Some Tests on Fourteen Year Old Concrete Affected by the Alkali-Silica Reaction

D.W. Hobbs
Cement and Concrete Association
Slough, UK

ABSTRACT

Laboratory measurements are reported of compressive strength, tensile strength, elastic modulus and ultrasonic pulse velocity tests on a range of 14 year old concretes affected by the alkali-silica reaction. The concretes were made using a number of UK cements and a UK aggregate. It is shown that cracking and expansion due to the alkali-silica reaction had the most marked effect upon elastic modulus, reducing the modulus by up to 40%.

INTRODUCTION

In concrete made using UK cement and UK aggregates, expansion and cracking due to the alkali-silica reaction (ASR) has rarely been observed under laboratory storage conditions. In 1971 a number of 150 and 100mm cubes prepared from a number of '70' and '90' MN/m² designated concrete mixes using several cements were observed to crack at an early age (<56 days). The concretes were made using Thames Valley fine aggregate and either a dense crushed coarse aggregate or Thames Valley coarse aggregate. The former concretes were stored in water at 20°C and the latter in a fog room. All of the concrete which cracked were made using a high alkali cement and had cement contents in excess of 500 kg/m³. It was subsequently established that the cracking was caused by ASR. The concretes stored in water were periodically examined for cracking and at an age of 14 years the following measurements were made:

(i) maximum crack width using a microscope with an illuminated scale and a magnification of 35.

(ii) compressive strength. The two faces to be loaded were ground flat and parallel prior to test.

(iii) indirect tensile strength by loading through 7mm wide strips of hardboard resting against the cube on the centre lines of 2 opposite ground faces.

(iv) stress-strain behaviour using a demec gauge with a gauge length of 50mm.

(v) ultrasonic pulse velocity using a 50kHz pulse from the PUNDIT apparatus.

This paper presents the results of these tests and discusses the effect of ASR and alkali content upon the measured parameters.

RESULTS AND DISCUSSIONS

Maximum Crack Width

The relationship between maximum crack width and the original acid soluble alkali content of the cubes expressed as equivalent sodium oxide, is shown in Figure 1. At an age of 14 years only concretes with alkali contents of over 5.8 kg/m^3 showed visible ASR cracking. The expansion of these cubes ranged from about 0.15 to 0.3%.

Thin Section Examination

Examination of thin sections taken from cracked cubes showed a number of micro-cracks filled with ASR gel surrounded by gel saturated paste and some voids filled or partially filled with gel. Very few micro-cracks were present in sections taken from uncracked cubes but some of the voids contained gel and there was evidence of gel saturated paste. Thus finding gel and gel saturated paste in a thin section taken from a cracked structure is not a sufficient condition for concluding that ASR is the primary cause of the observed macro-cracking. One may only be confident that ASR is the primary cause of cracking if, in a representative thin section of the concrete, considerable evidence of reaction is found and if in addition, other possible causes of deterioration are eliminated.

Compressive and Tensile Strength

The compressive and tensile strengths are shown plotted against maximum crack width in Figures 2 and 3 respectively. The mean strength and the range of strength values, together with compressive strength results obtained at 56 or 91 days are given in Table 1.

TABLE 1

Mean and range of strength values

Mix	Age	Compressive strength (MN/m^2)		Tensile strength (MN/m^2)	
		uncracked cubes	cracked cubes	uncracked cubes	cracked cubes
70MN/m^2	56d	81,76-86	72,66-77		
	14yr	111,103-119	94,84-107	7.3,6.0-8.5	5.7,4.9-6.9
90MN/m^2	91d	88,80-100	75,71-79		
	14yr	123,108-129	112,110-114	6.3,5.0-7.0	5.4,5.1-5.7

The reductions in mean compressive strength and tensile strength at an age of 14 years due to an ASR expansion of 0.3% were 15 and 20% respectively for the '70' MN/m^2 mix and 10 and 15% respectively for the '90' MN/m^2 mix. Similar reductions in compressive strength when the ASR expansion is below 0.3% have been observed by other investigators (Oberholster and Westra, 1981; Nixon and Bollinghaus, 1985; Swamy and Al-Asali, 1986). A similar reduction in compressive strength was also observed at an age of 91 days for the '90' MN/m^2 mix but a lower reduction was observed at an age of 56 days for the '70' MN/m^2 mix. A point of major importance is the fact that the cracked cubes gained in compressive strength as the years went by.

At an age of 14 years, the minimum compressive and tensile strengths of the cracked cubes were 84 and 4.9 MN/m^2 respectively, much higher than was expected from the visual appearance of the cubes.

Stress-Strain behaviour

The stress-strain behaviour of the uncracked and cracked concrete cubes

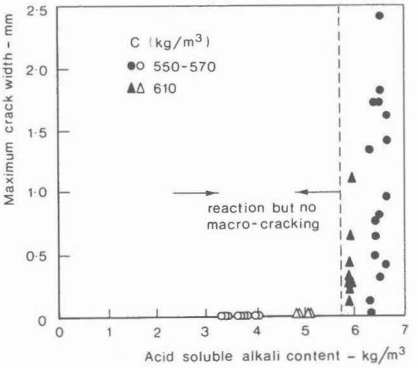

Figure 1 Variation of maximum crack width at an age of 14 years with acid soluble alkali content (expansion of cracked specimens 0.15 to 0.30%)

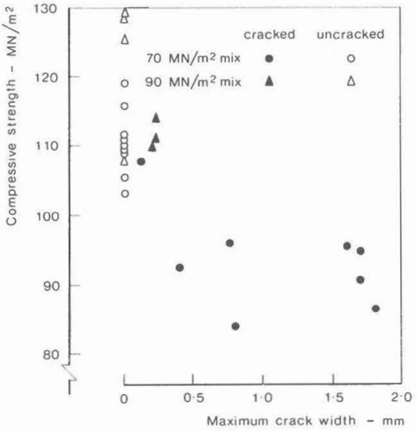

Figure 2. Relationship between compressive strength at 14 years and maximum crack width

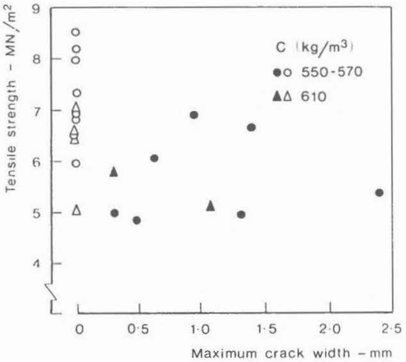

Figure 3. Relationship between tensile strength at 14 years and maximum crack width

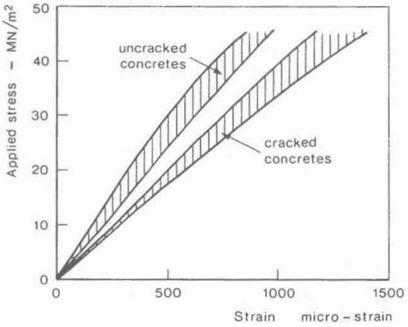

Figure 4. Stress-strain behaviour of cracked and uncracked concretes ('70' MN/m² mix).

cast from the '70' MN/m² mix, up to an applied stress of 45 MN/m², is shown in Figure 4. In Figure 5 the elastic modulus calculated from

$$E = 40/(\epsilon_{45}-\epsilon_{5})$$

is shown plotted against maximum crack width, where ϵ_{45} and ϵ_5 are the observed strains at applied stresses of 45 and 5MN/m² respectively.

The ASR expansions of up to 0.3% which induced maximum crack widths of up to 2.4mm reduced the elastic modulus by between 20 to 40 (see Figure 5). The lowest elastic modulus was 27GN/m². This means that the elastic modulus is affected to a greater extent by ASR expansion than either compressive or tensile strength. A similar observation has been made by Blight and Alexander (1985).

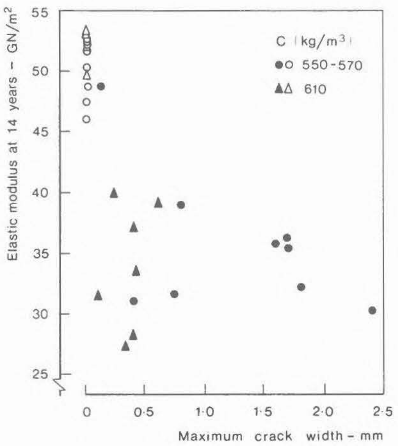

Figure 5. Relationship between elastic modulus at 14 years and maximum crack width

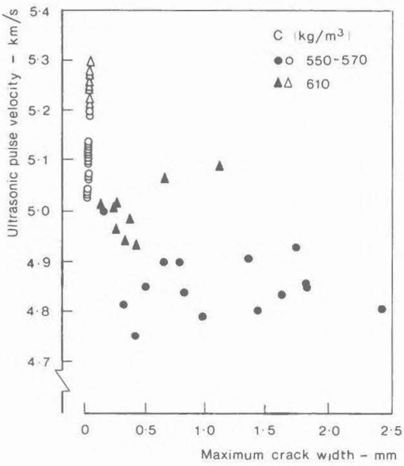

Figure 6. Relationship between ultrasonic pulse velocity and maximum crack width

Ultrasonic Pulse Velocity

The ultrasonic pulse velocity (UPV) is sometimes used as a means of checking the quality of concrete in a structure which is believed to be affected by ASR. A pulse velocity of above about 4km/s is considered to indicate good quality concrete and below 3km/s poor quality concrete. (Jones and Gatfield, 1955; Whitehurst, 1951). Figure 6 shows the relationship between UPV and maximum crack width. The minimum UPV was 4.7 km/s indicating that all the cracked concretes according to this technique were of high quality which is in agreement with their measured strengths (see Figures 2 and 3). The reduction in UPV caused by ASR expansion and cracking was between 0.1 and 0.4 km/s showing that the UPV is an insensitive indicator of ASR damage.

CONCLUSIONS

1. The presence of a reactive constituent in the Thames Valley sand induced cracking due to ASR in under 56 days in concrete cubes stored under water at 20°C.
2. At an age of 14 years no concretes with original alkali contents below 5.8 kg/m^3 had cracked due to ASR.
3. Considerable evidence of reaction was found in both uncracked and cracked cubes.
4. Where ASR had caused visible cracking the compressive strength was reduced by 10 to 15%, the indirect tensile strength by 15 to 20% and the elastic modulus by 20 to 40%.
5. For the '70' grade concrete the minimum observed values at 14 years were:

Compressive strength - cracked $84MN/m^2$; uncracked 103 MN/m^2
Tensile strength - cracked $4.9MN/m^2$; uncracked 6.0 MN/m^2
Elastic modulus - cracked $30GN/m^2$; uncracked 46.0 GN/m^2

6. Cracking and expansion due to ASR reduced the UPV from 5.10 ± 0.05 to

4.87 ± 0.06km/s for the 70 grade concrete and from 5.26 ± 0.03 to 4.87 ± 0.07km/s for the 90 grade concrete. These differences, whilst statistically significant do not provide evidence of inadequacy of the concretes in question.

ACKNOWLEDGEMENTS

The author is grateful to Mr D Gooch and Mr M P Webster for carrying out many of the tests and to Mr R M Grove for the preparation and examination of the thin sections.

BIBLIOGRAPHY

Blight, G.E. and Alexander, M.G. 1985, Concr. Concrete Society of South Africa, 10, 14-23

Jones, R., and Gatfield, E.N. 1951, DSIR Road Research Technical Paper, No.34

Nixon, P.J. and Bollinghaus, R. 1985. Durability Bldg. Mat.,2, 243-248.

Oberholster, R.E. and Westra, W.B.1981. In Proceedings of the Fifth International Conference on Alkali-aggregate Reaction in Concrete, paper S252/31, NBRI Pretoria.

Swamy, R.N., and Al-Asali, M.M. 1986, Private Communication, Sheffield University, U.K.

Whitehurst, E.A. 1951, J.Am.Concr.Inst.Proc., 47, 433-444.