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Potential alkali-silica reaction in aggregate of deformed granite

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Abstract: Granite is the most important source of construction aggregate in Peninsular Malaysia and is widely used in concrete. Granite aggregate is generally considered as not alkali-silica reactive. However, deformation by faulting has generated a diverse variety of deformed granites that may contain deleterious minerals. Petrographic examination and mortar-bar test were carried out to assess potential alkali-silica reactivity. Strained quartz and microcrystalline quartz are the main potentially deleterious mineral in deformed granites. The mortar-bar test recorded marginally deleterious to deleterious expansions. The expansion values can be related to the total strained and microcrystalline contents. Deformed granites with over 12% of total strained and microcrystalline quartz is expected to cause marginal to deleterious expansion and this should be verified by the mortar bar test. The deformed granites generally will not pose serious problems in the production of concrete aggregates as they constitute only a small proportion of the extracted rocks.

Abstrak: Batuan granit adalah sumber agregat pembinaan yang paling penting di Semenanjung Malaysia yang lazim digunakan dalam konkrit. Secara amnya, agregat granit dianggap tidak mempunyai kereaktifan alkali-silika. Sesar yang berlaku pada batuan granit telah menghasilkan pelbagai jenis batuan tercangga yang mungkin mempunyai mineral mudarat. Ujian petrografi dan bar mortar telah dijalankan untuk menilai batuan granit tercangga dengi potensi reaktiviti alkali-silika. Kuarza yang mengalami terikan dan kuarza mikrokristalin adalah mineral mudarat yang utama dalam granit tercangga. Ujian bar mortar menunjukkan terdapatnya pengembangan yang marginal hingga mudarat yang boleh merosakkan konkrit. Nilai pengembangan boleh dikaitkan dengan jumlah kandungan kuarza terikan dan mikrokristalin. Granit tercangga yang mengandungi lebih daripada 12% kuarza terikan dan mikrokristalin dianggap boleh menyebabkan pengembangan dan ini perlu ditentukan melalui ujian bar mortar. Secara amnya granit tercangga tidak akan menyebabkan masalah yang besar dalam penghasilan agregat konkrit kerana kandungannya dalam batuan adalah sedikit.

INTRODUCTION

Damage to concrete structures due to alkali silica reaction (ASR) were first recognised in North America in 1940 by Stanton (Staton, 1940, Staton *et al*., 1942) and since then ASR has been reported in many countries (Gillott, 1975; Hobbs, 1990). The problem of ASR was highlighted in Malaysia in 1988 when the Government of Singapore banned the import of volcanic rocks from southeast Johor which are potentially alkali silica reactive, for use as concrete aggregate (Chow and Abdul Majid Sahat, 1990; Yeap, 1992). In 1989, deterioration of a reinforced concrete bridge in east Johor was attributed to ASR (Razak and Powzie, 1989).

In Peninsular Malaysia, granite is the most important source of construction aggregates. About three-quarters of the crushed rock aggregates are produced from granite. Granitic aggregate is the preferred material in the production of concrete. Aggregate produced from granitic rocks is generally considered to be innocuous because their primary minerals are not reactive (Chow and Abdul Majid Sahat, 1990; Yeap, 1992; Sazali Yaacob *et al*, 1994). However, granite can contain reactive secondary minerals such as opal and chalcedony which infill discontinuities (Yeap, 1992).

Peninsular Malaysia is cut by several major fault zones (Burton, 1965; Stauffer, 1968; Shu, 1969; Tjia, 1972; Raj, 1982) and numerous smaller faults have also been identified, particularly in areas underlain by granite. Faulting has generated a diverse variety of deformed granites and caused severe straining and grain size reduction of the quartz grains in the granite (Ng, 1994). Strained quartz and microcrystalline quartz are potentially reactive (Gogte, 1973; Kerrick and Hooton, 1992; Wigum, 1995). This paper assesses potential ASR of deformed granites using petrographic examination and the expansion test. This is part of a study on the petrographic, physical and mechanical properties of granite rock and granite aggregates in the Klang Valley and adjacent areas between the towns of Rawang and Seremban (Figure 1).

ALKALI SILICA REACTION

Alkali silica reaction (ASR) results from the reaction of disordered forms of silica minerals in aggregates and the hydroxyl ions (OH^-) in the pore fluid of concrete (Hobbs, 1990). The hydroxyl ions usually originate from the sodium and potassium alkalis in the Portland cement during hydration. The reaction produces a gel-like material that can be expansive when exposed to water. Expansion and cracking of concrete due to ASR requires the combination of 3 main conditions: a significant quantity of reactive silica; alkalis (sodium and potassium) available above a critical level in the pore structure of the concrete; and the presence of water or moisture from an external source. Other factors such as porosity of the concrete,

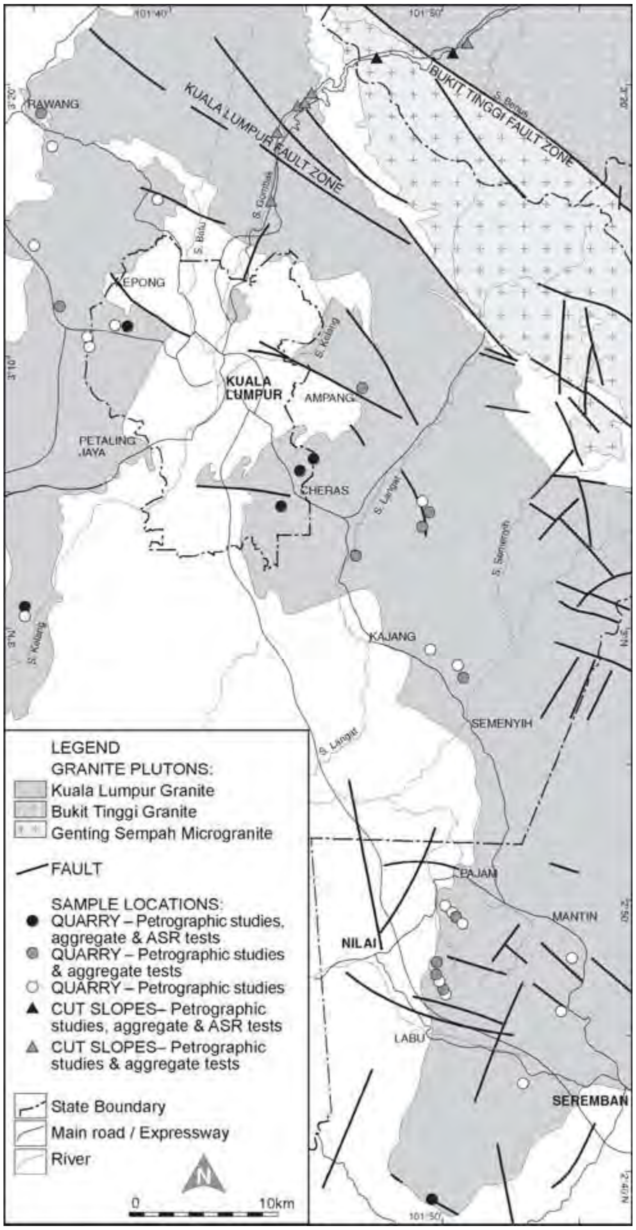

Figure 1. Simplified geological map of the study area showing the distribution of the granites and sample locations.

aggregate size, water-cement ratio, the presence of mineral admixtures and relative humidity of the environmental also have significant roles in influencing the expansion of the concrete (Hobbs and Gutteridge, 1979; Ferarris, 1995; Stark, 1995).

Reactive aggregates that cause deleterious expansion listed in decreasing order are: opal, chalcedony, volcanic glass, cristobalite, tridymite and cryptocrystalline quartz (McConnell *et al*., 1947; Gaskin *et al*., 1955). Strained and microcrystalline quartz which are potentially reactive are the main concern in this study.

DEFORMATION OF GRANITE

The study area is cut by the Bukit Tinggi Fault Zone and Kuala Lumpur Fault Zone (Figure 1), which are among the most prominent faults in Peninsular Malaysia. Faulting of the granites has given rise to a diverse assemblage of fault rocks including fault breccias, cataclasite and mylonite (Ng, 1994).

The Bukit Tinggi Fault has produced a zone of porphyroclastic mylonitic granite up to 4 km in width and is the only major zone of highly deformed granite in the study area. The other mylonitic granites observed in the field are mainly less than 1 m in width. The mylonitic granites are cohesive fault-rocks that have well developed foliation. In the mylonitic granite, the quartz and mica deformed plastically causing widespread polygonisation and dynamic recrystallisation. Feldspars often show brittle microstructures and plastic behaviour of feldspars occurs in some highly deformed mylonites.

Cataclastic granites occur in zones up to 10 m in width but are generally less than 3 m wide. The cataclastic granites are non-foliated cohesive fault-rock. They are mainly deformed in the brittle domain and microcracking is the dominant mechanism of deformation, affecting all the minerals in the granite (Ng, 1994). Minor polygonisation and recrystallisation are observed in the cataclastic granites.

Fault breccia observed in the granite is less than 3 m in width and it is usually bounded by sharp near planar fault. It consists of angular granite clasts ranging in size from a few mm to tens of cm, with subordinate fine gouge material as matrix. Most granite fault breccia are incohesive, uncemented and friable.

MATERIALS AND METHODS

About 150 *in-situ* rock samples were collected from 43 locations consisting of quarries and cut slopes (Figure 1). After preliminary examination of hand specimen and thin sections, 50 representative samples were selected for aggregate tests, of which 10 samples were tested for potential alkali silica reactivity. The 10 samples comprise three mylonitic granite (KL25 - slightly mylonitic, KL24 - moderately mylonitic, KL38 - highly mylonitic), three highly cataclastic granite (KL40, KL41, NL1), a fine to medium grained microgranite (KL37), a moderately cataclastic microgranite (KL22), and a granite with completely sericitised plagioclase (NL2). An undeformed granite with no reactive mineral (KL3) was also tested for comparative purposes (Figure 2). In addition to these, a fine grained rhyolite from Lanchang, Pahang that was reported to have deleterious expansion by Sazali Yaacob *et al*. (1994) was also tested for comparison.

For the preparation of aggregates, each sample consisted of 50 kg to 75 kg of rock blocks collected *in-situ*. Aggregates were prepared by crushing the rock blocks in a laboratory single toggle jaw crusher. The crushed aggregates were sieved to obtain the appropriate size fraction for laboratory tests.

Petrographic examination was carried out to determine the grain size, texture and mineralogy, particularly

Table 1: Summary of the petrographic properties of samples tested for alkali-silica reactivity. Note: Slightly: <10% affected, moderately: 10 - 35% affected, highly: 35 - 75% affected, extremely: >75% affected. P:plagioclase, K:alkali feldspar, B:biotite

Sample	Location	Colour	Grain Size	Texture	State of Weathering	State of Alteration	Deformation	Mafic Mineral	Petrological Name	Remarks/Pluton
KL3	Taman Segar, Cheras, Kuala Lumpur	Grey	Coarse Grained	Megacrystic, Allotriomorphic	Moderately discoloured	P- Moderately sericitised B- Extremely chloritised	None	Biotite	GRANITE	Kuala Lumpur Granite
NL2	Tanah Merah, Labu, Negeri Sembilan	Light Greenish Grey	Coarse Grained	Megacrystic, Hypiodiomorphic	Highly discoloured	P- Extremely sericitised, K- Slightly kaolinised, B- Extremely altered	None	Biotite, Muscovite	GRANITE	B- altered to chlorite, muscovite and iron oxide Kuala Lumpur Granite
KL24	Bukit Sg Besi, Kuala Lumpur	Yellowish Grey	Coarse Grained	Megacrystic, Mortar texture	Moderately discoloured	P- Moderately sericitised, B- Moderately chloritised	Moderately mylonitic	Biotite, Muscovite	GRANITE	B- also altered to muscovite Kuala Lumpur Granite
KL25	Bukit Sg Besi, Kuala Lumpur	Grey	Coarse Grained	Megacrystic, Mortar texture	Moderately discoloured	P- Moderately sericitised, B- Moderately chloritised	Slightly mylonitic	Biotite, Muscovite	GRANITE	B- also altered to muscovite Kuala Lumpur Granite
KL38	Karak Highway, km 45, Pahang	Dark Grey	Medium to Coarse Grained	Inequigranular (porphyroclastic), Weakly foliated	Slightly discoloured	B- Moderately chloritised	Highly mylonitic	Biotite	GRANITE	Bukit Tinggi Granite
KL40	Bukit Lanchong, Shah Alam, Selangor	Greenish Grey	Medium Grained	Fragmental texture	Highly discoloured	P- Moderately sericitised, B- Extremely chloritised	Highly cataclastic	Biotite, Muscovite	GRANITE	Kuala Lumpur Granite
KL41	Bukit Lanjan, Selangor	Grey to Greenish Grey	Medium Grained	Fragmental texture	Highly discoloured	P- Moderately sericitised, B- Extremely chloritised	Highly cataclastic	Biotite, Muscovite	GRANITE	Kuala Lumpur Granite
NL1	Tanah Merah, Labu, Negeri Sembilan	Greenish Grey	Fine to Medium Grained	Fragmental texture	Highly discoloured	P- Moderately sericitised	Highly cataclastic	Biotite, Muscovite	GRANITE	Kuala Lumpur Granite
KL37	Karak Highway, km 40, Pahang	Dark Grey	Fine to Medium Grained	Megacrystic	Slightly discoloured	P- Moderately sericitised, K- Slightly altered, B- Extremely chloritised	None	Biotite, Pyroxene	MICROGRANITE	Genting Sempah Microgranite
KL22	Taman Bukit Permai, Kuala Lumpur	Greenish Grey	Medium Grained	Fragmental texture	Highly discoloured	P- Highly sericitised, K- Slightly altered	Moderately cataclastic	Muscovite	MICROGRANITE	Kuala Lumpur Granite

potentially reactive minerals. The accelerated mortar bar expansion test was performed on samples following the method in ASTM C1260-94 (ASTM, 1994). This 16-day test adopted from procedures by Oberholster and Davies (1986) is an accelerated version of the original mortar-bar test (ASTM C227-90, ASTM, 1990) which requires at least 6 months to complete. Three bars (25 mm × 25 mm × 250 mm) were prepared for each sample. The proportion of the materials for the test mortar by mass was 1 part cement to 2.25 parts of graded aggregate to 0.47 part of water. Ordinary Portland cement supplied by Associated Pan Malaysian Cement (APMC) was used. The cement contained analysed alkali contents of K_2O: 0.73%, Na_2O: 0.11%, and alkali as Na_2O equivalent: 0.59%.

The mortar bars were demoulded after 24 hours, immersed in water in a sealed container and placed in an oven at 80 °C for 24 hours. The length of the mortar bars was measured using a comparator with a dial micrometer graduated to read 0.002 mm. The mortar bars were immersed in 1N NaOH at 80 °C in a sealed container and returned to the oven. Their length change was monitored after 2, 4, 7, 10 and 14 days. The average expansion of the three bars was calculated to the nearest 0.01%.

RESULTS

Petrographic characteristics

Petrographic examination is a useful and fast method for the identification of potentially deleterious minerals in the aggregates. The main mineral concerned in the granitic rock aggregates is strained and microcrystalline quartz. Strained quartz in this study refers to quartz with undulatory extinction angles larger than 15° and quartz with deformation bands and lamellae. The microcrystalline quartz is used here to refer to all fine grained (<60 µm) quartz including recrystallised quartz grains (neocrysts), fine quartz clasts produced by cataclasis, as well as quartz subgrains. In addition to the relative amount of strained and microcrystalline quartz, the microstructural features of the rock such as foliation may also have significant effect on the alkali-silica reactivity (Kerrick and Hooton, 1992). Although opal and chalcedony have been reported to infill fractures in granite (Yeap, 1992), they are rare and were not encountered in this study.

The petrographic characteristics of samples selected for ASR tests are summarised in Tables 1 to 3. The granitic rocks in the study area are commonly deformed. Indication of deformation such as undulatory extinction and microcrack in quartz and bending of micas are observed in many samples, including those with no sign of deformation when examined under the hand lens.

The moderately discoloured granite (sample KL3) contains a small amount (~2%) of strained and microcrystalline quartz. It is expected to be non reactive. Sample NL2 is highly discoloured and contains small amounts (~3%) of strained and microcrystalline quartz, as well as about 25% of completely sericitised plagioclase (Figure 3). Phyllosilicates are known to react with alkali (Gillott, 1975), thus potential expansion of sample NL2 cannot be ruled out.

The highly mylonitic granite (KL38) is foliated and contains about 15% of microcrystalline quartz and 5% of strained quartz. The moderately mylonitic granite (KL24) contains about 10% of microcrystalline quartz and 8% of strained quartz. The slightly mylonitic granite (KL25) contains about 5% of microcrystalline quartz and 10% of strained quartz. All the mylonitic granite aggregates are potentially alkali-silica reactive.

The cataclastic granites have higher total strained and microcrystalline quartz contents than the mylonitic granites

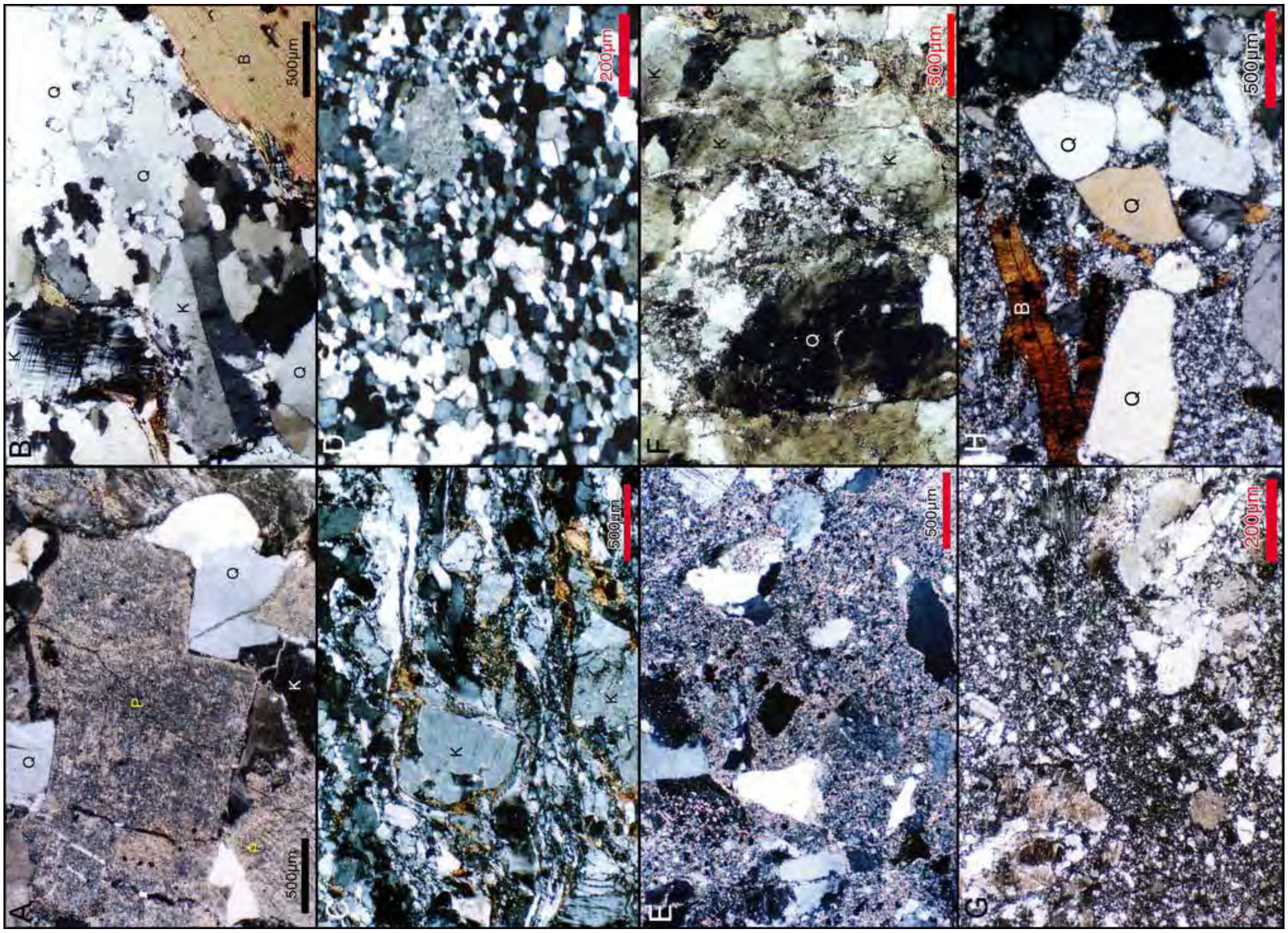

Figure 3: Caption in page 85.

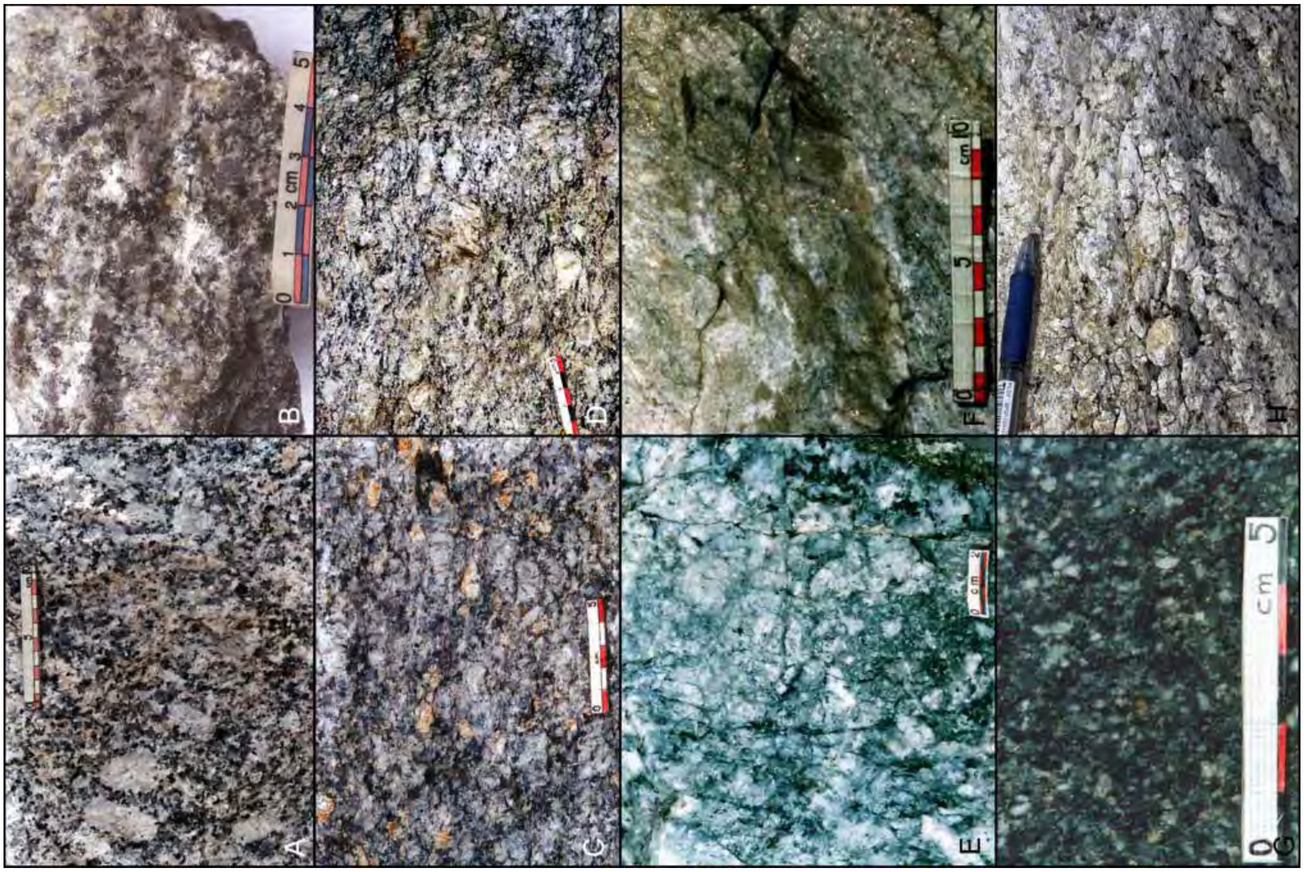

Figure 2: Caption in page 85.

(Table 2). The quartz grains in the highly cataclastic granite (KL40, KL41 & NL1) and moderately cataclastic microgranite (KL22) are fragmented into fine to very fine grained clasts (Figure 3). This grain size reduction increases the surface area of quartz available for reaction, and therefore enhances the alkali-silica reactivity. The cataclastic granite and microgranite aggregates are potentially reactive.

The slightly discoloured megacrystic biotite-pyroxene microgranite (KL37) has fine quartzo-feldsparthic groundmass (Figure 3). The fine grained quartz in the groundmass (~15%) is potentially reactive.

Accelerated mortar bar test

The expansion of the mortar-bars based on an average of three bars is plotted in Figure 4. According to the ASTM C-1260 (ASTM, 1994), expansions of less than 0.10% at 14 days under NaOH immersion are indicative of innocuous behaviour. Expansions of more than 0.20% at 16 days after casting are indicative of potentially deleterious expansion. Mortar bars with expansions between 0.10% and 0.20% have marginal behaviour that includes both innocuous and deleterious aggregates. According to Oberholster and Davies (1986), samples with expansion greater than 0.11% at 12 days is considered as deleterious.

The highest expansion is recorded in sample NL1, a highly cataclastic granite. This is the only granitic sample with expansion above the 0.20% limit at 14 days. Sample KL3 that is not deformed and non-reactive has the lowest expansion of 0.06%. Two other samples (KL25, KL41) have expansions less than the 0.10% limit. All the other samples have expansion between 0.10% and 0.20%.

The mylonitic granite aggregates, although predicted to be reactive from petrographic examination, have expansions ranging from 0.08% for a slightly mylonitic sample (KL25) to 0.13% for the moderately (KL24) and highly mylonitic (KL38) samples. The slightly mylonitic granite (KL25) appears to be innocuous. The moderately and highly mylonitic granites with higher microcrystalline quartz contents of between 10% and 15% have expansion values slightly above the 0.10% limit. Generally, the mylonitic granite aggregates can be regarded as having marginally deleterious expansion and should be used with precaution in concrete.

The highly cataclastic granite aggregates have varied expansion values ranging from being innocuous (0.09%, KL41) to marginally deleterious (0.14%, KL40) and deleterious (0.24%, NL1).

The moderately cataclastic microgranite sample (KL22) has a relatively high expansion of 0.19% at 14 days and about 0.16% at 12 days. It contains about 10% of microcrystalline quartz in the matrix and 15% of highly strained quartz. This sample is considered to have the potential to cause deleterious expansion. Sample KL37, a megacrystic microgranite with fine grained matrix rich in quartz has expansion of 0.17% at 14 days and about 0.15% at 12 days. It can be interpreted to be potentially reactive.

Figure 2: A) Sample KL3, a coarse grained biotite granite with no apparent deformation. B) Sample NL2, a coarse grained biotite granite with completely sericitised plagioclase. C) Sample KL24, a moderately mylonitic granite. D) Sample KL38, a highly mylonitic granite from the Bukit Tinggi Fault Zone. E) Sample NL1, a highly cataclastic granite. F) Sample KL22, a moderately cataclastic microgranite. G) Sample KL37, a fine to medium grained biotite-pyroxene microgranite. H) Fault breccia in biotite granite, Selayang.

Figure 3: Photomicrographs, crossed polars. A) Completely sericitised plagioclase in Sample NL2. B) Weakly deformed alkali feldspar (K) and quartz (Q) showing wavy extinction and recrystallisation at grain boundaries. Moderately mylonitic granite, Sample KL24. C) Alkali feldspar porphyroclasts (K) enclosed by matrix consisting of microcrystalline quartz and fine feldspar and mica. Sample KL38. D) Microcrystalline quartz in the matrix of Sample KL38 is consisting mainly of strain-free neocrysts. E) Sample KL40, a highly cataclastic granite with angular quartz and feldspar clasts in fine grained matrix. F) Sample KL22, a moderately cataclastic microgranite with highly strained quartz and microbrecciation of quartz along narrow zones of intense deformation. G) Sample NL1, a highly cataclastic granite where the rock is almost completely microbrecciated. H) Sample KL37, a microgranite showing quartz (Q) and biotite (B) phenocrysts in fine grained groundmass consisting mainly of quartz and feldspar.

Table 2. Mineral contents and amount of strained and microcrystalline quartz of samples tested for alkali-silica reactivity.

Sample	Quartz %	Alkali feldspar %	Plagio-clase %	Biotite %	Musco-vite %	Tour-maline %	Strained Quartz (%)	Micro-crystalline Quartz (%)
KL3	30.1	45.7	18.8	5.4	Trace	Trace	2	1
NL2	31.4	36.2	24.9	7.0	0.5	-	3	1
KL24	35.1	33.8	22.2	8.9	Tr	-	8	10
KL25	30.3	35.3	25.7	8.7	Tr	-	10	5
KL22	36.5	25.6	30.1	1.0	5.0	1.8	15	10
KL38	30.5	34.5	27.0	7.0	1.0	-	5	15
KL40	Not counted, consisting mainly of quartz, alkali feldspar and plagioclase. Minor biotite and muscovite						8	20
KL41	Not counted, consisting mainly of quartz, alkali feldspar and plagioclase. Minor biotite and muscovite						5	20
NL1	Not counted, consisting mainly of quartz, alkali feldspar and plagioclase. Minor biotite and muscovite						3	30
KL37	Not counted, consisting mainly of quartz, plagioclase and alkali feldspar. Minor biotite and pyroxene						3	15

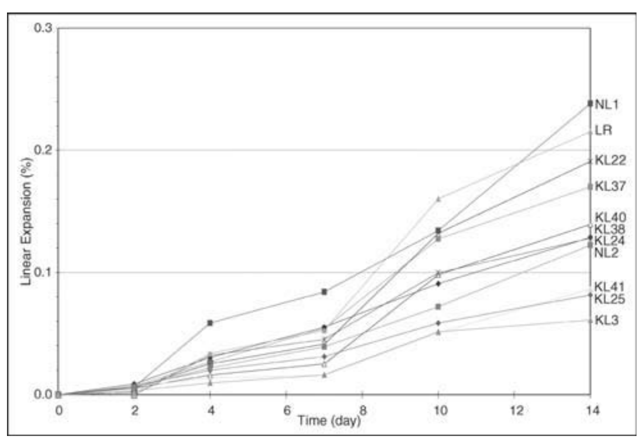

Figure 4: Results of the ASTM C1260 mortar-bar test. Linear expansion values are averaged from three bars, time is days of immersion in NaOH. Sample LR=Lanchang rhyolite.

The very fine grained rhyolite from Lanchang, Pahang shows expansion of 0.22%. The result is similar to that obtained by Sazali Yaacob *et al.* (1994).

DISCUSSION

Comparison between petrographic characteristics and mortar-bar test results

Aggregates of the non-deformed granite are interpreted to be innocuous, although sample NL2 has marginal expansion of 0.12%. The higher expansion in sample NL2 is probably caused by enhanced transport of alkali solution to the quartz by sericitisation. However, the reactivity of the fine sericite is not known and expansion due to alkali-phyllosilicate reaction cannot be ruled out.

Although the mylonitic granites contain up to 15% of microcrystalline quartz, the expansion is relatively low. This could be partly because the microcrystalline quartz comprising largely strain-free recrystallised quartz (neocrysts, Figure 3), which according to Grattan-Bellew (1992) is less reactive than quartz subgrains. The strained quartz appears to be less reactive than the microcrystalline quartz, as the increase on strained quartz content is not accompanied by increased expansion.

The quartz in the highly cataclastic granite sample NL1 is almost completely microbrecciated into fine microcrystalline quartz in the matrix (Figure 3). The abundance of microcrystalline quartz (about 30%) is the main cause for the potentially deleterious expansion. Sample KL40 has relatively coarser matrix and lower microcrystalline quartz contents (about 20%), therefore causing a lower but marginally deleterious expansion. The microcrystalline quartz in the matrix (about 20%) of sample KL41 do not form interconnected aggregates, but are separated by fine secondary sericite and chlorite. The relatively low and non-deleterious expansion in sample KL41 is probably caused by the scarcity of continuous network of microcrystalline quartz boundary, which impedes the ingress of alkali solution.

Table 3. Grain size of granitic rock samples.

Sample	Megacryst		Groundmass		
	Percentage	Range of grain diameter (mm)	Dominant Grain Size	Range of grain diameter	Mean volume diameter (mm)
KL3	15	15 - 25	coarse	20µm - 7mm	3.4
NL2	15	10 - 20	coarse	5µm - 8mm	2.4
KL24	25	15 - 30	coarse	20µm - 10mm	4.9
KL25	15	20 - 40	coarse	20µm - 12mm	5.2
KL38	25	15 - 25	medium-coarse	2µm - 5mm	1.8
KL40	Obliterated by deformation		medium	2µm - 5mm	0.6
KL41	Obliterated by deformation		medium	2µm - 6mm	0.7
NL1	Obliterated by deformation		fine-medium	2µm - 4mm	0.2
KL37	35	1 - 5	fine-medium	up to 0.5mm	Not determined
KL22			medium	2µm - 1mm	0.6

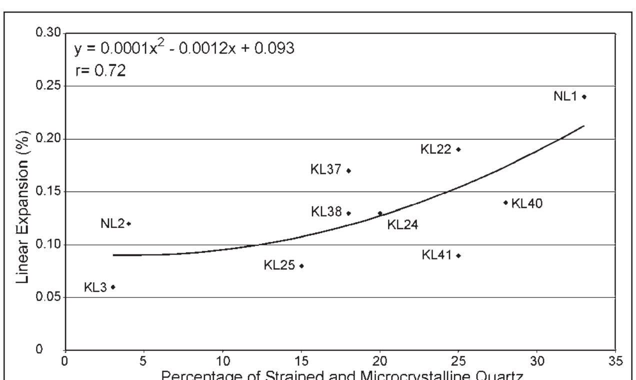

Figure 5. Plot of linear expansion of the mortar-bars against total strained and microcrystalline quartz content.

Relationship between strain and microcrystalline quartz contents and expansion

The total amount of strained and microcrystalline quartz of the samples is plotted against the linear expansion of the mortar bars in Figure 5. Although there is some scattering of data points, the relationship is statistically significant (r=0.72, p<0.001). The expansion increases with the increase in total strained and microcrystalline quartz contents. A 0.1% expansion corresponds to a strained and microcrystalline quartz content of 12% on the best fit curve and 0.2% expansion corresponds to about 32% of strained and microcrystalline quartz. These values can be used as a quick guide to assess potential ASR using petrographic examination. Deformed granites with over 12% of total strained and microcrystalline quartz are expected to have marginal to deleterious expansion and should be subjected to the accelerated mortar bar test to detect ASR.

The average quartz contents in the granite is about 30%, thus all the quartz in the granite needs to be strained or tranformed into microcrystalline quartz for them to be considered as deleterious based on the best fit curve. However, silicification can increase the quartz contents of the granite. Silification is common in cataclastic granites and is observed in samples NL1, KL22 and KL40.

Potentially deleterious granites in aggregate production

Potential deleterious deformed granites occur in quarries in the study area and due to widespread faulting, they probably exist in most granite quarries in the country. The presence of these potentially deleterious rocks is not likely to have a significant impact on the production of concrete aggregates. The potentially deleterious granitic rocks occur in narrow deformation zones. During the quarrying operation, these deformed granitic rocks will be mixed with the undeformed and innocuous rocks. The reactivity of the mixed aggregates will be reduced, as demonstrated by the expansion value of a mixed sample from the Tanah Merah, Negeri Sembilan. This mixture consisting of 20% of reactive aggregates (expansion

Table 4: The proportion of granitic rocks in the quarry produced aggregate in weight percentage.

Quarry Location	Granite, No Visible Deformation	Mylonitic & Cataclastic Granite	Weathered Granite	Microgranite, No Visible Deformation	Cataclastic Microgranite	Weathered Microgranite	Quartz vein
Nilai (1)	96.4	1.3	2.2	-	-	-	-
Nilai (2)	-	-	-	97.3	1.1	0.7	1.0
Nilai (3)	95.2	1.7	0.8	-	-	-	2.3
Tanah Merah	82.7	5.5	0.5	9.8	-	-	1.5
Ampang	80.1	0.7	0.3	17.9	-	0.1	0.9
Kajang	96.1	1.3	1.7	-	-	-	0.9

0.24%), 30% of aggregates with expansion of 0.12% and 50% of innocuous aggregates, produced aggregates with the expansion of 0.11%. Although the expansion is slightly more than the 0.10% threshold level, the proportion of deformed (potentially reactive) rocks in the quarries are generally much less than 20%.

Examination of aggregates produced by six quarries shows that the deformed rocks constitute less than 5.5%, and mainly less than 2% of the aggregates (Table 4). Nevertheless, it is important to map out significant zones of deformed granite in the quarries. A scenario may arise where rock is extracted from a narrow (a few m wide) fault zone that is parallel to the quarry face, producing aggregate with a significant proportion of deleterious deformed granite. In such a situation, the deformed granite should be used for the production of non-concrete aggregates (such as crusher run) or if to be used in concrete be sufficiently blended with innocuous aggregates.

A sample from the broad zone of the porphyroclastic mylonitic granite of the Bukit Tinggi Fault Zone shows marginally deleterious expansion. Quarrying for concrete aggregates within this mapable fault zone should be avoided unless innocuous behaviour is proven by mortar-bar test on a larger sample population. The same is applicable to the microgranites from the Genting Sempah Microgranite.

It should be noted that the physical, mechanical and durability tests show that the deformed granite aggregates are within the acceptance limits for concrete aggregate recommended by Public Works Department of Malaysia.

CONCLUSION

Faulting has generated a diverse variety of deformed granites in the Klang Valley and adjacent areas. Petrographic examination indicates that strained quartz and microcrystalline quartz are the main potentially deleterious mineral in deformed granites. Marginally deleterious to deleterious expansions are recorded in mortar-bar test. There is a significant relationship between total strained and microcrystalline contents and expansion values. Deformed granites with over 12% of total strained and microcrystalline quartz is expected to have marginal to deleterious expansion and this should be verified by accelerated mortar bar test. The deformed granites generally will not pose serious problems in the production of concrete aggregates as they constitute only a small proportion of the extracted rocks.

REFERENCES

ASTM (American Society for Testing Materials), 1990. *Standard test method for potential alkali reactivity of concrete aggregate combinations (mortar bar method)*. ASTM Designation C227-90. pp. 130-134.

ASTM (American Society for Testing Materials), 1994. *Standard test method for potential alkali reactivity of aggregates (mortar-bar method).* ASTM Designation C1260-94. 4 p.

Burton, C.K., 1965. Wrench faulting in Malaya. *J. Geology*, 73:781-798.

Chow, W.S. and Abdul Majit Sahat, 1990. Potential alkali-silica reactivity of tuffaceous rocks in the Pengerang area, Johor. *Bull. Geol. Soc. Malaysia*, 26:97-108.

Ferraris, C.F., 1995. Alkali-silica reaction and high performance concrete. National Institute of Standards and Technology, Report #5742, 20 p.

Gaskin, A.J., Jones, R.H. and Vivian, H.E., 1955. Studies in cement-aggregate reaction XXI. The reactivity of various forms of silica in relation to the expansion of mortar bars. *Australian J. Applied Science*, 6, p.78.

Gillott, J.E., 1975. Alkali-aggregate reactions in concrete. *Engineering Geol*., 9:303-326.

Gogte, B.S., 1973. An evaluation of some common Indian rocks with special reference to alkali-aggregate reactions. *Engineering Geol*., 7:135-153.

Grattan-Bellew, P.E., 1992. Microcrystalline quartz, undulatory extinction and the alkali-silica reaction. *Proc. 9th Int. Conf. Alkali-Aggregate Reaction in Concrete*. Concrete Soc. Publ. CS.104, Vol. I, London, pp. 383-394.

Hobbs, D.W., 1990. Alkali-silica reaction. In: Pike, D.C. (ed), *Standards for Aggregates*. Ellis Horwood, New York, pp. 91-108.

Hobbs, D.W. and Gutteridge, W.A., 1979. Particle size of aggregate and its influence upon the expansion caused by the alkali-silica reaction. *Magazine of Concrete Research*, 31 p. 235.

Kerrick D.M. and Hooton, R.D., 1992. ASR of concrete aggregate quarried from a fault zone: results and petrographic interpretation of accelerated mortar bar tests. *Cement and Concrete Res*., 22:949-960.

McConnell, D., Mielenz, R.C., Holland, W.Y. and Greene, K.T., 1947. Cement-aggregate reaction in concrete. *J. American Concrete Inst*. 44(2):93-128.

Ng, T.F., 1994. Microstructures of the deformed granites of eastern Kuala Lumpur — Implications for mechanisms and temperatures of deformation. *Bull. Geol. Soc. Malaysia*, 35:47-59.

Oberholster, R.E. and Davies, G., 1986. An accelerated method for testing the potential alkali reactivity of siliceous aggregates. *Cement and Concrete Res*., 16:181-189.

Raj, J.K., 1982. A reappraisal of the Bok-Bak fault zone. *Warta Geologi*, 8:35-41.

Razak, H.A. and Powzie, Z.A., 1989. Deterioration of concrete caused by alkali-silica reaction. *Proceeding of the Regional Conference on Concrete Engineering and Technology*, IV-89.

Shu, Y.K., 1969. Some NW trending faults in the Kuala Lumpur and other areas. *Newsletter, Geol. Soc. Malaysia*, 17:1-5.

Staton, D.E., 1940. The expansion of concrete through reaction between cement and aggregate. *Proc. American Soc. Civil Engineers*, Vol. 66, pp. 1781.

Stanton, T.E., Porter, O.J., Meder, L.C. and Nicol, A., 1942. Californian experience with the expansion of concrete through reaction between cement and aggregate. *American Concrete Institute Proceedings*, vol 30, p. 209.

Starks, D., 1995. Effects of water-cement ratio on expansion due to ASR. *Concrete Technology Today 1995*, p. 3-5.

Stauffer, P.H. 1968. The Kuala Lumpur fault zone : a proposed major strike-slip fault across Malaya. *Newsletter Geol. Soc. Malaysia* 15:2-4.

Tjia, H.D. 1972. Strike-slip faults in West Malaysia. *24th Int. Congr., Montreal 1972*, Section 3, pp. 255-262.

Wigum, B.J., 1995. Examination of microstructural features of Norwegian cataclasitic rocks and their use for predicting alkali-reactivity in concrete. *Engineering Geol*., 40:195-214.

Yeap, E.B., 1992. The mineralogical and petrological factors in the alkali-silica reactions in concrete. *Bull. Geol. Soc. Malaysia*, 31:1-15.

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