Petrographic Criteria for Recognition of Alkali-Reactive Strained Quartz

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ABSTRACT

Recognition that some of the quartz in some concrete aggregates could participate in alkali-silica reaction and produce excessive internal expansion led to an awareness of the need for criteria to recognize such material before it was used as aggregate. The conventional criteria of petrographic examination, mortar-bar tests, and the quick chemical tests were regarded as ineffective for this material. Therefore, the Corps of Engineers developed criteria in 1983 based on available data.

The present paper describes application of these criteria to aggregates in concretes already known to be affected by alkali-silica reaction. It is shown that these criteria would have been effective in recognizing these materials as potentially deleteriously reactive before their use had such criteria then been available.

INTRODUCTION

Since 1954 (Mielenz) and 1955 (Brown), there has been a growing awareness that some constituents of concrete aggregates were involved in cases of expansion due to the alkali-silica reaction where no such expansion was expected based on a characterization of the constituents by petrographic examination.

Petrographic examination (ASTM C 295), the mortar-bar test (ASTM C 227), and the quick-chemical test (ASTM C 289), if used singly or in combination, failed to detect any constituents regarded as potentially deleteriously reactive in such aggregates before their use. The aggregates ranged from materials such as quartzite and quartz gravels to rocks such as granite gneiss, phyllite, and argillite. Other examples of cases where quartz was known or suspected of being the reactive constituent were cited by Buck and Mather (1969); Duncan, Swenson, Gillott, and Foran (1973); and others.

Thus, it was apparent that new or modified criteria were needed that would detect such potentially deleteriously alkali-silica reactive constituents in aggregates before they were used in concrete. Evidence obtained by the Waterways Experiment Station (WES) of the U.S. Army Corps of Engineers indicated that the reactive component of the reactive rocks examined by WES was probably strained quartz. This evidence together with that provided by others formed the basis for criteria for recognition of reactive strained quartz that were added to the Corps of Engineers Engineering Manual (1983). These criteria were:

a. More than 20 percent of an aggregate is strained quartz with an average undulatory extinction angle (UEA) of greater than 15 degrees. The 20 percent value was taken from Gogte (1973) and the 15 degree value from Dolar-Mantuani (1981).

b. Mortar bars may be made in which five particles containing strained quartz are embedded at a temperature of 60 ± 5°C (140 ± 10°F) rather than at 37.8 ± 1.7°C (100 ± 3°F) as called for in ASTM C 227; the size of the particles should be 12.5 to 19.0 mm (1/2 to 3/4 in.).

Expansion criteria were set at 0.025 percent at 6 months or 0.040 percent at 1 year; preferably the latter. The procedure and the values were based on Buck and Mather (1984).

K. Mather (1976) described tests, including measurement of UEA for several quartzite and quartz gravels from the Atlantic Coastal Plain. Dolar-Mantuani (1981, 1983) described a modification of what K. Mather had described for measurement of UEA. The Dolar-Mantuani modification was used to measure UEA's in thin sections of concrete from several structures in the southeastern U.S. that had been determined previously to exhibit alkali-silica reaction. The aggregate types were quartzite, quartz, granite gneiss, and phyllite.

SAMPLES

Thin sections of concrete from five structures in the Southeastern United States were used for this work. They are identified below:

a. Charleston Dry Dock, S. Carolina, (Buck and Mather, 1969). Since it was built in 1942 it was 25 to 30 years old when this examination was made. The gravel coarse aggregate was largely quartzite and some quartz; most or all of the particles were strained. The fine aggregate was a natural sand composed of particles of quartzite, quartz, and feldspar.

b. Fontana Dam and Hiwassee Dam. Since both dams were built in the early 1940's, they were over 20 years old when these examinations were made. Both structures are in the same general area in North Carolina and the crushed aggregate in both was similar. This aggregate is referred to here as quartzite (brown) and phyllite (black); the two types differed in color and grain size but were similar in mineral composition consisting of quartz, feldspars, and micas plus minor amounts of other minerals; most or all of the quartz was strained.

c. Four Georgia Highway Bridges and New Savannah Bluff Lock and Dam. All five of these structures were built between 1937 to 1948 so they were 25 to 40 years old when these examinations were made. The coarse aggregate in all of these structures was a crushed granite gneiss which was always similar even though it came from at least two and possibly three different quarries in Georgia. Fine aggregate was natural sand from several different sources. Most but not all of the New Savannah Bluff concrete also contained some quartz-quartzite gravel. Some or all of the quartz in the granite gneiss and the gravel was strained.

In addition, several thin sections of a recent sample of granite gneiss rock from one of the same quarries used for some of the highway bridges and possibly for the dam were included for comparison.

PROCEDURE

The work reported in this paper is based on measurements of UEA in strained quartz crystals. The first description I encountered of how to do this was given by DeHills and Corvalan (1964). Their statement that the "first clear evidence of undulatory extinction" is the initial value (angle) to use led Dolar-Mantuani in 1981 to comment on the possible ambiguity of this phrase. Therefore, she attempted (1981, 1983) by a combination of words and photographs to provide a description with examples of how to perform this measurement. My efforts to use her method led me to the following which I believe is what she intended:

a. Select a suitable quartz crystal whose C axis is essentially parallel to the stage of the microscope. This can be done by selecting crystals of high birefringence; if the C axis tends to be perpendicular to the microscope stage such crystals will tend to remain uniformly gray during rotation and are not suitable for use. Orientation may be verified by the presence of a conoscopic flash figure if desired.

b. With this crystal in view at an appropriate magnification, rotate the microscope stage until the crystal is just ready to enter the angular range within which some part of it is showing extinction (i.e. is not brightly illuminated). Appropriate magnification is considered that which shows the crystal clearly while all of it remains fully in view during stage rotation. More magnification is required as crystal size decreases. My experience has shown that these magnifications will be from about 40 to 100X.

c. Rotate the microscope stage clockwise until any portion of the selected crystal, however small, has gone to maximum extinction (black). Rotate the stage back and forth as needed to obtain this position. Record this angular setting of the microscope stage (1st value).

d. Rotate the stage clockwise until the last evidence of extinction is seen as faint shadows. Extinction bands will have moved across the crystal before this position is reached. Rotate the stage back and forth as needed to obtain this setting. Record this angular setting of the stage (2nd value).

e. Repeat this procedure in a counter clockwise direction to obtain first dark (3rd value) and last faint (4th value) positions.

f. The foregoing steps have now accomplished measurement of the same UEA in one quartz crystal in two different directions. The differences in the first and second values and in the third and fourth values are the two UEA's. They should not differ by more than about 10 degrees and preferably less. It may be desirable to repeat part or all of the determination of UEA for one crystal several times, especially when unfamiliar with the technique, to minimize differences with direction of rotation. If these differences for a single crystal exceed approximately 10 degrees do not use this determination of UEA; instead, select another crystal. Once you are satisfied with your determination of UEA for this crystal, average these two values as the UEA for that crystal. While the minimum number of these UEA's that are needed for a good determination of an average UEA for a rock type such as quartzite or phyllite in an aggregate is not known, it is suggested that the average be for at least 10 pairs of determinations for different strained quartz crystals.

Bryant Mather* has recently pointed out that the method advocated by Dolar-Mantuani and used in this paper for determination of UEA is for a partial rather than the full UEA and thus will be about 10 degrees smaller than the true UEA. Dolar-Mantuani (1981, pg. 7) was aware of this when she wrote "Although this technique does not measure the angle between the first and the last visible extinction positions, which are fixed for each quartz grain, the angle it does measure is sufficiently reproducible that the results obtained by different petrographers are comparable."

A third possibility would be to measure the full UEA and divide it by two so it would be the distance between the N-S or E-W direction as seen in a microscope and the end of all undulatory extinction.

In any case, the following points should be noted:

a. A major difficulty in measurement of UEA is a successful continuous delineation of the crystal (grain) being observed as the stage is rotated. A sketch of the crystal may be helpful (Dolar-Mantuani (1981; 1983, pg 98)).

b. Determination of full extinction for a portion of a strained crystal will probably result in more consistent angular values than determina-

* Personal communication.

tion of the faint shadows position. This means that more of the range in angular value falls in the second portion of each determination as now done.

c. While the procedure for measuring UEA's was described as clockwise rotation followed by counterclockwise, this sequence is not important. What is important is that one does it the same way each time so the procedure becomes habit.

RESULTS

The data obtained from measurement of UEA's in the 46 thin sections of concrete from five structures and in 3 thin sections of rock from 1 quarry are shown in Table 1.

DISCUSSION

The UEA's that have been given clearly indicate that the present Corps of Engineers criterion would have identified all of these aggregates as potentially reactive if the criterion had been available for use many years ago.

At the present time it would seem prudent to follow petrographic examination with the Corps expansion test and criteria for those times when the amount of strained quartz in a potential aggregate is near 20% or the UEA is near 15° or both.

CONCLUSIONS

The use of UEA's as presently used by the Corps of Engineers has been shown to be effective if used to predict potential reactivity of concrete aggregates containing strained quartz.

Since the procedure for measurement of UEA by microscope is subject to several interpretations, agreement on a single universal method is urgently needed.

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Table 1

Undulatory Extinction Angle (UEA)[a] Data for a Variety of Samples

	Average UEA					
	Gravel		Crushed Rock			
	Quartzite	Quartz	Quartzite	Phyllite	Intermediate	Granite Gneiss
Charleston Dry Dock No. 2 SC	19	23, 17[b]				
Fontana Dam NC			34	32	29	
Hiwassee Dam NC			20	23	-	
GA Highway Bridges						24[c] 19[c]
New Savannah Bluff L/D GA-SC	21					24
GA Quarry						27

(a) All UEA's measured as described in this paper.

(b) In sand.

(c) Different quarries.