

## INVESTIGATION OF POTENTIAL ALKALI-SILICA REACTIVITY OF AGGREGATE SOURCES IN THAILAND

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**ABSTRACT:** Since the first local evidence of alkali-silica reaction (ASR) was reported in Thailand in 2011, awareness of ASR was raised and the importance of aggregate performance database was recognized, thus an attempt to set up local aggregate database was initiated. As part of the effort to establish the database, a study of potential ASR reactivities was carried out involving aggregates from several current industrial sources in eastern and central Thailand and the results were presented here. Aggregate samples were randomly collected from various sources and tested by two methods; accelerated mortar-bar test (AMBT) and petrographic examination. The types of aggregate sampled included limestone, greywacke, and rhyolitic tuff. The AMBT expansion results indicated that several aggregate types had larger expansion than the threshold of potentially deleterious ASR behavior as suggested by ASTM C 1260 standard. Furthermore, it was found that samples of same aggregate type, although apparently had mineralogically similar compositions, had different reactivities, particularly when sampled from around geological fault zone compared with that taken from the surrounding area and portions of parent rock were observed to be weathered in this area. Thin section analysis revealed evidence of ASR gel at the aggregates' rim, inside the aggregates and in the matrix. These findings suggest possible future ASR problems in Thailand as well as in neighboring countries where the continuity of geology pattern is observed.

*Keywords: Aggregate Database, Alkali Silica Reaction (ASR), Expansion, Petrographic Analysis, Thin Section*

### 1. INTRODUCTION

The first evidence of alkali-silica reaction (ASR) in Thailand was found in one large infrastructure in 2009 and reported by Sujjavanich et al. in 2011 [1]. The confirmed problematic rocks were black quartzite with traces of pyrite, mica and sericite. Some of these rocks were confirmed as slow late reactive types [2]. Therefore, the awareness of ASR was raised and the importance of aggregate's performance database was recognized as a basis for achieving a better understanding of the reactivity of local materials and the consequent activities to cope the future problems including mitigation, both for research and construction practice. Thus an attempt to set up local aggregate database was initiated. As one part of the ongoing effort to establish the database, a study of potential ASR reactivities was carried out involving aggregates from several current industrial sources in eastern and central Thailand.

Thailand is situated on two adjacent terranes, the Shan-Thai and the Indochina terranes. The Shan-Thai terrane covers the east of part of Myanmar, the west, north, central and southern

parts of Thailand with rocks dating back to the Precambrian eon. The Indochina terrane covers the northeastern and eastern parts of Thailand as well as Cambodia and the majority of Laos and Vietnam landmasses with rocks dating back to Paleozoic era. The suture joining the two run down north – south direction giving rise to the Loei-Petchabun mountain ranges that stretches from Thailand's northern border with Laos in Loei province down along the Petchabun fold belt bordering the rim of the Khorat plateau to the east and the central plain to the west. Evidence of ancient volcanic activities can be found along the Petchabun fold belt and igneous rocks such as granite, granodiorite, diorite, monzonite, rhyolitic tuff, andesite, and tuff. The suture runs further down through the eastern region of the country and extends to the upper part of the Gulf of Thailand.

This study investigated aggregates from working industrial mining operation from the central and eastern region of Thailand. These two regions of interest in Thailand have significant differences in landforms. The eastern region is bordered by the Gulf of Thailand to the south and southwest, the southern part of Loei-

Petchabun mountain ranges to the northwest and the rim of the Khorat plateau to the north. The area includes undulating coastal plains between the sea and the mountains covering the provinces of Chonburi, Rayong, Chantaburi and Trat. The landform in this region is highly discontinued with evidence of some geologic activities thus rocks with high degree of alteration were not uncommon in these areas. Granite can be found in three separate areas, in Chonburi, Rayong, and Chantaburi, and rhyolite can be found in the extreme east of the region close to the border with Cambodia. High-grade metamorphic rocks with important rock-forming minerals such as quartz, biotite and feldspar can also be found in Chantaburi and Trat provinces. Various sedimentary rocks are found in this region such as quartzite, shale, chert, and limestone found along Chonburi's coastline. Limestone, shale and greywacke are also found in Chantaburi and Trat provinces. Moreover, because of the suture running through this area and activities of various local faults, the characteristics of rocks found in this area are quite complicated. Some rocks have undergone metamorphism, others have undergone alteration, and the effect can be very localized. History of geological landform and time strongly influence the changes of some of these to low-grade metamorphic rocks [3]. The dominant characteristics of discontinued landform explain the variations of type of rock, which are the sources of industrial aggregates in these areas.

The central region of Thailand consists of fluvial flood plain bordering highlands and mountainous regions to the north and west, flanked by the Loei-Petchabun mountain ranges to the east and extending south to the Gulf of Thailand. The country's major rivers flow through this region depositing sediment from the highlands. Coastal deposit is found in the lower third of the region. The upper central plain region consists of Utradit, Sukhothai, Pitsanulok, Pichit, and Kampanget provinces and northern part of Nakhonsawan province. These provinces lie in the confluence of the major rivers that join together further south in Nakhonsawan province to form Chao Phraya river which forms the border of upper and lower central plains. The lower central plain begins in the southern part of Nakhonsawan province and continues south until the mouth of the Chao Phraya river on the gulf of Thailand. There are isolated rock formations scattered around the region with formations of plutonic rocks such as granite, granodiorite and diorite in the south and southwest of Nakhonsawan and formations of volcanic rocks such as rhyolite, andesite, and dacite in the east of the region as forming part of the Saraburi group of Permian rock formations [4]. In Saraburi area, there are six known formations

with mixed carbonate and clastic sequence of outcrops, especially on the most eastern area bordering the western rim of the Khorat plateau [5]. This area is also the source of good quality limestone used in construction industry and cement industry. Gray shale and siltstone with minor or major of sandstone and limestone are found in some formations while others may be characterized by limestone with interbedding with dolomitic limestone, shale, sandstone and tuffaceous sandstone including rhyolite dikes and chert nodules. In addition to the good quality limestone, which typically has been used for construction in the past, it is of interest that the diversity of landform and geological nature indicates various natural rock types in these two areas and these have been utilized as natural resources for construction and other industries. Some of them have been widely reported as potentially reactive aggregates [6]. The variations of these geological parent rocks have strong impact on the local industrial aggregates, which is the main component of concrete, and the chemical deterioration of concrete structure may be a consequence if the potential risk of reactivity of the rock is not properly assessed.

All of the aggregate mines are either privately owned or have been granted long-term government mining concessions and most of them are used for concrete production. Since no concrete deterioration problems as a result of reactive aggregates had previously been reported, it was not uncommon that there was a lack of local information concerning the aggregates except the conventional geology classification. Therefore this paper reports the results of an investigation of the industrial aggregates in term of both geological and chemical durability in engineering aspects. This is expected to provide information and insight into potential risk of chemical deterioration in future concrete structures in Thailand and neighboring countries.

## **2. MATERIALS AND METHODS**

### **2.1 Materials**

Three common rock types used as aggregates in Thailand were selected for this study, namely, rhyolitic tuff (RYSR) from the central region, limestone (LSCB) and greywacke from the eastern region. The greywacke aggregates were from two different sources approximately 100 km apart, one in Chantaburi province (GWCT), and the other in Trat province with two samples taken from this quarry (GRA and REA)

The three rock types were picked because of their differences. While the major mineral

compositions of limestone, a non-clastic sedimentary rock, are calcite and aragonite which are only different crystallographic forms of calcium carbonate ( $\text{CaCO}_3$ ), on the other hand, greywacke, a clastic sedimentary rock, is a result of sedimentation and lithification of mainly sandstone and other small rock fragments, angular quartz grains, feldspar crystals in a matrix of fine clay, whereas, rhyolite, a felsic volcanic rock is an igneous rock rich in silica.

These three different rock types were investigated in details for microstructure, mineral and chemical compositions as well as expansion in the accelerated mortar bars.

Type I Portland cement, according to ASTM C150-07 [7], with  $\text{Na}_2\text{O}_{\text{equiv.}}$  of 0.409 % was used for this study.

Table 1 Chemical composition of materials used in this study

	$\text{SiO}_2$	$\text{Al}_2\text{O}_3$	$\text{Fe}_2\text{O}_3$	CaO	MgO	$\text{SO}_3$	$\text{Na}_2\text{O}$	$\text{K}_2\text{O}$	LOI
GRA	58.22	13.93	6.11	6.96	2.53	0.24	3.08	1.32	6.77
REA	56.48	18.64	5.29	3.21	1.9	0.38	1.15	3.39	8.36
GWCT	57.63	15.33	7.37	5.52	3.19	0.24	2.97	1.41	5.31
RYSR	56.49	17.39	6.51	8.55	3.02	0.04	2.69	4.03	na
LSCB	34.24	7.99	4.53	25.94	2.25	1.92	0.42	2.47	19.34
Cement	18.74	5.22	3.2	65.3	0.82	2.8	0.08	0.5	2.75

## 2.2 Methods

To investigate the potential alkali-silica reactivity of the various aggregate types, samples of aggregates were taken from different sources in many parts of the country and were tested by laboratory methods, namely, petrographic examination and accelerated mortar-bar test (AMBT).

Thin section petrography was carried out using Olympus BX-41 imaging petrographic microscope equipped with plane and cross polarization illumination mode. The petrographic analysis was used to study the microstructure of the aggregates, to identify the constituent minerals and to classify the aggregates. The chemical compositions were analyzed with X-ray Fluorescence spectroscopy (XRF) and X-ray diffraction spectroscopy (XRD).

Accelerated mortar-bar test (AMBT) was used to measure expansion due to alkali silica reactivity of the aggregates and was carried out according to

ASTM C 1260 [8] standard testing procedure.

## 3. RESULTS AND DISCUSSION

### 3.1 Microstructural Analysis

The XRF results of all the aggregates are shown in Table 1. The investigation showed the major compositions of all studied aggregates. All the greywacke samples even though came from two different sources (GRA and REA from one, GWCT from the other) had very similar composition with amounts of major oxides falling in the same ranges (such as  $\text{SiO}_2$  56-58%,  $\text{Al}_2\text{O}_3$  13-18% and  $\text{Fe}_2\text{O}_3$  5-7%, CaO 5-7%, MgO 1.9-3.2%). However, the petrographic analysis and XRD analysis were performed on the same specimens and the results showed significant

difference, especially the microstructure of GRA and REA observed in thin-section petrographic analysis. GRA aggregates, which were collected from the same mine as REA but from the general areas of mine was coarse-grain greywacke. The microstructure of GRA is shown in Fig. 1 (a) composing of quartz, feldspar, and rock fragments. This was similar to the microstructure of GWCT aggregates that were collected from the other quarry. However, the REA samples, Fig. 1 (b), were collected from the same quarry as GRA but from the shear zone showed fine-grained matrix of subgrained quartz and rock fragments of clay/graphite and high-weathering chlorite, deformed by tectonic forces. The mineralogical compositions were confirmed by XRD analysis. Quantitative XRD analysis showed high content of muscovite and low content of albite found in REA, 31.9% and 7.1% respectively, which was opposite of what was found in GRA where low amount of

muscovite and high amount of albite was found,

anhedral crystals of opaque minerals and calcite

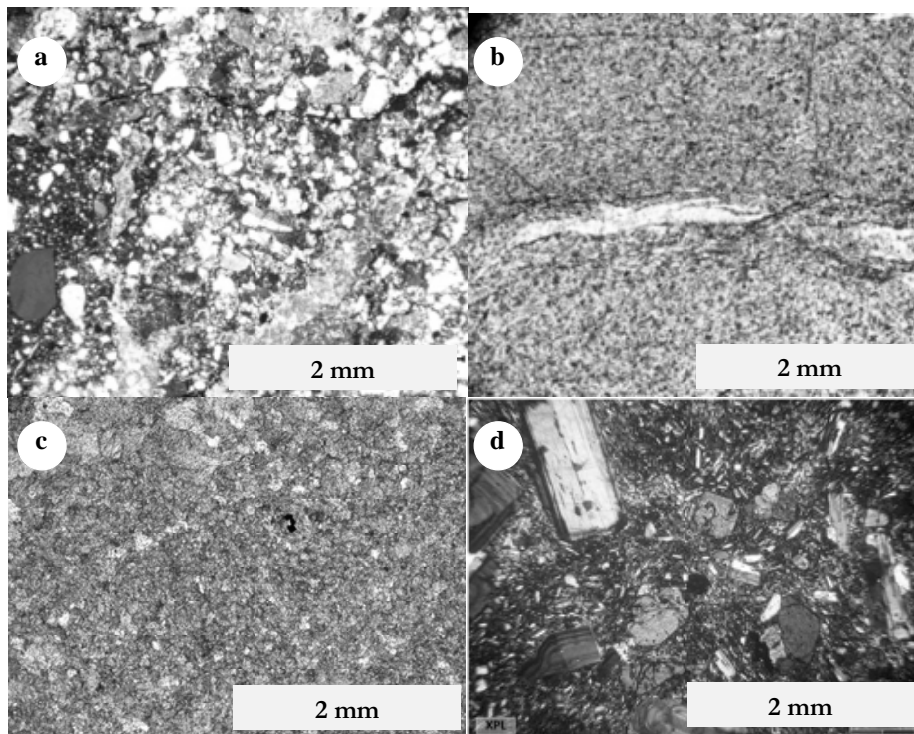


Fig.1 Thin section microscopy of different aggregates studied (a) greywacke (GRA), (b) greywacke (REA), (c) limestone (LSCB), and (d) rhyolitic tuff (RYSR)

13.1% and 32.1% respectively. Another striking difference was the difference in granularity of crystals in REA and GRA. REA consisted of small grains of quartz and rock fragments instead of big grains such as those found in GRA. The microstructure of REA consisted of deformation-induced subgrained quartz particles to become microcrystalline/cryptocrystalline matrix mixed with 30% clay/graphite matrix as shown in Fig. 1 (b). This may explain the highest ASR reactivity in this aggregate group and the proposed classification as “very likely to be alkali-reactive”. Compared to those of greywacke, the chemical compositions of rhyolitic tuff appeared to fall in the same ranges, only a slightly high oxide content of calcium and magnesium and low  $SO_3$  were observed. Slight weathering was observed in hand specimen and from the microstructure analysis. The mineral compositions of the very fine-grained, massive and slightly weathered pale green-gray colored sample was tested using XRD analysis and was found to consist of albite, quartz, calcite, chlorite, K-feldspar and illite. The mineral compositions content from modal analysis indicated subhedral crystals of plagioclase and pyroxene of about 70% and 10% respectively. The

were 10% and 5% as well as small amount of olivine, chlorite and epidote of about 1-2% as minor minerals. The average phenocrysts consisted of 0.05-3mm in size and most plagioclase showed zonal texture and lath shape. Some glassy phases were also observed, which, together with microcrystalline and cryptocrystalline quartz present, may account for its reactivity. Other authors also found this rock type to be a reactive aggregate in many countries [2,6].

The non-clastic and stylolitic sedimentary rock, limestone, from the eastern province of Chonburi was slightly high in silica (34.24%) but moderate in CaO (25.94%) with relatively high LOI (19.24%). Because of the high silica content, this aggregate can be classified as siliceous limestone and other authors found this rock type to be reactive [9]. The mineral grain size of the light gray colored sample ranges of 0.1-2 mm, while modal analysis showed major minerals to be calcite, clay, and microcrystalline quartz with some calcite veinlet and quartz veinlet. Opaque minerals, possibly pyrite, were also found in the thin section, which would account for its high LOI. No weathering but fracturing was more commonly observed.

### 3.2 AMBT Results

The results of the AMBT expansion tests of all the studied aggregates, limestone, greywacke and rhyolitic tuff, are shown in Fig. 2. The average expansion of each aggregates were higher than the suggested limit of 0.2% at 14 days exposure to sodium hydroxide solution (except rhyolitic tuff which was slightly less), which indicated that all three rock types were potentially reactive aggregates. The deformation induced subgrained greywacke (REA), showed the highest expansion and rhyolitic tuff the lowest. The comparison between the average expansion of greywacke with different granularity from different location of the same mine (REA and GRA) and the average expansion of similar aggregate type from different mine (GWCT) were also demonstrated in Fig. 2. These agreed well with the petrographic analysis. The effect of deformation-induced subgraining resulted in REA yielded the highest expansion than those of aggregates from typical area (GRA) and from other mine (GWCT). It was clear that mineralogical and the past history of the studied three types of aggregates were strongly influenced their reactivities of these materials, not the chemical compositions.

behavior as suggested by ASTM C1260 standard. Furthermore, samples of the same aggregate type, although with mineralogically similar compositions, had different reactivities, particularly when sampled from around geological fault zone compared with that taken from the surrounding area. Portions of parent rocks in this area were observed to be weathered. In addition, thin section analysis of concrete prisms made from REA and GRA from previous study [10] revealed evidence of ASR gel at the aggregates' rim, inside the aggregates and in the matrix. In light of these findings, it suggests possible future ASR problems in Thailand as well as in neighboring countries where the continuity of geology pattern from Thailand or similar are observed.

### 3.3 The ASR Risk In Thailand And South East Asia

The hot and humid weather in Thailand is typical for this region. This may create high risk of ASR in the future if the potentially reactive aggregates from some sources are used, in combination with some specific conditions such as high humidity environment. This is also important

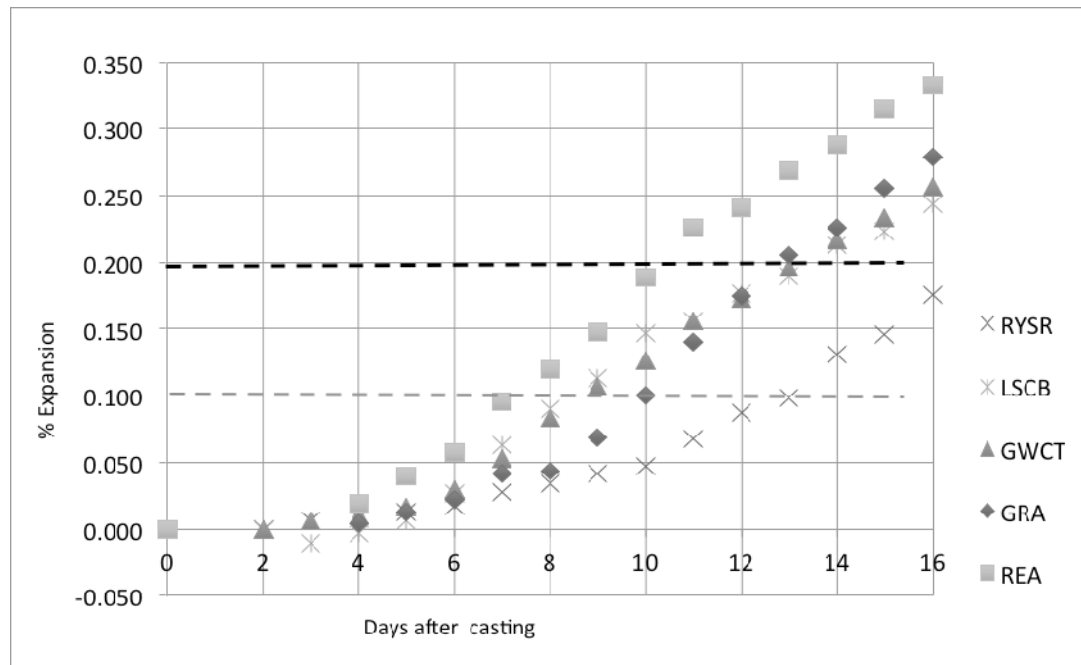


Fig.2 AMBT results of aggregates. Different granularity of greywacke aggregates affects their average expansions under accelerated conditions

The expansion results indicated that all studied aggregates, whatever types, had larger expansion than the threshold for potentially deleterious ASR

for the neighboring countries such as Laos, Myanmar and Cambodia, in which there has been no AAR deterioration reported yet. The similar

condition both for geology, materials and climatic condition is of concern for the potential AAR in this region.

#### 4. CONCLUSION

From the study, conclusions as follows are

- Two types of sedimentary rocks, greywacke and limestone from some sources in eastern region of Thailand, as well as an igneous rock, rhyolitic tuff, from the central region, showed the potential reactivity as the root of ASR problem in the future.
- Greywacke from the different sources were almost similar in compositions, but significantly different features have been observed in thin-section analysis. GRA and CTGW were coarse-grained greywacke composed of quartz, feldspar, and rock fragments but REA had different granularity than the other two, with high-weathering chlorite with a matrix of subgrained quartz, rock fragments and clay/graphite, deformed by tectonic forces. The ASR risk is increased significantly from subgraining of the microstructure. The highest expansion of REA agreed well with the microstructure analysis.
- The microstructure investigation of volcanic rock aggregate, rhyolitic tuff showed slight weathering and the expansion result indicated potential reactivity.
- The high silica content found in the limestone sample studied and the expansion higher than the limit suggested potential alkali reactivity.
- All studied samples in this paper revealed the potential alkali reactivity although aggregates types are different.

At present, ASR is not a serious problem in Thailand and only one case is reported. However awareness that ASR might be a possible problem in the near future is important based on the varieties of aggregates from local sources as well as the chemical variation particularly the alkali content of local cement. Therefore, continuing work on database development may be an appropriate use of available resources.

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