PETROGRAPHIC METHODS FOE DISTINGUISHING BETWEEN ALKALI-SILICA, ALKALI-CARBONATE REACTIONS AND OTHER MECHANISMS OF CONCRETE DETERIORATION

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Abstract

The DRI method evolved to provide a means of quantifying the amount of damage in concrete that is not possible using thin section analysis. The method consists of measuring the numbers of defects, on a polished surface of the concrete, observed under a stereobinocular microscope. Factors are then applied to the raw data in an attempt to reflect the influence of each type of defect on the condition of the concrete, and the results are normalized for an area of 100 cm^2. Establishing the minimum DRI that is indicative of significant deterioration of concrete is difficult because of the wide variation in the DRI's of concrete containing different types of aggregates. However, usually DRI's greater than about 50 are considered indicative of significant deterioration. Deterioration of concrete due to ASR, the so-called ACR, DEF and frost action can be distinguished from the appearance of the DRI charts.

Keywords: DRI, ASR, ACR, DEF,

1 INTRODUCTION

The Standard practice ASTM C 856, Petrographic Examination of Hardened Concrete, provides a sound basis for determining the cause of deterioration of concrete. Examination of petrographic thin sections readily permits identification of potentially reactive aggregates such as chert, opal, microcrystalline quartz, volcanic glass and reaction products such as alkali silica gel, ettringite, thaumasite and gypsum. The main disadvantage of the use of even large (50 x 75 mm) thin sections is that only a very small percentage of the mass of a concrete structure is examined. In the 1980's, a large number of concrete cores taken from North American Dams were received for petrographic evaluation. In the course of evaluating these cores, it became apparent that in some structures there were significant differences in the amount of damage in different parts of the structures. The Damage Rating Index (DRI) method evolved to address this problem and to permit quantification of the extent of damage in the concrete.[1-3] In recent years, the DRI method has been used in a number of laboratories [4-6]and it therefore appeared appropriate to offer some guidance for the interpretation of the results of DRI measurements on concrete cores.

2 EXPERIMENTAL PROCEDURE

The following is a brief outline of the procedure used to measure the DRI: Ideally, a surface area of a concrete core of about 200 cm^2 should be examined. The core is sawn in two axially and one half is smoothed by grinding using a succession of grits to at least 20 μm, or its diamond equivalent. Subsequent polishing has not been found to be necessary. If available, the surface should then be coated with uranyl acetate, which is preferentially adsorbed by alkali-silica gel and which fluoresces when viewed in ultra-violet light. This facilitates the detection of gel in narrow cracks. The smoothed surface is mounted under a stereobinocular microscope and viewed at a magnification of ~16X. The entire surface of the core is scanned and the features indicative of deterioration, Table 1, are counted. If a suitable mechanical stage is not available, a one cm grid can be drawn on the surface and the numbers of damage features counted in each square. The numbers of the individual damage features are then multiplied by factors designed, arbitrarily, to reflect the effect of the features on the damage to the concrete. The factored damage features are then summed and normalized for an area of 100 cm^2 which is the damage rating index (DRI). It may sometimes be necessary to count additional damage features, for example corroded particles of Norwegian sandstone, or Canadian Potsdam sandstone, or Sioux quartzite, that are indicative of reaction and deterioration. Selection of the factor to be applied to corroded particles is arbitrary, possibly 2 or 3.

The rationale for selecting a factor of 0.25 for cracks in coarse aggregate particles is that in some concretes that do not exhibit any deterioration there is a large amount of cracking in the aggregate particles. An example of this is the DRI of a concrete cylinder made with a non-reactive limestone coarse aggregate and cured for 3 months in a fog room at 23°C and ~ 100% humidity that yielded a DRI of 45, Figure 1. One hundred and fifty coarse aggregate particles were counted in an area of 100 cm^2. When this number was multiplied by 0.25 it yielded a contribution of 37.5 to the overall DRI.

It is difficult to put a minimum value of a DRI that is indicative of significant deterioration of concrete due to alkali-silica reaction (ASR), sometimes gel is observed in concrete that only has a DRI of ~35, but in other examples gel is only noted when the DRI is greater than ~50.

3 SOME TYPICAL DRI's FROM CONCRETES AFFECTED BY SEVERAL DETERIORATION MECHANISMS

3.1 ASR

The magnitude of the DRI varies considerably depending on the reactivity of the aggregates, the exposure condition of the structure and its age, Figure 2. Apart from the core containing BC volcanic rock and the Spratt limestone, the cores are in pairs, one with a high DRI the other with a lower DRI. Also, frequently large variations in the DRI's of cores from different parts of a structure are observed. In some instances, there may be several mechanisms of deterioration affecting cores, such as ASR and cycles of freezing and thawing or ASR and delayed ettringite formation (DEF). With the exception of the core containing the Spratt siliceous limestone, all the other cores were taken from large hydraulic structures. Most of the structures are old and were made with non-air-entrained concrete and were subject to cycles of freezing and thawing. Cores Check E center and Mid B exhibit ratios of the damage features typical of concrete affected by ASR. By comparison, core Pine #12 with a DRI of 108 has a much higher amount of cracks in the cement paste compared to other damage features indicating that some other mechanism of deterioration apart from a minor amount of ASR has affected the concrete. In large hydraulic structures, construction frequently occurs over a period of a few years during which the alkali content of the cement may have varied and the cement content of the concrete may have been different in different sections of the structure and even the aggregate may have varied. All these factors can have an effect on the extent of ASR in the concrete. The chart in the Figure 2 also shows that the concretes containing volcanic rock and greywacke exhibit more deterioration than other rock types.

Critical DRI

It is difficult, if not impossible, to determine the minimum DRI that is indicative of significant deterioration of concrete due to ASR. I usually consider DRI's of greater than ~50 to be indicative of significant deterioration. For example, core Check E center in Figure 2 with a DRI of 50 exhibits cracks filled with gel in both the coarse aggregate particles and in the cement paste. I consider this to be evidence of significant deterioration. However, core Tusk 10 bottom in Figure 2, with a DRI of only 25 also exhibits similar features. The differences in the DRI's of these two cores may be only due to the degree of deterioration that has occurred. A graph of DRI vs expansion of concrete prisms made with aggregates from the Sudbury area of Canada yielded an equation of: Expansion % = $1.45E^{-3}$DRI + 0.047. The equation derived from concrete prisms made with Spratt siliceous limestone aggregates by Rivard &Ballivy, [6] is Expansion % = 0.0017.DRI +0.03. Both these equations yield an expansion of ~0.1% for a DRI of 50. However, it must be kept in mind that these equations were derived from concrete prisms that generally show less deterioration than concrete under field conditions. For this reason, expansions derived from DRI's of concrete cores may underestimate expansion occurring in the structure. The problem of determining the minimum DRI indicative of significant deterioration in concrete is further complicated frequently by large differences in the DRI's measured by different operators. It is hoped that this problem can be overcome when a modified protocol for determining the DRI's is developed.

DRI's of So-Called Alkali-Carbonate Reactive Concrete (ACR)

Charts of the DRI's of concrete affected by the so-called alkali-carbonate reaction (ACR) are characterized by a large amount of reaction rims around dolomitic limestone particles and also by the presence of wide diffuse reaction rims, Figure 3a, that are not often observed in ASR concrete, except for concrete containing some siliceous limestones. A typical photograph of a wide rim is shown in Figure 3b. In most ACR concretes, alkali-silica gel is not observed on the polished surface. However, Katayama [8] observed that, in ultra-thin sections, gel was the main product responsible for crack formation and thus ACR is a special case of ASR.

An exception to the apparent absence of gel in the polished surfaces of concrete affected by ACR was found in a series of concrete prisms made from a non-expansive natural sand and aggregates from different layers from the Pittsburgh quarry in Kingston, Ontario, Canada, all of which contained gel in cracks in the dolomitic limestone coarse aggregate particles, and in most prisms, cracks in the cement paste, Figure 3c.

4 DRI's CHARACTERISTIC OF OTHER TYPES OF CONCRETE DETERIORATION

4.1 Frost Action

Cycles of freezing and thawing of non-air entrained concrete lead to expansion of the cement paste that results in cracking and expansion of the paste away from coarse aggregate particles (debonding). A core that, based on the DRI, was suspected of exhibiting some evidence of damage due to cycles of freezing and thawing was subjected to 30 cycles of freezing and thawing in ASTM C666. This resulted in a massive increase in the amount of cracking in the cement paste. The DRI's of two cores from a dam, one taken near the surface and the other at depth where the concrete would not be subjected to cycles of freezing and thawing are shown in Figure 4. The cycles of freezing and thawing of the concrete near the surface has resulted in a massive amount of cracking in the cement paste and also an increase in the amount of debonding relative to that of the core taken at depth.

Delayed Ettringite Formation (DEF)

Delayed ettringite formation in the cement paste results in its expansion and pulling away from the coarse aggregate particles (debonding) similar to what was observed in concrete subjected to frost action. In the case of deterioration due to DEF, ettringite is observed in the cement paste and filling debonding cracks around coarse aggregate particles. A DRI chart of concrete deteriorated due to DEF is shown in Figure 5a.

Ettringite needles are shown filling a crack around a coarse aggregate particle in Figure 5b. In cores from a bridge in Texas, the DRI's are proportional to the amount of ettringite in the concrete, indicating that DEF is the major cause of the deterioration, Figure 5c

DRI of Concrete Exhibiting Drying Shrinkage Cracks

In concrete flat work such as pavements and airport runways cast in hot dry conditions, and without adequate moist curing, shrinkage cracking develops. This takes the form of map-type cracking that has an appearance somewhat similar to cracking caused by alkali-aggregate reaction. Apart from the map pattern cracks, there is no other deterioration of the concrete. A typical DRI chart of cores taken from near the top and bottom of a badly cracked runway is shown in Figure 6. Evidently, neither core intercepted the cracks due to drying shrinkage and the only damage observed was cracking in the granitic coarse aggregate particles. Some cores that intersect the shrinkage cracks will also have cracks in the cement paste.

5 CONCLUSIONS

- The DRI procedure is a method for quantification of the amount of damage that has occurred in concrete.
- In addition to quantifying the amount of deterioration in concrete the DRI method also permits differentiation between damage due to ASR, ACR, cycles of freezing and thawing, DEF and drying shrinkage.
- For a number of reasons determining the critical DRI that is indicative of significant deterioration of the concrete poses a difficult problem. Tentatively, DRI's of greater than ~50 are considered to indicate significant deterioration of the concrete in the structure. However, at present due to the large differences in DRI's determined by different operators it is probably not possible to determine a critical value that would apply to DRI's of all operators.

6 REFERENCES

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TABLE 1: Factors applied to the total numbers of each type of defect.

Damage feature counted	Factor applied
Coarse aggregate (CA) with cracks	0.25
Coarse aggregate (CA) with cracks & gel	2.0
Coarse aggregate (CA) with open crack	3.0
Coarse aggregate (CA) debonded	3.0
Coarse aggregate (CA) with reaction rim	0.5
Cement paste (P) with cracks	2.0
Cement paste (P) with cracks & gel	4.0
Air Void with gel	0.5

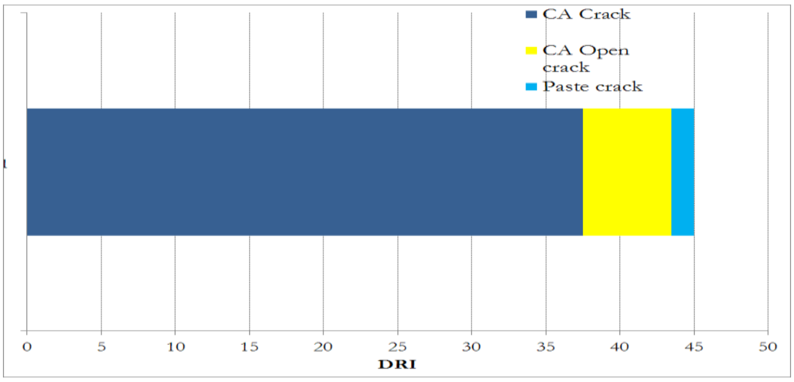

FIGURE 1: Chart of the DRI of a concrete cylinder, made with a non-reactive limestone aggregate, and cured for 3 months in a fog room.

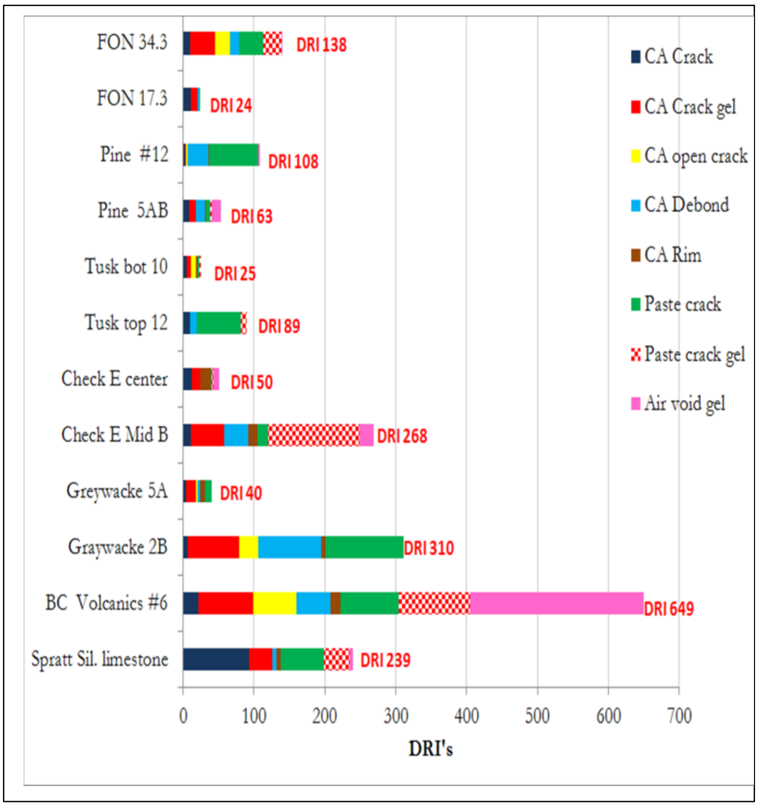

FIGURE 2: DRI chart showing variations in the DRI's of assorted cores, affected by ASR, taken from various parts of structures and of cores containing different types of aggregates.

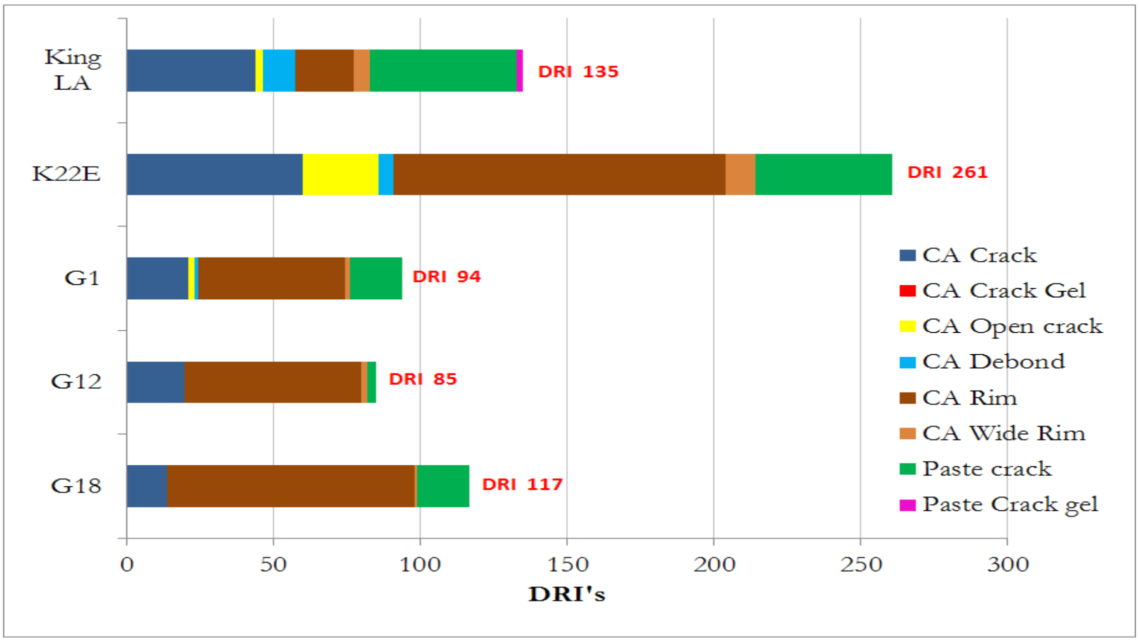

FIGURE 3a: Chart of the DRI's of assorted concrete cores affected by ACR. The core King LA that contains some gel in cracks in the cement paste was taken from, an experimental sidewalk in Kingston Ontario. The concrete was made with low alkali cement. Note the presence of wide reaction rims.

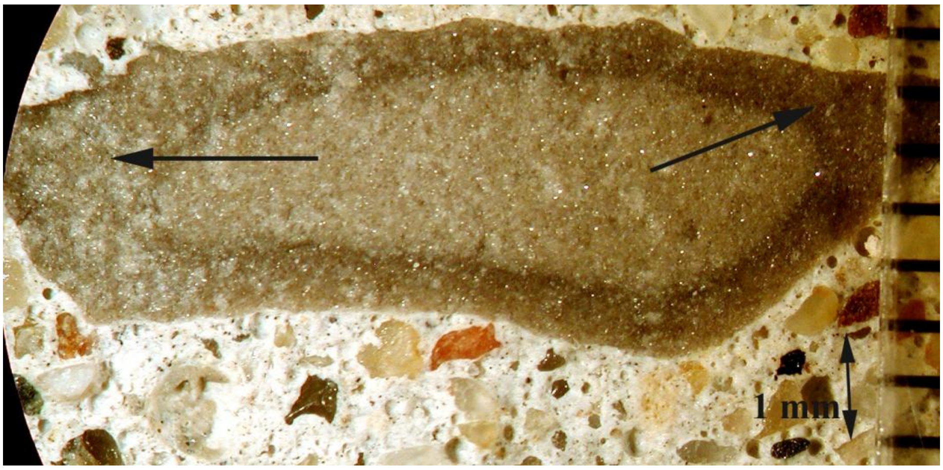

FIGURE 3b: Photograph of a wide reaction rim around a particle of dolomitic limestone. The arrows point to the rim. Scale divisions are in mm.

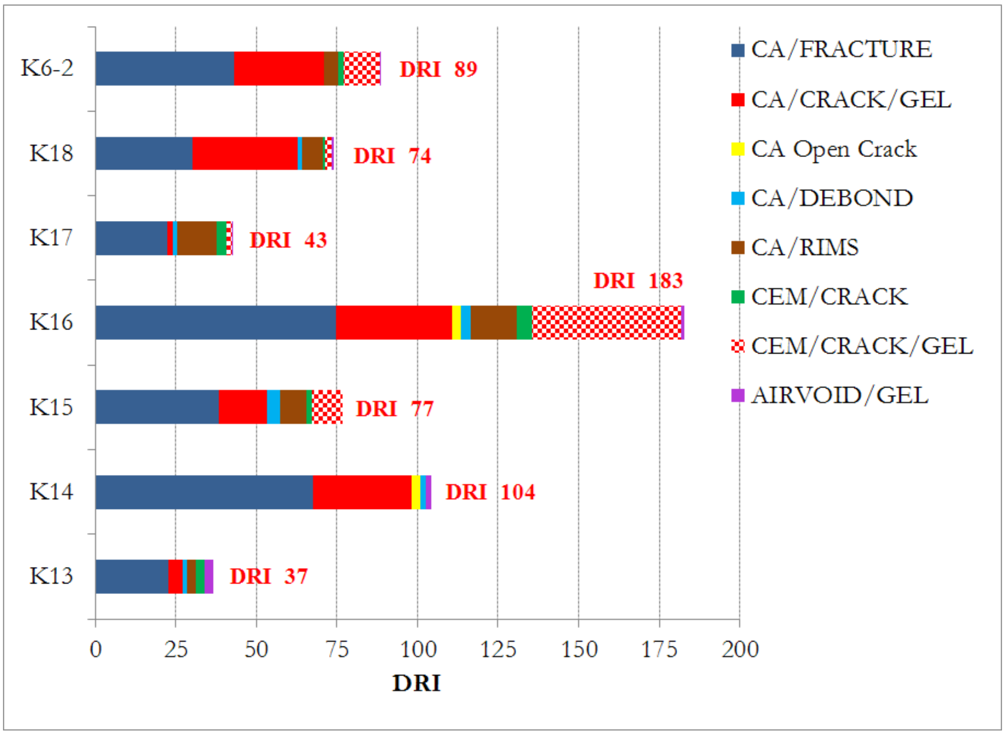

FIGURE 3c: DRI's of a series of concrete prisms made from different layers of the Pittsburgh quarry. Prism K6-2 was made from the stockpile that presumably represents the average of all the layers with a DRI of 86.

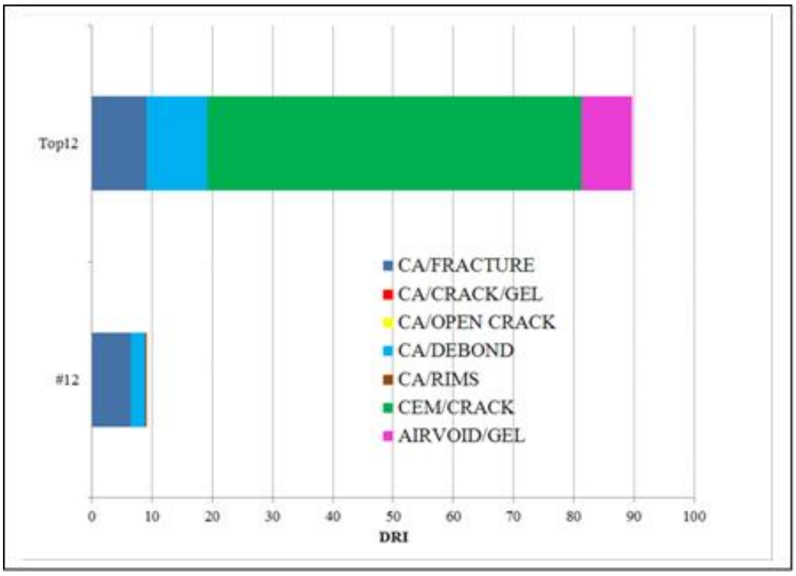

FIGURE 4: Chart of DRI's of two cores, one taken near the top (Top12) and the other at depth. Note there is some evidence of ASR in the form of gel in air voids.

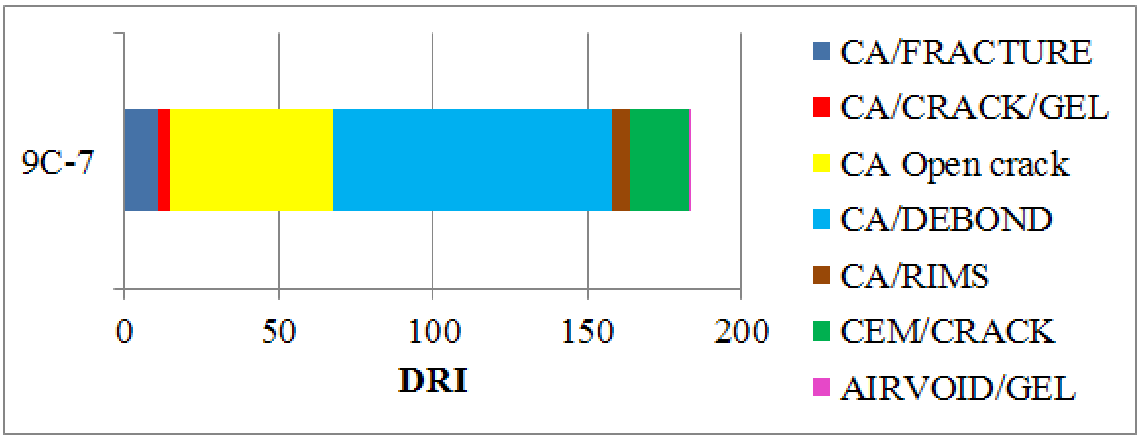

FIGURE 5a: DRI of a core from a bridge in Texas showing extensive debonding around coarse aggregate particles that is characteristic of concrete affected by DEF. Note that there is gel in some cracks in coarse aggregate particles indicating that ASR is occurring along with DEF.

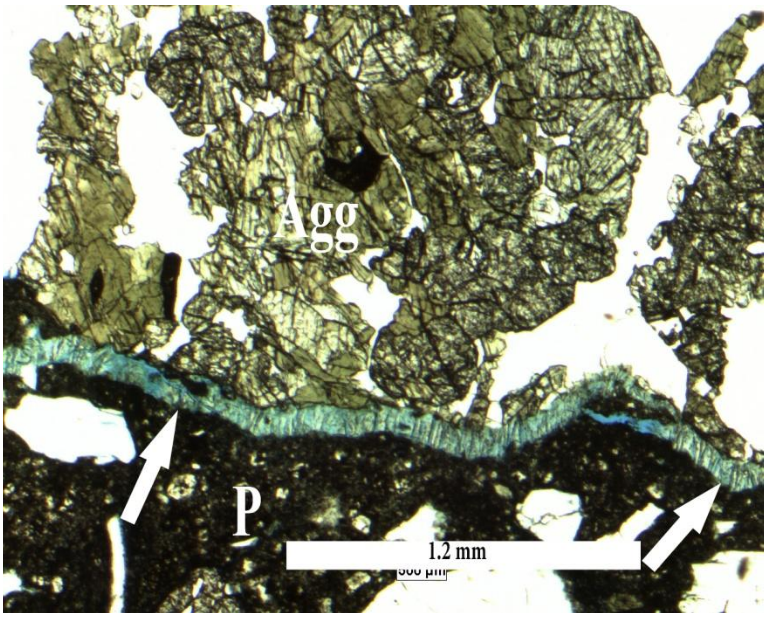

FIGURE 5b: Photograph of a thin section viewed in natural light showing compacted ettringite needles filling a crack at the paste aggregate interface (debonding) indicated by arrows. The blue color is due to blue epoxy used to impregnate the thin section.

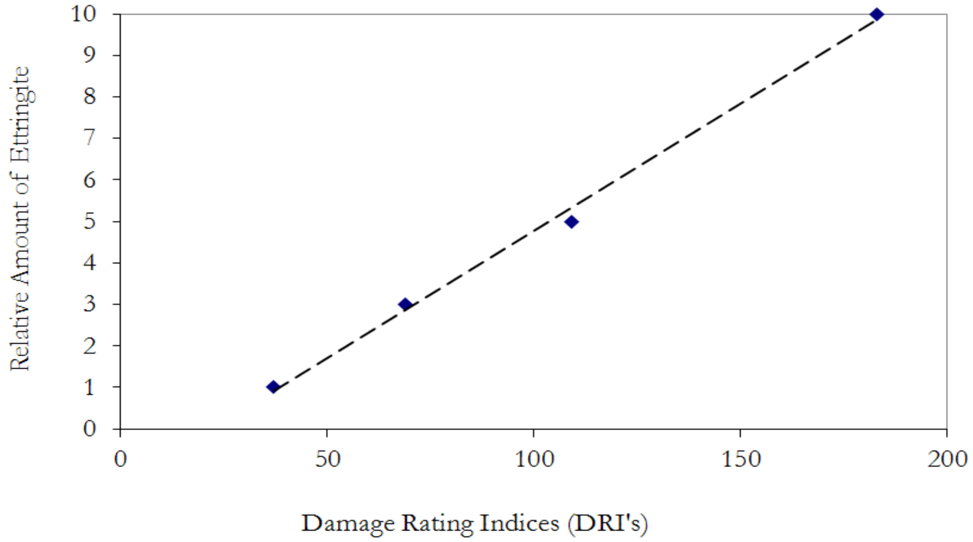

FIGURE 5c: Graph showing the correlation between the amount of ettringite in the concrete and the DRI's.

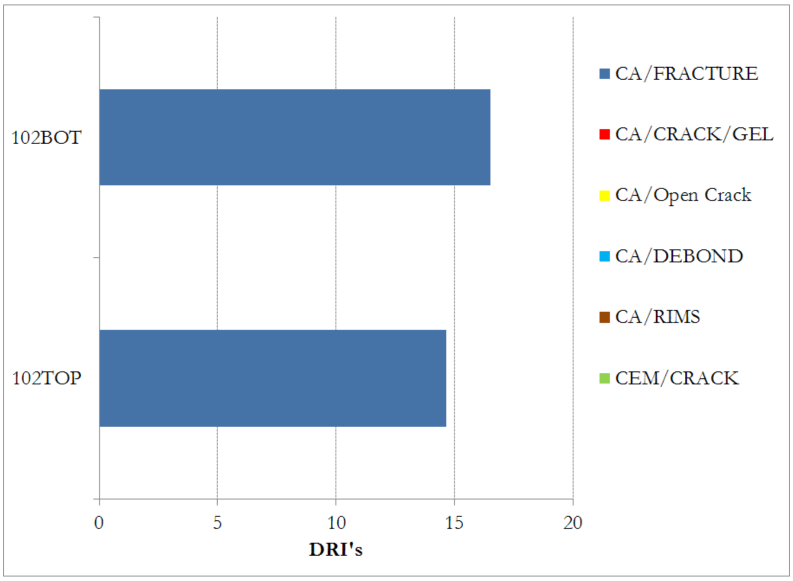

FIGURE 6: DRI chart of two cores taken from near the top and bottom of an airport runway that only exhibits cracking in the coarse aggregate particles.