

ACRYLIC RUBBER COATING TO CONTROL ALKALI SILICA REACTIVITY

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The paper presents test data on the effectiveness of a highly elastic acrylic rubber coating in controlling the deleterious effects of ASR in concrete. The test specimens were subjected to outdoor exposure and three accelerated aggressive regimes. Both uncoated and coated specimens were tested and an epoxy resin coating was also used for comparison purposes. The acrylic rubber coating gave the best results and slowed the alkali silica reactivity in all cases and maintained about 80% of the original concrete strength.

INTRODUCTION

Alkali-aggregate reactions are known to cause one of the major forms of deterioration of concrete structures, sometimes prematurely (1). Alkali-silica reactivity (ASR) is a particular form of this chemical reactivity involving alkali hydroxides from the cement binder and reactive forms of silica in the aggregates, but which also requires water for the reaction to initiate and propagate. There is much evidence to show that marine environments can accelerate ASR by intrusion of chloride ions (1, 2).

Alkali silica reactivity leads to expansion of concrete which results in cracking, spalling and pop outs, and occasionally, in serious loss of structural strength, stiffness and stability. Attack by ASR does not necessarily imply or lead to structural failure, (3), and in many instances, structures diagnosed to be suffering from ASR can be repaired and protected from further attack (1, 3-4). In literature, several methods of protecting ASR-damaged structures have been reported (5, 6). Although generally seemingly good results have been monitored with some of them, much more data are required to establish their long-term effectiveness in protecting ASR-affected structures from further deterioration.

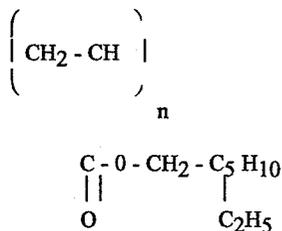
Surface or barrier coatings have a long but chequered history of effectiveness when applied to concrete to protect it from external agencies. If they are to be effective in protecting and preserving existing as well as new structures, they have to fulfil three basic requirements (7). First, they should prevent intrusion of aggressive agents such as water and chloride ions into concrete. Secondly, they should equally have the ability to permit evaporation of moisture trapped in concrete. Thirdly, they should have crack bridging ability to maintain the coating continuity and integrity. This paper presents a detailed study of the effectiveness of a high elastic rubber type surface coating (known as Aron Wall) in controlling expansion due to ASR, and in maintaining the engineering properties of strength and stiffness of the affected concrete.

EXPERIMENTAL DETAILSConcrete Mix Details

A concrete mix of 1:1.125:2.0 (cement:sand:coarse aggregate) by weight, having a cement content of 520 kg/m³ and a water-cement ratio of 0.44 was used in the tests. Ordinary portland cement, with equivalent sodium oxide content of 0.62%, washed and dried river sand, and river gravel rounded, with a maximum size of 25 mm were used as concrete materials. The alkali content of the concrete mix was increased to 1% equivalent sodium oxide by adding the necessary sodium hydroxide to the cement. The reactive aggregate used was an amorphous fused silica (2), which contained 99.7% pure silica and had a particle size of 0.14 to 0.6 mm.

Surface Coating

The development of the acrylic rubber coating to protect concrete from external attack has been reported by the authors (7-9). Basically the coating consists of a primer, base coat and top coat, with an overall thickness of about 1000 µm. The acrylic rubber contains 54% of acrylic polymer by weight, the rest being made up of inorganic filler and pigment. The main component of the base coat is 2-Ethyl hexyl acrylate (c.a. 92%) with the formula



The top coat used in these tests was of acrylic urethane of 100 µm thickness (7). For comparison purposes an epoxy resin coating of 500 µm thickness was also used. The diffusion properties and the crack bridging abilities of the coatings are shown in Table 1 (7).

Test Details

The test specimens used in this study were 100x100x500 mm prisms coated on all four sides. Both uncoated and coated specimens were exposed to one control and three accelerated regimes as follows:

- | | |
|----------|---|
| Test A - | Outdoor exposure: Control |
| Test B - | Salt spray shower with 3% NaCl solution at 50°C for 2 days and drying at 50°C for 1 day. |
| Test C - | High humidity test - 90% RH at 50°C |
| Test D - | Freeze-thaw test by immersion in 3% NaCl solution at a temperature cycle of -20°C (1 day) and 30°C (1 day). |

The expansion during the exposure period was measured in two ways - over a gauge length of 200 mm, and the overall expansion of the 500 mm long prism. During the exposure tests, the surface appearance of the coatings was carefully monitored and recorded. At the end of

the exposure period, water absorption, adhesion strength of the coatings, flexural strength (four-point bending), and compressive strength (modified test on the broken parts of the flexural test) were determined.

TEST RESULTS AND DISCUSSION

Surface Appearance

Table 2 summarises the visual changes observed on the uncoated and coated specimens during the various exposure regimes. The uncoated specimens cracked due to ASR expansion at the age of 36 days for exposure tests A, B and C, and at 196 days for test D, although they all showed surface scaling at 36 days when subjected to freezing and thawing in salt water. The epoxy coating initially performed well when exposed outside, but showed slight cracking at 76 days. Under accelerated tests B, C and D, however, blistering and cracking occurred at 18 days, earlier than the uncoated specimens, largely due to its limited crack bridging ability as shown in Table 1. The acrylic rubber coating showed no visual deterioration at any stage in any of the exposure regimes. Its very high extensibility and crack bridging ability had been very effective, even if cracking due to ASR had occurred within the concrete prism. The overwhelming evidence of the results of Table 2 is that the acrylic rubber coating showed the best performance under natural weathering and a range of accelerated aggressive environments in which uncoated concrete, with high cement content and low water/binder ratio would not survive when subjected to alkali silica reactivity.

Concrete Expansion

Table 3 summarises the concrete expansions measured on all the test specimens at various stages of their exposure periods. Although the expansions were measured over two gauge lengths, the discussion here is focused on overall changes in length over the 500 mm gauge length.

Uncoated specimens. The uncoated specimens showed a gradual expansion when exposed outdoor, as expected, and at the end of about 300 days the expansion was 0.632%. All the accelerated exposure regimes were highly favourable to, and accelerated the alkali silica reactivity. Expansions within 10 days ranged from 0.34% to 0.53%, and at the end of 76 days, the expansions ranged from 0.55% to 1.12%. The wet and dry high temperature salt spray regime caused the most severe acceleration and total expansion, whilst both the high humidity/high temperature and the freeze-thaw regimes were almost equal in their effects but considerably less destructive than the salt spray regime. These results confirm the data reported earlier (2, 10) and indicate the salt spray test as the most useful and direct rapid test to monitor the deleterious expansion capability of reactive aggregates.

Epoxy coated specimens. When exposed to natural weathering, the epoxy coating was generally effective until it cracked at 76 days. Beyond this period, epoxy coated specimens showed higher expansions due to moisture intrusion through the cracks, and at 299 days, the epoxy coated specimens showed 0.73% expansion compared to 0.632% of the uncoated specimen. Under accelerated tests, the epoxy coating was most effective in the freeze-thaw test, and although the coating showed blistering and slight cracking towards the end, the expansion at 299 days was less than 50% of the uncoated specimen. Because of the limited crack bridging ability of the epoxy coating, it showed cracking early on when exposed to wet and dry salt spray and high temperature/high humidity regimes, and as a result, the epoxy coated specimens were not

effective or only marginally effective in controlling ASR expansion under these conditions. It is clear from these test results, and other data not presented here, that the major drawback of epoxy coatings is their brittleness, and lack of ability to bridge cracks in the underlying concrete which prevents them from being able to control concrete cracking due to ASR.

Acrylic rubber coating. The acrylic rubber coating was very effective in three of the four exposure regimes. Under outdoor exposure, the coating reduced expansion to 68% of that of the uncoated concrete. When exposed to the salt spray wet and dry cycling, the coating reduced the expansion to 73% of that of the uncoated specimen. Under the freeze-thaw regime, the coating was very effective and reduced the expansion of the uncoated concrete by almost 60%. However, the acrylic rubber coating, like the epoxy coating, was not effective when exposed to continuous high humidity. Obviously, under this condition, the concrete was able to retain sufficient moisture because of the high ambient humidity, and the expansion due to ASR continued to occur due to the availability of moisture.

The results shown in Tables 2 and 3 highlight two important performance characteristics of the acrylic rubber coating. First, the coating can remain intact, and maintain its continuity and integrity without cracking and damage even under very aggressive environmental conditions. Second, the coating can substantially slow down the alkali silica reactivity and the consequent expansion under conditions most favourable to ASR. In particular, there is no visible external deterioration to concrete affected by ASR, and any cracking is contained within the coating.

Water Absorption

The water absorbed by the test specimens exposed outdoor to natural weathering is shown in Fig. 1, and the relation between water absorption and overall expansion is shown in Fig. 2. The results show clearly that the acrylic rubber coating prevented moisture penetration, and protected the concrete as a water-proofing material. The implication of Fig. 2 is that in the case of the acrylic coating, ASR continued to progress due to the initial moisture contained in the concrete, in spite of the presence of the coating. There are thus practical considerations before applying surface coatings to concrete already affected by ASR.

Adhesion Strength

The adhesion strength of the two coatings after their various exposure regimes is shown in Table 4. It is shown that both the epoxy coating and the acrylic rubber coating maintained their adhesion to the concrete substrate even after severe exposure conditions.

Strength Properties

The flexural and compressive strength data obtained from the uncoated and coated specimens after various exposure regimes are shown in Table 5 and illustrated in Figs. 3 and 4. These results confirm that expansion due to ASR causes substantial losses in flexural strength and considerable reduction in compressive strength as reported earlier (11). The acrylic rubber coating, even though it did not prevent ASR expansion fully, enabled the concrete to maintain a high proportion of the concrete's original strengths. In bending, the maximum strength loss in the acrylic rubber coated specimens was about 20% compared to about 45% with the epoxy coated specimens. Under compression, the maximum strength loss was about 20% for the acrylic coated specimens compared to about 40% for the epoxy coated specimens. The uncoated

concretes, apart from their unacceptable losses in strength, were also unacceptably cracked to be serviceable.

CONCLUSIONS

The major conclusions derived from this study are as follows:

1. The epoxy coating showed substantial blistering and cracking under all exposure conditions, and was thus unable to control the expansion of concrete containing reactive aggregates. Nevertheless, under freezing and thawing in salt solution, the coating reduced expansion by about 50%.
2. The acrylic rubber coating remained intact and maintained its continuity and integrity without any cracking or other visible damage under all the exposure conditions.
3. The acrylic rubber coating substantially slowed down the alkali silica reactivity even under conditions most favourable for ASR. There was no visible external deterioration of concrete affected by ASR, and any cracking in the concrete was contained within the coating.
4. Under outdoor natural weathering, the acrylic rubber coating showed no water absorption, but the concrete was able to continue expansion due to its initial moisture content.
5. Both epoxy and acrylic rubber coatings maintained their adhesion to ASR affected concrete under all exposure conditions investigated.
6. Even though the acrylic rubber coating was unable to prevent ASR expansion due to the moisture already present in the concrete, it contained flexural and compressive strength losses to about 20% whereas with the epoxy coating strength losses amounted to 40% to 45%.
7. These results provide substantial evidence to show that the acrylic rubber coating has the capability to prevent the intrusion of water and chloride ions into concrete whilst at the same time providing sufficient diffusivity for moisture initially contained in the concrete.

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TABLE 1-Properties of Coatings

Properties	Acrylic rubber coating	Epoxy resin coating
Crack bridging (20°C)	4.6 mm maximum	0.5 mm maximum
Diffusion properties		
water	0.56 g/m ² /day	0.12 g/m ² /day
water vapor	12.5 g/m ² /day	3.8 g/m ² /day
chloride ion	1.2x10 ⁻⁴ mg/cm ² /day	1.0x10 ⁻⁴ mg/cm ² /day

TABLE 2-Visual Appearance of Uncoated and Coated Surfaces

Test	Coating	Early changes	Final change
Test A Outdoor exposure	Acrylic	No change	No change
	Epoxy	Slight cracking (0.2mm) 76 days	Cracking (0.2mm)
	Uncoated	Cracking (0.2-0.5mm) 36 days	Cracking (0.2-0.5mm)
Test B Salt shower & dry cycle	Acrylic	No change	No change
	Epoxy	Cracking and blisters 18 days	Blisters Cracking (0.15-0.4mm)
	Uncoated	Cracking 36 days	Cracking (0.45-0.9mm)
Test C High temp. & humidity	Acrylic	No change	No change
	Epoxy	Cracking 18 days	Cracking (0.15-0.3mm)
	Uncoated	Cracking 36 days	Cracking (0.25-0.3mm)
Test D Freeze & thaw cycle	Acrylic	No change	No change
	Epoxy	Blisters 18 days	Blisters and slight cracking
	Uncoated	Scaling 36 days Scaling and cracking - 196 days	Scaling and cracking

TABLE 3-Percentage Expansion of Test Specimens

Test	Coating	Age in days								
			9	18	36	44	76	84	189	299
Test A outdoor exposure	Acrylic	L	0.010	0.012	-	0.086	-	0.282	0.382	0.430
		S	0.006	0.018	-	0.097	-	0.293	0.346	0.341
	Epoxy	L	0.017	0.041	-	0.172	-	0.458	0.684	0.725
		S	0.021	0.050	-	0.198	-	0.499	0.771	0.779
	Uncoated	L	0.018	0.022	-	0.185	-	0.406	0.600	0.632
		S	0.019	0.026	-	0.177	-	0.389	0.607	0.776
Test B Salt shower & dry cycle	Acrylic	L	0.371	0.520	0.673	-	0.818	-	-	-
		S	0.375	0.525	0.605	-	0.616	-	-	-
	Epoxy	L	0.464	0.695	0.910	-	1.207	-	-	-
		S	0.484	0.729	0.962	-	1.254	-	-	-
	Uncoated	L	0.527	0.944	0.941	-	1.115	-	-	-
		S	0.667	0.902	1.085	-	1.365	-	-	-
Test C High temp & humidity	Acrylic	L	0.316	0.427	0.487	-	0.552	-	-	-
	Epoxy	L	0.274	0.387	0.448	-	0.511	-	-	-
	Uncoated	L	0.339	0.431	0.496	-	0.579	-	196 days	291 days
Test D Freeze & thaw cycle	Acrylic	L	-0.006	-0.001	0.026	-	0.095	-	0.236	0.305
	Epoxy	L	-0.008	-0.004	0.032	-	0.112	-	0.250	0.336
	Uncoated	L	-0.409	0.450	0.484	-	0.549	-	0.643	0.717

L - overall expansion; S - expansion over 200 mm

TABLE 4 -Adhesion Strength, MPa

Test	Age	Acrylic	Epoxy
Initial	-	1.52	2.18
Test A	84 days	1.42	1.45
	299 days	1.30	1.38
Test B	76 days	1.23	1.37
Test C	76 days	1.72	1.41

TABLE 5-Flexural and Compressive Strength Data

Test	Coating	Age	Bending max load kN	Compressive strength MPa	Age	Bending max load kN	Compressiv e strength MPa
Test A Outdoor exposure	Acrylic	84 days	11.76	44.8	299 days	11.76	39.7
	Epoxy		10.78	38.9		8.82	29.9
	Uncoated		7.84	47.7		6.86	48.1
Test B Salt shower & dry cycle	Acrylic	76 days	9.80	43.4			
	Epoxy		5.88	32.4			
	Uncoated		3.92	39.1			
Test C High temp & humidity	Acrylic	76 days	11.76	49.1			
	Epoxy		11.76	48.1			
	Uncoated		10.78	48.2			

* Initial data: Bending max load 12,74 kN at 28 days Compressive strength 51.80 MPa

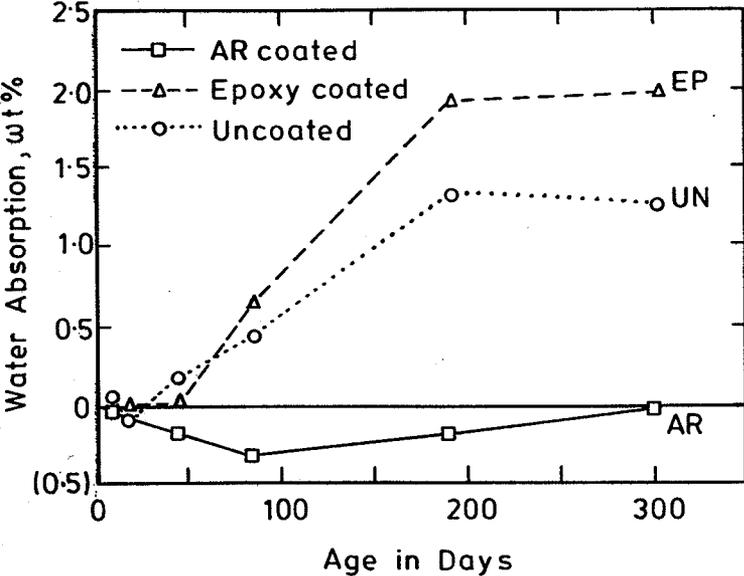


Figure 1 Water absorption of specimens exposed outside

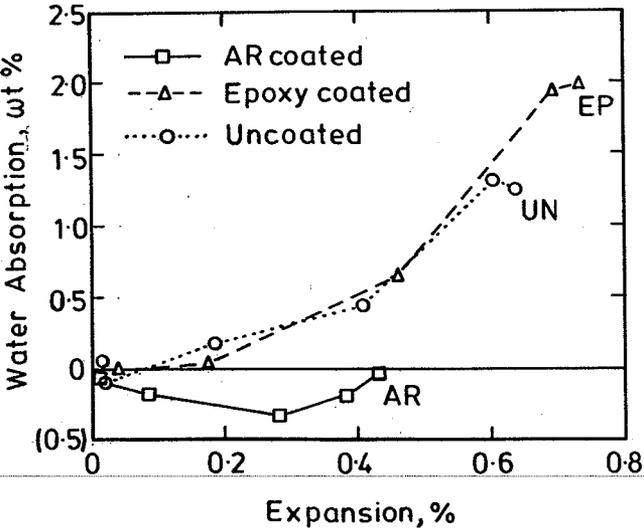


Figure 2 Relation between water absorption and expansion

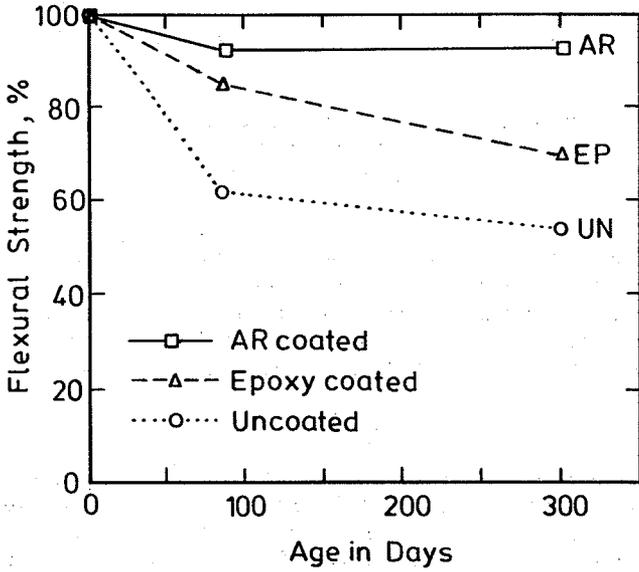


Figure 3 Effect of ASR on bending strength - outdoor exposure

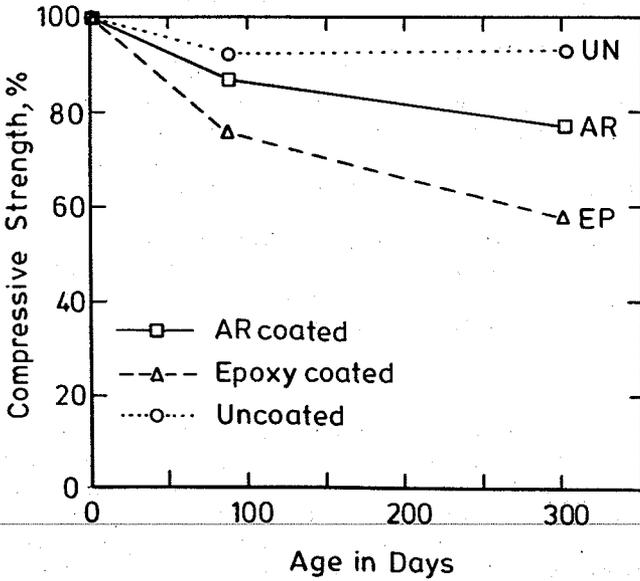


Figure 4 Effect of ASR on compressive strength - outdoor exposure