A FLEXIBLE ACRYLIC RUBBER SURFACE COATING
A CURE FOR ASR EXPANSION

S. Tanikawa
Toagosei Co Ltd,
1-1 Funami-cho,
Minato-ku, Nagoya 455
JAPAN

J-C Laiw
R & D Section
Taiwan Area National Expressway Engineering Bureau,
No 141, Minsheng E Road,
Taipei
TAIWAN

R. N. Swamy
Department of Mechanical and Process Engineering,
University of Sheffield,
Mappin Street,
Sheffield S1 3JD,
U K

ABSTRACT

Previous tests conducted by the authors have shown that a carefully developed acrylic rubber surface coating can prevent the intrusion of moisture and chlorides into concrete. This paper shows that such a coating can control the expansive strains due to alkali-aggregate reactivity. Concrete prisms containing synthetic reactive aggregates, and without and with this surface coating were exposed to water at 38°C and 4% sodium chloride solution at 20°C and 38°C with the test specimens fully or half immersed or subjected to wetting and drying. The coating was applied before exposure, after 0.15% expansion and after 0.35% expansion. It is shown that the coating was able to effect substantial and significant reductions in the expansions, particularly when it was applied prior to any reactivity, as well as when it was applied to cracked concrete undergoing alkali-aggregate reactivity and exposed to unfriendly salt-laden environments. However, the coating could not prevent expansion totally because of the presence of all the necessary reactive ingredients within the concrete right from the beginning. In real structures a total strategy involving the benefits of such protective coating systems can ensure continued service life without losing structural integrity.

Keywords: coating, expansion, protection, structures, ASR.

INTRODUCTION

When considering control of alkali-aggregate reactivity (AAR) and its effects on concrete materials and concrete structures, two major considerations confront us. One is the knowledge that AAR is basically a chemical reaction, internal to concrete, and time-dependent. The second is that the presence of moisture is essential and critical for the initiation and continuation of the reactivity, and its undesirable effects of cracking and, loss of strength and stiffness. Many tests have shown that AAR can be slowed down or even halted if the concrete is kept dry (Gudmundsson, G. & Asgeirsson, H. 1983; Ludwig, 1989). Since a certain level of humidity is required to promote AAR (Stark, 1990), methods that prevent the penetration of moisture into concrete made with alkali-reactive aggregates could also minimize the risk of expansion and subsequent cracking.

Surface or barrier coatings on concrete can provide an effective barrier to chlorides and water penetration (Swamy & Tanikawa, 1989a, 1993b), and should therefore be able to provide a much-needed protection for concrete elements suffering from AAR (Swamy & Tanikawa, 1992c). Test data show that the acrylic rubber coating developed by the authors can significantly slow down alkali-silica reactivity (ASR), even when the concrete is exposed to conditions favourable to ASR, and that the strength loss can be contained to about 20% (Swamy and Tanikawa, 1992c). Many tests have also shown that for a concrete element made with a given alkalinity in the concrete and type and amount of reactive aggregates, the exposure environment is the most critical factor in determining the rate and extent of expansion that will occur in that concrete. The effectiveness and ability of any surface coating on concrete to control the reactivity and its effects will then depend on the characteristics of the coating to remain intact, and maintain its integrity and diffusion properties when exposed to a variety of environments.

The aim of this paper is to investigate this effectiveness and ability of the acrylic rubber coating to control expansion and cracking when exposed to different environments and to variable conditions of water availability. In particular, the role and effectiveness of the surface coating in controlling expansion when applied to existing and deteriorating concrete, which has already suffered a degree of expansion is examined. Concrete prisms containing reactive aggregates, and without or with the protective coating were exposed to water and NaCl environments in a variety of water-availability conditions, and the expansion measured for about a year. The results are presented and critically analysed in this paper.

EXPERIMENTAL DETAILS

75x75x300 mm concrete prisms were used in these tests. The concrete mixture contained ordinary portland cement at 350 kg/m^3, and the water-binder ratio was kept constant at 0.60. A high alkali portland cement was used, and the concrete had an alkali content of 3.89 kg/m^3 sodium oxide equivalent. The fine and coarse aggregates used were washed natural aggregates: they contained very little chloride, and were considered innocuous so far as AAR was concerned. Fused silica, a moderately reactive aggregate, suitable for ASR expansion studies in the laboratory (Swamy and

Al-Asali, 1986a, 1988b), was used to create expansion by replacing the fine aggregate by 5% and the total aggregate weight by 15%. The reactive aggregate contained over 99.5% pure silica with practically no alkali in it. The test specimens were demoulded 24 hours after casting, then stored in 20°C water for 6 days, followed by ambient curing in air for 21 days, prior to exposure to other environments to initiate expansion.

Surface coating

The surface coating used in these tests is a highly elastic three-layer coating composed of primer, base coat and top coat. The main component of the base coat is 2-Ethyl hexyl acrylate, with a total thickness of about 1000 μm (Swamy and Tanikawa, 1989a, 1993b). After 28 days curing, the prisms were coated with the surface coating at three different stages: (1) before expansion and before the test specimens were exposed to different environments; (2) after the prisms had reached an expansion of about 0.15%; and, (3) after the prisms had reached an expansion of about 0.35%. These three conditions were adopted to simulate applications in practice, when the coating can be applied to a structure suspected of ASR activity but before any expansion has taken place, and the situations where deterioration due to ASR has commenced, and different degrees of cracking are evident.

Exposure regime

Three kinds of exposure environment were used in this study, namely 38°C water, and 4% sodium chloride solution at 20°C and 38°C. Under each exposure environment, the test specimens were exposed as follows.
1. Half immersion in water or salt solution.
2. Half immersion in water or salt solution, and the other half exposed to ambient conditions.
3. Full immersion in water or salt solution for 7 days and drying in ambient air for 7 days i.e. 7 day wetting/drying cycles.

The expansion was measured over the length of the specimen of 300 mm.

TEST RESULTS AND DISCUSSION

The expansion behaviour with time of the uncoated control and coated specimens under different exposure environments and modes of exposure are shown in Figs. 1 to 9. The final expansion values measured after 343 days of exposure is summarized in Table 1. The summary data given in Table 1 show that for the coated specimens, full immersion was the most severe exposure mode for ASR expansion. For uncoated specimens, on the other hand, the wetting/drying cycles caused the maximum expansion, except when exposed to NaCl at 38°C. In this type of exposure condition it was observed that salt with time, had crystallised on the surfaces of the concrete test specimens in the upper parts exposed to air. Obviously, chloride ions had been absorbed into the concrete and transported by capillary suction on to the non-immersed upper sections of the specimens, and then migrated on to the concrete surfaces. Similar behaviour was also observed when the uncoated specimens were
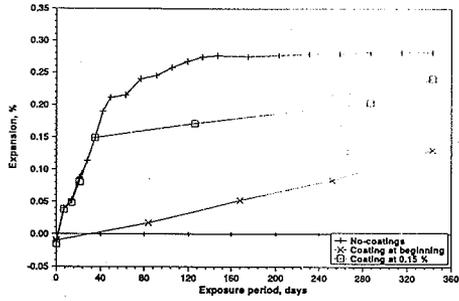
Figure 1. Expansion of 75 x 75 x 300 mm prisms without coating and with coating applied at different stages under 20°C NaCl: full immersion.
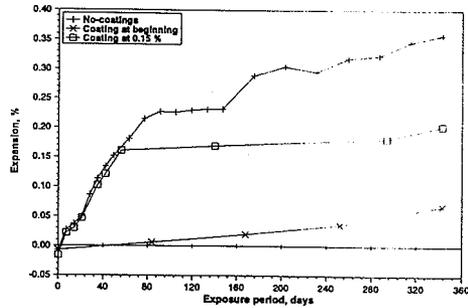

Figure 2. Expansion of 75 x 75 x 300 mm prisms without coating and with coating applied at different stages under 20°C NaCl: half immersion.
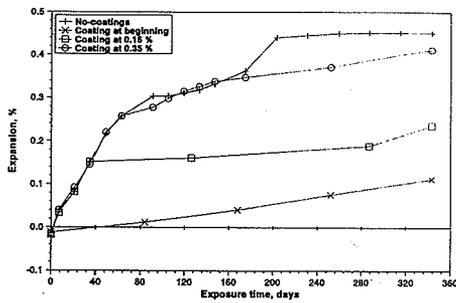

Figure 3. Expansion of 75 x 75 x 300 mm prisms without and with coating applied at different stages under 20°C NaCl: 7 days wetting/drying.
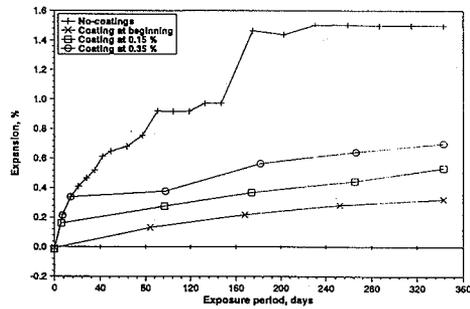

Figure 4. Expansion of 75 x 75 x 300 mm prisms without and with coating applied at different stages under 38°C NaCl: full immersion.
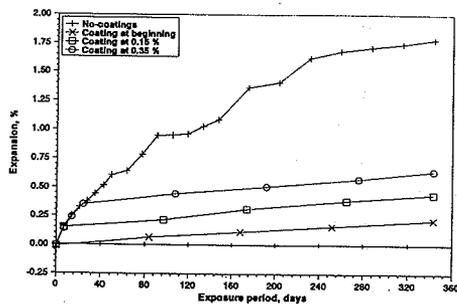

Figure 5. Expansion of 75 x 75 x 300 mm prisms without coating and with coating applied at different stages under 38°C NaCl: half immersions.
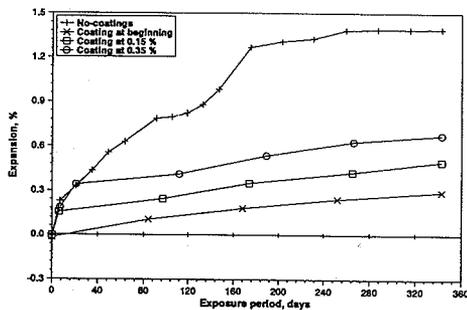

Figure 6. Expansion of 75 x 75 x 300 mm prisms without and with coating applied at different stages under 38°C NaCl: 7 days wetting/drying.
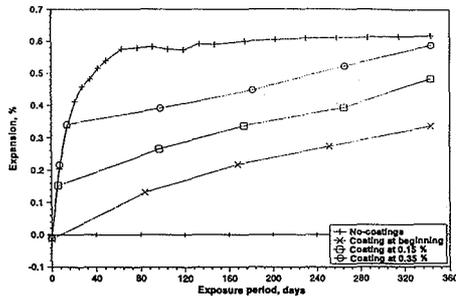
Figure 7. Expansion of 75 x 75 x 300 mm prisms without coating and with coating applied at different stages under 38°C water: full immersion.
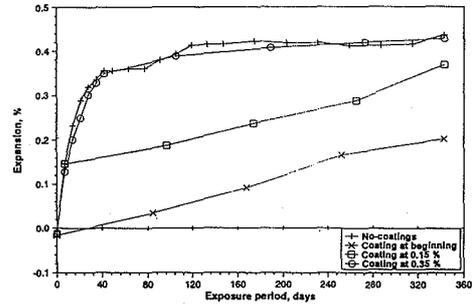

Figure 8. Expansion of 75 x 75 x 300 mm prisms without and with coating applied at different stages under 38°C water: half immersion.
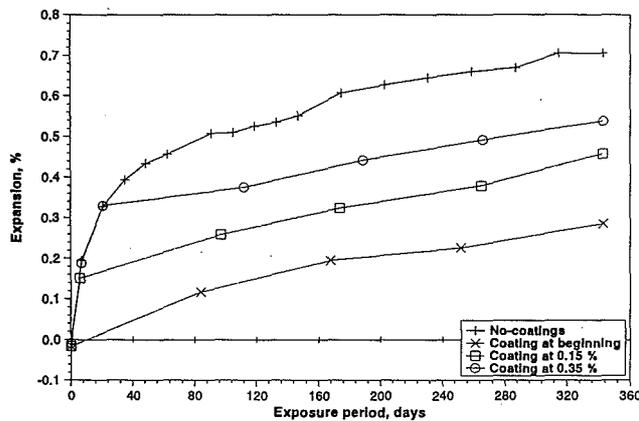

Figure 9. Expansion of 75 x 75 x 300 mm prisms without coating and with coating applied at different stages under 38°C water: 7 days wetting/drying.

Table 1 Expansion of prisms without coating and with coating applied at different stages after 343 days exposure(Unit : %)

Exposure environment	Coating application time	Exposure modes		
		Full immersion	Half immersion	7 days wetting /drying
20 °C NaCl	None	0.282(100 %)	0.358(100 %)	0.451(100 %)
	Coated before exposure	0.131(46 %)	0.068(19 %)	0.112(25 %)
	Coated at 0.15 %	0.241(85 %)	0.203(57 %)	0.236(52 %)
	Coated at 0.35 %	-	-	0.412(91 %)
38 °C NaCl	None	1.498(100 %)	1.785(100 %)	1.392(100 %)
	Coated before exposure	0.324(22 %)	0.214(12 %)	0.292(21 %)
	Coated at 0.15 %	0.535(36 %)	0.441(25 %)	0.495(36 %)
	Coated at 0.35 %	0.702(47 %)	0.641(36 %)	0.674(52 %)
38 °C Water	None	0.618(100 %)	0.436(100 %)	0.704(100 %)
	Coated before exposure	0.336(54 %)	0.202(46 %)	0.285(40 %)
	Coated at 0.15 %	0.485(78 %)	0.369(85 %)	0.458(65 %)
	Coated at 0.35 %	0.588(95 %)	0.427(98 %)	0.537(76 %)

exposed to NaCl solution at 20°C. This chloride transportation into the body of concrete is considered to be partly responsible for the increased expansion in the half immersion mode. The surface coating, on the other hand, forms a barrier on the surface of the concrete, thus isolating the concrete from the outside environment. The higher alkali concentration due to water transportation had therefore not built up as in the case of uncoated specimens during the drying period or in the parts exposed to air.

The results of the expansion tests given in Figs. 1 to 9 show that the coating has been unable to fully prevent the ASR expansion. This might give the impression that the coating is not fully effective and efficient in counteracting the expansive effects of ASR. It should, however, be borne in mind that the concrete mixture used in the tests had a water-binder ratio of 0.6, and that the ingredients for expansive reactions were already incorporated within the mix. Preventing further moisture penetration into the concrete is therefore not likely to prevent the chemical interactions being initiated within the concrete from the reactive ingredients already present. Even then, coating concrete before expansion is initiated, is a very effective method of controlling destructive expansive strains, particularly in wet and highly alkaline environment as shown in Figs. 4 to 6. The percentage reduction in expansion in this case varied from about 50% to 90% compared to the expansive strains in the uncoated concrete, depending upon the environment and mode of exposure. The maximum expansion recorded in the coated specimens was only 0.32 to 0.34% compared to about 1.8% when uncoated concrete was exposed to a hot and humid chloride environment.

Coating concrete after ASR expansion has occurred is always likely to be less effective than when the concrete is coated prior to any expansion. In the tests reported here, coating was also applied after ASR expansions of about 0.15% and 0.35%. At these expansive strains, extensive cracking had occurred, and further moisture and chloride had penetrated the concrete through these cracks. Under these circumstances it is unrealistic to expect any protective coating system to be able to totally prevent further expansion, because the ingredients for further expansion are already trapped in the concrete. Even then, Figs. 1 to 9 and Table 1 show reductions in percentage expansions varying from 15% to 75% for prisms coated after exhibiting 0.15% expansion, and about 10% to 65% for prisms coated after 0.35% expansion. What is significant, however, is the fact that when concrete is exposed to a wet chloride environment at temperatures of the order of 38°C, the reduction in expansion due to the provision of a protective surface coating can be between about 50% and 75%. These are major and impressive achievements of the coating, considering the material distress and structural degradations that are likely to occur if expansions are allowed to continue at the same rate.

The results of this study showing the protective effects of the surface coating when applied even after concrete expansions of 0.15% and 0.35% have occurred, have another important message. Because of the nature of AAR expansions - internal, chemical and time-dependent, the use of a single protective technique alone is unlikely to stop further expansion in AAR-affected concrete. On the other hand, a whole design strategy needs to be developed, in which the protective coating forms a major component, which then can and should be able to play an important role in reducing material degradation and structural instability arising from AAR (Swamy, 1995). Such a global strategy is under investigation and the results will be reported in due course.

The results of this study show that the best benefits of the acrylic rubber coating can be derived when it is applied to ASR-affected structures prior to visible signs of cracking. On the other hand, the data also provide evidence that the coating, even when applied to deteriorating and cracked concrete, can still substantially reduce subsequent damage and deterioration. Combining the coating with other preventive techniques can then show the way forward to preserve and enhance the durable service life of ASR-affected structures.

CONCLUSIONS

The major conclusions derived from this study are as follows:
1. The acrylic rubber coating reported here, when applied to concrete surfaces before any expansion occurs, can reduce the ASR expansion very significantly by 50% to 90%, depending on the environment and exposure mode. In a wet chloride environment at 38°C, the coated specimens showed substantially reduced expansions of 0.2% to 0.32% compared to 1.4% to 1.8% of uncoated concrete exposed to similar environments.
2. When the acrylic rubber coating is applied after concrete ASR expansions of about 0.15% and 0.35% had occurred, the percentage reduction in expansion varied from about 15% to 75% for the first case and 10% to 65% for the second case. In a wet chloride environment at 38°C, the reduction in expansion was very significant, varying between 50% and 75%. Concrete expansive strains of 1.4% to 1.8% were reduced by the coating to 0.65% to 0.7%.
3. The results taken as a whole show that the use of acrylic rubber coating of the type reported here, when applied prior to the occurrence of expansive reactions, can be very effective and efficient in significantly reducing destructive ASR expansions to acceptable levels of deterioration.
4. This coating can also be very effective in reducing expansive strains when applied to concrete already cracked due to AAR and undergoing further expansion. The effectiveness of the coating is such that ASR expansions of 1.4% to 1.8% can be reduced to about 0.44% to 0.54% and 0.64% to 0.70% when it is applied after in-situ expansions of about 0.15% and 0.35% respectively.
5. In real structures already cracked due to ASR and undergoing further expansion, and exposed to hot, highly humid and chloride-laden environments, where the chlorides and moisture can penetrate the concrete through the cracks, surface coatings cannot be expected to totally counteract the influences of the alkalis and water already trapped inside the concrete, although they can substantially reduce the expansion.
6. In such situations, relying on a single protective system alone is not reasonable and can only be partly productive. A total protective strategy system needs to be developed if the material degradation and structural instability arising from such internal distress mechanisms are to be avoided, and further useful service life is to be derived. Such a strategy involving an efficient protective coating system can make major contributions to extend the durable service life of AAR-affected structures.

REFERENCES

Gudmundsson, G. and Asgeirsson, H. 1983 'Parameters affecting alkali expansion in icelandic concretes', Proc. 6th Int. Conf on Alkalis in Concrete, Copenhagen, 217-222.

Ludwig, U. 1989, 'Effects of environmental conditions on Alkali-aggregate reaction', Proc. 8th Int. Conf on Alkali-Aggregate Reaction, Kyoto, Japan, 17-20 July, Elsevier London, 583-596.

Stark, D. 1990, 'The moisture condition of field concrete exhibiting alkali-aggregate reactivity', Int. Workshop on Alkali-Aggregate Reactions in Concrete: Occurrences, Testing and Control, Halifax, Canada, ed. J. A. Soles.

Swamy, R. N. and Tanikawa, S., 1989a, 'Surface coatings to preserve concrete durability' in *Protection of Concrete*, eds. R. K. Dhir and J. W. Green, E.F & Spon, London, 149-165.

Swamy, R. N. and Tanikawa, S., 1993b, 'An external surface coating to protect concrete and steel from aggressive environments', *Materials and Structures*, 26, 465-478.

Swamy, R. N. and Tanikawa, S., 1992c, 'Acrylic rubber coating to control alkali silica reactivity', Proc. 9th Int. Conf. on Alkali-Aggregate Reaction in Concrete, vol. 2, Concrete Society, London, 1026-1034.

Swamy, R. N. and Al-Asali, M. M., 1986a, 'Influences of alkali-silica reaction on the engineering properties of concrete', in *Alkalis in Concrete*, STP-930, ASTM, Philadelphia, 69-86.

Swamy, R. N. and Al-Asali, M. M., 1988b, 'Expansion of concrete due to alkali-silica reaction', *ACI Materials Journal*, 85(1), 33-40.

Swamy, R. N. 1995, 'A global design approach for cost-effective durable performance of concrete structures', Proc. Int. Symp. on New Developments in Concrete Science and Technology, Nanjing, China, 1-23.