



RESEARCH ARTICLE

ALKALI-SILICA REACTIVITY OF SOME GRANITIC ROCKS IN KUMASI, GHANA: IMPLICATIONS FOR USE OF ROCK AGGREGATES FOR CONSTRUCTION

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ABSTRACT

This paper seeks to assess the potential of Alkali-Silica Reaction on some granitic rocks in Kumasi in Ghana. Alkali-Silica reactions occur over time between alkaline cement paste and silica contained in rock aggregates as a result of the swelling due to the reaction of certain constituents in the rock aggregates with alkali hydroxides. Alkali-Silica reactions become potentially harmful when they cause significant expansion. Aggregates used for this research were sought from three different quarries, namely, Consar Stone Quarry in Barekese, Nnagot Quarry in Kona and Modern Granite Quarry in Buoho. To achieve the objectives of this project, two test methods were employed such as Accelerated Mortar Bar test (ASTM C1260) and Petrographic analysis. Presence of strained quartz is an indicator for the occurrence of Alkali-Silica Reaction. Samples from Kona contained quite an appreciable amount of strained quartz and exhibited an expansion above the ASTM C 1260 specification, implying that it is potentially reactive and thus not useful for construction works, whilst samples from Barekese, and Buoho were innocuous and may be used for construction works. Supplementary cementing materials such as pozzolans (which are readily available) can be added to concrete mixtures with aggregates from Kona to reduce the harsh effects of ASR.

KEYWORDS

Alkali Silica Reactivity, Granitic Bodies, Accelerated Mortar Bar, Petrography, Strain Quartz

1. INTRODUCTION

Alkali Silica Reaction (ASR) occurs in a chemical reaction between hydroxyl ions (OH⁻) of either sodium or potassium alkalis from hydraulic cement (or other sources), and certain siliceous rocks and minerals, such as opal, chert, microcrystalline quartz, and acidic volcanic glass, present in some aggregates. Cracks formed in concrete due to ASR is shown in Figure

1. The reaction can be well visualized as a two- step process (Figure 2):

- Alkali + Reactive Silica = Alkali- Silica gel
- Alkali-silica gel + moisture = Expansion

Concrete forms an integral part in most construction works in Ghana. Reaction between silica in the coarse aggregates and the alkali in the cement is the main cause for the deterioration in buildings. Preliminary surveys suggest that for most construction works in Ghana, engineers mostly focus on the engineering properties of aggregates such as specific gravity, shear strength, point load index, compressive and tensile strength of the rock aggregates, without taking into consideration the ASR potential of these aggregates. It would be disheartening if a structure designed to last for 50 years suddenly starts to deteriorate after just 5 to 15 years of existence. This will mean more resources would be required to maintain the building and if the deterioration observed is too intense to salvage, the building may be demolished. The same problem may be encountered in any new structure built if the necessary mitigating measures are not put in place.

The project area is in the Kumasi Basin in Ghana which is made up of various rock types and its associated granitoid intrusions. Granitic rock outcrops occur in almost all regions of Ghana and these are mainly developed as quarries across the country. Buoho, Kona and Barekese are towns within the Kumasi area known for their large granitic rock deposits which are mined for construction works and economic purposes. Buoho is centrally located in the Afigya-Kwabre district at longitude -1.6468' and latitude 6.7972'. Kona is located in the Afigya-Sekyer district formally known as the Sekyere-South district at longitude -1.508' and latitude 6.873'. Barekese is a town and the capital of Atwima-Nwabiagya North district located at longitude 1.7198' and latitude 6.8481'.

The paper investigates the alkali-silica reactivity (ASR) potential of some granitic aggregates in Kumasi in Ghana. To arrive at this main aim, work has to be done to investigate the alkali-silica reactivity potential of some granitic rocks from Kona, Buoho and Barekese using petrographic analysis; and also to determine the degree of expansion of mortar bars using ASTM C 1260 as a means of investigating the ASR potential.

2. GEOLOGIC SETTING

Geologically, Ghana is located in the confines of the Eastern portion of the Man shield covering the Southeastern portion of the West African Craton (WAC). The folded metamorphosed Birimian, Buem Formation, Tarkwaian, Voltaian, Dahomeyan System and the Togo series are the major rock assemblages in the country. The granitoids in Ghana consist of the belt type granitoids (formally called Dixcove granite) and the basin type granitoid (formally known as the Cape Coast granite). Other types of

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granitoids, usually restricted to a single locality are also present. They include Winneba granitoids, the Tongo granitoid. The basin type granitoids occur as large batholiths within the basin sediments (Nyarko et al, 2012). Buoho and Barekese are being identified in the basin type granitoids of which Buoho has hornblende-biotite tonalite, minor granodiorite and minor quartz diorite rock types. Barekese has sericite schist, quartz-sericite schist locally with garnet and/or staurolite.

Dahomeyan System occupies the south eastern corner of Ghana. The system consists of four alternating belts of acid and gneiss: The Togo outlier, the acid Dahomeyan, the alkali gneiss and the basic Dahomeyan (Kesse, 1985). Kona and Barekese are in two folds. These are, mafic Dahomeyan gneiss consisting of bands of felsic minerals and mafic metamorphosed gneiss. The location where sampling was done is shown in Figure 3.



Figure 4: (A) Modern Granite Quarry at Buoho; (B) Nnagot Quarry at Kona



Figure 1: Cracks formed in concrete due to ASR (Mercan, 2018)

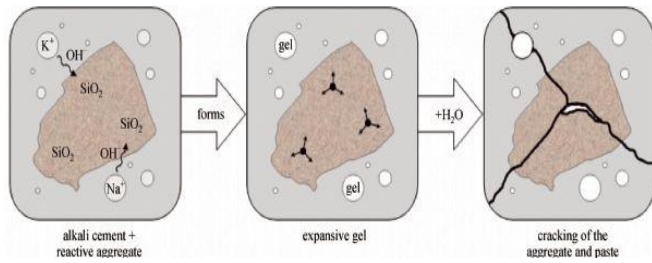


Figure 2: Mechanism of ASR (Wang and Noguchi, 2020)

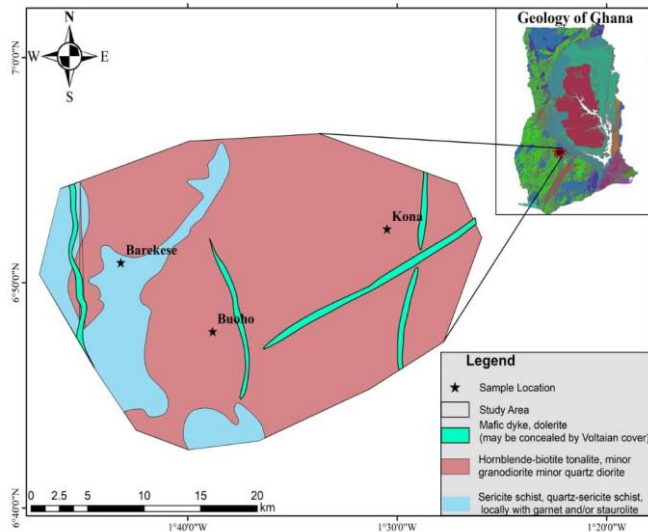


Figure 3: Geology of the study area

3. MATERIALS AND METHODOLOGY

3.1 Field Method

3.1.1 Source of Materials Used

Rock samples and quarry dust were used in this project. These materials were sought from some of the most popular quarries in Kumasi, well-known for supplying granitic aggregates for construction works. The selected quarries are Modern Granite Quarry in Buoho (Figure 4A), Nnagot Quarry in Kona (Figure 4B) and Consar Stone Quarry Limited in Barekese. The samples were collected in sacks, well labelled and transported to the Geological Engineering laboratory and Geotechnical laboratory in K.N.U.S.T.

3.2 Laboratory Method

Two different tests were performed on the aggregates and they are:

- Mortar Bar Test (ASTM C 1260); and
- Petrographic Analysis

Mortar Bar Test (ASTM C 1260) provides a means of detecting the potential of an aggregate intended for use in concrete for undergoing alkali-silica reaction resulting in potentially deleterious internal expansion. Petrographic analysis checks the mineralogical content of the rock.

3.2.1 Petrographic Analysis

3.2.1.1 Thin Section Preparation

Thin sections were prepared to enable the minerals well identified microscopically. The experiments (both petrographic and mechanical) were prepared at the Geological Engineering laboratory (KNUST) between April and June, 2021. Rock samples were sliced and mounted on a glass slide (Figure 5A) for petrographic analysis. They were prepared to the required thickness of 30µm to identify multiple minerals and their textural relationships under a microscope; Two slides were prepared for each of the rock samples from the three quarries; The specimens were cut and trimmed using the cutting machine into slabs suitable for mounting. The slabs were first physically lapped and grounded gradually using 60, 120, 240, 400, 600 and 1,200 grit sizes. This was done in order to achieve a completely smooth surface. Smoothed surfaces were mounted on glass slides using epoxy glue. Using the thin section machine, excess rock was then cut; The other surfaces were then lapped on the grinding machine to achieve the required thickness of 30µm. The thickness was determined by noting the interfering colours of common minerals such as quartz, biotite or feldspar under a petrographic microscope.

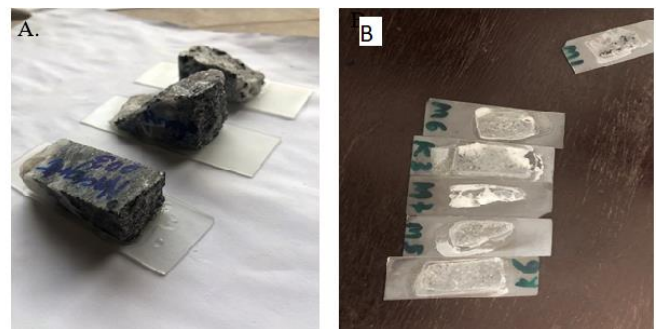


Figure 5: (A) Cut rock samples mounted on glass slides. (B) Thin section of rocks lapped to a thickness of 30µm.

3.2.2 Accelerated Mortar Bar Test (Oberholster,1986)

This test was conducted at the Building and Road Research Institute (B.R.R.I.) of the Council for Scientific and Industrial Research (C.S.I.R.), located at Fumesua in Kumasi between April and June, 2021.

3.2.2.1 Apparatus

- Sieves (Figure 6-B) – Square holes, woven wire cloth sieves.
- Mixer, Paddle and Mixing bowl (Figure 6-D) – Mixer, paddle and mixing bowl.
- Tamper and Trowel – The tampers and trowel conform to Test Method C 109/ C 109M.

- Containers – The containers can totally immerse mortar bars in either water or 1N NaOH solution. The containers were made of materials which can withstand prolonged exposure to 80 °C.
- Curing Cabinet (Figure 6-A) –For dry oven curing of mortar bars.
- Oven – For water bath and sodium hydroxide curing of mortar bars.
- Length comparator (Figure 6-C) – For taking length readings.
- Molds – 25 mm × 25 mm × 285 mm length with stainless steel studs.



Figure 6: (A) Curing Cabinet; (B) Test Sieves; (C) Length comparator; (D) Concrete mixer

3.2.2.2 Reagents

- Sodium Hydroxide Solution – 1M±0.05 NaOH solution.
- Water (distilled or ionized) was used for mixing.

3.2.2.3 Preparation of Cement

The cement (Ghacem Super Strong 42.5R) was sieved over the 850µm sieve to remove lumps.

3.2.2.4 Preparation of Aggregates

The aggregate to be tested were compared with the grading given in the Table 3.

Table 1: Classification table for grading test		
Sieve sizes (square openings)		Percentage by mass (g)
Passing	Retained	
4.75 mm	2.36 mm	10
2.36 mm	1.18 mm	25
1.18 mm	600 µm	25
600 µm	300 µm	25
300 µm	150 µm	15

3.2.2.5 Preparation of Mortar Bars

The mortar consisted of:

- Part of cement by mass;
- Part of aggregates were prepared to the grading specified in Table 1, by mass.

At least three mortar bars for each aggregate tested were manufactured. The amount of materials needed for 3 mortar bars was 440g cement and

1000 g of dry, graded aggregate.

The mortar was mixed noting that the mixer with approximately 5-liter bowl and appropriate paddle was used for mixing the amount of materials needed for one set of 3 mortar bars.

3.2.2.6 Procedure

The mortar bars were cured and measured as follows:

- Immediately after the specimen in the mold was prepared, the filled mold was placed in an oven at 23±2 °C for 24±2 hours.
- After 24 hours the molds were removed from the oven and demolded ensuring that the bars were protected from loss of moisture and care was taken to make sure the studs were not moved. The mortar bars were each given a unique identification comparator.
- They were then placed in a moist cabinet (relative humidity of very close to 100%, but not less than 98%) for 48±2 h, after which the measurement of length change was taken.
- The mortar bars were removed from the moist room and kept under a moist cloth. The bars are taken one at a time and the initial reading (L₁) of each mortar bar was recorded in the length comparator to the nearest 0.002mm.
- The mortar bars were immediately placed in a water bath at room temperature and heated gradually at a rate of 18-20 °C/hr. and maintained at this temperature at 24 hours.
- The bars were removed from the water bath, one at a time, wrapped in plastic and the end gauge studs dried. Using the length comparator, the length of the bar (L₂) was recorded. This process was completed within 20 seconds of removing specimen from water.
- The mortar bars were immersed in the bath containing the 1N NaOH solution at 80±2 °C. The bars were then completely immersed and supported in the bath so that the solution has access to the whole bar. The bars were made not to touch the sides of the bath or each other.

Subsequent comparator reading of the specimens (L_n) were taken 1, 7, 14, 21 and 28 days after placing in the 1M NaOH solution at 80 °C.

4. RESULTS AND DISCUSSIONS

4.1 ASR Based on Mortar Bar Test

Mortar bar test (Oberholster and Davis, 1986) results were analyzed after 14 days (i.e., one-day dry curing, one-day water curing and fourteen days of NaOH solution curing). The difference between the zero-comparator reading and the reading at each period to the nearest 0.001% of the effective gauge length were calculated and the expansion of the specimen for that period were recorded. The average expansion of the three specimens (three each from the three quarries) was also calculated to the nearest 0.01% using Eq. 1 as the percentage expansion. The interpretation of the percentage expansion is shown in Table 2.

$$\text{Percentage Expansion} = \frac{\text{After Curing (days)} - \text{Initial Reading}}{\text{Length of Rod}} \times 100 \dots \dots \text{Eq. 1}$$

Table 2: Expansion criteria according to ASTM C1260 (Oberholster and Davis, 1986)	
Expansion % after 14 days	Interpretation
Less than 0.1%	Innocuous aggregates (non-reactive)
Between 0.10 and 0.20%	Both innocuous and deleterious aggregates
More than 0.20%	Potentially reactive aggregates

After the 14 days as shown in Table 3, Kona had an average expansion of 0.17% which exceeds 0.10% and less than 0.20% (which can be considered to have aggregates of both innocuous and deleterious in field performance from Oberholster and Davis, 1986). Specimen from Barekese and Buoho had an average expansion of 0.07% and 0.05% respectively (which are considered innocuous). Figure 7 shows a graphical presentation of the mean expansion after 28 days.

Table 3: Mean percentages expansion of the various rock samples with days

Rock Sample	7 days (mm)	14 days (mm)	21 days (mm)	28 days (mm)
Barekese	0.03	0.07	0.10	0.10
Buoho	0.07	0.05	0.12	0.12
Kona	0.10	0.17	0.10	0.15

From Oberholster and Davis (1986), expansion between 0.10% and 0.20% after 14 days of NaOH curing include both aggregates that are known to be innocuous and deleterious in field performance. After 28 days of NaOH curing, the average expansion of specimen from Kona and Buoho were between 0.10% and 0.20% which are still considered as aggregates having a mixture of both innocuous and deleterious aggregates.

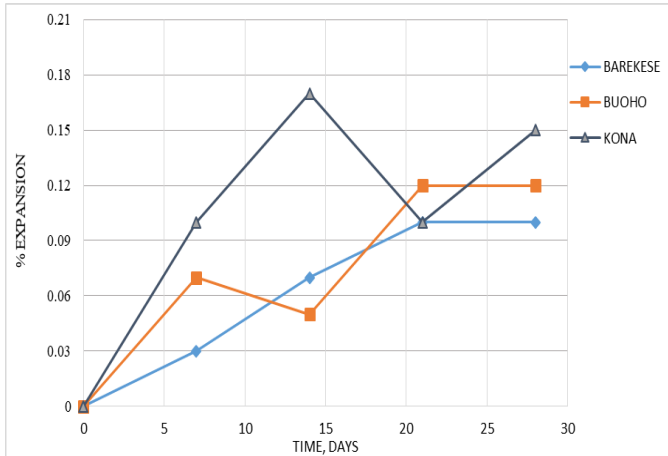


Figure 7: Expansion test results for ASTM C1260 after 28 days of NaOH curing.

4.2 Petrographic Analysis

4.2.1 Macroscopic Description

Sample A (Kona)

The rock sample (Figure 8A) is fine to medium grained and foliated subtly with bands of varying minerals. It is composed of quartz, biotite, and feldspar. The feldspar and quartz grains are in an interlocking texture.

Sample B (Kona)

Rock (Figure 8B) is a combination of light and dark colored minerals. The light colored minerals are predominantly plagioclase with small amount of quartz and dark minerals are hornblende and Biotite. The rock is generally intruded by the feldspar and quartz veins which has formed bands on it. The dark minerals are medium grained and the light-colored minerals are porphyritic. The rock is foliated.

(A)



(B)



(C)



(D)



Figure 8: Biotite Hornblende Gneiss (Kona) (A); Biotite Quartz Gneiss from Kona (B); Microcline Granite from Barekese (C); Microcline Quartz Granite from Buoho (D)

Sample C

Rock (Figure 8C) is generally light colored with some dark minerals interspersed in it. It is composed of quartz, feldspar and biotite with the minerals interlocking each other. The rock is not weathered and the cock is coarse grained.

Sample D

Rock (Figure 8D) has a porphyritic light-colored portion which is dominated by feldspar and quartz. The other portion is a combination of dark and light-colored minerals evenly distributed (which contains quartz, feldspar and biotite).

4.2.2 Microscopic Analyses

The framework of the thin section is composed of mainly medium to coarse anhedral to subhedral grains of quartz. In plane polarized light (PPL) the subhedral to anhedral quartz crystals are colourless, showing low relief, whilst the tabular to elongated plagioclase crystals in low relief, look cloudy with occasional parallel or intersecting cleavage planes. The orthoclase crystals in PPL also show low relief and cloudy in nature, but less cloudy compared with the plagioclase. The irregular small flaky biotite in PPL are pleochroic with colours ranging between dark to pale and greenish brown. Similarly, the pleochroic dark to dark green elongated chlorites as well as flakes in PPL are aligned in the direction of foliation in the framework.

In cross polarized light (XPL), the framework shows interlocking crystals of fine to medium sizes. However, there is incipient recrystallization at the contact boundaries of many of the crystals. Hence two or more grains/crystals appear fused together. The quartz crystals are mostly monocrystalline; however, few polycrystalline grains were observed comprising of at least two grains, with different extinction. The undulose extinction of the quartz depict deformation. The orthoclase crystals are differentiated from the quartz crystals by their cloudy appearance in PPL. The plagioclase feldspars look cloudier than the orthoclase feldspar crystals. Occasionally, some of the plagioclase show slight zonation probably due to alteration. However, alteration of some of the primary minerals (plagioclase and orthoclase) have also produced fine grained sericitic materials in the framework. Sericitization in some portions of the thin section probably result from alteration of some feldspars and possibly biotite. Some of the biotite are altered into chlorite to signify low grade metamorphism in the rock sample. This is probably due to the shearing during the deformation. Though the quartz is mostly monocrystalline, the polycrystalline grains suggest that the rock has suffered straining to a certain degree. The few dispersed hexagonal strong greenish minerals with intersection of the cleavage planes in the framework are hornblende (amphibole).

Structurally, the alignment of the platy minerals (biotites, chlorites) give the sample the foliated nature. Few dark and altered greenish subhedral crystals with blurred edges appear to be rotated to suggest shearing. It may be inferred that the samples are plutonic rocks located within either weakly sheared zone or near a sheared zone and is mildly metamorphosed. The main structural domain of the rock specimen is the altered biotite to chlorite which is seen to be the foliation whilst the microlithons are the other phenocrysts in the framework; this is also another evidence of deformation in the framework.

(B)

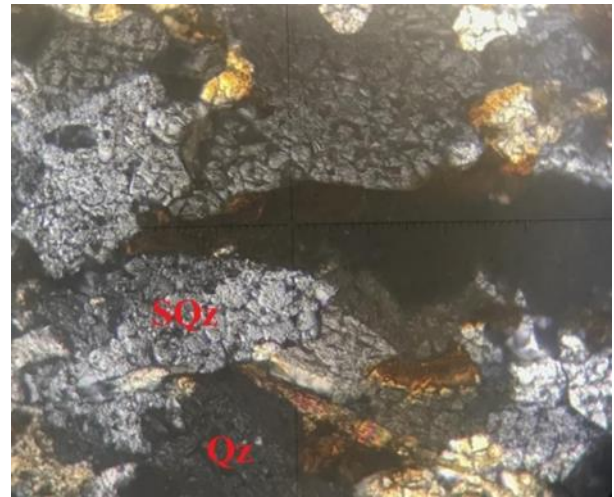
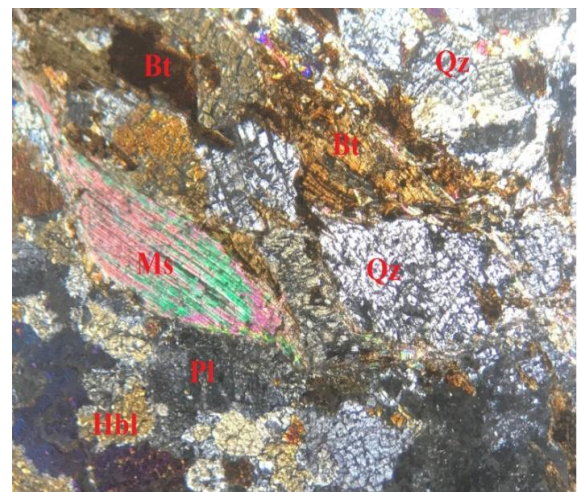


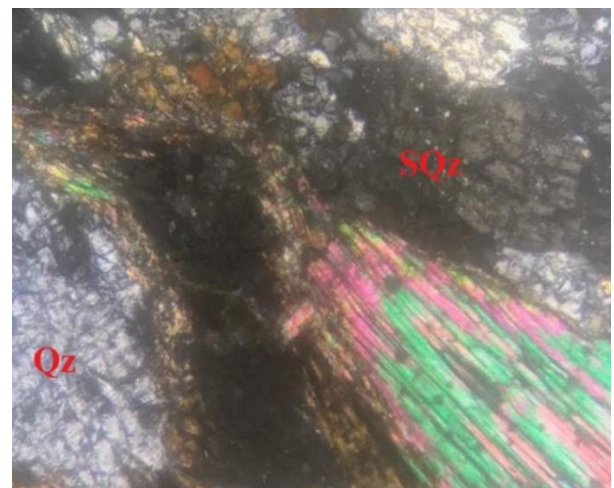
Figure 9: Photomicrograph of a biotite-hornblende gneiss under cross polarized light (4x magnification) sampled at Kona, showing: (A) minerals such as plagioclase (Pl), quartz (Qz), biotite (Bt), hornblende (Hlb); and (B) strained quartz in the gneiss rock

In thin section (Figure 9), the rock is medium grained and it is composed of biotite, quartz, plagioclase and hornblende which are mostly anhedral and interlocking. Biotite occurs in small sizes and has a tabular shape. Quartz grains are not distinct and are highly fractured. They exhibit undulose extinction at an angle of 24°. Plagioclase shows carlsbad (albite) twinning and they are surrounded by quartz and biotite grains. Hornblende grains are widely distributed in the rock and they turn greenish in color when rotated on the stage.

(A)



(B)



(A)

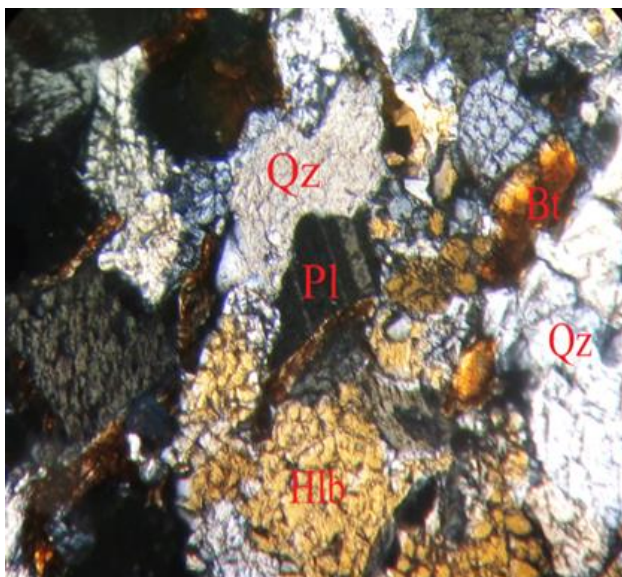
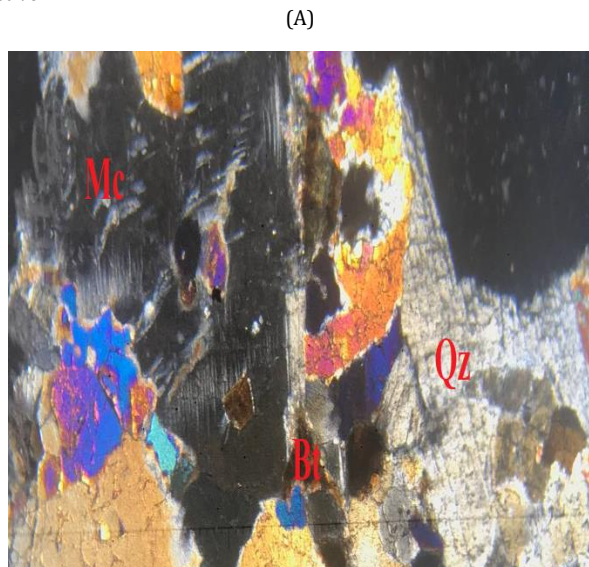


Figure 10: Photomicrograph of a biotite-quartz gneiss under cross polarized light (4x magnification) sampled at Kona, showing: (A) minerals such as plagioclase (Pl), quartz (Qz), muscovite (Ms), biotite (Bt), hornblende (Hbl); and (B) strained quartz (SQz) in the gneiss rock (Quartz grains are deformed and show slight undulose extinction)

In thin section, the rock sample (Figure 10A) is seen to contain biotite, quartz, hornblende, muscovite and some other minerals. The minerals are elongated and trending in the NW-SE direction. Biotite has a wood-like acicular habit with anhedral grains. Muscovite grains are bounded together and they have well-formed crystals which are elongated. Extinction angles are parallel to cleavage in all directions. Quartz grains are widely spread in the rock with fractures. The grains exhibit undulose extinction (Figure 10B). The measured extinction angle is 26° (Figure 10B) which gives an indication of some deformation in the quartz grains. Extinction angle of about 25° and thus indicates that the rock is potentially reactive.



(B)

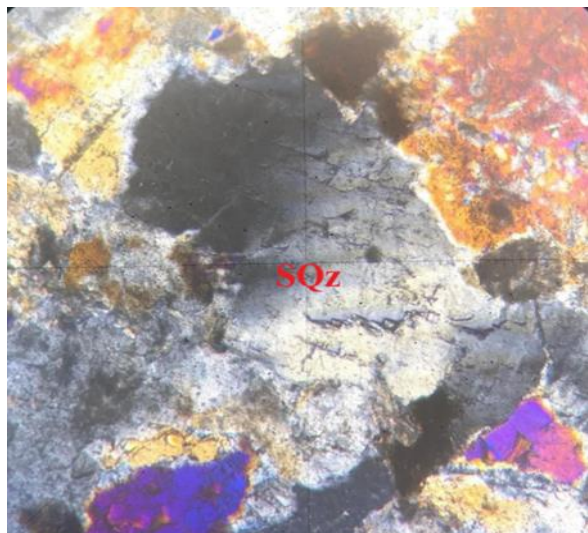
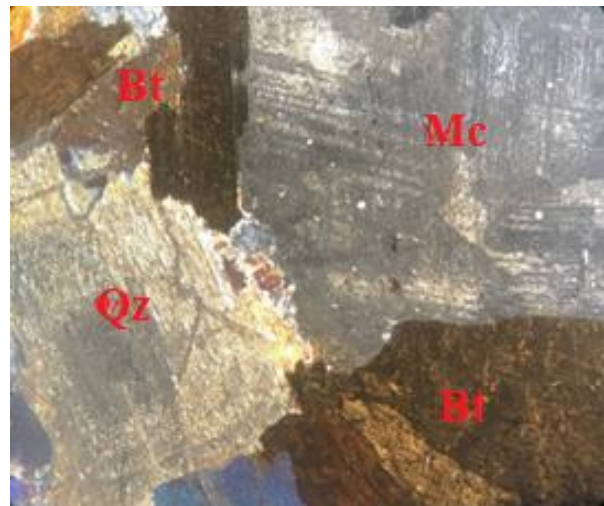


Figure 11: Photomicrograph of a microcline granite under cross polarized light (4x magnification) sampled at Barekese (mineral grains are poikilitic), showing: (A) minerals such as microcline (Mc), quartz (Qz), muscovite (Ms), biotite (Bt); and (B) strained quartz (SQz) in the granite rock (Quartz grains are deformed and show slight undulose extinction)

The thin section of the granite sample (Figure 11) contains biotite, microcline, quartz and some other minerals. The grain sizes are medium to coarse grains. Biotite grains are dispersed in the rock and are surrounded by microcline grains and quartz grains. Microcline grains are widely spread in the rock and the grain sizes are massive and has a poikilitic texture. They have perfect cleavage and show distorted cross-hatch twinning. Quartz grains in the rock are highly fractured and exhibit undulose extinction which are wavy in nature (Figure 11B). They extinct at an angle of about 19° hence they are innocuous.

(A)



(B)

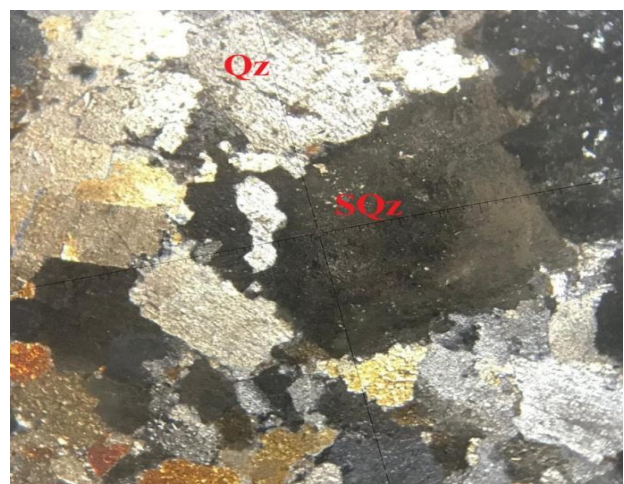


Figure 12: Photomicrograph of a microcline granite under cross polarized light (4x magnification) sampled at Buoho, showing: (A) phenocrysts such as microcline (Mc), quartz (Qz), muscovite (Ms), biotite (Bt); and (B) strained quartz (SQz) in the granite rock

The thin section of the microcline-quartz granite sample contains phenocrysts of microcline, biotite and quartz. Mineral boundaries are distinct. Microcline grains are subhedral and shows distorted cross-hatched twinning. Biotite exhibits a woody habit and shows parallel extinction. Quartz grains are anhedral and has some cracks in them. Quartz has an extinction angle of about 15° (Figure 12B).

5. CONCLUSION

- Samples from Kona showed straining of quartz (which is a clear indication of the mechanical deformation caused by reaction with alkali components in the cement) and an extinction angle greater than 25° confirming its potential reactivity.
- Buoho and Barekese samples showed insignificant amount of straining in quartz with an extinction angle of 15° and 19° respectively making them innocuous. Hence, rock aggregates from these areas can be used for various construction purposes.
- Aggregates from Kona are both innocuous and deleterious.
- Samples from Buoho and Barekese contain innocuous aggregates which portray less amount of alkali-silica reactivity.

Finally:

The use of rock aggregates from Kona for construction works should be avoided due to their potential to Alkali-silica reactivity, whilst the rock aggregates from Barekese and Buoho have minimal Alkali-silica reactivity and are therefore useful for construction. In cases where consultants or engineers are compelled to resort to aggregates from Kona,

Supplementary Cementing Materials (SCM) such as pozzolans should be used to mitigate or reduce the occurrence of ASR.

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