Fig. 1. test results from quick chemical method (ASTM C 289)

Dissolved silica mMole/l

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SUMMARY

There has been some continuing controversy about the validity of different test procedures, the significance of test data and the correctness of conclusions drawn from them. This paper examines the various objections levelled against the tests and explains the difficulties encountered in assessing the significance of the test data.

INTRODUCTION

Various qualitative tests have been devised to demonstrate aggregate reactivity. These tests generally show changes in the aggregate or in the hardened mortar. Observable changes in the aggregate and mortar must be assessed visually and somewhat subjectively by the operator. These tests can, however, yield very pertinent information about aggregate reactivity if properly evaluated by an experienced assessor.

Quantitative tests are of two different types, namely:

(a) A mortar bar expansion test, designated A.S.T.M. C-227, which was developed from the original studies of Stanton (1940) and

(b) A chemical reaction test, designated A.S.T.M. C-289, originally devised by Mielenz et al (1947).

Both tests yield numerical data which must be effectively evaluated. The validity, repeatability and correctness of the rapid chemical test results have been widely criticized. It is considered, however, that these criticisms are not soundly based and that, despite certain defects in the method, the chemical test yields data which permit a very rapid and reasonably accurate estimate of potential aggregate reactivity to be made. The rapid chemical test results can be confirmed by the slow developing expansions of cement-aggregate combinations in the mortar bar test. All the observable symptoms and the chemical and mortar bar test data must invariably be consistent and assessed with due allowances being made for anomalies in samples and sampling, for minor variations in test results and for the expected exposure conditions and working duty of the concrete.

THE MORTAR BAR EXPANSION TEST

The mortar bar expansion test permits performance studies on specific cement-aggregate combinations, the measurement of expansion of specimens and the observation of aggregate reaction and mortar or concrete damage when exposed to specified environmental conditions. The relatively long time required for significant aggregate reaction and mortar or concrete expansion to develop constitutes the major disadvantage of this test.

Various material and procedural factors, which can be varied arbitrarily, significantly affect the rates of aggregate reaction and mortar or concrete expansion. Such factors as amount of reactive component in the aggregate, size of reactive particles, mortar or concrete composition and compaction, cement alkali content, water/cement ratio, storage temperature of specimens, rate of drying etc., affect the test results. Consequently, accelerated test procedures,
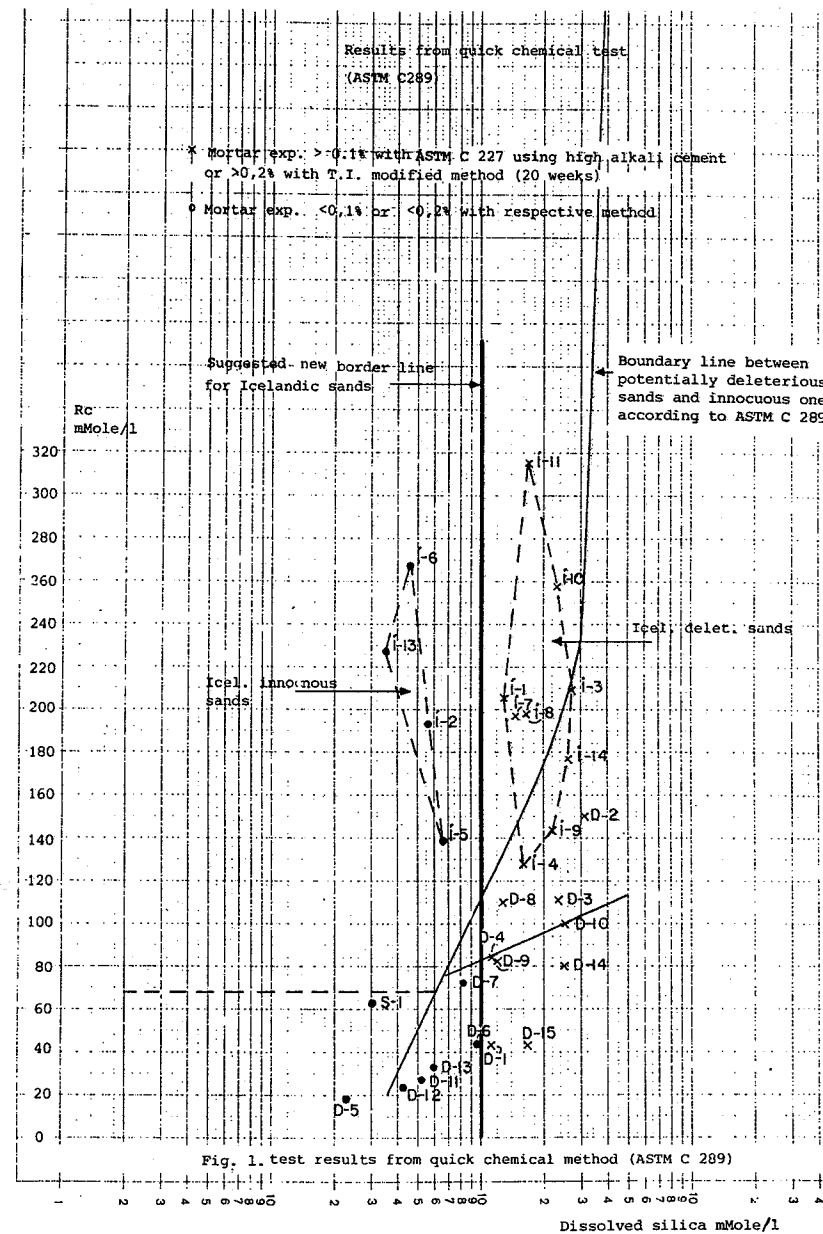
which involve increased alkali and water contents and elevated storage temperatures, have been devised. It should be noted, however, that accelerating procedures do not always modify the rates of aggregate reaction and mortar or concrete expansions consistently and may under some circumstances reduce or even inhibit expansions while under other circumstances they may promote reactions which do not proceed under normal conditions.

It has been observed that densely compacted mortars, when stored in a moisture saturated atmosphere at ambient temperatures, did not expand more than 0.05% unless the aggregate contained a component which was reacting with alkalis. When mortar expansion exceeds 0.05% all the observable symptoms namely, large numbers of reacted aggregate particles, gelatinous or sol reaction products and cracks associated with reacting particles must be present in the specimen. All these symptoms will also be present in similar mortars or concretes which are subjected to accelerated test procedures. It must be concluded, therefore, that the aggregate in mortar test specimens which expand more than 0.05% and which exhibit the typical reaction and cracking symptoms must be considered to be potentially deleterious for use in concrete.

The time required for mortar expansion to exceed 0.05% is variable and depends on all the above-mentioned material and procedural variables. Within three months, however, it is usual for reactive aggregate to show signs of attack when mortar specimens are stored at ambient temperatures while reactive aggregate in similar mortar specimens stored at elevated temperatures will be exhibiting signs of attack in approximately one week. Some judgement is needed to determine whether these early reaction symptoms are of sufficient magnitude to justify classifying the aggregate as being deleteriously reactive. If early mortar expansions exceed 0.05% without clear evidence of the onset of extensive aggregate reaction, it must be concluded that expansion is being caused by some other factor (probably cement unsoundness) and that the aggregate is non-reactive. When exposed to ambient environmental conditions, concrete may not develop the usual reaction symptoms observed on the surfaces of mortar specimens stored under laboratory test conditions and the incidence of aggregate reaction and consequently of crack development and expansion may be considerably delayed. However, when aggregate contains a reactive component some concrete cracking, surface pop-outs and deleterious expansion will inevitably occur if the alkali content of the cement is moderately high. It has been generally accepted that when the total alkali content ($\%Na_2O + 0.658\%K_2O$) of cement is less than 0.60%, aggregate reaction will be minimal and concrete will not expand abnormally. When a reactive aggregate has to be used in a concrete strucutre which has a long designed working life, it is considered that the 0.60% maximum for total alkalis in cement is too high and that the total alkali content of the cement should preferably be less than 0.30% and in no circumstances should exceed 0.40%.

THE CHEMICAL TEST FOR POTENTIAL REACTIVITY OF AGGREGATE

The chemical test described by Mielenz et al (1947) can be completed in 2-3 days. A quantity of an arbitrary sized fraction of aggregate is treated with N sodium hydroxide solution at 80°C for 20 hours and, after filtering, portions of the solution are taken for determinations of (a) alkalinity and (b) dissolved silica. Although the test can be carried out readily major difficulties may be encountered in assessing the significance of the test results. It should be noted that uncritical reference of test results to an arbitrary alkalinity reduction - dissolved silica curve may lead to erroneous conclusions about the aggregate's potential reactivity in concrete. The simple test concept of "reduction in solution alkalinity" and "silica dissolved in solution" constituting the two significant factors which determine the potential reactivity of aggregate, is confused by the fact that aggregates are neither pure materials nor monomineralic, that mineral components other than reactive silica may remove alkalis from solution and that "silica in solution" is an hydrated alkali-silica complex which, as it undergoes partial peptization, returns reacted silica to the solution phase. Since aggregates are likely to contain variable amounts of cation exchanging or adsorbing clays and partially weathered or altered minerals, they possess a potential capacity to reduce the alkali content of the solution. Such a reduction has no significant effect on aggregate reactivity. "Dissolved silica" on the other hand is produced by reacting alkalis and silica and dispersing the alkali-silica complex in the solution. The high reaction temperature specified in this test could also cause some limited reaction of normally non-reactive forms of silica such as macro- and micro-crystalline quartz, surface weathered or altered feldspars and basic siliceous minerals which may be present in the aggregate. Consequently, after making due allowance for the variable mineralogical content of aggregates and for the arbitrary test conditions, "dissolved silica" must be considered to be the pre-dominant factor which determines the potential reactivity of the aggregate. Unless the amount of dissolved silica is relatively large, and experience has shown that it should exceed 100 milli-moles/litre, the aggregate should be classified as non-reactive. This critical figure, 100 milli-moles/litre of dissolved silica, indicates whether an aggregate contains sufficient reactive material to cause a deleterious concrete expansion. Although some typically non-reactive aggregates may yield test results which would place them in the potentially reactive zone of the arbitrary curve, they should be classified as non-reactive because their low alkalinity reductions and more pertinantly their low dissolved silica test results (< 100 milli-moles/litre) show that they contain insufficient reactive material to cause deleterious concrete expansions.

Large amounts of dissolved silica can be obtained only from aggregates which contain significantly large amounts of opaline silica, cryptocrystalline silica, crystobalite, tridymite and various artificial and naturally-occurring siliceous glasses present respectively as manufactured glass objects or fragments and in volcanic rock such as obsidian, rhyolite, pitchstone and andesite. Cryptocrystalline silica, which has the same refractive index as quartz, is reactive whereas macrocrystalline quartz, crystalline silicates present in granites, diorites and gabbros, crystalline and glassy silicates in basic volcanic and hyperbyssal rocks such as basalt and dolerite and all types of devitrified glasses present in some volcanic rocks are non-reactive. Aggregates which yield small amounts of dissolved silica may in mortar tests exhibit occasional pop-outs and a few surface reaction spots. They do not cause serious cracking, or expansion and disruption of mortar and concrete. Extensive check tests have been made on a wide variety of reactive and non-reactive aggregates which were finely-ground and subjected to sink-float separations. The low density float fraction was dried, weighed and examined microscopically. These examinations have confirmed the presence of very small amounts, generally << 0.1%, of potentially reactive material in the non-reactive aggregates which behave normally and do not cause deleterious mortar and concrete expansions.

It should be stressed that the chemical test should be used as an aggregate reactivity acceptance test and that it should not be used to determine comparative orders of reactivity for different aggregates. When due allowances are made for varying mineralogical contents of aggregates, correlation between the chemical test predictions and aggregate performances in mortar tests and in concrete structures has invariably proved to be satisfactory.

CONCLUSIONS

1. – The chemical test gives a rapid and reliable assessment of the potential reactivity of an aggregate.

2. – The potential reactivity of aggregate can be confirmed by petrographic examinations, various qualitative tests and by quantitative expansion measurements of mortar or concrete specimens.

3. – All the essential symptoms must be clearly present at significant levels in mortar or concrete specimens to confirm aggregate reactivity as the cause of expansion and disruption.

4. – Correct assessment of test results is essential and should be made only by an experienced assessor.

REFERENCES

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THE INFLUENCE OF TEST SPECIMEN DIMENSION'S ON THE EXPANSION OF ALKALI REACTIVE AGGREGATE IN CONCRETE

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1. ABSTRACT

Experiments demonstrate that the cross-section of the specimen can have a great influence on the expansion. It was found that the larger the cross-section, the larger the expansion. In the mortar-bar test method (ASTM C 227) for the determination of the potential alkali-reactivity of cement aggregate combinations, specimens are used with a cross-section of 1 by 1 inch. Recommendation to increase the cross-section to at least 40 x 40 mm is made on the results of the investigation in order to increase the susceptibility of the test method.

Key words: dimension of test specimen
            alkali-reactive aggregates

2. INTRODUCTION

At the Research Institute of the Dutch Cement Industry research has been carried out into the behaviour of blastfurnace slag cement with respect to the alkali-silica reaction. During this work expansion measurements have generally been performed on prisms with dimensions 40 x 40 x 160 mm, as are used in the Netherlands in cement testing according to the RILEM recommendations. On several occasions measurements were performed on smaller prisms with dimensions 20 x 20 x 160 mm, which equal more or less the dimensions prescribed in ASTM C 227. It was found that the measurements on smaller prisms did not always accord with the results found on other occasions with larger prisms. As the expansion is usually given as the increase in length per unit of length it is suggested that the expansion is independent of the cross-section of the specimen of which the length change is measured. Because of the above mentioned conflicting results some research was undertaken into the effect of test specimen dimensions on the expansion.

3. LITERATURE

A great number of factors that influence the amount of expansion have been investigated during the last decades. Little has been published in literature about the influence of dimensions. The only experiments on the influence of dimensions of test specimens were reported by Davis /1/. Davis compared mortar prisms 1 x 1 x 11¼ inch with mortar prisms 2 x 2 x 11¼ inch and found an increase in expansion with increasing cross-section (see table 1).
Locher /2/ mentioned a greater susceptibility of the RILEM prisms (40 x 40 x 160 mm) compared with the ASTM prisms. However, the grading of the aggregate was adapted to the larger cross-section.
A clear conclusion as to the effect of the dimension can therefore not be taken from these experiments.