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GEOLOGICAL STUDY AND MINING PLAN IMPORTANCE FOR MITIGATING ALKALI SILICA REACTION IN AGGREGATE QUARRY OPERATION

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Graphical Abstract

Abstract

More than 80 million tonnes of construction aggregate are produced in Peninsular Malaysia. Majority of construction aggregate are produced from granite. Developing regions of Johor Bahru, Kuala Lumpur, Penang and Selangar utilize granite aggregates. Normally it is considered aggregates as non-alkali reactive. Geological study can identify various rock types, geological structures, and reactive minerals which contribute to Alkali Silica Reaction (ASR). Deformed granites formed through faulting results in reduction of quartz grain size. Microcrystalline quartz and phyllosilicates are found in granites in contact with country rocks. Secondary reactive minerals such as chalcedony and opal may be found in granite. Alkali Silica reaction is slow chemical reaction in concrete due to reactive silica minerals in aggregates, alkalis in cement and moisture. For long term durable concrete, it is essential to identify potential alkali silica reactive aggregates. Lack of identifying reactive aggregates may result spalling, cracking in concrete and ultimately ASR can result in hazard to concrete structure. This paper deals with geological study of any aggregate quarry to identify rock type and geological structures with laboratory test –petrographic analysis and bar mortar test can identify type of aggregates being produced. Mine plan with Surpac software can be developed for systematic working for aggregate quarry to meet construction aggregate demand.

Keywords: Alkali Silica Reaction (ASR); deformed granite; bar mortar test; petrographic analysis; geological study; mine plan

1.0 INTRODUCTION

Malaysia is moving ahead with a status of developed nation by 2020 from the present status of developing nation. Various socio economic activities are planned in various states of Malaysia such as Selangor, Perak, Sarawak, Terengganu, Johor, Negeri Sembilan. Construction sector is back bone of industrial and economic development which contributes for basic infrastructure in Malaysia. With growing annual income of Malaysian population, there is increased demand of housing in urban areas. Bulk building material requirement for concrete manufacturing consist of aggregates and sand which are low in value. Majority of construction aggregates are produced from granite. Developing regions of Johor Bahru, Kuala Lumpur, Penang and Selangar utilize granite aggregates. Alkali silica reaction is not considered common with granite. During 1988, Singapore Government banned the import of volcanic quarry stones from the Pengerang area from Johor which contained reactive minerals and found not suitable as concrete aggregates [1, 2]. Aggregates produced from various rock types such as tuff, rhyolite, hornfels, sandstone and quartzite were found to be reactive [3]. Kuala Lumpur fault zone is found in granite rocks in Bukit Legong area has caused deformation resulting alteration and mineralizations have produced alkali reactive minerals [4, 5]. The production of Aggregates in Malaysia is given in Table 1.

Table 1 Aggregates production in Malaysia [6]

STATE	2005	2006	2007
Johor	4.1	5.4	5
Kedah	3.6	3.2	2.8
Kelantan	1.9	2.4	2.6
Melaka	1.9	1.1	1.4
Negeri Sembilan	2.3	7.1	3.9
Pahang	3.1	3.2	3.1
Perak	10.8	11.6	14.1
Perlis	1.2	0.8	0.9
Pulau Pinang	4.6	3.8	3.2
Sabah	6.4	4.2	3.2
Sarawak	7.9	6.9	6.3
Selangor	12.3	25.5	25.3
Terengganu	2.7	4.5	5.7
Total	62.8	79.9	77.7

Note: All figures in million T

2.0 WHY ASR IS A CONCERN?

Alkali Silica reaction is slow chemical reaction in concrete due to reactive silica minerals in aggregates, alkalis in cement and moisture. For long term durable concrete, it is essential to identify potential alkali silica reactive aggregates. Deterioration process due to ASR is slow and catastrophic failure may not occur if periodic inspection is carried out and remedial measures are taken. Dimensional stability is important for bridges and the expansion can impact functioning of bridges due to ASR. In concrete pavements and transportation infrastructure, ASR can cause spalling of cracked sections. ASR can accelerate deterioration in concrete structures with other deterioration processes such as, sulphate attack from soils of concrete foundation, corrosion of reinforced concrete near sea or river or other water bodies. Moisture variation in tropical climate, additional alkalis from deicing salts, and traffic loading causing vibration in bridges along with ASR accelerates deleterious impact on concrete structures. Figure 1 shows acid attack on limestone aggregates and Map crack due to AAR at the abutment of Tamparuli Bridge [7]. Presence of moisture and hydraulics are main problems for bridges in Malaysia. In the past, the bridges that had collapsed due to hydraulics are Sg Buloh, Selangor (1988); Tanjong Laboh, Muar (1993); Gurun, Kedah (1995); Muar, Johor (1996); Sg. Batang Busu, Gombak (1998).

Figure 1 Problems to bridge components (a) Acid attack on limestone aggregates (b) Map Crack due to AAR at the abutment of Tamparuli Bridge [7]

3.0 CURRENT UNDERSTANDING OF ASR

Concrete damage due to ASR was recognized during 1940 in North America [8, 9]. Various researchers have carried out studies related to ASR over last 75 years in many countries [10, 11]. Quartz a mineral having amorphous silica having unstable structure is attacked easily by alkaline cement paste as compared to crystallized silica having stable structure [12, 13]. Portlandite or Ca ions are required for formation of ASR gel [14 - 20]. There are various factors which result in swelling of ASR gel and map like cracks further deteriorates concrete [7, 21, 22]. In primarily alkali susceptible rocks such as opal, rhyolite, chert, schist, granite and gneiss with tectonic distortion, ASR gel develops cracks with natural cleavages of each rock type [23]. Essential components of ASR are sufficient moisture, sufficient reactive silica and sufficient alkalis [22, 24 – 31]. There are external sources of alkalis such as Supplementary Cementitious materials having higher alkalis, high alkali cement, potassium acetate or sea water can adversely affect ASR [32-35]. Rock deformation is observed with increase in depth [36]. Potential reactive rocks contain cryptocrystalline and strained quartz [37–39].

4.0 OVERVIEW OF GEOLOGICAL STUDIES OF PENINSULAR MALAYSIA

Peninsular Malaysia can be subdivided into four major tectonic regions –western, main range, central and eastern belt [40-43]. The granites of main range belt are uplifted and country rock is isoclinally folded. The alkali feldspar is microcline in nature. The granites of eastern belt are equiangular to weakly porphyritic texture. Alkali feldspar is intermediate microcline. The granites of western belt (Langkawi) contain intermediate microcline and have pronounced contact with metamorphic rock. Granites in central belt are complex as metamorphic rocks have been uplifted. Benton granite of this belt has high-level characteristics with fine grained granetoid rocks. Peninsular Malaysia consists of several inactive major faults such as Bukit Tinggi Fault, Bok Bak Fault, Kuala Lumpur Fault, Lebir Fault, Lepar Fault, and Mersing Fault [44]. Various smaller local faults exist in underlying granite areas. Deformed granites are generated due to these major regional as well as local faults. Deformed granites has resulted severe straining and grain size reduction of the granites [45]. 150 in-situ rock samples were collected from Selangor, Negeri Sembilan, Pahang and Kuala Lumpur area for assessing potential reactivity of granite [46]. Microscopic examination of rock samples from 0.5 to 1 m thick fault zone of Bukit Tinggi at Kuala Lumpur showed strained microstructures and brittle ductile deformation. The cataclastic granite which is deformed in the brittle regime and occurs in fault zone consisting of few metres where microbrecciation is the main cause of grain size reduction. Samples of cataclastic granite from 2 m wide fault zone in Perkuat Quarry showed greenish grey, medium grained, highly discoloured and moderately altered microgranite. Results of physical and mechanical tests of undeformed and deformed granites showed no significant difference. Petrographic evidence of Malaysian rock aggregates showed that alkali silica minerals are chalcedonic (sepherulitic) quartz in volcanic tuff, chert clasts in sandstone, strained quartz in quartzite and microcrystallined and cryptocrystallined quartz in hornfels [3]. Volcanic Tuffs of Pengerang area of Johor are found Alkali Silica Reactive which is deleterious to concrete [47]. Reactive minerals found in volcanic tuff are chalcedony and strained quartz, crypto to microcrystalline quartz and tridymite. Strained quartz and microcrystalline quartz are the main potentially deleterious minerals in deformed granites found in fault one [47]. The granitic rocks in Bukit Lagong area are cut by Kuala Lumpur fault zone and several other faults. Potentially alkali reactive minerals are produced due to deformation caused by faulting and associated alteration and mineralization [49]. Microcrystalline quartz and phyllosilicates are found in granites in contact with country rocks. Secondary reactive minerals such as chalcedony and opal may be found in granite. Faulting exist in most granite quarries in Malaysia [50 - 52].

5.0 MINE PLANNING OVERVIEW

In advanced countries like US, UK, Australia and Canada, mine planning is required for government agencies for obtaining license, extension of lease [53]. This mine plan is for 5 years including conceptual plan, environment management plan. Guidelines for preparation of mining plan by Indian Bureau of Mines [54]. Mining plans for each mine is prepared by experienced mining professionals with the guidelines provided by IBM. Mining Plan consists of 2 volumes – Volume I Text and Volume II Drawings.

Volume I consists of chapters on general information of mine, location and access to mine, geology, mining, mineral processing and environment management plan. Volume II consists of various drawings. Various drawings with brief description are shown in Table 2.

Table 2 A list of drawings for mine plan [54]

Name of drawing	Scale	Brief description
Location Plan	suitable	Location of mine with surrounding area
Lease Plan	suitable	Approved lease area with co-ordinates
Surface Plan	1:2,000	Topographic features, infrastructure with latest mine face
Geological Plan	1:2000	Geology of mine, geological features – faults, dykes etc, location of bore holes, dip and strike
Geological section	1:2000	Every 100 m along strike and longitudinal section showing geology of ore body , bore holes etc
Yearly production and development plan	1:2000	Advancement of mine face during the year from 1st to 5th year showing roads, benches, drainage system,
Yearly production and development sections	1:2000	Corresponding sections of yearly production and development plan
Conceptual Plan	1:5000	
Environment Management Plan	1:5000	To meet long term goals of EMP

Benefits from practice of mining plan:

i. Systematic working of mines with conservation of minerals.
ii. The document is also useful for mine management for production planning, preparation of yearly budget based on yearly production and overburden to be removed based on mine plan.
iii. Design of roads, benches take into account safety parameters.
iv. Quarry operation team can prepare short term plan of monthly/ quarterly plans and practice the same for implementation.
v. Various constraints such as stacking of overburden, design of roads based on ultimate pit limit.
vi. Mine plan also becomes integrated document with other planning such as environment management plan, CAPEX for mobile equipment etc.
vii. Some of the buyers ask mine plan from where mineral supply plan during the year. Mine plan becomes valuable document from marketing of minerals.

6.0 GEOLOGICAL STUDY IN AGGREGATE QUARRIES

Geological study of any aggregate quarry is basic input for preparation of mine plan [54, 57-59]. Geological study is important during feasibility stage and operation of any aggregate quarry. Geological study may be carried during different stages of aggregate quarry and objectives are given in Table 3.

6.1 Geological Exploration

Geological exploration is required to establish area and thickness of granite deposit [55]. Core hole drilling is carried out in predetermined location. Different rocks are identified based on borehole logs. Weathered rock, joints, fault zones are identified based on borehole logs at an early stage of mining. Geological reserves based on borehole logs which are important to decide rate of production and to carry out mine planning. Certain test such as petrographic examination of different rocks can identify potential alkali silica reactivity at an early stage of aggregate quarry.

Table 3 Type of Geological Study with objectives [55-63]

Type of geological study	Aggregate Quarry Stage	Objective
Geological Exploration	Feasibility stage Every five to ten years	Aggregate reserves estimate; physical and mechanical properties of rock types; identify potential alkali silica reactivity
Geological Mapping	Feasibility stage Every five to ten years	Mapping different rock types; geological structures such as faults, dykes, folds; identify potential alkali silica reactivity
Geo hazard	After 5 years , every alternate year	Identification of hazards created due to geological conditions
Mine Planning	Feasibility stage and every five years	Preparation of 3D Model and systematic mine planning to meet market demand
Physical and Mechanical Test	Need based	With every test different objectives are met
ASR Test	Every year	To identify ASR of ongoing production

6.2 Geological Mapping

For planning geological exploration, geological mapping is essential to locate bore holes. Geological mapping also provides extent of aggregate deposit from surface mapping [55]. With advancement of technology, Unmanned Aerial Vehicle (UAV) can be used for preparation of topographic map and geological map [52]. Agrisoft software can convert Aerial Photographs into Digitized Terrain Model (DTM). Figures 2 and 3 provide photographs of Unmanned Aerial Vehicle (UAV) and UAV while taking aerial photographs in granite quarry. Different rock types and geological structures such as faults, dykes, folds found in the field are identified. By carrying out ASR test, field data can be correlated to identify potential alkali silica reactivity of different rock types.

Figure 2 Unmanned Aerial Vehicle (UAV) with Canon camera and remote control [52]

Figure 3 Unmanned Aerial Vehicle taking aerial photographs in granite quarry [52]

6.3 Geohazard Study

Aggregate quarries are mined with high benches of 15 m in Malaysia. There always exists danger of rock fall to personnel working in quarry [56]. This danger is increased due to tropical climate in Malaysia. With this study, stability of different benches, hazardous areas are identified based on geological observation. Operating personnel are provided training to carry out periodic inspection and maintain record. Appropriate measures are suggested against geohazard identified in the field. Geohazard study at Kintag Valley revealed that out of 7 hills, 3 hills slopes are weak and balance 4 hills have moderate slopes with unfavourable joint orientation. Rockfall may be triggered off in cliff area due to blasting vibration, movement of machinery or rainfall [56].

6.4 Mine Planning

Short, medium and long term mine plan is prepared using software such as Surpac. 3 D Model and ultimate pit in graphical form provides good visualization [57-59]. Exploration data based on borehole logs, topographic survey are basic inputs for preparation of mining plan. Figure 4 shows existing aggregate quarry in Malaysia [52].

Figure 4 Bird's eye view of existing Aggregate Quarry in Malaysia [52]

Figure 5 shows ultimate pit planning of an aggregate quarry at the end of its life. Figure 6 shows post mining planning as converted into water reservoir.

Figure 5 Ultimate pit planning of Aggregate Quarry [82]

Figure 6 Post mining Aggregate Quarry Planning[82]

6.5 Physical and Mechanical Test

Following are common physical and mechanical test carried out on aggregates:

Flakiness index, elongation index, aggregate impact value, aggregate crushing value, Los Angeles abrasion value, aggregate crushing value, $MgSO_4$ soundness value, water adsorption, dry relative density, saturated relative density, apparent relative density, mean grain size.

Physical and mechanical test of aggregates produced from recycled concrete, palm oil kernel and laterite were carried out [62, 64-66].

6.6 Test for Identifying Potential Alkali Silica Reactivity of Aggregates

The first step to mitigate ASR is identifying reactive aggregates by suitable test methods. Chemical test ASTM C289 standard states that one more type of test to be carried out for confirming alkali silica reactivity [69]. Various researchers have reported that this test is not reliable for confirming alkali silica reactivity [74-76]. Petrographic examination ASTM C289 identifies minerals which are potential alkali silica reactive [45-52]. As bar mortar tests are similar to concrete being used, various types bar mortar tests were developed. ASTM C227 bar mortar test takes longer duration of 3 to 6 months and may not detect slowly reactive rocks [77-78]. Accelerated bar mortar test ASTM C1260 is accepted by many researchers due to short duration of test of 14 days [79-82]. Prism mortar test ASTM C1293 takes long duration of 1 year [72]. Petrographic examination ASTM C295 followed by ASTM C 1260 can detect alkali silica reactivity easily [52].

Thus following are common methods to identify potential Alkali Silica Reactivity of Aggregates:

- Chemical test ASTM C289
- Petrographic examination ASTM C295
- Accelerated Bar Mortar Test ASTM C1260

7.0 CONCLUSION

Aggregates from granite are generally used for manufacturing concrete in construction industry in Malaysia. Granite is generally considered nonreactive. However, various studies carried out in Malaysia has revealed that there exist major faults such as Bukit Tinggi Fault, Bok Bak Fault, Kuala Lumpur Fault, Lebir Fault, Lepar Fault, and Mersing Fault. Various underlying local faults exist in granite where aggregates are produced. Faults create deformed granite resulting in strained quartz and microcrystalline quartz which are potentially reactive. Petrographic evidence showed that alkali silica minerals are chalcedonic (sepherulitic) quartz in volcanic tuff, chert clasts in sandstone, strained quartz in quartzite and microcrystalline and cryptocrystalline quartz in hornfels. ASR is concern for manufacturing concrete due to reactive aggregates. Each quarry is unique with geological formation and geological setting. Geological study needs to be carried out for each quarry to identify potential alkali silica reactivity of different rock types. Mine planning will support geological findings for systematic mining and eliminate areas for mining where there exist potential alkali silica reactive rocks for concrete aggregates

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