Effect of Protection Painting On Main Characteristics of Highway Concrete Layer Against Ground Water Solutions

Ilham Abd Al-Majeed1, Fatimah Fahem Al-khafaji2

1 Engineering of Ceramic and Building Materials Department, College of Materials Engineering, University of Babylon, Iraq, Babil
2 Engineering of Ceramic and Building Materials Department, College of Materials Engineering, University of Babylon, Iraq, Babil

Abstract: One of the durability problems which can be occurred during the service life of a concrete structure like highway concrete layer is sulfate attack. Sulfate ions has been found in the ground water in some regions of Iraq. In these regions, water ground solution usually affects the concrete layer that result in strength decrement and volume increment and ettringite cracking. Therefore the permeability decreasing of concrete plays significant role for more durability. In this study there are four types of epoxy resin used as painting and may be good solution for the problem. Two types of protection painting used with and without (base material) primer for concrete specimen prepared for investigating the main characteristics needed in design of highway concrete layer thicknesses. Concrete specimen painting by the epoxy resin had positive effect on all main character (compressive strength, Elastic modulus) and significantly on flexural strength. This type of protection is recommended to use for concrete layer at more important high traffic load, highway segment life approaches of bridges and overpasses structure.

KEYWORDS: Protective Painting, Characteristics, Ground Water concrete Layer, Highways.

1. Introduction
According to (ACI Committee 201) the durability of Portland cement concrete is its ability to resist weathering action, chemical attack, abrasion, or any other process of deterioration. The durable concrete will retain its original form, quality, and serviceability when it is exposed to its environment. The sulfate attack which was previously described as a one problem for durable concrete structure, is indicated to the volume increment of cement mortar belong to chemical effect of solution in ground water on concrete mix. When the hardened concrete is subjected to sulfates solution from soil or ground water, these sulfates in solution may be reacted with hydrated Tri-calcium aluminate in the hardened cement paste to form a new compound called Ettringite.

One of the durability problems that may occur during the service life of a concrete structure is sulfate attack. Sulfate attack may result in expansion, cracking, spalling and eventually reduction of the strength of concrete. Deteriation due to ettringite, happens effecting with harden state of concrete mix especially at later ages. An ettringite formation is not necessarily related to the sulfate attack. Early ettringite formation occurs immediately (within hours) in a plastic fresh mixture does not produce any damaging expansion and is associated with the regulation of setting time of Portland cement paste (this type of ettringite acts as a set retarder in Portland cement mixtures). Ettringite formation can be advantageously used for the development of shrinkage compensating concrete by...
using expansive cement. Delayed ettringite formation (DEF) occurs at late ages and the related heterogeneous expansion in a hardened concrete can produce cracking and spalling. The variation in concrete properties showed the effect of solution CL$^{-1}$ & SO$_4$$^{-2}$ in ground water on chemical composition of hardened concrete due to formation of calcium sulfoaluminate. This compared had harmful effect on concrete deformation by doubling the internal volume of solid phase. [12]

Almost, solutions from surrounding soil and ground water attack the concrete mix with availability of three condition; permeable concrete, solution presence and water founding. The loss of one of these element, the damage cannot be found. [6]

Solid sulfates do not attack concrete but, when present in solution, they can react with hydrated cement paste. Particularly common ones are sulfates of sodium, potassium, magnesium and calcium which occur in soil or in ground water, which lead to formation of expansive salts like calcium-sulfo-aluminatehydrate (ettringite) and calcium sulfate (gypsum). These results in expansion, spalling, cracking and loss of concrete strength. [10], [11]

2. Experimental Work

2.1. Materials

2.1.1. Cement. Sulfate resistance cement was utilized. The specific gravity of the cement used was 3.10, which confirms to (Iraq specification No. 45/1984).

2.1.2. Fine Aggregate. Natural sand from Kerbala region was used as fine aggregate. The grading of the requirement of Iraqi specification No.45/1984, grading area (2).

2.1.3. Coarse Aggregate. The grading was within the limits of gravel by Iraq specification No. 45/1984. Maximum size 14mm.

2.1.4. Concrete Mix. The concrete mix and water-cement ratio based on target C 30.

2.1.5. Curing. A specimens were cured in tap water for a curing period of 7 days to ensure the early hydration process, the specimens that protected or were not cured in ground water partially that simulated the case of highway concrete layer in the field.

2.1.6. Ground Water. This water was brought from well beside an arterial constructed by concrete layer with the following concentration:

| Specification (mg/L) | Test value (mg/L) |
|---------------------|------------------|
| Chlorides CL$^{-1}$ | 350              |
| Sulphate SO$_4$$^{-1}$ | 400          |

2.1.7. Protective Painting (Epoxy Resin):

2.1.7.1. Nitocote EP405:

- Multi-purpose coating, due to non-toxicity.
- Low cost service life - resistant to mould growth, chemical attack and abrasion.

Table 1 show the properties of Nitocote EP405.

| Requirement                  | Characteristic          |
|------------------------------|-------------------------|
| Specific gravity             | Approx 1.45 (mixed)     |
| Solids by weight @ 25°C      | 100 % (mixed)           |
| Pot life @ 20°C              | 30 to 40 minutes        |
|                              | 15 to 20 minutes        |
@ 35°C
Drying time @ 20°C @ 35°C
Touch dry 6 hrs 3 hrs
Recoatable 6-18 hrs 3-12 hrs
Fully cured 7 days 5 days
Bond strength (ASTM 4541-85) Substrate failure first at 2 N/mm²

Chemical Resistance:

| Substance | Concentration | Resistance |
|-----------|---------------|------------|
| Phosphoric acid | 10% | Very good |
| Lactic acid | 1% | Very good |
| Hydrochloric acid | 30% | Good |
| Sodium Hydroxide | 40% | Excellent |

2.1.7.2. Nitocote EPU:
- Wall and floor coating for concrete protection.
- Flexible coating.
- Environment friendly.

Table 2 shows the properties of Nitocote EPU.

| Requirement                        | Characteristic                                      |
|------------------------------------|-----------------------------------------------------|
| Specific gravity                   | 1.48 g/cm³ at 23°C                                  |
| Pot life (ASTM D1475):             | 3 hours @ 23°C                                      |
| Tack free time (ASTM D1640):       | 1-2 hours @ 45°C                                    |
| Min. Over-coating time (ASTM D1640): | 4 hours @ 35°C                                  |
| Full cure (ASTM D1640):            | 2 hours @ 45°C                                      |
| Adhesion Strength*                 | 1.5 - 2.5 N/mm²                                     |
| Water Absorption (ASTM C570):      | 0.2%                                                |
| Tensile Strength (BS2782):         | 10 N/mm²                                            |
| Elongation at break (BS2782):      | Approx 25%                                          |

* Depending on the type of concrete substrate

Chemical Resistance:

| Substance     | Resistance |
|---------------|------------|
| Hydrochloric acid | 10%       | Resistant |
| Sulphuric acid  | 25%       | Resistant |
| Nitric acid    | 10%       | Resistant |
| Phosphoric acid | 15%       | Resistant |
| Tap water      |            | Resistant |
2.2. Tests:

2.2.1. Compressive Strength Test. The compressive strength test was implemented according to (B.S.1881: PART116: 1989). The cubes with an edge length of 150 mm had been tested by using a hydraulic compression machine of 1900 kN, at a loading rate of 18 MPa per minute. The average of three cubes was adopted at each test and test was conducted at ages of 7, 28, 56 days. ‘Figure 1’ offers compressive strength test.

|          | Sea water | Resistant |
|----------|-----------|-----------|
| Ground water |           | Resistant |
| Sewage |           | Resistant |

**Figure 1. Compressive strength test**

2.2.2. Flexural Strength (Modulus of Rupture). The flexural strength was conducted according to (ASTM C78, 2002), concrete prisms (100 × 100 × 400 mm) which were prepared. The average of two prisms was adopted at each test condition. ‘Figure 2’ shows flexural strength test. Modulus of rupture is calculated from the simple beam bending formula:

**a.** If the fracture initiates in the tension surface within the middle third of the span length, then:

\[ f_r = \frac{PL}{bd^2} \]  \hspace{1cm} (1)

Where:

- \( f_r \) : Modulus of rupture , (MPa)
- L : Span length, (mm)
- P : Maximum applied load, (N)
- d : Maximum depth of specimen, (mm)
- b : Average width of specimen, (mm)

**b.** If the fracture occurs in the tension surface outside the middle third of the span length by not more than 5% of the span length, than :

\[ f_r = \frac{PL}{bd^2} \]  \hspace{1cm} (1)
\[
fr = \frac{3Pa}{bd^2}
\]  \hspace{1cm} (2)

Where:
\(a\) : average distance between line of fracture and the nearest support measured on the tension surface of the prism, (mm).

*Figure 2.* Flexural strength test

2.2.3. *Static Modulus of Elasticity.* The static modulus of elasticity was performed according to (ASTM C469, 2002). This test method present a stress-strain curve for hardened concrete at whatever age and exposure condition which may be designated. The slope of this curve which represents the chord modulus is given by the slope of a line drawn from a point representing a longitudinal strain of 50 microstrains to the point that correspond to 40% of the ultimate load. ‘Figure 3’ shows static modulus of elasticity test set up and the cylinder specimen that used at the test. The average of two cylinders \((150 \times 300)\) mm was taken at each test. The modulus of elasticity is calculated, as follows:

\[
E = \frac{S_2}{\varepsilon_2 - 0.000050} \times 10^{-3}
\]  \hspace{1cm} (3)

Where:
\(E\) : Chord modulus of elasticity, (GPa)
\(S_2\) : Stress corresponding to 40% ultimate load, (MPa)
\(S_1\) : Stress corresponding to a longitudinal strain \(\varepsilon_1 = 0.000050\), (MPa)
\(\varepsilon_2\) : Longitudinal strain produced by stress \(S_2\).
3. Results and Discussions
Highway rigid pavement consist of a Portland cement concrete layer with specified thickness resting on subbase layer. The load carrying capacity is designed according to the modulus of elasticity and modulus of rupture of concrete. While the compressive strength must be agreed with the required specification of roadway durability and strength. Therefore, the using of protective painting in some cases decrease the negative effect of surrounding ground water, especially at later ages to keep the infrastructure of highway from deterioration and distresses. The deterioration process of pavement subjected to external sulfate attack occurs due to two types of attack: Chemical attack and physical attack. Chemical attack known as deterioration by ingressing sulfate ions reactions with cement hydration products leading primarily to the formation of ettringite and gypsum. While scaling of concrete as a result of sulfate salt crystallization in the pores of concrete, known as physical attack.[7]

In fact, the external harmful on the quality of concrete and solution concentration. Therefore, the permeability removing and reduction by painting seem to be good solution for avoiding solution pentration [5].

3.1. Compressive Strength Test:
As shown in table 3, the curing in ground water involved reduction in compressive strength. This reduction is due to attack of sulfate ions, which leads to formation of expansive salts such as calcium sulfate (gypsum) and calcium sulfoaluminate hydrate (ettringite). These compounds result in expansion, spalling, cracking and loss of strength of concrete. The strength deterioration is also due to leaching out of salts deposited in the voids of concrete. However, the effect of protection painting was clear in result. The painting after 7 days curing cause a reduction in compressive strength at 28 day when cured in ground water but the strength was kept for later age 56 days. That believes to reduction in voids by which the defamation can be happened. Painting (405 specially when used with primer ) showed pastorally significant effect on compressive strength at later ages that reflect on durability and service life of concrete layer.

Table 3. Results of compressive strength for concrete mixes with different protection painting cured in tap or ground water

| Painting Type      | Age | Cured in Tap Water | Cured in Ground Water (After 7 days age) |
|--------------------|-----|--------------------|----------------------------------------|
| Without painting   | 7   | 21.5               | 21.5                                   |
3.2. Flexural Strength Test:
As shown in table 4 significant negative effect appeared when using ground water in result of modulus of rupture (flexural strength). That believes to creating a weak point by exposing ground water and the beam was failure rapidly. However, the painting by protection epoxy resin specially (405+ primer), had the positive effect on bending behavior of concrete layer that simulated by flexural beam at test. All used painted mode mere reduction in weak points by protection tested beam from CL\textsuperscript{1} and SO\textsubscript{4}\textsuperscript{2} exposure. That involved closing all voids in concrete surface against that Deterioration exposure of CL\textsuperscript{1} and SO\textsubscript{4}\textsuperscript{2}.

Table 4. Results of flexural strength for concrete mixes with different protection painting cured in tap or ground water

| Painting Type       | Age | Flexural Strength MPa | Cured in Tap Water | Cured in Ground Water (After 7 days age) |
|---------------------|-----|-----------------------|--------------------|----------------------------------------|
| Without painting    | 28  | 5.32                  | 4.72               |
|                     | 56  | 5.89                  | 5.05               |
| 405 alone painting  | 28  | 5.20                  | 5.01               |
|                     | 56  | 5.21                  | 5.10               |
| 405 + primer painting | 28 | 5.01                  | 4.90               |
|                     | 56  | 5.15                  | 5.13               |
| CPU alone painting  | 28  | 5.11                  | 4.98               |
|                     | 56  | 4.90                  | 4.69               |
| CPU + primer painting | 28 | 4.90                  | 4.79               |
|                     | 56  | 4.77                  | 4.52               |

3.3. Static Modulus of Elasticity Test:
Table 5 illustrate that, in general all specimen exposed to ground water SO\textsubscript{4}\textsuperscript{2}, CL\textsuperscript{1} solution, exhibit a percentage of decrease in elastic modulus. The reason of this decrease in modulus of elasticity is belong to the decrease in elastic modulus of the matrix caused by the loss of the interfacial bond strength between cement paste and aggregate reaction by using protective painting as shown in table (3), the decrement become less significantly at later ages and by using effective painting like epoxy
resin (405 with primer) the plugged the voids and decreased the negative effect of $\text{SO}_4^{2-}$, $\text{CL}^{-1}$ solution.

Table 5. Results of modulus of elasticity for concrete mixes with different protection painting cured in tap or ground water

| Painting Type     | Age | Modulus of Elasticity Gpa |
|-------------------|-----|---------------------------|
|                   |     | Cured in Tap Water | Cured in Ground Water (After 7 days age) |
| Without painting  | 28  | 27.2             | 24.6             |
|                   | 56  | 27.7             | 25.0             |
| 405 alone painting| 28  | 25.9             | 24.5             |
|                   | 56  | 25.5             | 24.1             |
| 405 + primer painting | 28  | 25.1             | 24.4             |
|                   | 56  | 25.9             | 25.4             |
| CPU alone painting | 28  | 26.1             | 24.3             |
|                   | 56  | 25.6             | 23.4             |
| CPU + primer painting | 28  | 25.4             | 24.1             |
|                   | 56  | 25.4             | 24.7             |

4. Conclusion & Recommendation:
An overview of main characteristics of concrete mixes protected by painting against the effect of ground water solution and according to results of experimental investing at that are presented in the research. In general all specimen exposed to cure in ground water exhibit a percentage of decrease in characteristic about 15%. Concrete specimen painting by epoxy resin had positive effect on characteristic, significantly on bending behavior (flexural strength). Two types of protective painting were utilized in research: 405 epoxy and EPU epoxy with and without primers (base material in painting). Painting (405 epoxy) exhibit superior protection against ground water solution especially when used with primer at later ages. These type of protective painting were recommended to use for concrete layer at high traffic load highway segment like approaches of bridges and interchanges structure to keep the mixes against exposure of surrounding and beneath ground water solution.

5. References
[1] ACI Committee 201, (2001) " Guide to Durable Concrete ", ACI Manual of Concrete Practice, Part 1, Detroit, Mich .
[2] ASTM C469, (2002), "Standard Test Method for Static Modulus of Elasticity and Poisson's Ratio of Concrete in Compression ", American Society for Testing and Materials .
[3] ASTM C78, (2002), "Standard Test Method for Flexural Strength of Concrete Using Simple Beam With Third-Point Loading " ASTM international, West Conshohocken, PA, www.astm.org .
[4] BS 1881: Part 116, (1989), "Method for Determination of Compressive Strength of Concrete Cubes ", British Standards Institution .
[5] Chen, W.F., and Liew, J.Y.R., (2003), "The Civil Engineering Handbook ", Crc Press, ISBN 0-8493-0956-1
[6] Collepardi, M., (2000) " Ettringite Formation and Sulfate Attack on Concrete ", Civil Engineering Faculty, Leonardo Da Vinci, Politechnic Milan Italy, 2000, pp.1-17.
[7] Hadi, A.M., (2009), "The Effect of Sulfates in Ground Water on Some Mechanical Properties of Self-Compacting Concrete ", M.Sc. Thesis , University of Babylon .
[8] Iraqi Organization of Standards (IQS), No.45/1984, "Portland Cement".
[9] Iraqi Organization of Standards (IQS), No.45/1984, "Aggregate from Natural Sources for Concrete and Construction".
[10] Mullick, A.K., (2007), "Performance of Concrete with Binary and Ternary Cement Blend", The Indian Concrete Journal, January, 2007.
[11] Neville, A.M., (2010), "Properties of Concrete", Five, and Final Edition, Wiley, New York and Longman, London, pp.844.
[12] Shetty, M.S., (2005), "Concrete Technology Theory and Practice", by S. Chand Publisher, ISBN: 81-219-0003-4, Multicolour illustrative Edition, Ram Nagar, New Delhi-110 055.