The effect of Concrete Quality on Performance of Surface Treatment materials

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ABSTRACT: The paper examines the performance of four surface treatment materials in protecting concrete. Three different type of concrete were chosen for this study. The concrete specimens with w/c = 0.6 and the concrete specimens with w/c = 0.4 with and without silica fume were made. The types of coating materials were polyurethane, epoxy, epoxy/coal tar and silane/siloxane with acrylic as top coat. The concrete were evaluated for corrosion potential, corrosion damage, sulfate resistance and heat-cool cycles. The results showed that all types of coating were effective and improved the performance of concrete. But effectiveness of coating depends on the type of concrete and the type of coating material. There was no single coating that could improve all types of concrete against all type of deterioration.

Key Words: Concrete, Surface Treatment, Chemical Attack, Corrosion, Heat and Cool Cycle

1 INTRODUCTION

It is a commonly held belief that the deterioration of concrete structures due to environmental factors is determined almost entirely by the ability of the surface to keep out the harmful agents in the environment [1].
A literature survey revealed that the use of surface treatment materials can be effective in reducing the diffusion of oxygen, moisture and chloride [2-5]. No information was found which deal directly with evaluation of surface treatment performance base on concrete quality and environmental conditions.
Cabera and Hassan [3] have indicated that the use of an effective surface treatment material not only protects concrete against penetration of substances, but also improve the performance of badly cured concrete. This conclusion applies only to concrete for which the design mix composition and water/cement ratio would give satisfactory performance when cured at 100% RH.

2 EXPERIMENTAL PROGRAM

2.1 *Materials*

Type II portland cement was used in making plain cement concrete specimens, while silica fume from Iranian factory was used in the pozzolanic cement concrete specimens.
The coarse aggregate was 14mm maximum size crushed limestone with a bulk specific gravity of 2.5. Crushed sand of specific gravity 2.6, with particle size distribution conforming to the requirements of zone “C” of the British standards BS 882 [6] was used.
Four different kinds of compounds were selected for this study. Table 1 show the compound used.

2.2 *Mix design*

Three concrete mixes were used in this study. One of the mixes made with high water-cement ratio containing only Portland cement and two of the mixes made with low water-cement ratio. This mixes of the concrete were deliberately chosen to allow a direct comparison between a plain Portland cement concrete and a Silica Fume concrete on the basis of equal total binder content and equal water/binder ration. The compositions of concrete mixes are given in table 2.

Table 1. Surface treatment compounds

Code	The name of compound
SIL+ACR	Silane/Siloxane with Acrylic as top coat
PU	Polyurethane
EPC	Epoxy Coal-tar
EP	Epoxy

Table 2. Composition of concrete mixes

Code	Cement content kg/m^3	Silica Fume kg/m^3	Fine aggregate kg/m^3	Coarse aggregate kg/m^3	W/C
A	400	-	745	875	0.6
B	400	-	828	972	0.4
M	360	40	828	972	0.4

2.3 *Curing and exposure conditions*

After 24 hours of casting, all, the specimens were demolded and then were cured in standard condition for three days. After this initial curing, the specimens were divided into two equal groups. One group was placed in the laboratory, while the other was exposed in Simulated Persian Gulf condition (%50 relative humidity and 40°C). At age of 14 days, the specimens were coated with a surface treatment compound following the instruction of the suppliers.
The specimens were then returned to the laboratory and environmental room till the age of testing of samples.

2.4 *Specimen Preparation and Testing*

Reinforcing steel corrosion - The accelerated reinforced bar corrosion tests were carried out on 60×60×150 mm prisms containing 10 mm bar embedded centrally. The specimens were partially immersed in a 5 percent NaCl solution. The tank containing the specimens was kept at 40°C. The corrosion was monitored by obtaining half-cell potentials with a “Saturated Calomel” electrode. The threshold potential is taken at -270 millivolts. At the end of corrosion testing, the specimens were broken for observation examination of reinforcing bars.

Sulfate-resistance - To monitor the extent of deterioration due to sulfate attack, the deterioration was evaluated by strength loss and expansion. The 100 mm cubes and 40× 40× 160 mm prisms were used for compressive strength and expansion tests respectively.
The specimens at age 28 days were kept in a 3% Na_2SO_4 and 3% $MgSO_4$ solution. The tank containing specimens was exposed to 40°C.

Thermal Cycles testing – for heat-cool cycle test, the 100 mm cube specimens at age 28 days were placed in an oven which was maintained at 70°C for 16 hours and then 20°C for 8 hours to complete one heat-cool cycle. At the different number of cycles, the specimens were tested for water absorption and compressive strength.

3 TEST RESULTS AND DISCUSSION

3.1 Corrosion testing

The variation of half-cell potential with time for control specimens (without surface treatment) exposed to NaCl solution is illustrated in Fig. 1. The time of potential shift from passive to active state for concrete with w/c= 0.60 was found to be nearly one month. In the case of concrete “B” with w/c = 0.40 the specimens attained their active states in 4 months. While in the case of concrete “M” which made of Silica Fume with w/c= 0.40, the time of potential shift from passive to active states was 12 months.

None of the specimens made with different type of concrete and treated with different types of coating did not show active corrosion potential. In other words all specimens with surface treatment showed corrosion potential below -270 mV which is threshold value.

Visual examination of the reinforcing steels after 30 months of exposure is illustrated in Table 3.

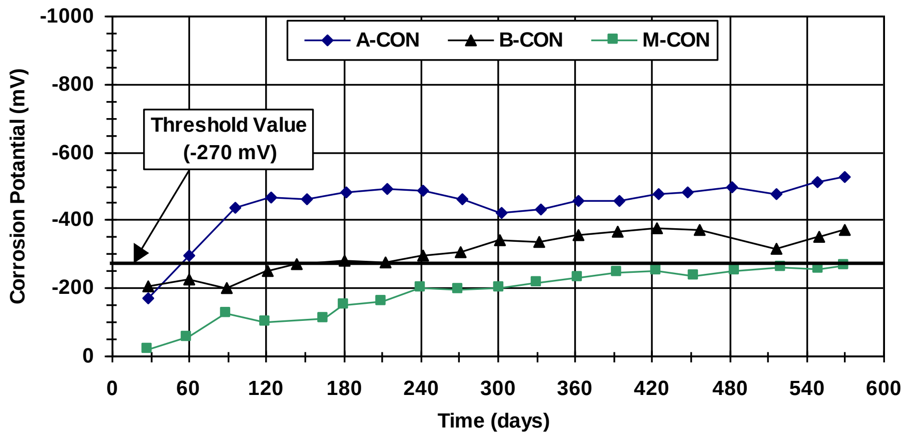

Figure 1: Variation of corrosion potential with time for control specimens

Table 3: Rate of corrosion damage based on visual observation

Type of concrete	**Type of surface treatment**	**Rate of damage**	
		Corroded area (%)	**Reduction in bars diameter (%)**
A	Control	100	30% reduction in dia
	Sil+ ACR	30	-
	EPC	6	-
	PU	70	-
	EP	40	-
B (1)	Control	40	-
	Sil+ ACR	15	-
	EPC	5	-
	PU	30	-
	EP	20	-
M	Control	30	-
	Sil+ ACR	-	-
	EPC	5	-
	PU	4	-
	EP	5	-

As the results of Table 3 shows that there are some corrosion of the surface of reinforcing bars in specimens coated with “PU” and ”EPC”. Despite the corrosion potential measurement in these specimens which showed passive state. This finding shows that “PU” and “EPC” coating have effect on potential measurement and with creating a electrical buffer, making the measurement with error.
However, the results showed that there is significant improvement in the resistance of corrosion of reinforcing steel due to all types of surface treatments in all the concretes. But the concrete “M” with “SIL + ACR” coating is the most effective from corrosion point of view.

3.2 Sulfate attack

Figures 2 to 4 show the expansion of concrete prisms. It can be seen from the figures that expansions observed in specimens coated with different type of coating are significantly lower than control specimens. The reason can generally be attributed to the effect of reduced permeability in coated specimens.
Table 4 shows the rate of sulfate deterioration base on visual observation after 30 months of exposure
Figure 2 shows that in concrete “A” specimens, the lowest expansion belongs to “PU” coating. But the Table 4 indicates that the only specimens which remained sound was with “EP” coating, despite of higher expansion comparing to “PU” coating.
Figure 3 compares the expansion observed in concrete “B” specimens. It can be seen from the Figure that all coated specimens have an expansion 400 to 800 micro strain. But the results of table 4 show that none of the specimens were damaged except the control specimen. Thus “B” concrete is expected to have better resistance to expansion than “A” concrete, when the concrete is coated.
The effect of Silica Fume on expansion of concrete specimens “M” is shown in
figure 4. The important feature of these figures is that although there is no much difference between expansion values of concrete specimens “M” and concrete specimens “B”, but all the specimens damaged (Table 4).
Two important points can be concluded from the above results:
In contrast the use of Silica Fume would generally provide an improved performance in Na_2SO_4 solution [7], but it provided a poor performance in Na2SO4 and $MgSO_4$ solution.

The improvement of resistance is not only depends on the type of surface treatment, but also the quality of concrete is important factor.

Table 4: Rate of sulfate damage base on visual observation

Code of concrete	**Code of coating**	**Rate of damage**
A	Control	High damage
	EP	Sound
	SIL + ACR	Low damage
	PU	Low damage
	EPC	High damage
B	Control	High damage
	EP	Sound
	SIL + ACR	Sound
	PU	Sound
	EPC	Sound
M	Control	Extreme damage
	EP	Low dmage
	SIL + ACR	High damage
	PU	Sound
	EPC	High damage

Low damage : Few holes in coating and concrete
High damage: Significant cracking and popping out of concrete and softening of concrete
Extreme damage : Fully deterioration of the specimen

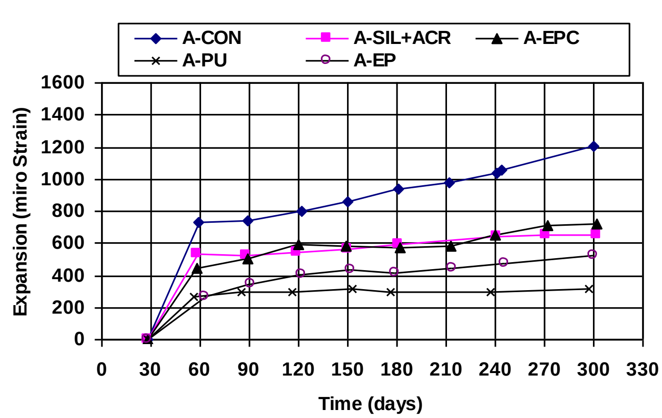

Figure 2: Expansion of the uncoated and coated concrete a specimens

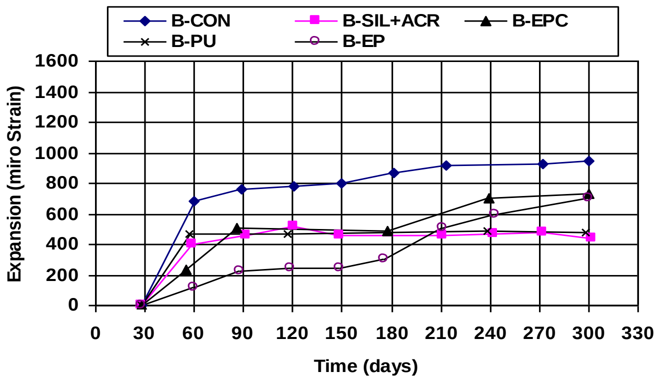

Figure 3: Expansion of the uncoated and coated concrete B specimens

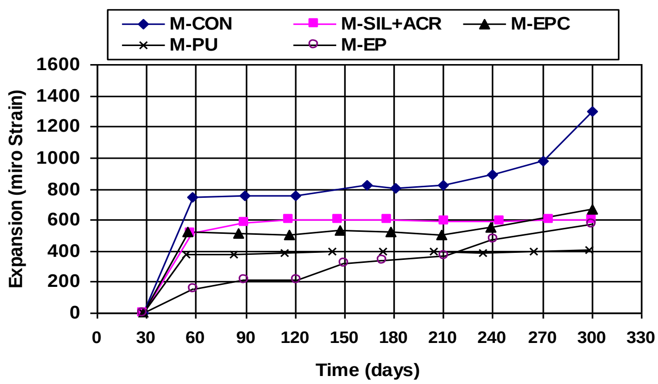

Figure 4: Expansion of the uncoated and coated concrete M specimens

3.3 Heat – Cool Cycles

The water absorption in uncoated concrete specimens, exposed to heat-cool cycles is shown in figure 5. The concrete specimens with higher water/cement ratio (concrete A) showed higher water absorption compared to concretes with lower water/cement ratio (Concrete B and M). The figure also shows that there is no significant variation in water absorption at different cycles. In other words formation of cracks in uncoated concrete specimens due to thermal variation is not significant.

Figure 6 shows the water absorption in concrete specimens coated with “SIL + ACR”. The water absorption of all concretes was affected markedly by the surface treatment. But the values of absorption increased with the number of heat-cool cycles in all the concretes. This may be attributed to reduction of effectiveness of “SIL + ACR” coating.

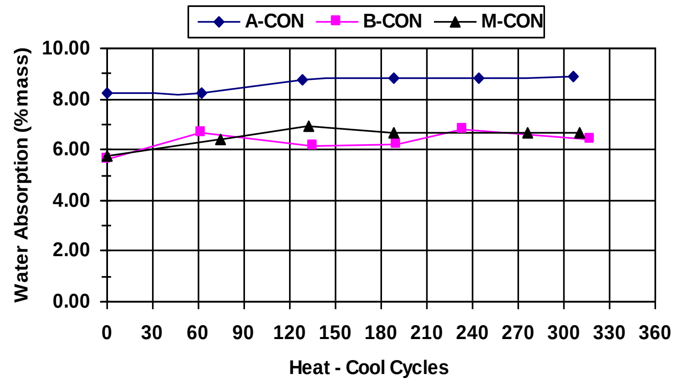

Figure 5: Effect of heat-cool cycling on water absorption in the uncoated concrete specimens

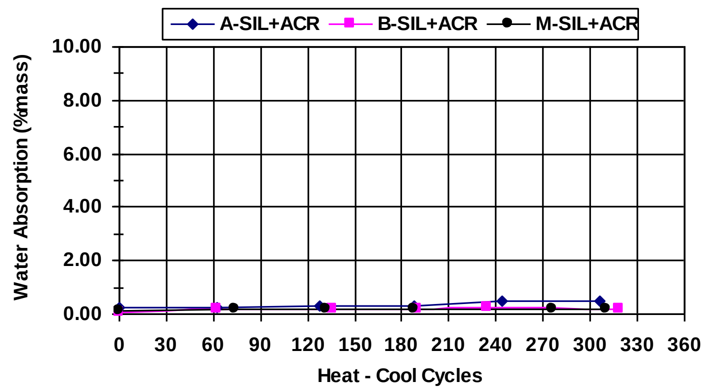

Figure 6: Effect of heat-cool cycling on water absorption in the concrete specimens coated with SIL+ACR

Figures 7 and 8 also show the effect of Epoxy and Polyurethane coating in absorption of the specimens exposed to heat-cool cycles. Comparing these two figures indicates that Polyurethane is more effective in reduction of absorption; Except that the lowest absorption belongs to concrete containing Silica Fume (concrete M) coated with Epoxy. But similar to figure 6, the reduction of effectiveness of coating due to Thermal variation can be noted, especially in concrete with higher water/cement ratio (Concrete A).

Figure 9 shows the effect of heat-cool cycles on the compressive strength of coated and uncoated concrete specimens after about 180 cycles. The lowest reduction in compressive strength was registered in concrete specimens coated with “SIL+ACR”.

In cases of concretes B and M, there was no reduction of compressive strength. As matter of fact compressive strength of these specimens were increased. This means that the "SIL+ACR" coating not only prevents the reduction of compressive strength, but also improve the hydration of cement paste.

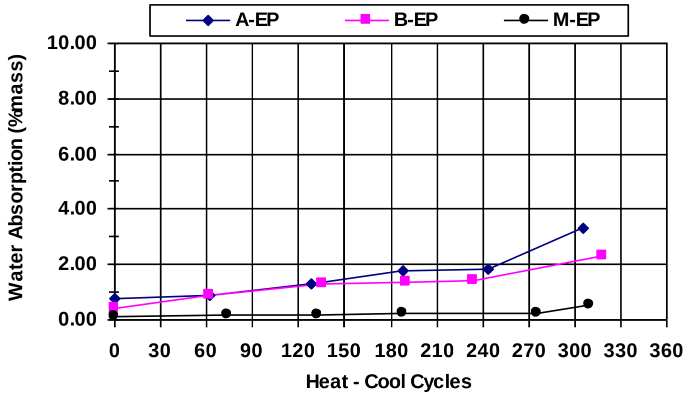

Figure 7: Effect of heat-cool cycling on water absorption in the concrete specimens coated with EP

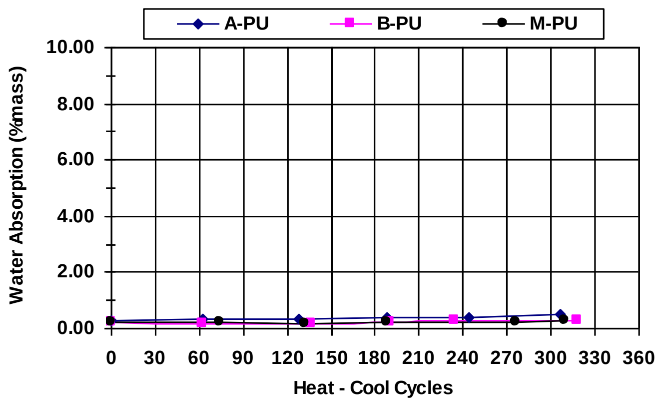

Figure 8: Effect of heat-cool cycling on water absorption in the concrete specimens coated with PU

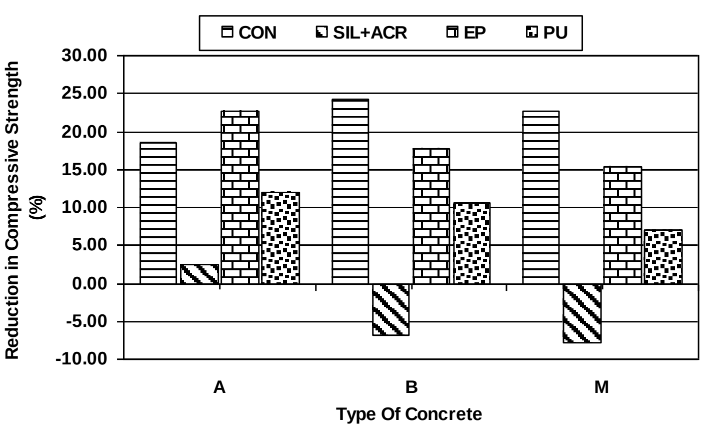

Figure 9: Effect of heat-cool cycling on compressive strength in the coated and uncoated specimens

This phenomenen may be attributed to finding of Cabrera and Hassan [2] which showed that the surface treatment can redistribute the internal moisture of concrete. Due to this effect, the process of rehydration may be affected. However this phenomenen needs more investigation works.

4 CONCLUDING REMARKS ABOUT SILICA FUME

The improvement in sulfate resistance of blended cements containing pozzolznic materials such as silica fume is attributed to the combined effect of reduced permeability and reduction in CH in the hardened cement paste [7]. This explains the low expansion observed in silica fume blend (figure 4). But $MgSO_4$ solution deteriorates the C-S-H gel and makes the concrete soft. As silica fume concrete converts CH to C-S-H gel, therefore this concrete is more vulnerable to reduction of compressive strength.

Figure 10 shows compressive strength of concrete specimens in sulfate solution. It can be seen that, at last day of test, reduction of compressive strength of Silica fume concrete is about 26 percent. While the other concretes showed lower reduction of compressive strength.

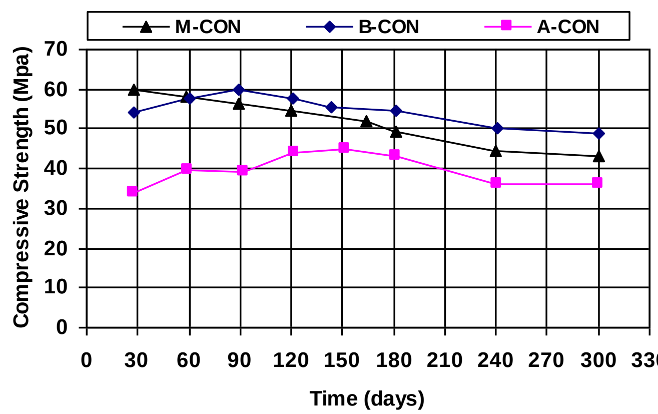

Figure 10: Compressive strength of all types of concrete with time in sulfate solution

But the obtained data (fig. 1) and reference 5 indicate clearly that Silica Fume concrete would provide improved chloride diffusion and corrosion resistance. This can be attributed to concentration of cations in the pore solution of pozzolanic-cement pastes. Some ions like Al^{+3} , Ca^{+2} and Si^{+4} have lower diffusion rates and restrict the mobility of the coexisting Cl^- ion, where K^+ ion, on the contrary increases the Cl^- ion, mobility [8]. The concentration of K+ is much lower in silica fume paste compared to normal portland cement paste pore solution [9].

Therefore it seems that the concentration of different types of ions is responsible for improved resistance of corrosion in silica fume concrete.

5 CONCLUSIONS

- The surface treatment to material ivestigated in this study was effective in corrosion resistance of concretes. But the effectiveness of surface treatment materials depends on concrete quality. The improvement of concrete quality increased the effectiveness of surface treatment materials. The most effective material was “Silane + Siloxane” with “Acrylic” as top coat on concrete with Silica Fume.

- The corrosion potential measurement on in coated specimens may give misleading results. This aspect needs more investigation.

- The surface treatment materials increased sulfate resistance of concretes. But as corrosion, the effectiveness of materials depends on the type of concrete. Combination of good quality concrete and the proper surface treatment can improve sulfate resistance significantly. In contrast with with improvement of concrete containing Silica Fume from Sulfate attack point of view, this type of concrete did not show good resistance against sulfate. The best performance was indicated by concrete with low water/cement ration without Silica Fume, which coated with all types of surface treatment in this study.

- The water absorption in coated specimens decreased in heat-cool cycles test. But the effectiveness of coating materials depends on the type of concrete.

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