Linseed Oil-Based Concrete Surface Treatment for Building and Highway Structures in Hong Kong

Y Xie BSc(Eng) MSc(ConcTechi MSc(StructEng)
Department of Civil and Geological Engineering, The University of Manitoba

H C Chan BSc(Eng) PhD DIC CEng FICE FHKIE
Department of Civil Engineering, The University of Hong Kong

A K H Kwan BSc(Eng) PhD CEng MICE MHKIE
Department of Civil Engineering, The University of Hong Kong

S H Rizkalla PhD PEng FACI FASCE FCSE FEIC
Department of Civil and Geological Engineering, The University of Manitoba

This experimental program investigated the effectiveness of concrete surface treatment using four Canadian linseed oil-based sealants on concrete specimens made from G30/20 and G45/20 concretes, which are typically used for building and highway structures in Hong Kong. The tests were conducted at the University of Hong Kong and the University of Manitoba independently, using samples cast from the same mixes in Hong Kong. A total of more than 500 specimens were tested in each university for salt spray resistance, carbonation, bond strength, dripping and ultra-violet weathering. The results show that the four sealants were capable of penetrating through vertical, upward horizontal and downward horizontal concrete surfaces up to depths of 2.5 mm. All the four sealants significantly enhanced the resistance of G30/20 concrete against salt spray attack and carbonation. The resistance of G45/20 concrete to salt spray was also increased. Up to a duration limit of 500 hours of quick ultra-violet weathering, the treated specimens still demonstrated higher resistance against salt spray attack and carbonation than the untreated ones. However, no conclusion can be made regarding the effect on carbonation resistance of G45/20 concrete, since both the treated and untreated specimens showed no signs of carbonation after the test.

Keywords: Linseed Oil, Concrete Surface Treatment, Salt Spray Resistance, Carbonation, Bond Strength, Ultra-Violet Weathering

Introduction

Linseed oil, a natural product extracted from flax, is a yellowish drying oil containing a large proportion of glycerides. Boiled linseed oil is one of the most widely used surface treatment materials for protection of concrete structures [1]. It can be used in the form of either solution or emulsion. The solution consists of linseed oil and mineral spirit with the proportional ratio of linseed oil to mineral spirit ranging from 90:10 to 30:70, among which the most commonly used one is 50:50. To accelerate dryness of the oil, the solution often contains dryers such as cobalt, manganese, lead salts or napthenic acids. Another form of linseed oil solution consists of 50% linseed oil and 50% kerosene. Linseed oil emulsion is generally composed of equal volume proportions of oil phase and water phase.

Linseed oil-based products are capable of penetrating into hardened concrete [2] and can thus reduce the total porosity and change the pore size distribution of concrete [3]. Starting in late 1960s, boiled linseed oil products have been commonly and effectively used as curing compounds [4,5], antisalting agents [4,6] and chloride screen [7,8] for concrete pavements. As pointed out by Carter [9,10], the use of linseed oil for protection of bridge decks is economically beneficial.

In a 3-year research program [11] conducted recently at the University of Manitoba, the Canadian linseed oil was proved to be one of the most effective sealants for reducing chloride intrusion, salt water absorption and surface scaling of concrete. However, Hong Kong has different environmental conditions and engineering practices, and therefore a separate study is needed. Hong Kong, as reported by Wilkins [12], has a tropical monsoon climate with a mean relative humidity of 78%, mean air temperature of 22.8°C and mean annual rainfall of 2225 mm. It is also a marine environment suffering from high concentrations of industrial and automotive emissions into the atmosphere. In 1985, it was announced that 577 out of the 1000 Housing Authority’s blocks had durability problems with the concrete. The primary destructive agents were chlorides, sulfates and carbon dioxide in combination with water. On the other hand, the common practice in Hong Kong of applying a cement render with some kinds of decorative finish such as glass mosaic tiles to external walls brings an important problem of bonding between concrete and mortar after surface treatment with linseed oil.

Ultra-violet ray usually produces little damage on concrete surface and is not generally a matter of concern. However, when coatings or sealants are applied to concrete surface, the weathering effects of the ultra-violet ray become significant. It is therefore also necessary to examine the effects of ultra-violet weathering on the concrete protected by the four Canadian linseed oil-based concrete sealants.

Use of penetrating sealants may be a promising solution to the concrete durability problems in Hong Kong. The present research program, sponsored by the Flax Council of Canada, was designed to examine the effectiveness of several Canadian products as sealants for concrete structures in Hong Kong.

Materials

Four types of concrete sealants were provided by the Flax Council of Canada, noted as P1, P2, P3 and P4. These four products are based on Canadian linseed oil. Different admixture and procedure are specially designed for each product to provide the sealants with the capability to enhance the durability of the treated concrete from severe environmental conditions in Hong Kong. All four sealants are suitable for spray application.

The cement used for preparing concrete and mortar was Emerald Brand Portland cement supplied by China Cement Company (HK) Limited. The aggregates were supplied by Pioneer Quarries (HK) Ltd. The retarding type water reducing/plasticising admixture used for making the concrete, Daratard 17, was produced by Grace Construction Products.

Two concrete mixes were used, as listed in Table 1. The concrete mix G30/20 was identical to that used by the Hong Kong Housing Authority in a foundation works project in Tin Shui Wai. The concrete mix G45/20 was the same as that used by the Hong Kong Highways Department.
in a bridge and road works project in Tsuen Wan. Their mean 28-day cube strengths were 52 MPa and 61 MPa respectively. All concrete specimens were fabricated at a construction site in Hong Kong, following the same procedure as commonly used in the construction practice. The concrete specimens were fabricated in three different sizes: 1500 x 500 x 50 mm, 500 x 500 x 50 mm and 300 x 300 x 25 mm. Among the three types of specimens, only the 1500 x 500 x 50 mm panels were provided with steel reinforcement. After casting, the specimens were wrapped in polyethylene sheets and then sent back to the University of Hong Kong or shipped to the University of Manitoba in Canada for testing.

<table>
<thead>
<tr>
<th>Constituent</th>
<th>Quantity (per m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cement, kg</td>
<td>G30/20 360</td>
</tr>
<tr>
<td>20 mm aggregate, kg</td>
<td>G45/20 670</td>
</tr>
<tr>
<td>10 mm aggregate, kg</td>
<td>G45/20 515</td>
</tr>
<tr>
<td>Crushed rock, kg</td>
<td>G45/20 500</td>
</tr>
<tr>
<td>Free water, kg</td>
<td>G45/20 185</td>
</tr>
<tr>
<td>Admixture, litre</td>
<td>G45/20 0.72</td>
</tr>
</tbody>
</table>

Table 1 - Concrete mix proportions

Test Procedure

The experimental program was conducted simultaneously at the Department of Civil Engineering of the University of Hong Kong, Hong Kong and the Structural Engineering and Construction Research and Development Facility at the University of Manitoba, Canada.

Application of Sealants

The sealants were applied to the concrete specimens at the University of Hong Kong and the University of Manitoba at the same time, which was 70 days after casting. Before application of the sealants, the concrete surfaces were cleaned using wire brushing followed by high pressure air blasting. A Graco spray machine was used to apply the sealants. The specimens of 500 x 500 x 50 mm and 300 x 300 x 25 mm sizes were placed horizontally with the test surface oriented upward during the application. Each specimen was covered by one sealant. A total of eight 1500 x 500 x 50 mm specimens were used for the dripping test. Four of the eight specimens were placed vertically and the other four horizontally with the test surface facing down. Each test surface was divided into two half portions with the dividing line parallel to the 1500 mm sides and the two half portions were covered by two different sealants respectively. Tables 2 and 3 list the sizes, quantities and test surfaces used and the dosage rates of the sealants.

<table>
<thead>
<tr>
<th>Specimen</th>
<th>Test surface used</th>
</tr>
</thead>
<tbody>
<tr>
<td>500 x 500 x 50 mm</td>
<td>rough (trowelled)</td>
</tr>
<tr>
<td>300 x 300 x 25 mm</td>
<td>rough (trowelled)</td>
</tr>
<tr>
<td>1500 x 500 x 50 mm (vertical)</td>
<td>rough (trowelled)</td>
</tr>
<tr>
<td>1500 x 500 x 50 mm (horizontal)</td>
<td>smooth (moulded)</td>
</tr>
</tbody>
</table>

Table 2 - Test surface used by the University of Hong Kong

<table>
<thead>
<tr>
<th>Sealed</th>
<th>Passes applied</th>
<th>Dosage rate (kg/m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>P1</td>
<td>4</td>
<td>0.301</td>
</tr>
<tr>
<td>P2</td>
<td>3</td>
<td>0.360</td>
</tr>
<tr>
<td>P3</td>
<td>3</td>
<td>0.321</td>
</tr>
<tr>
<td>P4</td>
<td>3</td>
<td>0.238</td>
</tr>
</tbody>
</table>

Table 3 - Dosage rates of sealants on horizontal specimens oriented upward

Curing and Cutting of Test Specimens

After application of the sealants, the treated specimens were left undisturbed for 2 days inside the laboratory and then stored in a curing room until the dates of testing or cutting. The curing room was maintained at 25 ± 2°C and 60 ± 5% relative humidity. At 42 days after application of the sealants, 100 x 100 x 50 mm square blocks were cut from the control and treated 500 x 500 x 50 mm specimens for salt spray and carbonation tests. 200 x 90 x 50 mm rectangular blocks were cut from the control and treated 500 x 500 x 50 mm specimens for bond strength test. 75 x 75 x 25 mm square blocks were cut from the control and treated 300 x 300 x 25 mm specimens for ultra-violet weathering test. All the block specimens were cut under dry condition.

At the end of the 3rd day and 42nd day after application of the sealants, 2.5” diameter cores were extracted from the 1500 x 500 x 50 mm specimens for dripping test, using wet process because the dry coring machine was not suitable for cutting concrete with steel reinforcement embedded inside.

Salt Spray Test

The salt spray test equipment was designed and constructed by the University of Manitoba. It consisted essentially of an automatically controlled environmental chamber with sprinklers installed inside. The artificial sea water was made up of 30 ± 5 g/liter sodium chloride in distilled water, corresponding to 3% by weight sodium chloride solution, in compliance with the method specified by British standard BS 3900: Part F12.

The salt spray test was conducted using 100 x 100 x 50 mm concrete blocks, which were cut from the 500 x 500 x 50 mm concrete panels. Three triplicate blocks were used for each sealant in addition to the three control blocks from each concrete mix for each test. The final results were calculated as an average of the results from the three specimens.

Before test, the specimens were coated with a protective epoxy coating on all surfaces except the test surface. The concrete blocks were then placed to the test chamber and subjected to 4 hours of salt water spray followed by 8 hours drying period at 30% relative humidity in alternate cycles for a total of 500 hours and 1000 hours respectively. The salt spray was controlled at a flow rate of 2.5 gallon/minute. The temperature in the test chamber was controlled at 40 ± 2°C. During the test, the concrete blocks in the test chamber were repositioned at the end of every 3 or 4 days of operation to ensure that they were subjected to uniform salt water spray.

Upon completion of the salt spray cycles, the concrete specimens were removed from the test chamber, washed with distilled water and dried under normal room conditions. Four holes were drilled on the test surface of each specimen, using a Bosh hammer drill with a 1” diameter solid carbide bit. As the drilling proceeded, the concrete filings were collected for each 5 mm depth increment. The collected fillings were used as samples for chloride content analysis, which was carried out in accordance with BS 1881: Part 124.

Carbonation Test

The test set up, constructed by the University of Manitoba, included a carbonation test chamber, a gas cylinder containing Industrial grade carbon dioxide (concentration > 95%) and two washing bottles containing water. The two washing bottles were connected to the carbon dioxide inlet and outlet of the carbonation chamber respectively. The preparation of concrete specimens for carbonation test was the same as for salt spray test. Three triplicate block specimens were used for each sealant in addition to the three control block specimens from each concrete mix.

The specimens were placed in the carbonation chamber containing over 95% carbon dioxide at 90% relative humidity for 18 days and 36 days respectively. The test temperature was maintained at 25 ± 3°C. The carbon dioxide inside the test chamber was continuously replaced at a flow rate.
of 500 ml/minute and the gas pressure in the chamber was kept slightly higher than the atmospheric pressure.

Upon completion of the test duration, the concrete specimens were removed from the test chamber. Four holes were drilled on the test surface of each tested block, using a Bosh hammer drill with a 1" solid drill bit. As the drilling proceeded, concrete fillings were collected for every 5 mm depth increment for chemical analysis of their pH values. The concrete blocks were then split into halves or quarters with the splitting lines beyond the sampling holes. 1% phenolphthalein solution was then sprayed onto the newly split surfaces to expose the carbonation zone. The carbonation depths were evaluated based on the profiles of the visible carbonation zones.

**Bond Strength Test**

This test followed ASTM C952-91 for evaluation of bond strength between mortar and masonry units. 200 x 90 x 50 mm concrete blocks cut from the 500 x 500 x 50 mm concrete panels were used for the bond strength test. Every two blocks were bonded together by mortar crosswise with the test surfaces facing each other to form a test couplet. The mortar used in bond strength test was prepared in the laboratory using a water/cement ratio of 0.45 and a sand/cement ratio of 2.0. Three replicate couplets were made for each sealant in addition to the three control couplets from each concrete mix. All the test couplets were cured under the condition of 25°C and over 65% relative humidity for a total of 28 days. At the end of the curing period, the concrete couplets were pushed apart using a universal testing machine. The bond strengths were calculated based on the area of the mortar-concrete interface and the force applied during debonding. The average value from the three couplets was used as a final result.

**Dripping Test**

The dripping test was conducted to examine the penetration ability of the sealants upon concrete specimens in different orientation. 1500 x 500 x 50 mm concrete panels were used as the test specimens. The sealants were applied to the test surface as described before. After 3 and 42 days following the application, 2.5" diameter cores were extracted from the concrete specimens at three locations along the direction parallel to the 1500 mm side: at ends and in middle. A concrete disk of approximately 1" thick was cut from the treated side of each core and was split into halves or quarters. Water was then sprayed onto the newly split surfaces to delineate the sealant penetration zone. The penetration depths were measure based on the visible penetration zone profiles. Each penetration depth result was the average of ten readings taken along the penetration zone.

**Quick Ultra-Violet (QUV) Artificial Weathering Test**

The quick ultra-violent ray (QUV) test was based on the procedure outlined in the Hong Kong Specifications for Civil Engineering Works [13] and the equipment specified by ASTM C 53-84 [14]. The QUV artificial weathering test was manufactured by Q-Panel Company of the United States of America. Special specimen holders were made at the University of Manitoba to hold the concrete specimens against the ultra-violent ray. UV-A lamps were used for the tests.

Concrete specimens of 75 x 75 x 25 mm size were cut from the control and treated 300 x 300 x 25 mm concrete panels for the QUV weathering test. After completion of various QUV weathering cycles, the effects of the QUV weathering were evaluated by testing the salt spray and carbonation resistances of the weathered concrete specimens, i.e. subjected the weathered specimens to salt spray and carbonation tests. For the salt spray test, the concrete specimens after 500, 1000 and 4000 hours of QUV weathering cycles were subjected to 4 hours salt water spray at 40°C followed by 8 hours drying at 40°C and 30% relative humidity for a total of 500 hours. At the end of the salt spray test, the samples were washed with distilled water to clear the salt precipitates on the test surface. The top 5 mm layer of each test surface was removed and discarded using a Bosh hammer drill with a 7/8" solid drill bit. In the same hole, a further 10 mm depth was drilled and the fillings were collected as a sample for chloride content analysis.

For the carbonation test, the concrete specimens after 500, 1000 and 2000 hours of QUV weathering cycles were placed into the carbonation chamber containing more than 95% carbon dioxide at a temperature of 25°C and a relative humidity of 90% for 18 days. After the carbonation period was over, each specimen was split into two halves and sprayed with phenolphthalein for carbonation depth measurement.

**TEST Results**

The test results of the G30/20 concrete specimens from the University of Hong Kong are summarized below. Similar results were obtained using G45/20 concrete specimens except that all control and treated G45/20 concrete specimens demonstrated good resistance to carbonation. To avoid over-length, the test results for G45/20 concrete are not presented here.

**Salt Spray Test**

By visual inspection, it was found that after 500 hours and 1000 hours of testing, the originally smooth surfaces of the concrete blocks without sealant became rough and covered with salt while those of the treated blocks remained smooth and clean.

Figures 1 and 2 depict the results of chloride content analysis after 500 hours and 1000 hours of salt spray test. The test results are categorized according to the nominal depth of the sample representing the depth increments from which the concrete fillings were collected. For example, samples corresponding to a nominal depth of 10 mm are the samples collected between depths of 5 mm and 10 mm from the tested surface. From these two figures, it can be seen that the chloride contents decreased with the depth from concrete surface. It can also be seen that all the
specimens treated by the sealants have much lower chloride contents in comparison to the control (untreated) specimens. In all cases, the chloride content in treated concrete was less than 40% of that of untreated concrete at same depth. It may thus be concluded that all the four sealants are effective in reducing chloride penetration.

Carbonation Test

For the control and treated specimens from G45/20 concrete, both pH value analysis and carbonation depth measurement showed no evidence of carbonation reaction after the carbonation test. The pH values of all analyzed samples were well within the range of 12.4 to 12.7, which is the normal pH range of ordinary Portland cement. The carbonation depths of the specimens after 18 days and 36 days of carbonation test were all too small to be measured and recorded as zero. No conclusion can therefore be made on the effectiveness of the sealants in improving the carbonation resistance of G45/20 concrete.

Figures 3 and 4 present the results of pH value analysis for the G30/20 concrete. The mean measured carbonation depths for the G30/20 concrete specimens are plotted versus the test duration in Figure 5.

The pH value analysis indicated very clearly that the sealants had significant effect on enhancing the carbonation resistance of G30/20 concrete. The original pH value of G30/20 concrete was around 12.6. When carbonation takes place, the most important effect is the reduction of pH value in the concrete. From the pH value results, it is seen that the pH values of the control (untreated) specimens dropped dramatically in 18 days and even more in 36 days. On the other hand, the treated concrete specimens experienced much smaller drop in pH value after the carbonation test.

Measurements of the carbonation depths also confirmed the effectiveness of the sealants in improving the carbonation resistance of G30/20 concrete.

Bond Strength Test

The bond strength results are summarized in Table 4. All failures occurred at the interface between concrete and mortar. The results show that the presence of the sealants greatly reduced the bond between the treated concrete surface and the mortar bed. Half of the concrete couplets failed even before being loaded, i.e. when subjected only to the self weight of the specimen, corresponding to about 0.004 MPa of tensile stress. The highest bond strength between treated concrete surface and mortar was only about one fifth of the bond strength between untreated concrete and mortar.

<table>
<thead>
<tr>
<th>Sealant</th>
<th>Concrete G30/20</th>
</tr>
</thead>
<tbody>
<tr>
<td>None</td>
<td>0.39</td>
</tr>
<tr>
<td>P1</td>
<td>0.06</td>
</tr>
<tr>
<td>P2</td>
<td>0.08</td>
</tr>
<tr>
<td>P3</td>
<td>0.05</td>
</tr>
<tr>
<td>P4</td>
<td>0.03</td>
</tr>
</tbody>
</table>

Table 4 – Results of bond strength test (MPa)

Dripping Test

Significant dripping was observed for sealants applied to vertical surfaces immediately after spraying. No dripping was observed for sealants applied to downward horizontal surfaces but a few hanging drops of sealant were found on the surfaces.

P1 and P2 applied to similar concrete surfaces dried at more or less the same rate. However, after surface treatment, troweled (rough) surfaces generally dried faster than moulded (smooth) surfaces. Most of the surfaces treated by P1 and P2 became completely dry within 18 hours but some moulded surfaces treated by P1 and P2 remained tacky even after 3 days. Relatively, surfaces treated by P3 and P4 dried at faster rates. Complete dryness of P3 and P4 occurred within 4 and 7 hours, respectively, after the application.

For sealants applied to vertical surfaces, the penetration depth experienced little change with location, as shown in Figures 6 and 7 for G30/20 concrete. Horizontal penetration depth measurement were also performed.

Figure 3 – pH value of G30/20 concrete after 18 days of carbonation test

Figure 4 – pH value of G30/20 concrete after 36 days of carbonation test

Figure 5 – Carbonation depth of G30/20 concrete after different durations of carbonation test
using specimens facing downward when the sealants were applied. The results are shown in Figure 9. These penetration depth results show little change with time. Overall, the measured penetration depths of the sealants range up to 2.3 mm for G30/20 concrete and 3.2 mm for G45/20 concrete.

QUV Test

The results of 500-hour salt spray test after different durations of QUV test are given in Figure 9 where the chloride content ratio, defined as the ratio of the chloride content of the treated concrete specimen to the chloride content of the corresponding control specimen, is plotted against the duration of QUV weathering. It is seen that the chloride contents of all the treated concrete specimens were well below those of the control specimen up to 500 hours of QUV weathering. However, when the period of QUV weathering was increased to 2000 hours, the chloride content of the concrete specimen treated by P3 became higher than that of the corresponding control specimen while those of other treated concrete specimens remained lower than that of the control specimen.

The results of 18-day carbonation depth measurement after different durations of QUV test are shown in Figure 10. The QUV artificial weathering cycles had significant effects on the carbonation resistance of the treated G30/20 concrete specimens. In general, the carbonation depths of all treated concrete specimens increased with the QUV test duration. After 500 hours or longer of QUV test, the carbonation depths of concrete specimens treated by the four sealants were close to or slightly greater than the carbonation depths of the corresponding control specimens. The life of the sealants to remain effective under the test conditions is thus limited to 500 hours of QUV weathering.

Conclusions

(1) All the four concrete sealants studied are effective in enhancing the resistance of G30/20 and G45/20 concretes against salt spray attack.

(2) All the four concrete sealants studied are effective in enhancing the resistance of G30/20 concrete against carbonation. Since the G45/30 concrete specimens have high resistance to carbonation even without sealants, no conclusion can be made regarding the effect of the sealants on the carbonation resistance of G45/20 concrete.

(3) The concrete sealants would substantially reduce the bond strength between concrete and mortar. With the surface treatment applied, the bond strength between the concrete surface and mortar would be reduced to less than one fifth of original value.

(4) The concrete sealants are capable of penetrating through vertical, upward horizontal and downward horizontal concrete surfaces up to depths of about 2.5 mm.

(5) QUV weathering would gradually reduce the effectiveness of the four sealants. Nevertheless, the treated concrete would remain superior to untreated concrete in terms of both salt spray resistance and carbonation resistance up to a duration limit of 500 hours of QUV weathering.

Acknowledgement

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Y P Xie
Mr Y P Xie is a project engineer with SGB (Far East) Ltd. He obtained his first degree from South China University of Technology in 1983 and thereafter an MSc degree in concrete technology in 1986 and an MSc degree in structural engineering in 1996 from South China University of Technology and University of Manitoba respectively. He has worked for a number of years in the construction industries of both Canada and Hong Kong, and is particularly interested in concrete materials and concrete structures.

A K H Kwan
Dr A K H Kwan is a Senior Lecturer of Department of Civil and Structural Engineering, University of Hong Kong. He has worked for a number of years in the construction industry before returning to the academic circle. His research interests include concrete technology, tall building structures and earthquake engineering.

H C Chan
Dr H C Chan is a Professor and the Head of Department of Civil and Structural Engineering, University of Hong Kong. His main research interest include concrete technology, reinforced concrete structures and computer aided design of structures. He has published many journal papers and chapters of books, and served on several technical committees for the local government and engineering institute.

S H Rizkalla
Prof S H Rizkalla is a Professor of Civil Engineering at University of Manitoba and President of the Canadian Network of Centres of Excellence on Intelligent Sensing for Innovative Structures. He is also Chairman of American Concrete Institute Technical Committee 440 on Fibre Reinforced Polymer for Reinforcement. Vice President of the Board of the Advanced Composites Materials in Bridges and Structures Network of Canada. Chief Editor of FRP International, past Associate Editor of the Canadian Journal of Civil Engineering and a member of Editorial Board of the Composites for Construction Journal. His current research is in the field of advanced composite materials and its use for civil engineering applications.