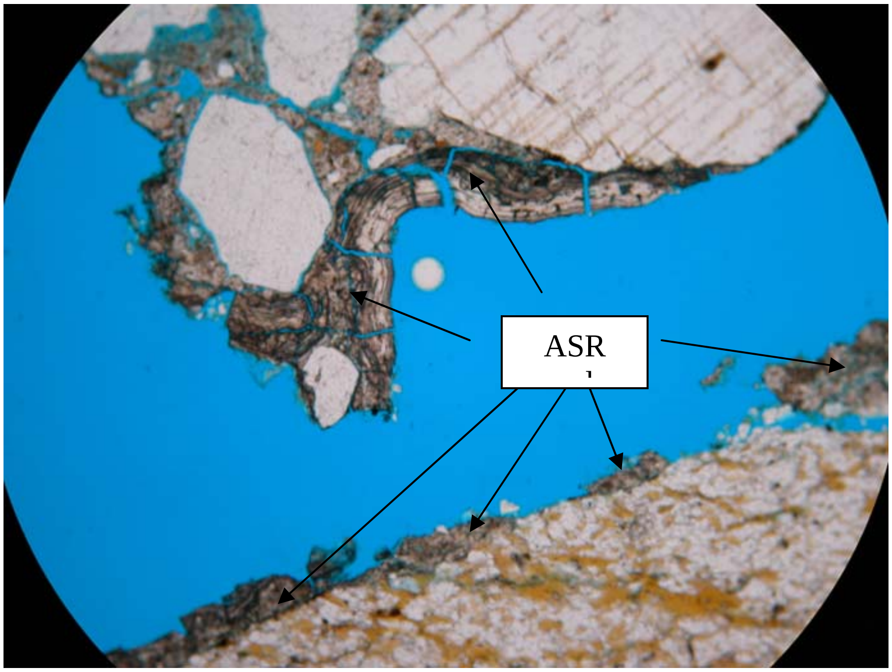

Figure 33 Core 13 vertical section showing a lower magnification view of Figure 31 and 32

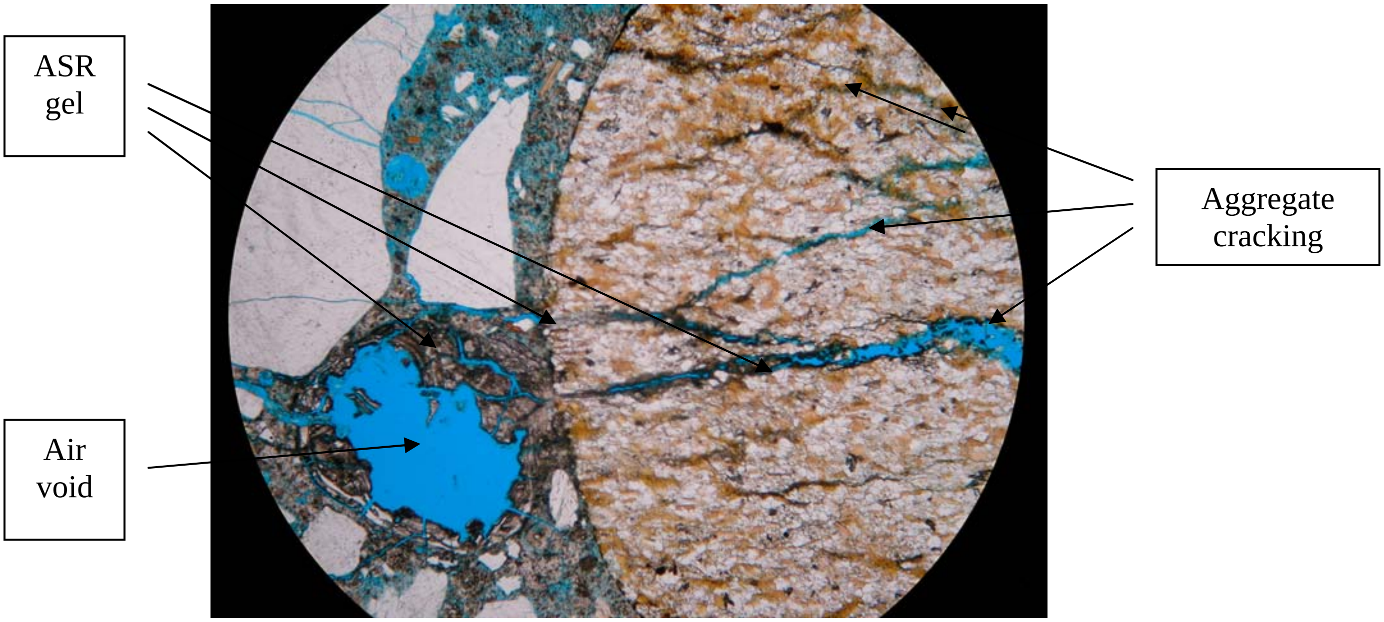

Figure 34 Core 13 vertical section showing aggregate cracking, ASR gel

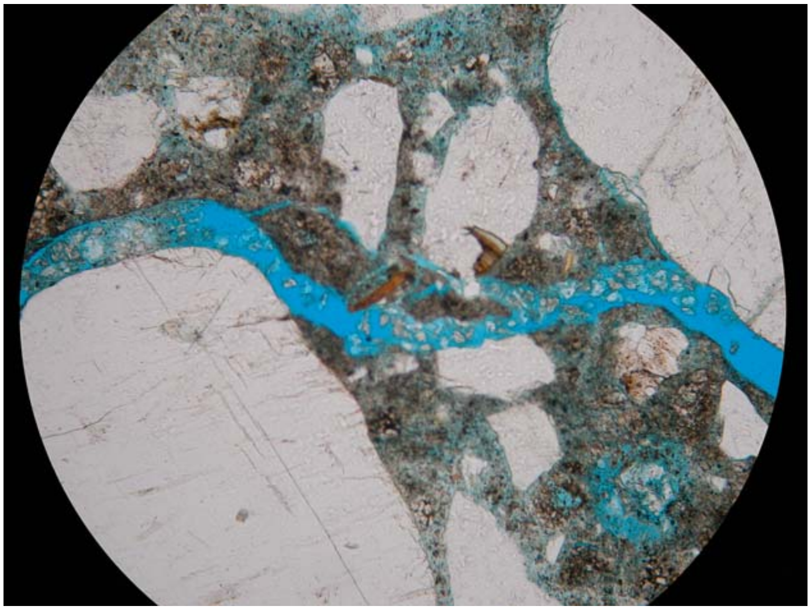

Figure 35 Core 13 vertical section showing Ettringite along the crack at the aggregate-paste interfaces

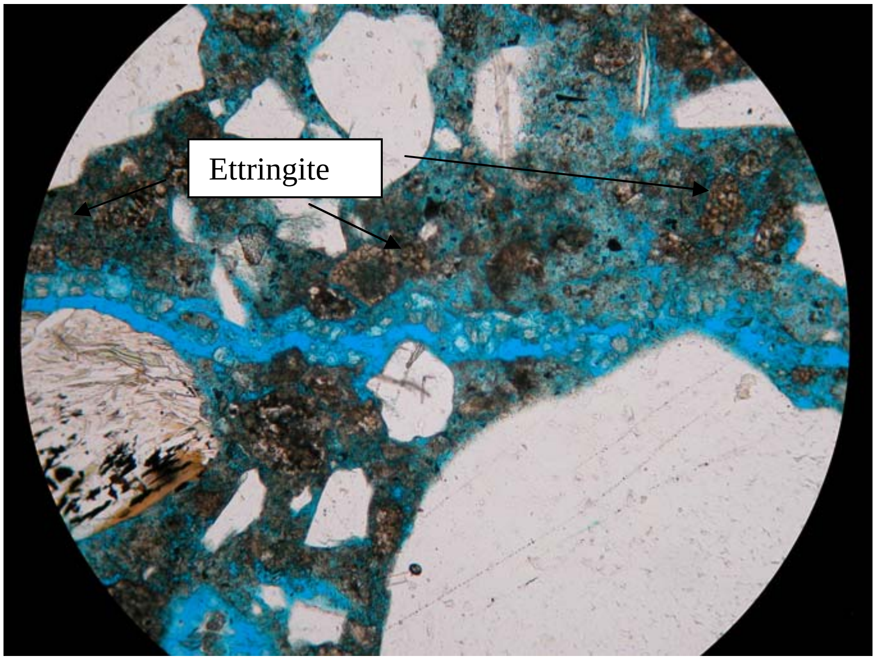

Figure 36 Core 13 horizontal section showing secondary ettringite

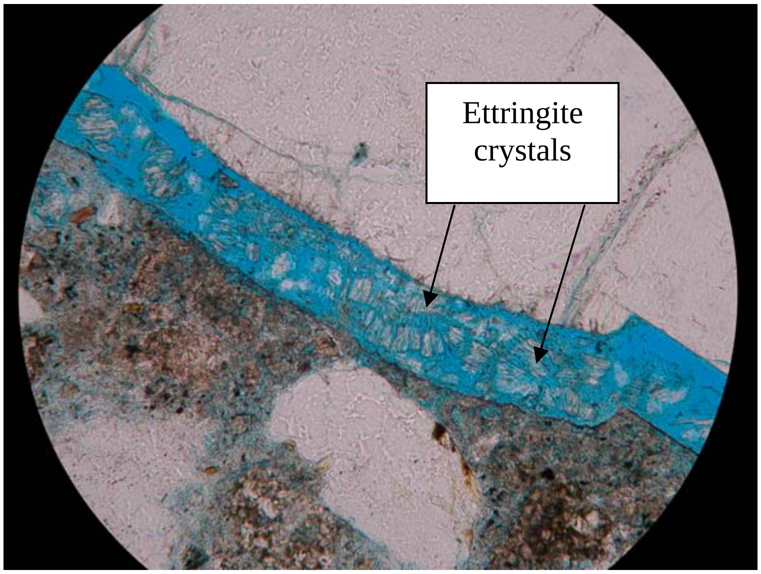

Figure 37 Core 13 horizontal section showing enlarged view of Figure 36

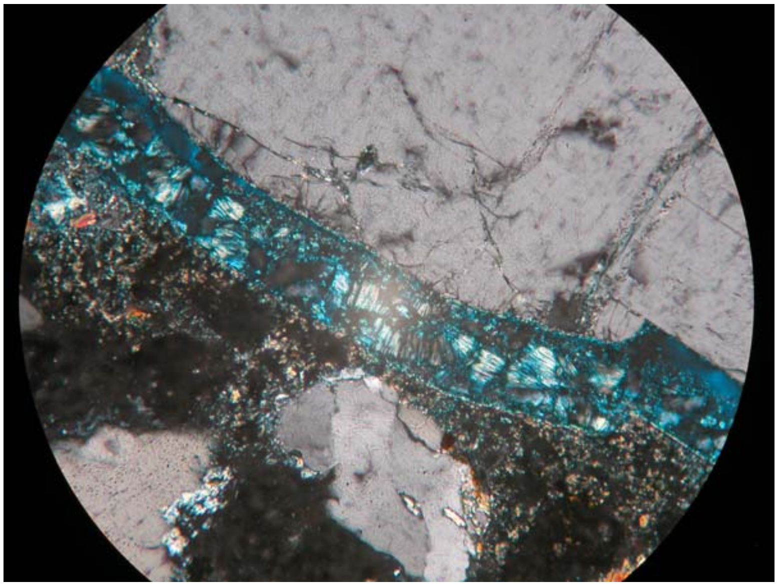

Figure 38 Core 13 horizontal section showing cross polarized light (see Figure 37)

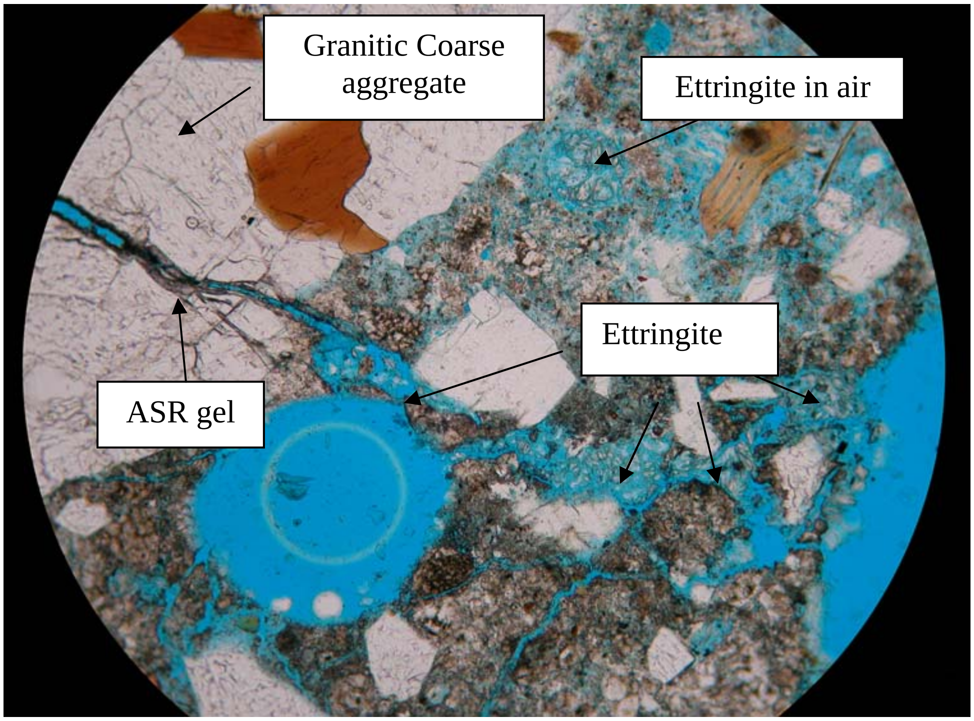

Figure 39 Core 13 horizontal section showing ASR and secondary Ettringite

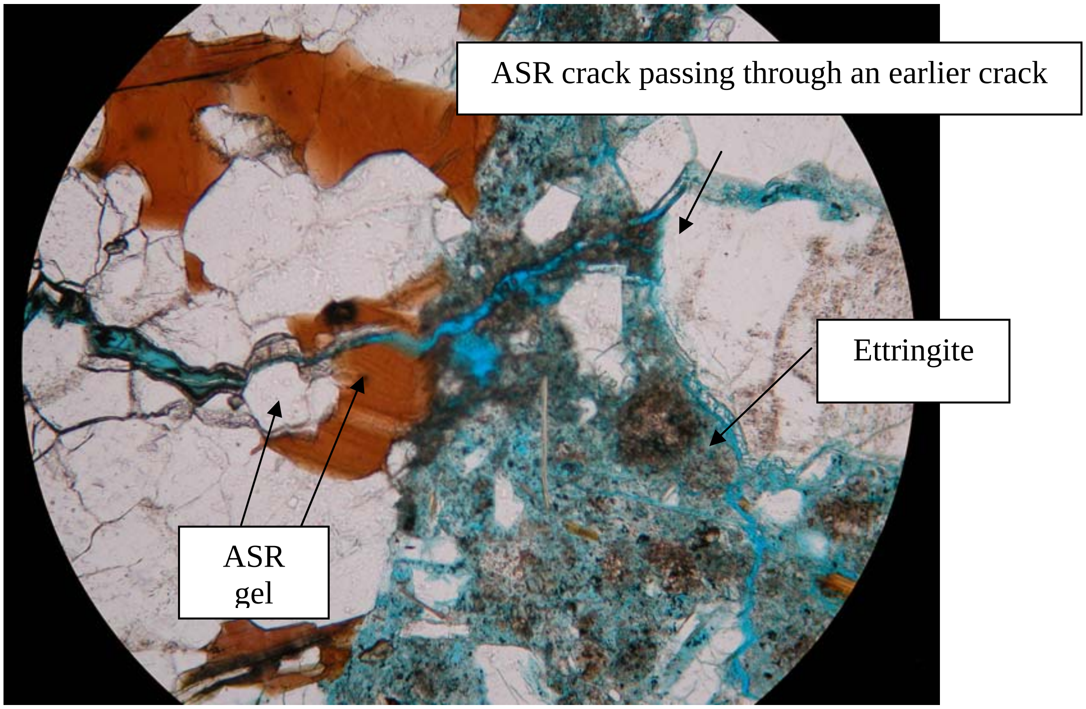

Figure 40 Core 13 horizontal section showing ASR and DEF in the same place

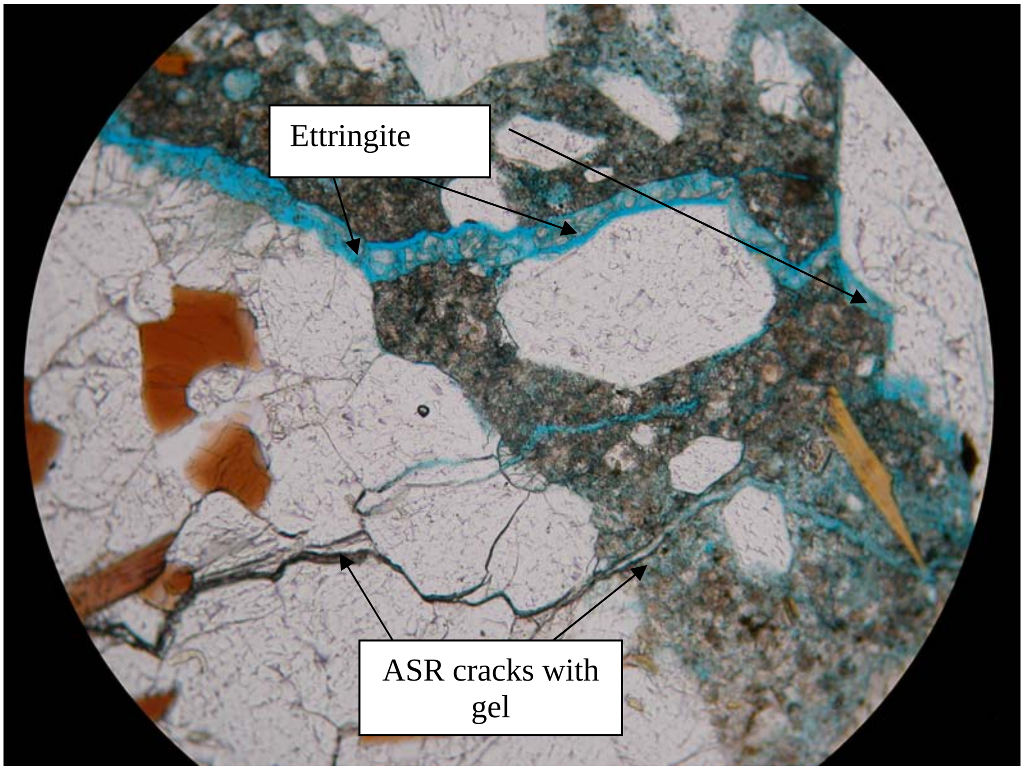

Figure 41 Core 13 horizontal section showing ASR and Ettringite

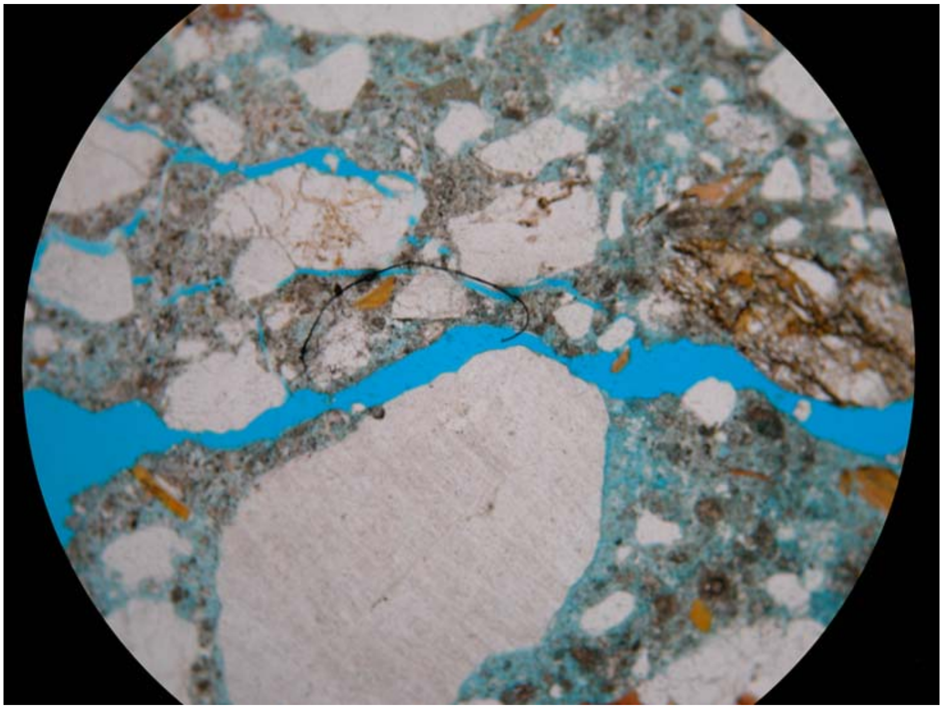

Figure 42 Core 13 horizontal section showing Typical crack pattern

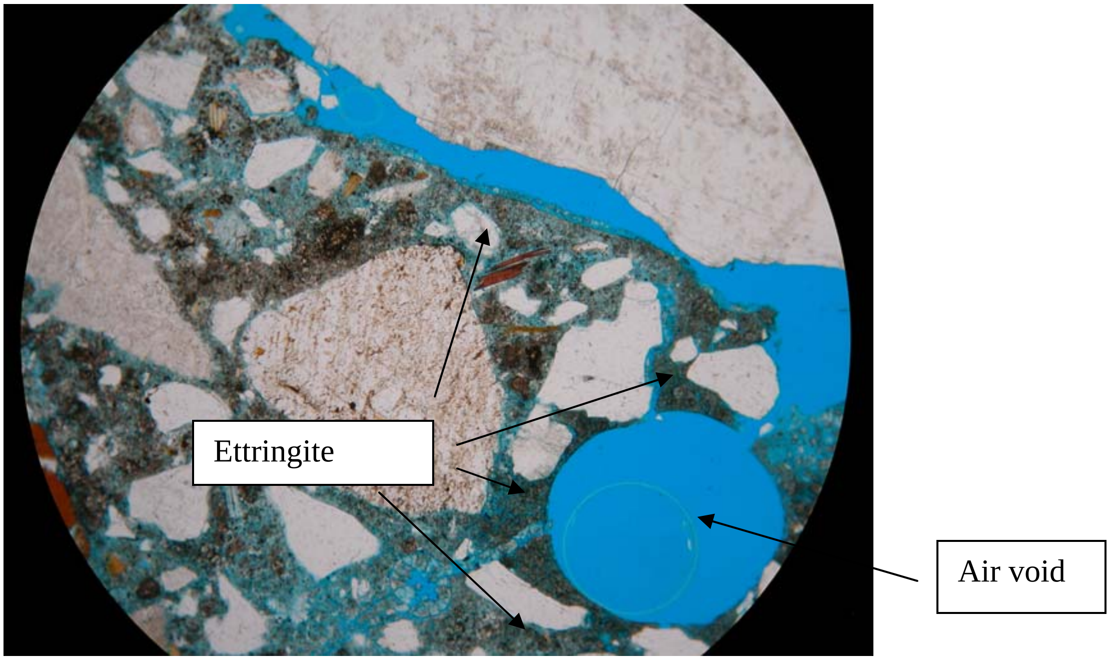

Figure 43 Core 13 horizontal section showing Another example of crack pattern

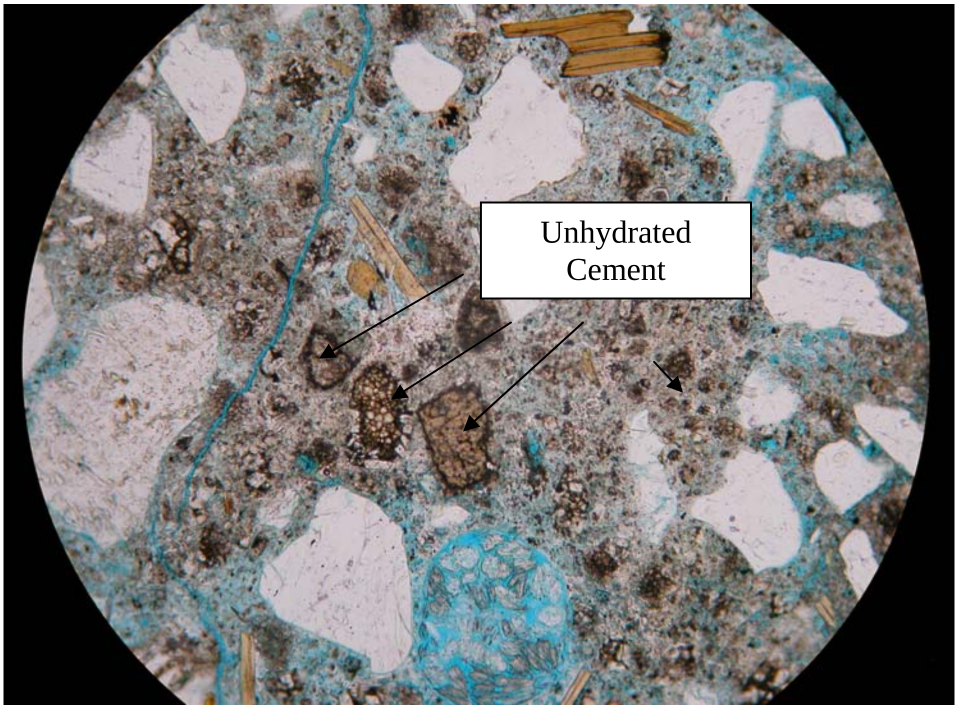

Figure 44 Core 13 horizontal section showing large number of unhydrated, coarser portland cement particles typical of Rosendale cement.

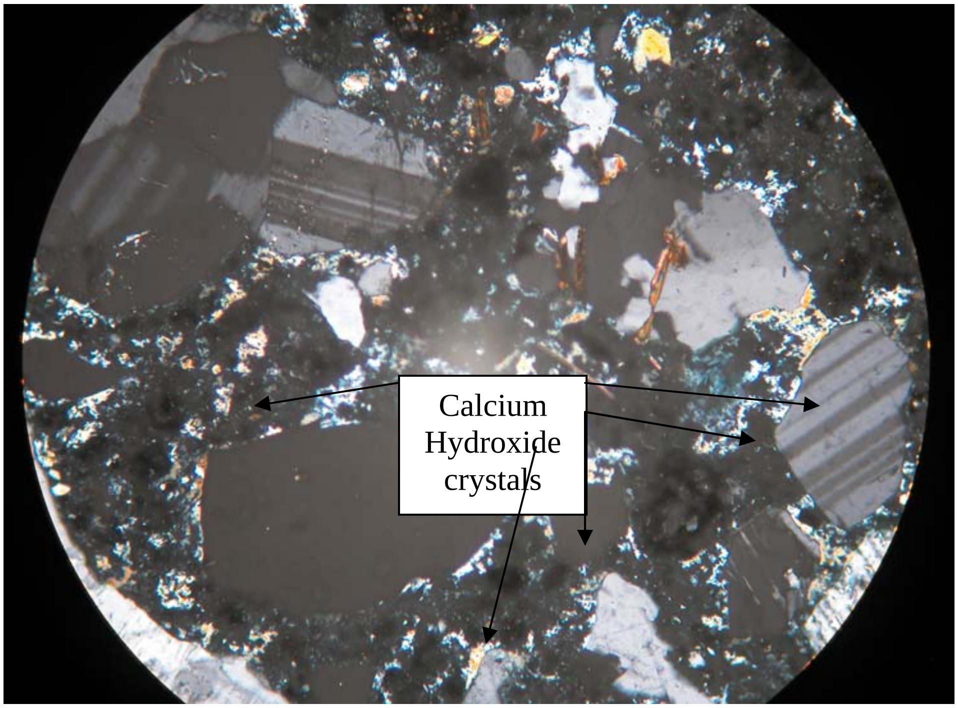

Figure 45 Core 13 horizontal section showing well crystallized, coarser calcium hydroxide crystals at the aggregate-paste interfaces as well as in the matrix.