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THE EFFECTS OF ALKALI SILICA REACTION ON THE PUNCHING SHEAR STRENGTH OF REINFORCED CONCRETE SLABS

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1. INTRODUCTION

This paper reports the results of punching shear tests on reinforced concrete slabs cracked due to alkali silica reaction (ASR). It has been found that for free expansions of up to about 6000 microstrain, alkali silica reaction did not have a significant effect on the punching shear strength of a slab although the tensile strength of the concrete was reduced by about 25%. In addition, the ductility of a slab with both top and bottom flexural reinforcement was found to increase as a result of alkali silica reaction expansion. This increase in ductility did not occur to such a large extent for slabs with only bottom flexural reinforcement. This difference in behaviour is attributed to the different distributions of compressive stress in the concrete induced by the internal restraint to expansion.

2. TEST DETAILS

2.1 Concrete

The concrete was composed of high alkali cement with a sodium oxide equivalent of 0.85%, Thames Valley sand (0-5 mm) as reactive fine aggregate, and limestone (5-10 mm) as inert coarse aggregate. The alkali content of the concrete was increased either to 7kg/m³ by adding 2.83kg/m³ of sodium sulphate and 6.65kg/m³ of potassium sulphate or to 9kg/m³ by adding 10.1kg/m³ of potassium hydroxide.

2.2 Slabs

The slabs were 80 mm thick and either 610 mm or 406 mm square. The reinforcement consisted of an isotropic mesh of 6 mm deformed bars, with a yield stress of 534 N/mm², at either 50 or 100 mm centres with 10 mm cover in either the bottom only or both the top and bottom of a slab. No shear steel was provided. Details of the slabs are given in Table 1. The slabs were cast in twelve pours each of four slabs. Pours 2 and 4 have not been included because there appears to have been errors made during casting of the control specimens. The four slabs in each of pours 1,3,6 and 7 were tested at different ages so as to investigate the effects of expansion, steel percentage and steel location. The four slabs of pour 5 were tested at the same age but with different punch diameters (see 2.4). Pour 8 was used to study the effect of external restraint and the slabs had reinforcement only within a central square of 406 mm, which was the external diameter of the punching test support ring (see 2.4). Slabs 8/1 and 8/2 were both reinforced in the bottom only, but slab 8/2 was restrained externally by a steel channel section with a cross-sectional area of 853 mm^2; whilst slabs 8/3 and 8/4 had reinforcement in both faces with slab 8/4 restrained by a steel channel section. The slabs of pours 9 to 12 were 406 mm square, which was the external diameter of the punching test support ring, and, thus, the reinforcement was poorly anchored. However, the bars of pours 11 and 12 were bent at their ends to improve anchorage.

Table 1 Slab details

Pour	Size mm	Reinforcement Spacing	Reinforcement Position*	Alkali Kg/cu.m.
1	610	100	B	9
3	610	100	T	7
5	610	100	T	7
6	610	50	B	7
7	610	50	T	7
8	610	100	L	9
9	406	100	B	9
10	406	100	T	9
11	406	100	BH	9
12	406	100	TH	9

* B = Bottom face
T = Top and bottom faces
BH = Bottom face, bends at ends
TH = Top and bottom faces, bends at ends
L = Local over centre 406 mm (See text)

2.3 Control Specimens

100 mm cubes and 100 x 200 mm cylinders were cast with the slabs. The cubes were tested in compression either in the conventional manner or with friction eliminating pads between a cube and the testing machine platens to enable the uniaxial compressive strength to be determined [1]. The cylinders were monitored for expansion and ultrasonic pulse velocity, and used to obtain the splitting tensile strength.

2.4 Test Procedures

The slabs and associated control specimens were stored under damp hessian and polythene sheets for 28 days after casting. They were then transferred to tanks where they were stored under water kept at 38°C. At intervals of one month expansion measurements on the slabs and cylinders and pulse velocity measurements on the cylinders were taken. The slabs were tested in punching shear when the free expansions of the cylinders attained predetermined values.

In a punching test, a slab was bedded on a support ring of 366 mm internal and 406 mm external diameter. A central load was applied through a punch of, generally, 80 mm diameter. However, slabs 5/1, 5/3 and 5/4 were loaded through 40, 160 and 240 mm diameter punches, respectively. The punching tests were conducted under displacement control so that the post-peak behaviour could be monitored: 0.25 mm increments of central displacement were applied up to a maximum of 10 mm, and the load at each increment recorded.

3. RESULTS

3.1 Concrete Strength

Measured concrete strengths are given in Table 2. The values for zero expansion were obtained at about 28 days. The compressive cube and uniaxial strengths increased due to continuing hydration until cracking occurred due to ASR at about 1500 microstrain. At larger expansions the compressive cube and uniaxial strengths gradually decreased so that at 6000 microstrain they were about 90 and 75%, respectively, of their peak values. Hence, uniaxial strength decreased at a faster rate than cube strength: the ratio of these two strengths decreased from the usual value of 0.8 at zero expansion to about 0.6 at 6000 microstrain free expansion.

Table 2 Results

Slab	Expansion Microstrain	Concrete Strength (N/mm^2) Cube	Uniaxial	Tension	Load (kN) Peak	Residual	Normalised Load*
1/1	0	45.1	35.2	3.56	118	26	20.0
1/2	1320	56.1	38.8	2.94	108	25	17.3
1/3	4220	56.2	35.5	2.72	119	16	20.0
1/4	5520	56.0	31.4	2.81	125	22	22.3
3/1	0	56.0	44.6	4.30	127	35	19.0
3/2	2370	64.3	50.7	3.69	138	29	19.4
3/3	5370	58.4	42.7	3.03	136	26	20.8
3/4	6410	56.2	38.9	3.08	101	30	16.1
5/1					79	26	12.3
5/2	5670	62.0	41.2	3.32	103	27	16.1
5/3					197	72	30.7
5/4					315	111	49.1
6/1	0	56.8	45.7	4.09	152	32	22.5
6/2	1380	68.0	52.8	3.93	156	45	21.4
6/3	4940	64.4	41.2	3.42	144	33	22.4
6/4	5440	64.6	38.3	2.95	138	37	22.2
7/1	0	56.3	43.2	4.12	139	56	21.1
7/2	1850	67.1	37.4	3.59	168	61	27.5
7/3	4810	59.6	40.8	3.16	172	63	26.9
7/4	5770	61.1	41.8	3.15	145	62	22.5
8/1					92	20	16.8
8/2	5800	51.5	30.3	2.60	146	20	26.6
8/3					97	47	17.6
8/4					153	39	27.9
9/1	5490	50.2	30.8	2.99	82	13	14.8
10/1	5890	51.5	29.0	2.79	94	27	17.4
11/1	6050	47.5	29.7	2.90	77	27	14.2
12/1	6040	48.3	30.1	2.87	111	28	20.1

*Normalised load = Peak load/ $\sqrt{\text{Uniaxial strength}}$

In contrast to the compressive strengths the indirect tensile strength was decreased at all levels of expansion, and was about 75% of its peak (28 day) value when the free expansion was 6000 microstrain.

the central region subjected to punching. Slab 1/4 had reinforcement extending beyond the support ring to the edges of the slab, and thus ring tension could develop in the slab outside the support. The ring tension applied in-plane restraint to the central region. Slab 8/1 had reinforcement extending only to the edge of the support ring, and, thus, could not develop significant ring tension, whilst slab 8/2 was reinforced as slab 8/1 but was restrained at the slab edges by steel channel sections. The slabs were tested at similar values of free expansion of the order of 5800 microstrain. As expected the normalised peak loads increased as the degree of lateral restraint increased (i.e. in the order 8/1,1/4,8/2), but the residual loads were similar to each other. Similar behaviour occurred for slabs 8/3, 3/3 and 8/4 which were reinforced in both faces.

3.2.4 Reinforcement Anchorage Pour 9 consisted of 406 mm square slabs (i.e. equal to the outer diameter of the support ring) with straight bars which were, thus, poorly anchored. Pour 11 consisted of slabs of the same size as those of pour 9, but the ends of the bars bent to improve their anchorage. Pours 10 and 12 were similar to pours 9 and 11, respectively, but had reinforcement in both faces. Slabs 9/1 and 11/1 can be compared with slab 1/4 which had reinforcement extending at least 97 mm (16 times the bar diameter) beyond the support ring and was, thus, well anchored. The normalised peak loads of slabs 9/1 and 11/1, with poor anchorages, were only about 65% of that of slab 1/4 with well anchored reinforcement. However, strength reductions were not apparent for poorly anchored slabs 10/1 and 12/1 (with top reinforcement) when compared with well anchored slabs 3/3 and 3/4.

4. CONCLUSIONS

1. ASR cracking reduced the uniaxial compressive strength of concrete more than the cube strength.
2. The punching shear strength and residual load carrying capacity of reinforced concrete slabs were found not to be affected by severe ASR cracking induced by free expansions of up to 6000 microstrain provided that allowance was made for the actual uniaxial compressive strength of the concrete at the time of test.
3. ASR cracking increased the ductility of a punching shear failure, particularly when a slab had both top and bottom reinforcement.

REFERENCES

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