16th ICAAR
LISBOA 2020-2022

16th International Conference on
Alkali-Aggregate Reaction in Concrete
Lisboa | LNEC | Portugal | 31 May - 2 June 2022

http://icaar2020-2022.lnec.pt

Assessing AAR potential of processed Wadi Aggregates in Qatar, Arabian Gulf

Ian Sims (1), Khaled Hassan (2), Murray Reid (3), Alex Smith (1), and Mohammed bin Saif Al-Kuwari (4)

(1) RSK Environment Ltd, Hemel Hempstead, UK
(2) Infrastructure Research and Development (IRD), Doha, Qatar
(3) Infrastructure Research and Development (IRD), Glasgow, UK
(4) Ministry of Municipality and Environment (MME), Doha, Qatar

Abstract

Good quality structural concrete in Qatar has traditionally been achieved using expensive imported igneous rock aggregates, but recently a method of successfully processing local gravel materials to remove sulfates has been developed. This paper concentrates on the AAR potential of the new aggregate material and shows that it is suitable for use to replace up to 100% of imported aggregate in structural concrete. Petrographic composition of the local gravel, from different deposits, is reviewed before and after processing. Samples of the processed aggregate, plus samples of the individual rock constituents, were subjected to an up-to-date sequence of ASTM, RILEM and BS screening and concrete prism expansion test procedures, in order rigorously to assess the potential for any AAR expansion. Checks were also included for any releasable alkalis and post-test petrography was conducted on prism specimens.

***Keywords**: alkali-aggregate reaction; concrete; durability; expansion; wadi gravel*

1. INTRODUCTION

The Arabian Gulf region is the world's largest producer of fossil fuel with high emissions of carbon dioxide and negative impacts on the environment and climate change [1]. The region is also witnessing rapid infrastructure development with challenges to meet sustainable development. The vast construction projects consume large quantities of natural resources and generate waste materials with further impact on land use and the surrounding environment.

The State of Qatar is within the Arabian Gulf region and is the largest supplier of liquefied natural gas. Construction is the fastest-growing sector in the State with major infrastructure schemes for hosting the 2022 FIFA World Cup. The hot desert climate imposes challenges for the construction industry including excessive heat and humidity, a saline environment, aggressive ground conditions and a high level of groundwater for coastal areas [2]. Other challenges facing construction are the lack of local quality materials and reliance on imports. Taking into account the cost of imports and the additional environmental impact due to the transport of materials, there is a significant scope for reduction of imports and efficiency gains from the utilisation of local and waste materials accumulated in landfills.

Concrete materials are widely used in Qatar and the Arabian Gulf region. Up to the 1970s, the concrete industry in Qatar used beach sand as fine aggregate and local limestone as coarse aggregate. The beach sand had high contents of sulfate and chloride salts, and resulted in rapid deterioration of concrete. From the late 1970s beach sand was replaced by fine aggregate from an ancient alluvial deposit, the Hofuf Formation of Eocene age, locally available in Qatar. The underlying limestone of the Rus, Dammam and Dam Formations, which outcrops over most of Qatar, is relatively weak and also contains bands of potentially expansive clays and gypsum. Local limestone is therefore banned from use in structural concrete, and current practice is to use washed sand and imported gabbro as fine and coarse aggregates, respectively.

For over 30 years, locally produced washed sand has been used as fine aggregate in various applications of ready mixed and precast concretes. Deposits of the Hofuf Formation are located in the southern part of the State, and comprise predominately sand with smaller quantities of gravel (approximately 10-20%). The largest deposits at Mekaines and Al-kharaij, each approximately 20 square km and up to 18m thick, are largely exhausted by the high demand for concrete sand. The deposits are heavily cemented in parts with gypsum, making a substantial proportion of the material unsuitable for use in concrete. An exposure of the Hofuf Formation of the Al-kharaij sand deposit is shown in Figure 1.1. Sand washing is essential for the removal of sulfate, silt and clay, and produces a fine aggregate suitable for use in concrete. The washing process results in oversize materials (>4mm) referred to as “Wadi gravel”, and the fine particles, “filter cake”, which is currently used in agriculture.

Figure 1.1: An exposure of the Hufof Formation sand deposit at Al-kharaij – Qatar

Large quantities of this Wadi gravel are currently available in Qatar. A topographic survey of the Mekaines site indicated the presence of approximately 4.6 Million tonnes (Mt) of Wadi gravel (>4mm) [3]. The Mekaines Wadi gravel included natural sand deposits with about 10% gravel, with high sulfate contents, as well as the dumped oversize materials rejected from nearby sand washing facilities. Additional quantities of Wadi gravel are also available from the more recently tipped oversize material from the Al-kharaij deposit. Developing Wadi gravel as a high-value source of coarse aggregate in concrete would improve the land use and environment of both sites, mitigate the high demand for imported aggregate, and support the Government’s policy and strategy of sustainable development.

This paper presents a laboratory investigation on the potential use of Wadi gravel in concrete. Wadi gravel aggregate was obtained from different deposits in Qatar and quantitatively examined for rock and mineral constituents. Accelerated and long-term expansion tests were used to assess the AAR potential of the Wadi gravel.

2. AAR OF WADI GRAVEL

Wadi gravel is not currently used as coarse aggregate in Qatar, mainly due to its high gypsum content, leading to a risk of damage to concrete from internal sulfate attack, and also the perceived risk of alkali-aggregate reactivity (AAR). The susceptibility of Wadi gravel to AAR was assessed through a multi-phase testing programme. It involved 3 inter-related sequential phases, comprising an initial aggregate assessment; an accelerated screening test; and longer-term expansion tests as shown in Figure 2.1. The Wadi gravel was obtained from the largest deposits of Mekaines and Al-kharaij to assess variability from different sources in Qatar. A reference aggregate of imported crushed gabbro was also tested for comparative purposes.

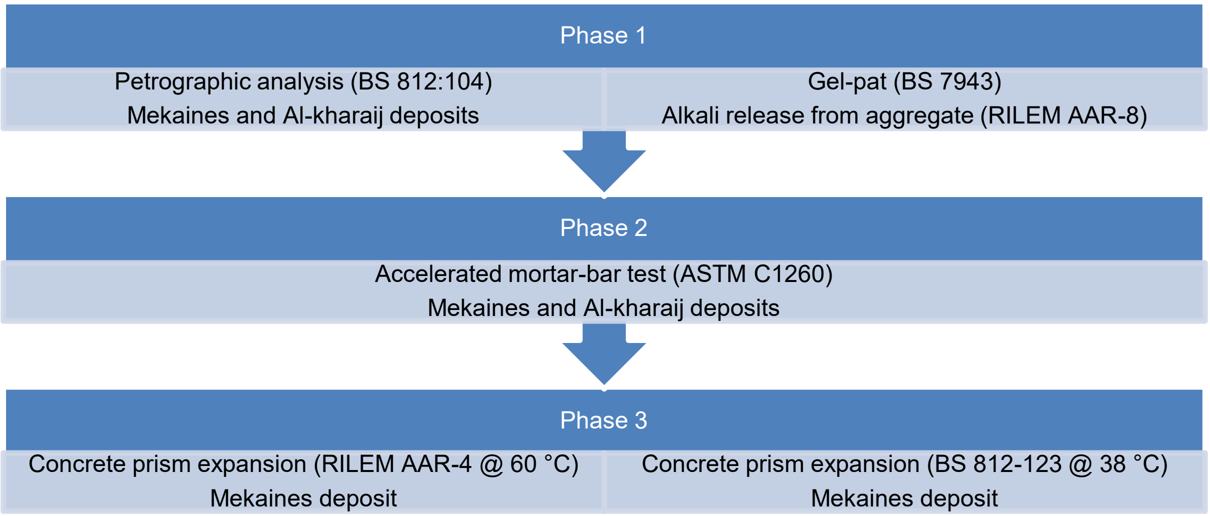

Figure 2.1: AAR testing programme of Wadi gravel

2.1 Aggregate assessment

Phase 1 focused on assessing the alkali-reactivity potential of the aggregates, as well as identifying the potential risk of each of the main components of Wadi gravel for use in concrete. Petrographic analysis was conducted on the as-received Wadi gravels from Mekaines and Al-kharaij deposits and also after processing to minimise the sulfate content. An example of the as-received Wadi gravel, oversize reject material from the sand washing plant, is illustrated in Figure 2.2, whereas Figure 2.3 shows the processed Wadi gravel (10-14mm) after intensive multistage mechanical processing and washing, following the procedure developed in reference [3] to produce aggregate compliant with the Qatar Construction Specification (QCS 2014) [4].

Figure 2.2: As received Wadi gravel – Al-kharaij, after initial washing

Figure 2.3: Processed Wadi gravel (10-14mm)

The initial AAR potential comments, which relate to the advice stated in Table 1 of BS 7943 [5] and guidance in BRE Digest 330 [6], are given below. These publications give UK guidance on the interpretation of the results of petrographical examination of coarse and fine aggregates, in terms of potential susceptibility to the ASR form of AAR.

2.1.1 Petrographic examination

The main composition of Wadi gravel aggregate was determined by the UKAS-accredited RSK laboratory in the UK. At least 3 samples were tested from each location and the average results are summarised in Table 2.1. Petrographic examination was conducted in accordance with BS 812-104 [7]. A minor deviation from the standard was observed, where the threshold between coarse and fine material was lowered from 5 mm to 4 mm to match with current European Standard sieve sizes. All material passing 4 mm size was omitted from the examination. The petrographic examinations of the as-received “raw” gravel identified six rock constituent types, which accounted for at least 94 % of the Wadi gravel. Trace constituents, totalling for less than 2%, of sandstone, chert, metamorphic rock fragment and mylonite were also detected in the petrographic examination. Traces of GBD, less than 1% of the overall materials examined, were also found in the processed Wadi gravel (Al-Karaij).

Table 2.1: Main rock constituents (% by mass) of raw Wadi gravel and after processing

Main constituents	Raw Wadi gravel		After processing	
	Mekaines	Al-kharaij	Al-kharaij 10-14mm	Al-kharaij 14-20mm
Limestone	36	41	48	51
Gypsum-bound deposits (GBD)	20	16	-	-
Quartz	17	12	23	20
Rhyolite	9	7	9	10
Granite	7	14	8	8
Quartzite	5	7	7	7
Total	94	97	95	96

Limestone: The limestone appeared in a variety of forms and colours, chiefly white, cream and pale reddish pink varieties. The main limestone types were classified in accordance with Folk’s classification scheme [8] of carbonate rock textures as sparite and biosparite. Limestone is considered typically to be of “low” reactivity in BS 7943 and BRE Digest 330.

Gypsum-bound deposits (GBD): These are pale orange, pale cream and pale brown coloured particles comprising fine sand-sized grains, cemented together with secondary gypsum. The clasts, bound by gypsum, comprise chiefly mature quartz grains, with minor proportions of limestone, granite, plagioclase feldspar, alkali feldspar, quartzite and rhyolite. Although not covered by BS 7943 or BRE Digest 330, the GBM was considered to be “normally” reactive, based on observations and experience.

Quartz: Milky white to translucent grey coloured pebbles comprising almost exclusively mono/polycrystalline silica, which was probably largely derived from vein materials (or possibly from some breakdown of granite in the processed samples). Rare inclusions of opaque minerals (well-crystallised pyrite and magnetite) and iron oxides were observed. The pebbles were typically rounded. Rare pebbles exhibited small areas of recrystallized silica. Quartz is classified as “low” reactivity as per BRE Digest 330.

Rhyolite: Typically reddish brown to dark grey coloured, porphyritic volcanic igneous rock with a fine to very finely crystalline groundmass, comprising chiefly quartz, alkali feldspar (orthoclase) and plagioclase feldspar. In some examples, the groundmass was observed to comprise interstitial glass. Rhyolite is considered to be of “normal” reactivity in BS 7943 and BRE Digest 330.

Granite: Typically mottled white, translucent grey, black, orange, brown coloured, fine to coarse grained, equigranular to porphyritic igneous rock. The granites comprised chiefly quartz and alkali feldspar, with varied proportions of plagioclase feldspar, biotite mica and muscovite mica. Accessory minerals included hornblende and opaque minerals, such as magnetite and well-crystallised pyrite. The pyrite did not appear to show signs of oxidation or deterioration. Granite is considered to be of “low” reactivity in BS 7943 and BRE Digest 330.

Quartzite: Partially translucent, white, pale grey, pale brown coloured, fine to medium grained rock comprising interlocking crystals of quartz, likely to have been mainly derived from metamorphic regimes (metaquartzite). Traces of alkali feldspar, plagioclase feldspar, pyrite and magnetite were sometimes observed. The pyrite crystals were well-crystallised and appeared to be stable. Secondary veins of silica, opaque minerals and iron oxides were also present. Occasionally the quartzite exhibited weak metamorphic foliation. Quartzite is considered to be of “normal” reactivity in BS 7943 and BRE Digest 330.

In general, the petrographic examinations of the aggregate samples were found to be ‘low’ to ‘normally’ alkali-silica reactive in relation to the UK guidance given in BS 7943 and BRE Digest 330. None of the constituents examined could be regarded as ‘highly’ reactive.

The proportions of the various constituents did not show large variations between the samples obtained from different deposits. After mechanical processing and washing, Table 2.1 shows clearly the removal of gypsum-bound deposits (GBD). The constituent rocks showed only limited variation for different aggregate sizes for the gravel samples obtained from different deposits. The initial results suggest that the properties of concrete made from the resulting aggregate should not vary significantly, providing the aggregate is processed sufficiently thoroughly to remove the gypsum cementation. Table 2.1 shows that when the GBD are excluded, about half the gravel consists of limestone and the other half a mixture of igneous and metamorphic rocks. The latter are probably derived from the Arabian Shield, whereas the limestone may have been derived from a variety of sources in the Arabian Shelf. The provenance of the various rock types is not known, and some may have been through several cycles of erosion and deposition. The pebbles are all relatively well-rounded, indicating a considerable amount of transport in rivers at some point in their life cycle.

The igneous and metamorphic rocks are resistant to weathering and decomposition, consisting predominantly of quartz and alkali feldspars. Even the limestones are relatively strong and resistant to weathering, unlike the weak, geologically young limestones forming the Rus, Dammam and Dam Formations in Qatar. The natural processes that form Wadi gravels winnow out unsuitable friable rock material, so that only physically durable materials remain. The Wadi gravel is thus potentially suitable for use as coarse aggregate in concrete, subject to investigation of its susceptibility to AAR.

2.1.2 Gel-Pat test

The gel-pat test for detection of opaline silica was conducted in accordance with BS 7943 [5]. The test causes any opaline silica or other exceptionally alkali-reactive siliceous material to react with alkalis, producing a visible gel on the surfaces of aggregate particles. Six samples were selected for this test, with five samples representing the highest proportions of potentially reactive constituents. Constituents including quartzite, chert and rhyolite were regarded as potentially reactive in accordance with the advice given in BS 7943. The sixth sample was selected as bearing the highest carbonate content across the examined samples, to check for any forms of finely disseminated reactive silica present within the carbonate component. None of the Wadi gravel samples exhibited any reaction.

2.1.3 Alkali release from aggregate

An initial assessment of potential ‘alkali release’ from aggregate was conducted in accordance with RILEM draft AAR-8 [9]. This test method is intended to assess the potential amount of alkalis that might be released in the long term within field concrete by aggregates, through the determination of amounts of sodium and potassium ions released by aggregate immersed in KOH and NaOH solutions, respectively for extracting sodium and potassium, when in the presence of excess calcium hydroxide.

Representative samples of Wadi gravel and reference gabbro aggregates were selected for the alkali release test. The Wadi gravel contains constituents which could potentially release alkalis when used in concrete, such as potassium and sodium feldspar-rich rocks, including rhyolite and granite. The alkali release results after 14 days, as Na_2O equivalent, were 0.025% for Wadi gravel and 0.035% for gabbro. Both values are less than 0.06%, which is negligible when calculating the total alkali content in concrete. The AAR-8 method remains to be finalised and published. These releasable alkali tests should be repeated using the latest methodology when it is published.

2.2 Accelerated expansion testing

The accelerated mortar-bar expansion test was conducted as per ASTM C1260 [10] for assessing the potential AAR of Wadi gravel from Mekaines and Al-kharaij deposits. This screening test utilises conditions that are conducive for most alkali-reactive siliceous material to react and produce potentially deleterious internal expansion. The coarse Wadi gravel aggregate samples were crushed and sieved to produce fine aggregate to cast the mortar-bars. The fine grading allows for more rapid reaction of the aggregates than the coarse grading used in concrete. The immersion period was extended from the standard 14 days to 28 days, during which expansion measurements were continued, to observe any delayed reactions.

Sims et al. [11] previously investigated the ASTM C1260 expansion of the individual constituent rocks of Wadi gravel, Table 2.1, and reported values within the range of 0.02 % to 0.18 % after 14 days immersion. The most reactive individual constituent mixtures were the rhyolite, granite and quartzite mixtures, producing average expansions after 14 days immersion of 0.18 %, 0.13 % and 0.11 %, respectively. The most reactive individual constituents continued to react between 14 and 28 days immersion, which brought them into the deleterious classification. The limestone and quartz constituents returned innocuous results. Further testing is reported in this paper to assess the expansion values of Wadi gravel from different deposits in Qatar.

Three mortar-bars were used for each mix and the average expansion was calculated. Alongside each measurement, observations of any possible gel or other secondary mineral growths were noted. The development of expansion within the mortar-bars during a specified period of storage indicates the probable presence of expansive processes, which may or may not indicate alkali-aggregate reactions. The interpretation guidance presented in ASTM C1260, in relation to expansion after 14 days' immersion, is given below:

- Expansion <0.10 %: Indicative of innocuous behaviour in most cases;
- Expansion >0.20 %: Indicative of potentially deleterious expansion;
- Expansion between 0.10 % and 0.20 %: Includes both aggregates that are known to be variously innocuous and deleterious in field performance. In these situations, it may be useful to take comparator readings until 28 days.

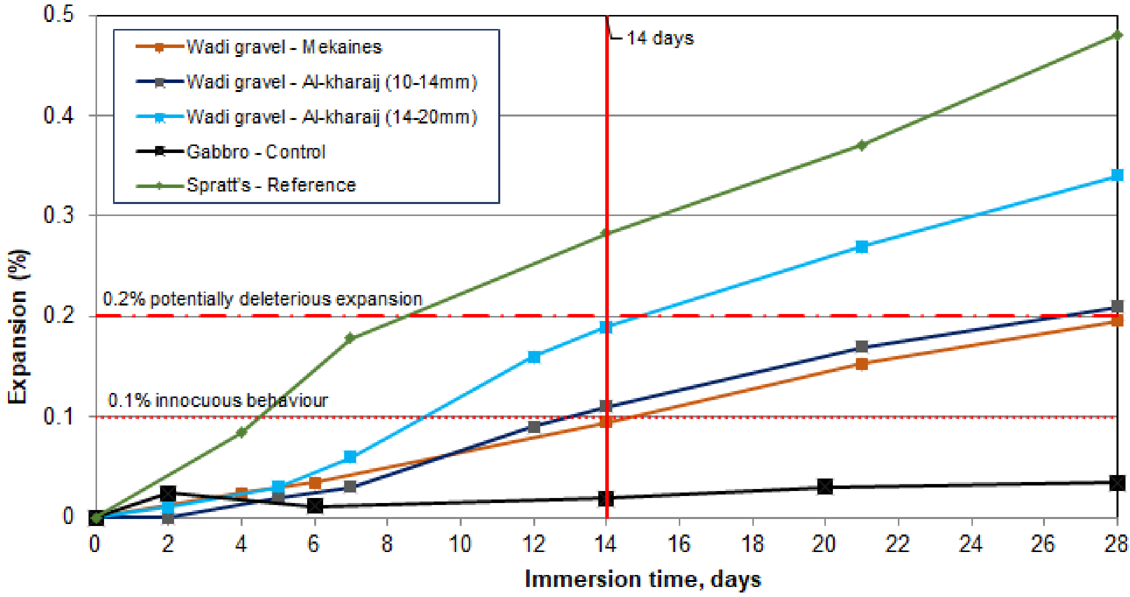

Figure 2.4: ASTM C1260-14 expansion of mortar-bars

Figure 2.4 shows the processed Wadi gravel from the Mekaines and Al-kharaij (10-14 and 14-20mm) deposits, a control gabbro aggregate, and a reference Spratt's reactive aggregate. The Spratt's reference reactive aggregate is specified in RILEM AAR-0 [12], and was used for comparison purposes. Spratt's silicified limestone aggregate, obtained from the Ontario Ministry of Transportation (MTO) [13], was chosen to represent a known alkali-silica reactive aggregate.

The Mekaines Wadi gravel and gabbro aggregate samples fall into the innocuous category of ASTM C1260 after 14 days immersion (16 days after casting). The processed Wadi gravel from Al-kharaij exhibited different rates of expansion for different aggregate sizes. The 10-14mm gravel showed slightly higher values than the Mekaines gravel, with considerably higher values for the 14-20mm gravel, only just below the 28 days limit for potentially deleterious expansion. The reference Spratt's aggregate produced a mean expansion after 14 days immersion of nearly 0.3 %.

The treated Wadi gravel from Mekaines and Al-kharaij continued to expand at consistent rates up to 28 days immersion (30 days age), with the Mekaines gravel remaining beneath the threshold for deleterious reactive aggregates. Al-kharaij Wadi gravel of 10-14mm was slightly higher with an average expansion value of 0.21 % at 28 days, and a much higher value of 0.34 % for the 14-20mm Wadi gravel. The Spratt's aggregate continued expansion after 14 days to reach the highest expansion of 0.48% at 28 days, confirming the high reactivity of the materials as widely published [14]. Further testing is planned on the post-expansion mortar bars for sulfate content and petrographic analyses to understand the different expansion behaviour of Al-kharaij gravel with different sizes.

2.3 Long-term expansion testing

Following the completion of Phase 2 screening testing, selected concrete mixtures were subjected to long-term concrete prism tests using the RILEM AAR-4.1 [15] and BS 812:123 [16] test methods. The BS concrete prism testing is known to take a relatively long time (52 weeks), by comparison with the accelerated AAR-4.1 tests (20 weeks), but is considered to be probably more realistic at representing typical behaviour of aggregate materials used in the field.

At this stage, only Wadi gravel from the Mekaines deposit was considered in the long-term expansion testing (the Al-kharaij material will be assessed separately, once the variation exhibited by different particle sizes is better understood). Coarse aggregate samples of treated Wadi gravel and imported gabbro, together with local washed sand as fine aggregate, were used in the mixtures. Hanson CEM I 52.5N cement, with an alkali content of 0.73 % Na_2O equiv., was supplied from Ribblesdale works in the UK. It was decided that the 0.73 % alkali content was sufficiently close to the 0.8 % alkali content for use in BS 812-123 testing, given that the alkali content would be boosted by the controlled addition of sodium hydroxide, as permitted in accordance with BS 812-123. Specialist reference cement was used in RILEM AAR-4.1, as recommended in RILEM AAR-3. CEM I 42.5 R Industry Cement, with an alkali content of 1.3 % Na_2O equivalent, was sourced from Norcem's Brevik plant in Norway.

To investigate the effect of using cement replacement materials, fly ash (FA) and ground granulated blastfurnace slag (GGBS) were supplied from Qatar. The FA was Class F and supplied by AshTech Middle-East, in accordance with QCS 2014, BS 3892-1 [17] and BS EN 450-1 [18]. The GGBS was supplied by Aljobar Cement Industries in Qatar and complied with the requirements of both QCS 2014 and BS EN 15167-1 [19].

The aggregates, cement replacement materials and reference cements were combined to form the mixtures summarised in Table 2.2. The cements and alkali levels were adjusted for the specific test methods; the aggregates and mineral additions were similarly proportioned for both methodologies of expansion test. The coarse aggregate samples were sieved to produce the required aggregate grading for the concrete prisms. Storage conditions varied between the two tests. RILEM AAR-4.1 concrete prisms were exposed to 60 °C temperatures at as close as possible to 100 % relative humidity (RH), whereas BS 812-123 concrete prisms were exposed to humid > 96 % RH atmospheric conditions at 38 °C. The humidity required for each test method was achieved using the techniques specified within the relevant standard and similarly using state-of-the-art reactors as detailed in RILEM AAR-4.1, thus minimising the common risk of misleading low expansion results due to poor control of humidity.

In total, five concrete mixtures were investigated (Table 2.2), with three test specimens used for the expansion measurements of each mix. Alongside each measurement, observations of any possible gel or other surface deposits were noted and the average expansion calculated for each mix. Whilst concrete prism expansion tests more reliably represent conditions experienced by concrete in service than mortar-bar screening tests, they may still not be a wholly accurate representation.

Table 2.2: Summary of concrete prism mixtures

Mix ref	Mix abbreviation	Description of components
Mix 1	Gabbro 100 %, PC	Qatari washed sand, 100% imported gabbro, and high alkali cement.
Mix 2	Gravel 100 %, PC	Qatari washed sand, 100% Wadi gravel, and high alkali cement.
Mix 3	Gravel 50 %, PC	Qatari washed sand, 50% Wadi gravel, 50% imported gabbro, and high alkali cement.
Mix 4	Gravel 100 %, GGBS	Qatari washed sand, 100% Wadi gravel, 50% high alkali cement, and 50% GGBS.
Mix 5	Gravel 100 %, FA	Qatari washed sand, 100% Wadi gravel, 70% high alkali cement, and 30% FA.

2.3.1 RILEM AAR-4.1 (60°C test method)

The interpretation guidance presented in RILEM AAR-0 is shown in Table 2.3 and summaries of the results are presented in Figure 2.5. The guidance given in RILEM AAR-0 allows tentative classification against a criterion of 0.03 % expansion at 15 weeks age. The 100% treated Wadi gravel with Qatari sand (Mix 2) was slightly higher than the suggested 0.03 % criterion, with 0.04 % at 15 weeks. Results for blending the Wadi gravel with imported gabbro (Mix 3) were encouraging, with expansion dropped to 0.015 % at 15 weeks for Mix 3, which notably was exactly the same expansion as Mix 1, which used 100 % imported gabbro.

Table 2.3: RILEM AAR-4.1 Interpretation guidance at 15 weeks from RILEM AAR-0

Maximum expansion %	Interpretation
≤ 0.03	Indicative of non-reactive aggregate combination
> 0.03	Indicative of reactive aggregate combination that requires precautions to minimise the risk of ASR damage to concrete in which the material is used.

Previous work [11] indicated the Qatari sand contributes to additional alkali-silica reactivity, resulting in high expansion values. Qatar washed sand was tested separately for the accelerated mortar bar test (ASTM C1260-14) and the resulting expansion value of 0.06 % at 14 days immersion (16 days age) was deemed to be innocuous behaviour. However, when the Wadi gravel (Mix 2) was tested with a crushed limestone reference sand, the mixture exhibited a lower expansion of 0.025%. Therefore, in Mix 2 with local sand, a moderate amount of expansion was attributed to the washed Qatari sand.

As expected from many previous studies and recommendations [20], the most substantial reduction in expansion was noted when cement replacement materials (GGBS and FA) were used to replace proportions of the cement (Mixes 4 and 5). Both the GGBS (Mix 4) and FA (Mix 5) mixtures resulted in minor shrinkage at 15 weeks (-0.05 % and -0.020 %, respectively). Whilst not expected, the shrinkage recorded was unlikely to be a consequence of drying out as high humidity levels within the containers were maintained throughout the testing. Indeed, Mix 4 and Mix 5 samples recorded net weight gains (0.52 % and 0.43 %, respectively) by the end of the test, indicative of a moist atmosphere being maintained. The prisms from the GGBS and FA mixes had significantly fewer white deposits on the outside, compared with the other mixes. Figure 2.6 shows an example of the white deposits formed on the surface of Mix 2 (Wadi gravel 100%, PC), whereas Figure 2.7, by comparison, demonstrates the significant reduction through the use of cement replacement materials (Mix 4, Wadi gravel 100%, GGBS). Deposits may be of ASR origin or related to leaching present within the samples. GGBS and FA additions can react with the calcium hydroxide and reduce the observed leaching of lime.

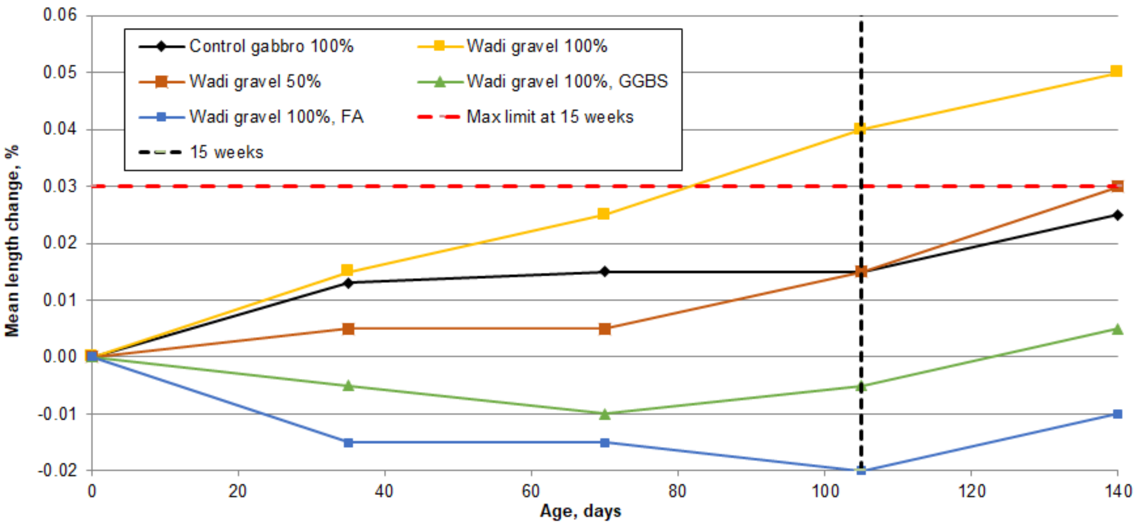

Figure 2.5: RILEM AAR-4.1 expansion of concrete prisms

Figure 2.6: White deposits on the surface of concrete prism (Mix 2)

Figure 2.7: Significant reduction in white deposits with the use of GGBS (Mix 4)

2.3.2 BS 812 (38 °C test method)

Summaries of the expansion results are presented in Figure 2.8. The multiple criteria for assessment given for BS 812:123, within BRE Digest 330-2, are shown in Table 2.4. These are based on UK materials and cases of ASR.

In contrast to the AAR-4.1 tests, the measured prism expansions for all of the treated Wadi gravel mixtures, including 100 % Wadi gravel (Mix 2), fell into the non-expansive aggregate classification (based on UK experience). This classification suggests no significant expansive behaviour and a low reactivity type for the Wadi gravel. Mixtures containing FA (Mix 5) and wholly imported gabbro (Mix 1) consistently reduced expansion by 20-50 %, compared with the 100% Wadi gravel mixture (Mix 2). The blended gravel and gabbro (Mix 3) and GGBS (Mix 4) mixtures produced similar expansions to the Wadi gravel (Mix 1) throughout the testing. Only during the latter part of the testing did the Wadi gravel uniquely produce the highest overall expansion (0.03 %) for the project mixtures (Mixes 1-5). The degree of AAR within the BS 812-123 prisms was notably lower than those within RILEM AAR-4.1 prisms of the same mixtures.

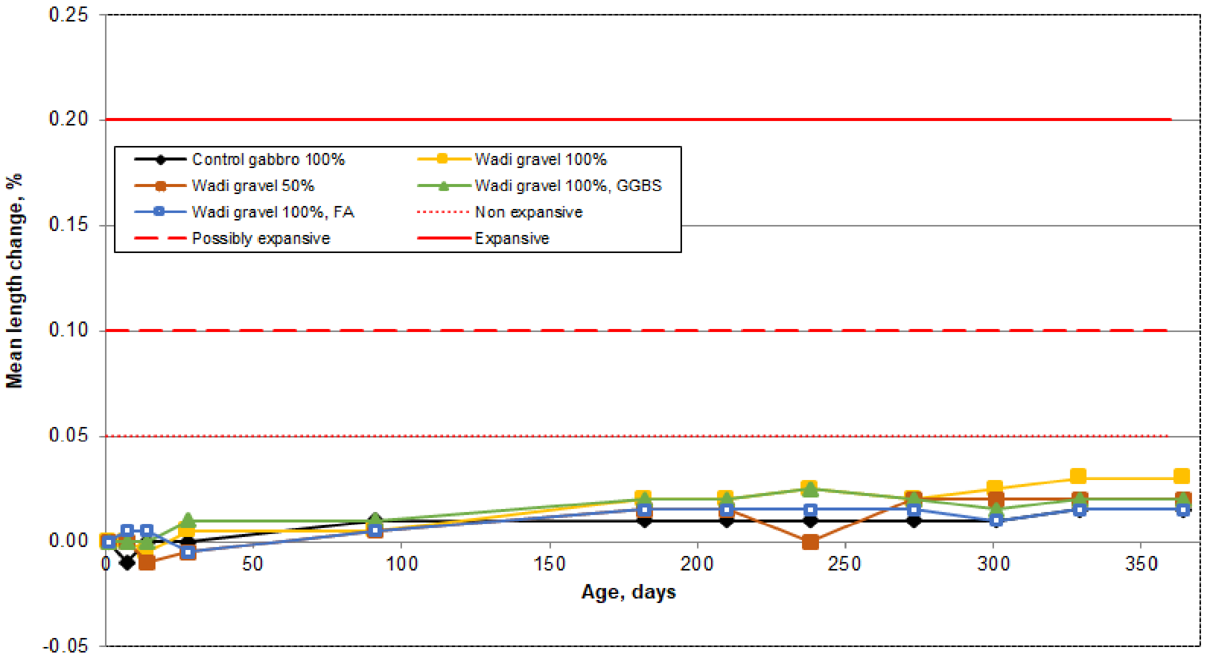

Figure 1.8: BS 812-123 expansion of concrete prisms

Table 2.4. BS 812-123 Interpretation guidance at 12 months from BRE Digest 330-2

Maximum expansion %	Classification	Alkali-silica reactivity	Notes
≤ 0.05	Non-expansive	Low	Combinations which have no record of causing damage to concrete
>0.05 ≤0.10	Probably non-expansive	Low	Combinations in this range have rarely been associated with actual cases of damage to concrete structures. However, these might be considered unsuitable in extreme conditions
>0.10 ≤0.20	Possibly expansive	Normal	Includes combinations which have sometimes been involved in cases of actual damage to concrete structures, but also includes some widely used combinations with no record of causing damage to concrete
> 0.20	Expansive	Normal	Exhibited by combinations known to have been involved in cases of actual damage to concrete

3. AAR OF WADI GRAVEL

The Wadi gravels from Mekaines and Al-kharaij contain some *potentially* reactive constituents, including rhyolite, quartzite and altered granite. Although these rock types displayed some evidence of AAR, they typically each account for less than 10% of the Wadi gravel. Samples collected from different deposits, consisting mainly of limestone and quartz, displayed innocuous behaviour [11]. A rigorous schedule of expansion testing returned chiefly satisfactory results, in particular using the more reliable 38 °C method (BS 812-123). Certain measures, such as blending with imported gabbro, or the use of FA or GGBS as a cement replacement, have further reduced observed ASR related expansion. The use of GGBS (50 % of binder) or FA (30 % of binder) replacement with the treated Wadi gravel aggregate combinations is potentially an effective measure to mitigate potential expansion from the presence of ASR. The GGBS and FA should adhere to recognised standards (BS EN 15167-1 or BS EN 450, respectively) and have limited alkali content, as recommended in [6].

Other options for mitigating potential AAR include limiting the alkali content of structural concrete (including CEM I component of any cement type), as recommended in BRE Digest 330. Ideally, this would involve using relatively low-alkali cement, with a guaranteed Na_2O equivalent of ≤ 0.60 %, or perhaps a declared mean Na_2O equivalent content of ≤ 0.75 %. Limiting the alkali content of the concrete must also take into account the extra alkalis that might possibly be released by the aggregates and also any admixtures used, plus any other potential sources of available alkali. The treated Wadi gravel only contributed a reasonably low (<0.06 % Na_2O equivalent) releasable alkali content in the tests carried out in this programme, which is unlikely to be a significant contributing factor to the overall alkali content.

4. CONCLUSIONS

Wadi gravel was obtained from the Mekaines and Al-kharaij deposits in Qatar and tested for potential AAR reactivity in concrete. The results show that treated Wadi gravel could be successfully used to replace up to 100% of imported aggregate in structural concrete. Petrographic examination showed very similar composition of the local gravel from both sources with 6 main constituent rock/mineral types, accounting for at least 94% of the Wadi gravel. The main constituents of limestone and quartz are innocuous, whereas the potentially reactive particles of rhyolite, granite and quartzite are present as small proportions of the gravel. Processing of the Wadi gravel, through multistage mechanical crushing and washing, reduced the gypsum-bound deposits to acceptable levels for use in concrete. The Wadi gravel did not exhibit any reaction in the gel-pat test, with negligible values of alkali release despite the presence of potential alkali-releasable constituents within rhyolite and granite,

The accelerated mortar-bar test to ASTM 1260 (2014) showed non deleterious expansion, with values less than 0.2 % after 14 days immersion for both Mekaines and Al-kharaij deposits (but see the bulleted criteria summarised in Section 2.2). However, the expansion of concrete with Wadi gravel was higher than that with gabbro aggregate, with a considerable difference between Al-kharaij Wadi gravel of different 10-14 and 14-20mm particle sizes. Further investigations are planned to clarify this different expansion behaviour for different gradings.

Concretes containing the treated Wadi gravel aggregates from Mekaines exhibited moderate to low levels of AAR during the concrete prism expansion testing. A difference between results for the 60°C and 38°C concrete prism tests was observed, however this was expected. Wadi gravel was classified as potentially reactive in the 60°C test over 15 weeks and of low reactivity in the longer established 38°C test over 12 months (according to UK experience). This is consistent with the 60°C test being intended to be ‘fail-safe’, with the longer-term 38°C test being considered more representative of performance in practice, providing high humidity is maintained. Similar indications for Al-kharaij is presently based only on their petrographical similarity, with checks on variations between aggregate sizes and concrete prism tests to be published later.

Successfully overcoming the problems of gypsum content and AAR potentially provides a valuable local resource of Wadi gravel aggregate for concrete. The limited variation of Wadi gravel constituents from different deposits encourages the wider use of the material as coarse aggregate in concrete. Wider implementation will contribute to the Government construction project to reduce reliance on imports and contribute to sustainable development. Wadi gravel is present in other States in the Arabian Gulf region, and could potentially also become a useful source of coarse aggregate for concrete.

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