

STUDY OF THE POTENTIAL FOR FURTHER ALKALI SILICA REACTIVITY OF AGGREGATES IN HARDENED CONCRETE

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Mortar bars were prepared from crushed concrete exhibiting a measure of alkali aggregate reaction. The material passing 5 mm was used, after washing to remove dust, to make the bars. Both the original cement paste and aggregate were incorporated into the mortar bar. The bars were made and treated according to the ASTM and NBRI procedures. The aggregates and reaction products were then studied using both the optical and scanning electron microscopes. The reactive components in the aggregate were identified by this method and the potential for further reaction evaluated.

INTRODUCTION

Samples from five concrete structures were crushed, sieved and washed before being proportioned according to ASTM C227-69 (1). These materials were then used as aggregate to prepare mortar bars. The cement used to prepare the mortar bars contained an Na_2O eq. of 0.82%. The samples were demoulded after 24 hours, cured in water for 48 hours, and placed in an alkaline solution which was half molar with respect to both sodium and potassium hydroxide. Sufficient bars were made for each aggregate type to allow samples to be placed both in a constant temperature room at 38°C and in an oven at 80°C. No length measurements were made since the object was to identify sites of reaction and these were observed by petrographic means.

DETAILS OF SAMPLES

The concrete samples described were obtained from external structures in the U.K. which were subject to moist environments at least for part of the time. The original samples were provided as cores ranging in diameter from 50-150 mm. The aggregate composition and volume proportions were determined by point counting at least three surfaces of approximately 78 cm². The volume proportions were converted into equivalent weight proportions (kg/m³) by calculation in order to establish the original aggregate/cement and water/cement ratios. The alkali contents were determined by the method given in BS 1881 part 124 (2).

Concrete 1 displayed extensive evidence of alkali-silica reaction. The sample was severely cracked and alkali-silicate gel was evident on the surface of the cores. The volume

proportions of the concrete were determined to be, aggregate 67.0%, paste 31.4% and voids 1.0%. Calculations from these figures gave equivalent weight fractions of 1756 kg/m³ aggregate, 384 kg/m³ cement and 192 kg/m³ water. The coarse aggregate consisted of 95% crushed greywacke-type sandstone and argillite and 5% quartzite, other sandstones and chert. The fine aggregate comprised 65% quartz, 20% quartzite, 5% feldspar, 5% chert and 5% sandstone. The reaction product was associated with the greywacke some of which contains significant amounts of metallic sulphides probably pyrite. The alkali content was determined to be 4.22 kg/m³ of Na₂O eq..

Concrete 2 displayed extensive evidence of A.S.R with abundant alkali-silicate gel and severe cracking attributable to the A.S.R. The volume proportions of the concrete were determined to be, aggregate 65.2%, paste 32.8% and voids 2.0%. The aggregate consisted of crushed greywacke and siltstone. The gel present was associated with the greywacke. The alkali content was determined at 0.083% Na₂O and 0.094% K₂O giving an Na₂O eq. of 0.145%, equivalent to 3.61 kg/m³ of Na₂O eq.

Concrete 3 displayed extensive evidence of A.S.R. with abundant alkali-silicate gel and severe cracking attributable to A.S.R. The volume proportions of the concrete were determined to be aggregate 68.3%, paste 30.9% and voids 0.8%. Calculations from these figures gave equivalent weight fractions of 1841 kg/m³ aggregate, 395 kg/m³ cement and 185 kg/m³ water. The aggregate consisted of a crushed limestone aggregate and a siliceous sand and gravel. The limestone comprises 92% of the coarse aggregate and some 22% of the fine aggregate. The sand and gravel provides the remainder of the fine aggregate and comprises 20% chert and 50% quartzite and vein quartz. The remaining 8% of the coarse aggregate is composed of oversized chert pebbles from the gravel. It is the chert that has reacted. The alkali content was determined at 0.062% Na₂O and 0.180% K₂O giving an Na₂O eq. of 0.180%. This is equivalent to 4.20 kg/m³ of Na₂O.

Concrete 4 displayed no evidence of A.S.R. The volume proportions of the concrete were determined to be aggregate 68.9%, paste 29.2% and voids 1.9%. Calculations from these figures gave equivalent weight fractions of 1791 kg/m³ aggregate, 357 kg/m³ cement and 179 kg/m³ water. The coarse fraction of the aggregate consisted of 100% chert while the fine fraction was composed of 89% quartz, 10% chert and 1% sandstone. The alkali content was determined as 0.042% Na₂O and 0.115% K₂O giving an Na₂O eq. of 0.118% or 2.62 kg of Na₂O eq.

Concrete 5 displayed signs of A.S.R in the form of slight amounts of alkali-silicate gel and slight to moderate cracking that can be attributed to A.S.R. The volume proportions of the concrete were determined to be, aggregate 67.1%, paste 32.4% and voids 0.5%. Calculations from these figures gave equivalent weight fractions of 1745 kg/m³ aggregate, 431 kg/m³ cement and 194 kg/m³ water. The aggregate was a natural mixed gravel composed of 49% quartz as natural sand, metaquartzite and vein quartz, 35% sandstone and siltstone, 10% chert, 2% limestone, 2% feldspar and 2% igneous fragments. The alkali content was determined as 0.075% Na₂O and 0.189% K₂O giving an Na₂O eq. of 0.200% or 4.54 kg/m³ of Na₂O eq..

RESULTS

All samples were examined after six weeks. Those stored at 38°C showed no obvious evidence of reaction in the mortar bars. The samples stored at 80°C however all appeared to have reacted with copious amounts of a gel-like substance being present on the surfaces of the samples.

Polished pieces and a thin section were then prepared from each of the samples which had been stored at 80°C. The polished pieces were stored in a moist environment for 48 hours. During this time varying amounts of a free flowing gel welled out onto the polished surface of each sample. In general on all samples the gel was to be found on the paste and surrounding the largest aggregate particles rather than coating the aggregate. Due to the fluid nature of the gel it was sometimes difficult to determine precisely which aggregates had reacted but some observations could be made.

In the mortar containing Concrete 1 the fluid gel coated much of the sample but the gel appeared to be particularly associated with greywacke containing pyrite. Also some gel was associated with one or two particles of dark grey, fine-grained, argillite.

In the mortar containing Concrete 2 very little gel was present in relation to the other concrete samples. It was very difficult to relate the gel production to aggregate type but occasional particles of a fine grained, dark grey, argillite were coated with a thick layer of dried white gel.

The bars for Concrete 3 produced the largest amount of gel with perhaps 80% of the sample surface being coated. There was no indication that the limestone aggregate had reacted or deteriorated in any way, but chert which was a dark cream to pale brown in colour had reacted. Gel could be observed issuing from several porous chert particles. The majority of the chert particles had been considerably softened. This was particularly obvious in the thin section and on the polished surface and it was apparent that some material had been removed during the preparation stages.

The bars containing Concrete 4 had copious amounts of free flowing gel coating the surface of the sample making it difficult to determine from where the gel originated. The gel was particularly associated with the white to light cream coloured chert. Some of these light coloured cherts had become softened and they were obviously porous. The darker brown coloured cherts had not been apparently softened.

The bars for Concrete 5 again showed gel that was very fluid but lesser amounts had been produced than for sample 4 with perhaps only 30% of the sample surface being coated. The nature of the gel made it difficult to relate it to any particular rock type in this mixed aggregate but there were some deposits of thicker dried white gel associated with particles of quartzite which contained significant amounts of metallic compounds.

The samples maintained at 38°C were re-examined after six months and were observed to have reacted with each sample having a gel-like substance present on the surface. A sample of this gel from each mortar bar was analysed by scanning electron microscope. Some typical results are shown in Table 1.

TABLE 1 - Typical analyses of gel reaction products from concrete mortar bars.

	Concrete 1	Concrete 2	Concrete 3	Concrete 4	Concrete 5
SiO ₂	52.0	46.6	46.4	46.5	41.4
Al ₂ O ₃	0.4	0.3	0.2	0.1	0.2
MgO	0.4	0.2	0.3	0.2	0.6
CaO	20.1	27.5	29.3	25.4	29.4
Na ₂ O	6.2	5.8	6.6	6.4	6.6
K ₂ O	19.5	17.9	15.4	20.3	20.3
SO ₃	0.9	1.2	1.3	0.6	1.0

CONCLUSIONS

As expected the samples of concrete that had originally reacted, reacted again in the mortar bars when additional alkalis were made available. This implies that reaction could continue in the original structure if the supply of alkalis is not exhausted or if alkalis are added to the structure for instance as de-icing salts or are recycled. It was usually easier to determine which aggregate types were reactive in the mortar bars than in the original samples. The reaction of the chert in concrete 4 which had originally not displayed reaction could be due to an insufficient alkali concentration present in the original structure or because the process of crushing had disturbed the structure of the chert making it more likely to react. The results appear to show that reactivity is not limited by reactive aggregate abundance but by access of mobile alkalis to the reactive aggregate. The method may allow the potential for reaction to be established early in the life of a structure and permits evaluation of concrete that might be recycled.

REFERENCES

1. American Society for Testing and Materials: Standard methods of test for potential alkali reactivity of cement-aggregate combinations (mortar bar method). ASTM Standard Designation C227-69. Annual Book of ASTM Standards. Part 10: Concrete and Mixed Aggregates.
2. British Standards Institution (1988) British Standard BS 1881: Part 124: 1988. London.