Potential alkali-silica reaction in some Malaysian rock aggregates and their test results

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Abstract: It is widely known that the deterioration of concrete due to alkali-silica reaction (ASR) will occur when aggregates containing pessimum amounts of reactive silica minerals are used with high alkali cement. Petrographic examination and expansion tests on several natural rock aggregates collected throughout Peninsular Malaysia indicate some to be potentially alkali-silica-reactive. Petrographic evidences confirm that potential alkali silica reactive minerals in the aggregates consist of chalcedonic (spherulitic) quartz in volcanics, chert clasts in sandstone, strained quartz in quartzite and microcrystalline and cryptocrystalline quartz in hornfels, volcanics and schists are the likely causative factors in the expansion of the concrete bar used in the tests.

The hot and humid climatic condition of this country is conducive for the occurrence of alkali-silica reaction in concrete. Therefore, appropriate precautions should be taken when using the Malaysian aggregates for the production of concrete to avoid the risk of alkali-silica reaction.

INTRODUCTION

Alkali-silica reaction (ASR) in concrete recently become a subject of great concern in Malaysia after the Singapore Government banned the import of volcanic rock aggregates of less than 40 mm in 1988. This has affected the export of aggregates from Pengerang, Johore.

Deterioration of concrete due to alkali-silica reaction was first reported in Malaysia in 1989 (Razak and Powzie, 1989). It occurs on parts of a 27 year old reinforced concrete bridge, linking the towns of Kuala Rompin and Endau, east coast of Peninsular Malaysia. Following this report, an investigation on the status of the potential alkali-silica reactivity of Pengerang aggregates were carried by Chow and Sahat (1989).

Deterioration of concrete due to alkali-silica reaction will occur when aggregates containing pessimum amounts of reactive silica minerals are used with high alkali cement to make concrete. Petrographic examination and expansion tests on several natural rock aggregates collected throughout Peninsular Malaysia indicate some to be potentially alkali-silica-reactive.

REACTION MECHANISM

Alkali-silica reaction is a slow reaction between the hydroxyl ions of the pore solution in concrete and certain types of reactive silica minerals which occur occasionally as a part of the rock aggregate. The hydroxyl ions originate from the sodium and potassium alkalis in the cement and are released in the presence of water. The product of the reaction is a silicate gel which imbibes water from the pore fluid. The expansion of this gel increases the volume and produced internal stresses which sometimes are large enough to cause tension and cracking leading to the destruction of concrete.

Deterioration of concrete due to alkali-silica reaction will occur only when the following three conditions are met simultaneously (see Neville, 1977; Diamond, 1978; BRED, 1982):

1. Sufficient amount of rock aggregate containing a pessimum amount of reactive silica minerals.
2. Sufficient supply of alkali in the pore solution.
3. Sufficient supply of water to be adsorbed by the reaction products.

REACTIVE SILICA MINERALS

The silica minerals which have been suggested to be capable of reacting at a sufficient rate to induce expansion due to ASR in concrete include opal, chalcedonic quartz, microcrystalline and cryptocrystalline quartz and strained quartz. Yeap (1992) discussed in detail the mineralogical and petrological aspects of such reactions.

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Table 1. Rock types and their location (quarries) from Peninsular Malaysia used in this study.

Rock Samples	Location
Granite	Bt. Lanjang, Selangor
Rhyolite 1	Lancang, Pahang
Rhyolite 2	Santi, Johore
Agglomeratic tuff	Bt. Belungkur, Johore
Sandstone 1	Bt. Tunjang, Kedah
Sandstone 2	Jitra, Kedah
Sandstone 3	G. Semanggol, Perak
Hornfels	Gurun, Perak
Quartzite 1	Teluk Intan, Perak
Quartzite 2	Grik, Perak

Microcrystalline and cryptocrystalline quartz can also be present as chert clasts in quartzite and sandstone.

METHOD OF INVESTIGATION

Ten rock samples were collected from ten quarries in Peninsular Malaysia. The rocks were examined petrographically and tested for expansion capability in alkali-rich concrete. The types of rocks investigated and their locations are summarized in Table 1.

Expansion test

Expansion tests were performed in accordance to the accelerated mortar-bar method proposed by Oberholster and Davies (1986). These tests require the use of high alkali concentration and high temperature in order to accelerate the reaction. Results can be obtain as fast as 14 days compared to a period of between six to twelve months by using the normal ASTM method (ASTM C227-81).

Petrographic examination

The presence of potentially reactive silica minerals in the rock aggregate particles was determined by the petrographic examination of thin sections of the rocks. Modal point counting analysis was used to determine the quantity of reactive silica minerals present in the rock aggregate before they were used for expansion tests.

The procedures for petrographic examination of rock samples as given in ASTM C295-85 was used for this study.

Reaction product

The reaction products were examined under stereomicroscope and then electron microscope. These two methods were used to confirm that the expansion of the mortar-bars are due to the mechanism of alkali-silica reaction rather than to other factors. The elemental composition of the reaction products were determined using an energy dispersive X-ray analysis.

TEST RESULTS

Petrographic characteristics

Granite

This granite is coarse-grained, holocrystalline, composed mainly of quartz, alkali feldspar and plagioclase. Quartz occurs as subhedral to anhedral grains in size from 0.1 mm to 0.2 mm. It shows a straight to slightly undulose extinction. Rare grains are observed to show undulose extinction. Alkali feldspar and plagioclase are extensively replaced by serisite.

Biotite and muscovite were present as a minor constituent. Biotite sometimes shows an alteration to chlorite.

Agglomeratic tuff

The agglomeratic tuff is holocrystalline and mainly composed of quartz, alkali feldspar, plagioclase and lithic-clasts of andesite, rhyolite and sandstone. Crypto- to microcrystalline quartz, alkali feldspar, plagioclase and sericite form the groundmass.

The quartz phenocrysts occur in anhedral to subhedral form, range in size up to 1.5 mm in diameter and shows a straight to undulose extinction. Chalcedony is commonly presents in this rock (Fig. 1(a)). The phenocrysts of alkali feldspar and plagioclase are sometimes partly replaced by sericite.

Epidote is present in minor amounts as a secondary mineral. It occurs in voids and as fillings of veins cutting through the rock.

The modal amounts of crypto- to microcrystalline quartz (plus chalcedony) is approximately 50%.

Rhyolite

The rhyolite is holocrystalline, crypto- to microcrystalline quartz with feldspars and sericite forming the groundmass (Fig. 1(b)). Quartz also occurs as phenocryst. Phenocrysts of quartz are up to 2.0 mm in diameter and do not show undulose extinction, and is rounded in shape.

Phenocrysts of alkali feldspar and plagioclase occur as subhedral to euhedral grains, ranging up to 3.0 mm in size.

They are sometimes partly replaced by sericite. Chloritoid and some opaque minerals occur as minor constituents.

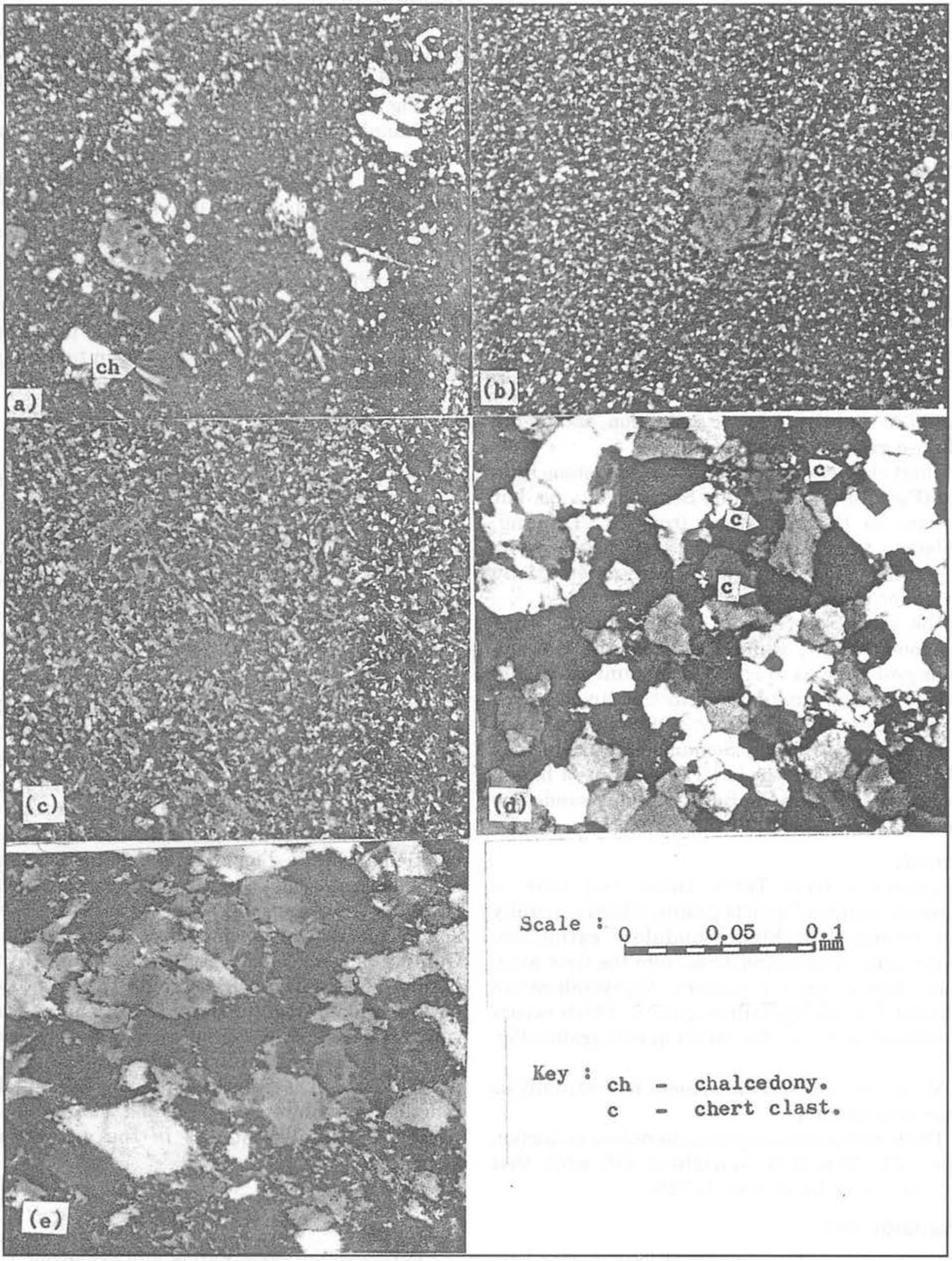

Figure 1. Photomicrograph of thin section. (a) Spherulitic chalcedony in agglomeratic tuff. (b) Crypto- to microcrystalline quartz in rhyolite. (c) Microcrystalline quartz in hornfels. (d) Chert clasts in sandstone. (e) Strained quartz in quartzite.

Hornfels

The rock shows a hornfelsic texture and mineralogically it consists of mainly microcrystalline quartz and actinolite (Fig. 1(c)). A brown biotite is present as subhedral grains distributed at random throughout the fine matrix of quartz and actinolite. Epidote occurs as accessory mineral and it forms granules and anhedral grains.

Sandstone

The sandstone is texturally and mineralogical mature. Quartz clasts are sub-rounded to rounded, well sorted, with grain sizes ranging from very fine to coarse. Quartz grains make up 80% to 90% of the detrital fraction and are close to closely packed. Some of the quartz in the sandstone from Jitra and Gunung Semanggol area shows slightly undulose to highly undulose extinction. Most of the quartz grains from the Bt. Tunjang sandstone shows straight to slightly undulose extinction, and highly undulose grains are absent.

Chert clasts are observed in the sandstone from Jitra (Fig. 1(d)) and Gunung Semanggol area, but are rare in the sandstone from Bt. Tunjang. Sandstone from Bt. Tunjang is characterized by the presence of serisite which occurs interstitially as a minor constituent.

The modal percentage of chert in the Jitra sandstone is 18%, while that from the Gunung Semanggol area is 6%. The amount of highly strained quartz (undulose extinction angle > 15°, see Anderson and Thaulow, 1989) in the Jitra sandstone and Gunung Semanggol sandstone is 10% and 23% respectively. The amount of highly strained quartz from the Bukit Tunjang sandstone is negligible.

Quartzite

Quartzite from Teluk Intan and Grik is composed mainly of quartz grains, which generally show undulose to highly undulose extinction. Quartz grains in the quartzite from the Grik area, Perak, show a "lensiod" texture. Recrystallization produced a microcrystalline quartz, which occurs interstitially between the larger quartz grains (Fig. 1(d)).

Muscovite and serisite present interstitially as minor constituents.

The highly strained quartz (undulose extinction angle > 15°) from Grik quartzite is 48% while that from the Teluk Intan area is 22%.

Expansion test

The average of expansion of four mortar-bars obtained from accelerated mortar-bar test are plotted against time as shown in Figure 2. Oberholster and Davies (1986), established that the sample having expansion greater than 0.11% at 12 days is considered deleterious.

Reaction product

The products of reaction consist of a translucent gel which can be seen to infilled the pore of concrete bars and is also present on the surface as exuded gel (Fig. 3).

Scanning electron micrograph and the elemental compositions of the reaction products observed within the mortar bar specimens subjected to the accelerated test is shown in Figure 4(a) and 4(b). There are two types of reaction products, namely the massive gel and textural gel. The textural gel appears to form scaly masses while the massive gel does not. Both types of gel are rich in silica (Si), sodium (Na) and calcium (Ca), but the percentage of Calcium (Ca) is relatively higher in textural gel than in massive gel.

DISCUSSION

The greatest expansion in the accelerated mortar-bar test for the ten aggregate samples is shown by the agglomeratic tuff, followed by quartzites, hornfels, rhyolite and sandstone. Granite from Bukit Lanjang and sandstone from Bukit Tunjang, Kedah show the lowest expansion and they are regarded as showing non-deleterious expansion.

The results of expansion of the mortar bars correlates very well with the petrographic examination of the rock aggregate. It is established that the chalcedonic quartz is regarded as more reactive compared to microcrystalline and cryptocrystalline quartz and strained quartz.

Deleterious expansion due to alkali-silica reaction is observed for rock aggregates consisting of agglomeratic tuff from Bukit Belungkur, Johore, rhyolites from Lancang, Pahang and also Santi, Johore, sandstones from Jitra, Kedah and also Gunung Semanggol, Perak, hornfels from Gurun, Kedah, and quartzite from Teluk Intan and also Grik, Perak. Granite from Bukit Lanjang and sandstone from Bt. Tunjang showed no deleterious expansion although gel-like products were observed after 12 days. The gel is the product of alkali-silica reaction contributed by strained quartz, which present in small amounts in the granite and sandstone.

CONCLUSIONS

Petrographic examination and expansion tests on several selected natural rock aggregates collected throughout Peninsular Malaysia indicate that some to be potentially alkali-silica reactive. Petrographic evidences confirm that potentially alkali-silica

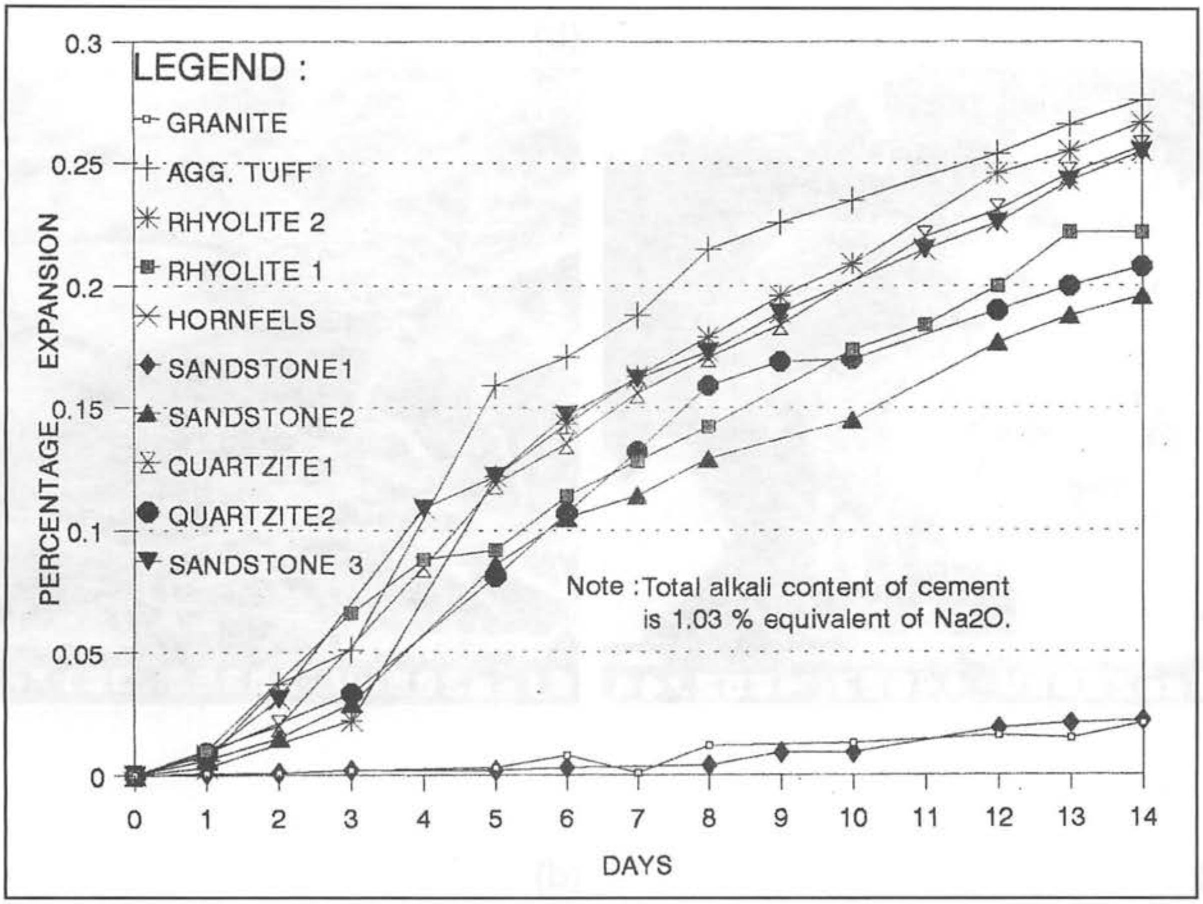

Figure 2. Results of accelerated mortar bar test.

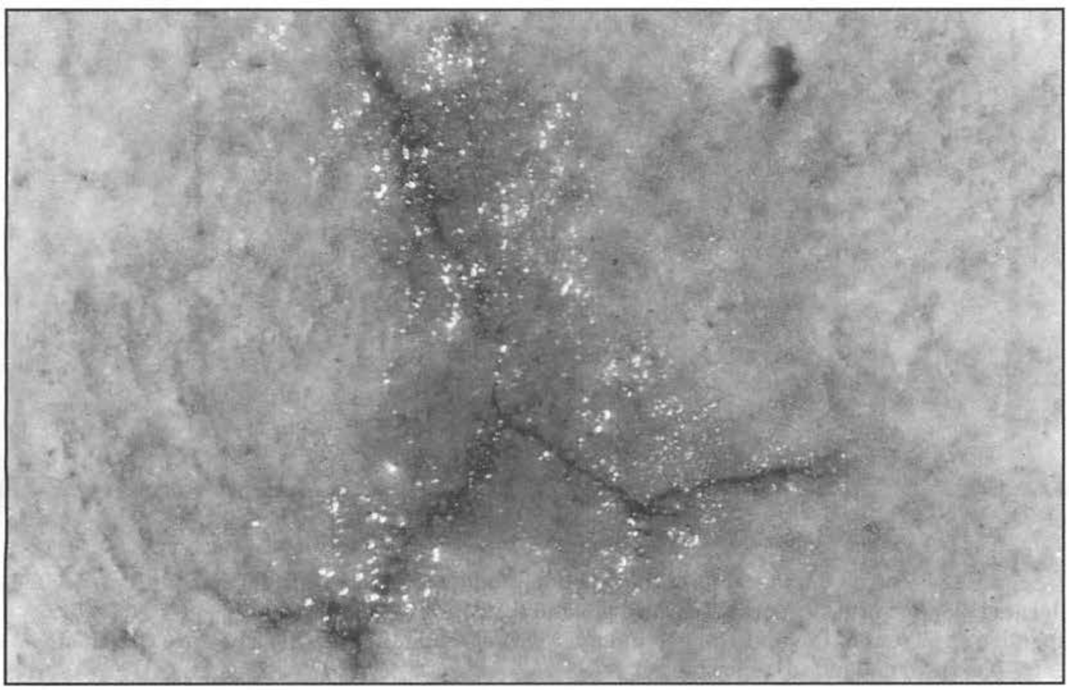

Figure 3. Photomicrograph of mortar bar tested positive for ASR. "Three-arm" pattern microcrack accompanied the damp patches of exuded gel.

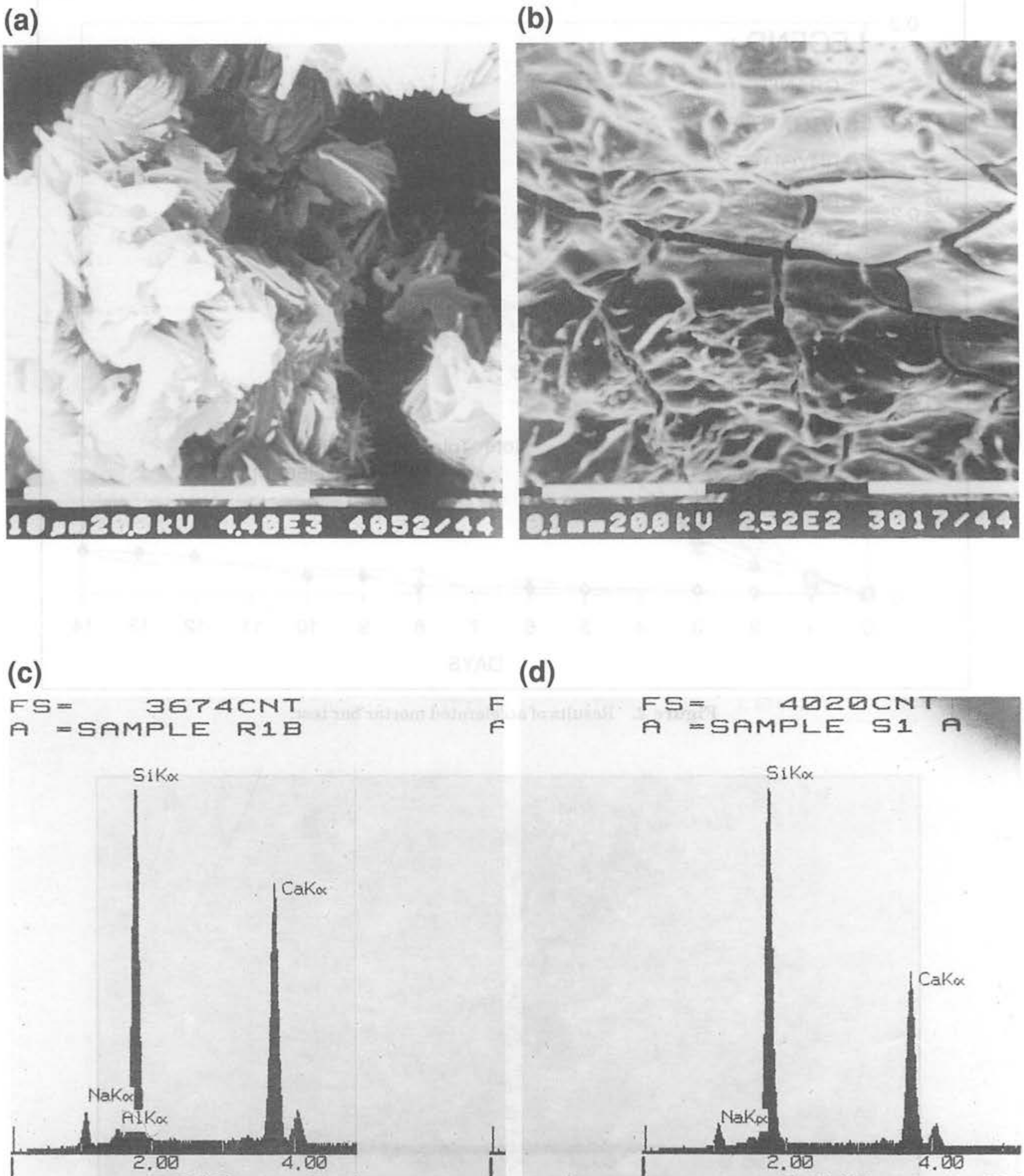

Figure 4. Scanning Electron micrographs of the reaction product formed within the mortar bar specimens subjected to the accelerated expansion test — (a) Textural gel and (b) Massive gel.
Energy dispersive spectrum of the textural gel and massive gels as in (a) and (b). They are rich in silica, sodium and calcium — (c) Textural gel and (d) massive gel.

reactive minerals in the aggregates consist of chalcedonic (spherulitic) quartz in agglomeratic tuff, chert clasts in sandstone, strained quartz in quartzite and microcrystalline and cryptocrystalline quartz in hornfels and rhyolite are the likely causative factors in the expansion of the concrete bar used in the accelerated mortar bar tests of NBRI.

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