ALKALI SUSCEPTIBILITY OF UK AGGREGATES

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The result of Concrete Prism Tests to determine the alkali reactivity of UK natural aggregates is reported. Results are compared with field performance and a limit for classification as reactive aggregate is proposed. Variations on the test carried out are reported and a threshold alkali level for damaging expansion is proposed.

A range of rapid tests have been evaluated and their results compared with those from the Concrete Prism. The NBRI and Autoclaved Microbar Tests are recommended for further evaluation.

INTRODUCTION

Engineers in the United Kingdom have been given guidance by the Concrete Society (1) on precautions to be taken to minimise the risk of damaging alkali-silica reaction in concrete. Included in the range of options available to them is that to differentiate between aggregates likely to be reactive and those not. No definitive test method is proposed for this differentiation although reference is made to a method being developed as a British Standard (2) using concrete prisms. Differentiation based on the classification of aggregates into mineralogical groups is offered although in all but the more clearly defined situations this is unlikely to be helpful.

This paper sets out work which has been carried out to investigate the concrete prism test as a means of differentiating between the alkali reactivity of aggregates. It goes on to examine those UK aggregate types which are alleged to be the cause of damaging ASR in concrete structures comparing them with others having long term satisfactory performance in field concrete . A threshold value for the classification of an aggregate as potentially reactive using this test is proposed. Further variations on the test method are reported in which aggregates classified as being potentially reactive have been subjected to varying levels of alkali and from their performance a threshold alkali level necessary to induce damaging reaction with UK aggregates is proposed.

In view of the protracted nature of the concrete prism test which requires twelve months for a definitive result a range of alternative rapid tests have been evaluated. The results from these methods on a selected range of UK aggregate types is reported and further work is proposed which should result in defining a rapid method suitable for routine aggregate control.

THE CONCRETE PRISM TEST

Principles of the test

A concrete prism expansion test has been developed for possible adoption by BSI (2) as a UK standard method. Prisms of size 7.5 x 7.5 x 25 to 30 cm. are prepared from concrete with a cement content of 700 kg/m^3 using cement either with an alkali content of 1.0%, expressed as sodium oxide equivalent, or with added potassium sulfate necessary to achieve the same total alkalinity. Where a fine aggregate is to be evaluated it has been tested in combination with a coarse inert limestone, coarse aggregate is tested in combination with inert crushed limestone fines. Where coarse and fine aggregates are to be evaluated together they have been tested as both components of the mix. The method is thus capable of providing basic information on individual aggregates as well as combinations or overall mix constituents.

Test method

Prisms are demoulded at 24 hours, wrapped in wet cotton towel, sealed in closely fitting polythene and stored in closed containers at 38°C± 2°C. At six days after demoulding they are unwrapped, weighed and their length measured by means of reference pieces cast into each end face. They are resealed and stored at a controlled temperature of 38°C until further measurements are made at regular intervals up to one year. The expansion is expressed as the percentage length gain at one year compared with the length at seven days. Comparison of the weights recorded at each age confirms whether the prism has been subjected to drying at any time which would show as a weight loss and invalidate the test.

Results for UK aggregates

Table 1 sets out the range of results for the UK aggregates tested by this method to date. It is not a representative spread of aggregates since more attention has been paid to sources likely to be reactive.

TABLE 1 - Expansions of UK aggregates measured by the Concrete Prism Test

Expansion (%)	0.00 to 0.05	0.06 to 0.10	0.11 to 0.15	0.16 to 0.20	0.21 to 0.30	>0.30	Total
Number	66	24	10	10	3	7	120

FIELD PERFORMANCE OF UK AGGREGATES

Comparison with Concrete Prism Test values

A comparison has been carried out of the field performance of UK aggregates with the test results from the Concrete Prism Test. Aggregate combinations considered are those for which reports are available on their field performance and whose results from the Test fall within the range of expansion values between 0.05% and 0.25%. Aggregates with expansions less than 0.05% have invariably performed satisfactorily whilst those with expansions greater than 0.25% are considered to be at risk. The results are summarised in Table 2.

TABLE 2 - Comparison of Concrete Prism expansion and field performance of UK aggregates

Expansion (%)	Coarse aggregate type	Fine aggregate type	Field performance(*)
0.06	Gravel 2% Chert	Sand 15% Chert	Unreactive
0.07	Gravel 5% Chert	Sand 15% Chert	Unreactive
0.07	Gravel 8% Chert	Sand 9% Chert	Unreactive
0.09	Clean limestone	Sand 4% Chert	Unreactive
0.09	Gravel 4% Chert	Clean limestone	Unreactive
0.10	Clean limestone	Sand 5% Chert + 2% strained quartzite	Unreactive
0.10	Basalt	Sand 4% Chert	Unreactive
0.11	Limestone 5% SiO_2	Limestone 5% SiO_2	Unreactive
0.11	Clean limestone	Sand 10% Chert + 20% strained quartzite	Low reactivity
0.12	Gravel 4% Chert	Sand 3% Chert	Low reactivity
0.13	Gravel 11% Chert	Sand 1% Chert	Low reactivity
0.14	Siltstone/Dolerite /Hornfel	Clean limestone	Low potential reactivity
0.15	Siltstone/Dolerite /Hornfel	Sand 2% Chert	Unreactive
0.16	Gravel 9% Chert	Sand 9% Chert	Slow reacting
0.18	Fine grained sandstone	Crushed fine grain sandstone	Slow reacting
0.19	Gravel 19% Chert	Sand 9% Chert	Slow reacting
0.22	Limestone 24%SiO_2	Limestone 24% SiO_2	Potentially reactive
0.23	Clean Limestone	Sand 10% Chert +20% strained quartzite	Potentially reactive

NOTE (*) Field performance is estimated on the following basis :

Unreactive - No history of cracked structures linked to observed ASR gel.

Low reactivity - No history of cracked structures but small amounts of gel have been observed.

Slow Reacting - Some reported cracks linked to ASR gel.

Potentially Reactive - Combinations for which laboratory observations would indicate potential for reaction but no field experience.

From these results 2 it is concluded that aggregates showing expansions less than 0.15% at one year by the Concrete Prism Test can be regarded as being unlikely to exhibit damaging Alkali-Silica reaction in concrete, irrespective of its alkali level.

THRESHOLD ALKALI VALUE

Variations on the Concrete Prism Test have been carried out to determine the threshold value of alkali necessary to induce expansion at twelve months. Comparison of the alkali level required to achieve the degree of expansion established above as that necessary for an aggregate to be likely to result in damaging alkali-silica reaction (0.15%) has been used to provide a test of the threshold alkali value. The results are set out in Table 3.

From these results it is concluded that even where concrete contains alkali reactive aggregates a threshold alkali value greater than 5 kg/m^3 is necessary for significant expansion to occur in concrete. This conclusion is in agreement with that reported by Hobbs (3).

ALTERNATIVE (RAPID) TEST METHODS

The Concrete Prism Test is proving to correlate well with the field performance of UK aggregates. It provides a valuable guide by which concreting materials can be assessed and classified. However, since it requires twelve months before a definitive measure can be obtained, it is of limited suitability for the routine control of aggregate supplies. A number of alternative methods have been examined with a view to establishing their relationship with the Concrete Prism Test, relative to field performance and the time

TABLE 3 - Concrete Prism expansions as a function of alkali level

Alkali level (kg/m^3)	Aggregate Type	
	Coarse	Fine
	Clean limestone	Crushed flint
7.0	0.275%	
6.5	0.410%	
6.0	0.305%	
5.5	0.195%	
5.0	0.030%	
	Coarse	Fine
	Clean limestone	61% Chert sand
7.0	0.410%	
6.0	0.355%	
5.0	0.030%	

scale required to produce results. For this exercise a range of aggregate types has been selected including those with reactive and unreactive field performance records. Aggregates compared are :

Ref. No.	004	High purity limestone
	007	Low silica limestone
	016	Crushed flint sand
	025	Thames Valley sand
	028	Beach sand
	076	Trent Valley sand
	084	High silica limestone
	090	Quartz sand

Petrographic examination

A draft British Standard method (4) is being developed by which the mineralogical composition of aggregates can be determined. It is intended that the results are compared with the table of aggregate types considered to be unreactive published by the Concrete Society (1). Reproducibility of results has been a problem particularly where small proportions of potentially reactive types are involved. Table 2 has already demonstrated that for potentially reactive constituents such as chert the content is no reliable guide to the aggregate reactivity.However, having established the reactivity by other means it could be a measure of the ongoing consistency of an aggregate source. Results for this series of aggregates are set out in Table 4.

Chemical tests

Aggregates have been analysed for total chemical content by fused borax bead using X-ray fluorescence and by the ASTM method (5) for dissolved silica and reduction in alkalinity. In the latter test an additional category has been included termed Borderline for results close to but not exceeding the line separating innocuous and potentially deleterious classes. Results are set out in Table 5. Only a very general relationship has been found between the classification according to the ASTM test and field performance. The chemical analysis, although a rapid method, is applicable only to demonstrate the consistency of a source.

TABLE 4 - Petrographic analysis of aggregates

Ref.No.	004	007	016	025	028	076	084	090
Mineralogy (%)								
Quartz			32	28	82	29		77
Quartzite			1	1		13		2
Chert			56	61	3	7		3
Sandstone			7	2	1	45		13
Siltstone			4	4	1	4		
Feldspar					5	2		3
Limestone	100	100		4	6		100	1
Acid igneous					1			1
Basic igneous					1			

TABLE 5 - Chemical tests on aggregates

Ref. No.	004	007	016	025	028	076	084	090
Chemistry (%)								
SiO_2	1	5	90	85	88	86	15	92
Al_2O_3	0	1	1	0	2	1	1	1
Fe_2O_3	0	1	1	2	1	4	1	1
$CaCO_3$	98	89	6	12	8	6	79	6
$MgCO_3$	1	3	1	1	1	2	2	1
ASTM C-289								
Dissolved Silica	1	9	90	310	23	60	48	26
Reduction in Alkalinity	27	113	157	195	95	136	195	75
Clasification (*)	Inn	Inn	Del	Pot Del	Inn	Bor	Bor	Inn

NOTE (*) Classification according to modified ASTM C-289 :
Inn - aggregates considered to be innocuous
Bor - aggregates borderline between innocuous and potentially deleterious
Del - aggregates considered to be deleterious
Pot Del - aggregates considered to be potentially deleterious

NBRI Rapid Expansion Test

Oberholster and Davies (6) have developed a rapid test using mortar bars prepared according to ASTM C-305 (7). After demoulding at 24 hours prism lengths are measured and then immersed in distilled water at 80°C for 24 hours. After re-measuring they are immersed in 1M sodium hydroxide solution at 80°C for a further twelve days before their length is again measured. When carried out on some aggregates exhibiting pessimum effects in concrete expansions indicated that the aggregate was innocuous. Further tests were carried out substituting proportions of clean limestone for the aggregate under examination revealing the prescence of the pessimum tendency. Results of the tests are set out in Table 6. When tested in the same proportions as the aggregates in the Concrete Prism Test there was good agreement on classification.

Microbar Expansion Test

Ciments Francais (9) have refined the autoclave test of Tang et al (10). Mortars in the ratios of 2:1, 5:1 and 10:1 cement to aggregate with water/cement ratio equal to 0.30 are prepared and vibrated into moulds sized 1.0 x 1.0 x 4.0 cm. These are then cured for 24 hours at 20°C and 100%RH, demoulded and their length measured. They are steam cured at 100°C for four hours and, after storing at room temperature overnight, autoclaved in 10% potassium hydroxide at 150°C for six hours. After cooling to room temperature the length expansion is measured. The largest expansion of the series of three proportions is taken as a measure of reactivity. Again there were difficulties in comparing the results for some aggregates exhibiting the pessimum effect and also to some which are used in concrete at low proportions. Repeated tests substituting clean limestone for various proportions of the

TABLE 6 - Expansions by the Concrete Prism, NBRI and Microbar Tests

Aggregate ref.	004	007	016	025	028	076	084	090
Concrete Prism								
% aggregate	100	100	25	30	27	100	100	31
expansion	35	100	240	375	30	150	250	45
% aggregate		65		40			70	
expansion		35		305			240	
NBRI Test								
% aggregate		100	100	100	100	100	100	100
expansion		70	60	40	60	140	180	150
% aggregate			50	50				
expansion			90	70				
% aggregate			35	35				
expansion			160	110				
% aggregate			20	20				
expansion			120	90				
Microbar Test								
% aggregate	100	100	100	100	100	100	100	100
2:1 mix expn	34	94	220	190	170	155	250	205
5:1 mix expn	36	43	230	220	80	130	130	90
10:1 mix expn	36	21	200	180	40	80	75	30
% aggregate				50	35			30
2:1 mix expn				205	65			80
% aggregate				35	25			
2:1 mix expn				215	55			
% aggregate				20	13			
2:1 mix expn				170	45			

NOTE Results are expressed as % expansion x 1000

aggregate being examined showed both the pessimum effect and the reduced expansion at low proportions for others. Almost invariably the 2:1 mix gave the highest expansion but there was reasonable correlation between the results for mixes at other cement/aggregate ratios with those mixes diluted with limestone. Some mixes resulted in highly cohesive mortars at 0.30 w/c and were difficult both to mix and to compact. In these cases the addition of water up to a maximum w/c of 0.33 during the mixing sufficient to give a freely workable mortar resulted in improved repeatability of results without affecting the maximum expansion. Results are set out in Table 6.

CONCLUSIONS

The draft BS Concrete Prism, NBRI mortar bar and Autoclaved Microbar tests have given good correlation with reported field performance of UK aggregates.

The Concrete Prism test results for the limited range of aggregates tested have indicated that those with expansions below 0.15% at one year are unlikely to exhibit damaging reaction in field concrete and that alkali levels in excess of $5kg/m^3$ are necessary before damaging expansion occurs.

In both the NBRI and the Autoclaved Microbar methods tests over a range of aggregate concentrations are necessary to identify pessimum and dilution effects. These results suggest that expansions of less than 0.10% indicate unreactive aggregates.

Petrology, chemical analyses and the ASTM C-289 chemical test have been shown to be of limited value in predicting the alkali-reactivity of UK aggregates.

Work is continuing to relate the Concrete Prism test to the field performance of UK aggregates and to evaluate further the NBRI and Microbar test methods.

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REFERENCES

1. Concrete Society Working Party. Alkali-silica reaction : minimising the risk of damage. Guidance notes and model specification clauses. Technical Report 30. Concrete Society, London, Oct. 1987.
2. British Standards Institute. Testing Aggregates. Alkali-silica reactivity. Concrete prism method. BSI, London, 1990, draft BS812:Part 123.
3. Hobbs, D.W., Alkali-silica reaction in concrete. Thomas Telford Ltd., London, 1988.
4. British Standards Institute. Testing Aggregates. Qualitative and quantitative petrographic examination. BSI, London, 1989, draft BS812:Part 104.
5. American Society for Testing and Materials. Standard test method for potential reactivity of aggregates (chemical method. ASTM Standards Volume 04.02 Concrete aggregates. C- 289-81.
6. Oberholster, R and Davies, G. An accelerated method for testing the potential reactivity of siliceous aggregates, Cement and Concrete Research, Vol.16, 1986, pp.181-189.
7. American Society for Testing and Materials. Standard Practice for Mechanical Mixing of Hydraulic cement mortars. ASTM Standards Volume 04.01 Cement; Lime; Gypsum. C-305-82(87).
8. Tang M.S., Han S.F. and Zhen S.I., A rapid method for identification of alkali-reactivity of aggregates, Cement and Concrete Research, 13, 417, 1983.
9. Criaud A., Vernet C. and Defosse C. The microbar method, an accelerated expansion test for evaluating aggregates. Canadian Developments in Testing Aggregates, Toronto, Canada, 1990.