CORROSION PROTECTION FOR CONCRETE FARM SILOS

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Portland cement concrete is subject to corrosion if it comes in contact with the silage juices present in farm silos. Alternative solutions to this problem are (a) replacement of the Portland cement with an acid-resistant binding agent, (b) protection by means of an acid-resistant barrier and (c) protection by impregnation with an acid-resistant material. In each of these three categories of protection, several solutions were evaluated by test. The results of the tests in which an aluminous cement and rice hull ash cement were used in lieu of Portland cement indicate only small improvements in performance. The impregnation method provided short-term protection, depending on the particular product used. The best results were obtained with acid-resistant coatings. The best coating could not be determined by laboratory testing alone and the selection of the most suitable coating will probably have to be made using other criteria than durability, such as cost, ease of application, flexibility and abrasion resistance.

INTRODUCTION

In the production of good silage, lactic and acetic acids are produced by the lactobacilli present in the ensiled plant material. This fermentation process stops after a few days when a certain level of acidity has been reached. The amount of acid produced and the final pH depends on the type of crop material and, to a large extent, on its moisture content (Lopez et al. 1970; McDonald et al. 1968). For instance, Lopez et al. (1970) have reported pH levels of 3.64 for low dry matter material (52% DM) after 42 days' storage. McDonald et al. (1968) have reported pH values for wilted grass ranging from 4.1 for 34.7% DM to 4.8 for 48.5% DM after 58 days' storage.

Portland cement concrete is subject to corrosion if it comes in contact with acids. The rate of corrosion is dependent on the acidity of the solution, the type of acid and on the quality of concrete. Both lactic and acetic acids in the concentrations present in silage cause concrete to disintegrate slowly (American Concrete Institute (ACI) Committee 515 1966).

The effect of concrete quality on the durability of silo concrete has been studied extensively some 30 - 40 years ago. These studies included field observations and laboratory tests (ACI Committee 714 1961; Hughes 1940; Hughes and Anderson 1942; Miller 1938). The results of this earlier research indicate that the water-cement ratio of the concrete mix is the most important factor in making durable concrete for silos. Low water-cement ratio concrete, if properly consolidated, will be dense and far less permeable. The corrosive agents in this case will not easily penetrate into the concrete and corrosion will only take place at the contact surface.

The second important factor in concrete corrosion is aggregate quality. After some time, the cement mortar at the contact surface will be corroded away, exposing the aggregate to direct attack by the silage juices. A good quality aggregate of a type that is not subject to corrosion by acids will therefore help to slow down further deterioration of the concrete silo wall.

Field observations referred to earlier were done on silos that were 12 - 15 m (40 - 50 ft) high which may be considered small by today's standards. Protective coatings over and above a cement "wash coat" were seldom used and the silos stood up well, provided the concrete was of good quality. Today, silos up to 30 m (100 ft) high are becoming quite common. This has resulted in much higher maximum silage pressures and consequently in greater amounts of free silage juice, particularly in the bottom portion of the silo where it is forced into very immediate contact with the concrete of the silo walls.

For this reason, the problem of concrete corrosion in tower silos and the need for solutions to this problem have again come to the forefront. This paper presents the results of a study in which various solutions to the corrosion problem were investigated.

There are three basically different alternatives to protecting the silo concrete against silage juice attack which were tested in this study. They are:

(1) to replace the Portland cement with a

<table>
<thead>
<tr>
<th>Test no.</th>
<th>Specimens</th>
<th>Avg 28-day cube strength kPa (psi)</th>
<th>Avg 28-day cyl. strength kPa (psi)</th>
<th>Treatment</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>PC† concrete (control specimens)</td>
<td>44,860 (6,506)</td>
<td>35,000 (5,080)</td>
<td>None</td>
</tr>
<tr>
<td>2</td>
<td>PC concrete</td>
<td>40,040 (5,807)</td>
<td>31,200 (4,530)</td>
<td>PC mortar coating, 7.5 mm (0.3 inch) thick</td>
</tr>
<tr>
<td>4</td>
<td>PC concrete</td>
<td>41,260 (5,984)</td>
<td>32,200 (4,670)</td>
<td>Linseed oil/kerosene mix</td>
</tr>
<tr>
<td>5</td>
<td>PC concrete</td>
<td>44,230 (6,415)</td>
<td>34,500 (5,000)</td>
<td>Polystyrene polymer impregnation</td>
</tr>
<tr>
<td>6</td>
<td>PC concrete</td>
<td>39,780 (5,770)</td>
<td>31,000 (4,500)</td>
<td>Water-based epoxy (2 coats)</td>
</tr>
<tr>
<td>7</td>
<td>PC concrete (air-entrained)</td>
<td>31,510 (4,570)</td>
<td>24,600 (3,570)</td>
<td>None</td>
</tr>
<tr>
<td>9</td>
<td>AC† concrete (w/c ratio = 0.5)</td>
<td>48,630 (7,053)</td>
<td>37,900 (5,500)</td>
<td>None</td>
</tr>
<tr>
<td>10</td>
<td>AC concrete (w/c ratio = 0.45)</td>
<td>50,240 (7,287)</td>
<td>39,200 (5,690)</td>
<td>None</td>
</tr>
<tr>
<td>11</td>
<td>PC concrete</td>
<td>40,590 (5,887)</td>
<td>31,600 (4,590)</td>
<td>Asphalt emulsion (2 coats)</td>
</tr>
<tr>
<td>12</td>
<td>PC concrete</td>
<td>41,440 (6,010)</td>
<td>32,300 (4,690)</td>
<td>AC mortar coating, 7.5 mm (0.3 inch) thick</td>
</tr>
</tbody>
</table>

† Portland cement
‡ Aluminous cement.
Of the three alternatives, the first one is the most attractive, if economically feasible, because it would result in a silo that is virtually maintenance-free. Two possible solutions were considered:

(a) The use of alumina cement (Ciment Fondue) a fast-setting cement made by sintering limestone and bauxite; this cement has a considerable resistance to attack by acids down to a pH of about 3.5 - 4.0.
(b) the use of rice hull ash (RHA) cement, a black cement made of the ash of rice hulls burned under controlled temperature, mixed with lime; this cement was developed recently by Dr. Mehta and is, at the moment, being produced commercially on a small scale (ACI 1975). Many commercially available coatings can be used as a barrier to protect Portland cement concrete. Those considered were (a) several solvent-based epoxies, (b) a water-based epoxy, (c) a liquid urethane resin, (d) a water-based acrylic elastomer, (e) a butyl elastomer, and (f) an asphalt emulsion.

For the third group of alternatives, three materials were considered: (a) a polystyrene polymer in a volatile base, (b) a mixture of boiled linseed oil and kerosene, (c) sulphur. In order to determine the relative merit of the various solutions listed above, a research project was carried out at the University of Guelph during 1974 and 1975. A description of the testing procedure follows.

## CORROSION TESTS

The testing program was carried out over two separate periods, the first (test series I) lasting 18 wk, the second (test series II) lasting 30 wk. During both periods, the testing procedure was essentially the same.

Test specimens consisted of 100-mm (4-inch) cubes made with 10-mm (3/8-inch) maximum size local aggregate and with a water-cement ratio of 0.5. Each test consisted of three specimens in test series I and two specimens in test series II with the exception of tests nos. 14 and 31 for which three and five specimens were used, respectively. Details of each test series are provided in Tables I and II, together with the 28-day cube strength and an estimate of the 28-day cylinder strength calculated from the cube strength. All coated specimens were treated on five sides only. The specimens were placed in a shallow fiberglass tank filled with water to which a mixture of lactic and acetic acids was added in such a way that the pH of the solution was 3.8. The ratio of lactic to acetic acid was 3 to 1 by weight. The pH of the solution was controlled automatically by a control system consisting of a pH meter, a titrator and a solenoid valve. A mixer provided continuous agitation. The specimens were supported on racks and were submerged up to 1 cm (0.4 inch) below the unprotected top surface. Figure 1 shows a general view of the testing arrangement. Hughes (1940) found that intermittent testing in an acid solution causes more severe deterioration of the concrete than does continuous submersion. In view of those findings and also in view of the fact that in a silo the contact with silage juice is not likely to be continuous, intermittent testing was used in this program. A typical sequence of events for a period of a week was as follows: (a) 5 h complete submersion in water, (b) preparation for weighing and weighing, (c) placing the specimen in a shallow fiberglass tank filled with water to which a mixture of lactic and acetic acids was added in such a way that the pH of the solution was 3.8. The ratio of lactic to acetic acid was 3 to 1 by weight. The pH of the solution was controlled automatically by a control system consisting of a pH meter, a titrator and a solenoid valve. A mixer provided continuous agitation. The specimens were supported on racks and were submerged up to 1 cm (0.4 inch) below the unprotected top surface. Figure 1 shows a general view of the testing arrangement.

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**TABLE II DETAILS OF TEST SERIES II**

<table>
<thead>
<tr>
<th>Test no.</th>
<th>Specimens</th>
<th>Avg 28-day cube strength kPa (psi)</th>
<th>Avg 28-day cyl. strength kPa (psi)</th>
<th>Treatment</th>
</tr>
</thead>
<tbody>
<tr>
<td>14</td>
<td>PC concrete</td>
<td>46,010 (6,673)</td>
<td>35,900 (5,200)</td>
<td>None</td>
</tr>
<tr>
<td></td>
<td>(control specimens)</td>
<td></td>
<td></td>
<td>(tests 14-19 inclusive)</td>
</tr>
<tr>
<td>15</td>
<td>PC concrete</td>
<td></td>
<td></td>
<td>Water-based epoxy (2 coats)</td>
</tr>
<tr>
<td>16</td>
<td>PC concrete</td>
<td></td>
<td></td>
<td>Liquid urethane resin (1 coat over 1 coat of primer)</td>
</tr>
<tr>
<td>17</td>
<td>PC concrete</td>
<td></td>
<td></td>
<td>Liquid urethane resin (2 coats over 1 coat of primer)</td>
</tr>
<tr>
<td>18</td>
<td>PC concrete</td>
<td></td>
<td></td>
<td>Epoxy coating (2 coats)</td>
</tr>
<tr>
<td>19</td>
<td>PC concrete</td>
<td></td>
<td></td>
<td>Epoxy coating (2 coats)</td>
</tr>
<tr>
<td>20</td>
<td>PC concrete</td>
<td>42,570 (6,174)</td>
<td>33,200 (4,800)</td>
<td>Polystyrene polymer impregnation</td>
</tr>
<tr>
<td></td>
<td>(tests 20-26 inclusive)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>22</td>
<td>PC concrete</td>
<td></td>
<td></td>
<td>Water-based acrylic elastomer (2 coats)</td>
</tr>
<tr>
<td>23</td>
<td>PC concrete</td>
<td></td>
<td></td>
<td>Water-based acrylic elastomer (1 coat)</td>
</tr>
<tr>
<td>24</td>
<td>PC concrete</td>
<td></td>
<td></td>
<td>Polymerized butyl elastomer (1 coat)</td>
</tr>
<tr>
<td>25</td>
<td>PC concrete</td>
<td></td>
<td></td>
<td>Polymerized butyl elastomer (2 coats)</td>
</tr>
<tr>
<td>26</td>
<td>PC concrete</td>
<td></td>
<td></td>
<td>Water-based acrylic elastomer (1 coat over 1 coat of primer)</td>
</tr>
<tr>
<td>27</td>
<td>PC concrete</td>
<td>43,760 (6,347)</td>
<td>34,100 (5,000)</td>
<td>Epoxy coating (1 coat)</td>
</tr>
<tr>
<td>28</td>
<td>PC concrete</td>
<td>(tests 27-30 inclusive)</td>
<td></td>
<td>Epoxy coating (2 coats)</td>
</tr>
<tr>
<td>30</td>
<td>PC concrete</td>
<td></td>
<td></td>
<td>RHA cement mortar coating 7.5 mm (0.3 inch) thick</td>
</tr>
<tr>
<td>31</td>
<td>RHA cement concrete</td>
<td>61,030 (8,852)</td>
<td>47,600 (6,900)</td>
<td>None</td>
</tr>
<tr>
<td>32</td>
<td>PC concrete</td>
<td>43,760 (6,347)</td>
<td>34,100 (5,000)</td>
<td>Asphalt emulsion (1 coat)</td>
</tr>
<tr>
<td></td>
<td>(tests 32-34 inclusive)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>33</td>
<td>PC concrete</td>
<td></td>
<td></td>
<td>Epoxy coating (1 coat)</td>
</tr>
<tr>
<td>34</td>
<td>PC concrete</td>
<td></td>
<td></td>
<td>Sulphur impregnation</td>
</tr>
</tbody>
</table>

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Visual inspection of the specimens during and at the end of the test period of series I revealed that (a) the water-based epoxy coating (no. 6) softened and bubbled soon after submersion in the acid base and the test was discontinued; (b) the asphalt emulsion coating (no. 11) also softened and peeled off in places; this test was also discontinued in the early stages of testing; (c) the specimens impregnated with polystyrene polymer (no. 5) lost surfact material over most of the exposed area (Fig. 2); (d) the specimens impregnated with boiled linseed oil (no. 4) and those made of AC (nos. 9 and 10) exhibited corrosion similar to that of the control specimens (no. 1) (see Figs. 3, 4 and 5).

Visual inspection of the series II specimens showed that (a) the water-based epoxy coating (no. 15), although cured for one month, failed again by softening and bubbling; this time the test was continued. At the end of the test about 40 - 50% of the specimen area was bare; (b) the specimens impregnated with polystyrene polymer (no. 20) again lost surface material over most of the exposed areas; (c) the water-based
acrylic elastomer coating (nos. 22, 23 and 26) also softened slightly when submerged in water. In tests nos. 22 and 23 the coating formed some large bubbles during testing but because of the flexibility and toughness of the coating, it remained intact. By inspection, it was evident that the bond to the concrete was poor. The primer used in test no. 26 improved the bond considerably. A primer is not normally specified by the manufacturer; (d) specimens of test no. 24 showed bare concrete areas over about 10% of the total exposed area at the end of the test period; (e) the asphalt emulsion coating (no. 32) softened badly when submerged in water; as a result, about 40% of the exposed surface area was bare concrete at the end of the test period; and (f) specimens of tests nos. 16 - 19 incl., 25, 27, 28 and 33 were not changed visibly by the exposure to acid during the test period.

DISCUSSION OF TEST RESULTS
The following conclusions may be drawn from the test results of the previous section.
1. The rate of scaling of the control specimens of test series I (test no. 1) was about 25% greater than that of test series II (test no. 14). This may be attributed to the weekly air jet blasting carried out in series I. The cement matrix around aggregate particles deteriorates faster than do the aggregate particles and the air jet blasting tends to remove the protruding aggregate faster than simple brushing.
2. Air-entrainment of the concrete (no. 7) led to a greater rate of scaling than normal concrete with the same water-cement ratio. This coincides with lower density and strength of air-entrained concrete.
3. The use of aluminous cement (nos. 9, 10 and 12) and RHA cement (nos. 30 and 31) resulted in a somewhat smaller rate of scaling than the use of Portland cement but not sufficiently so to warrant its use, taking into account the high costs of these cements.
4. From the performance of the various mortar coatings, there was an indication that exclusion of coarse aggregate from the surface of the structure decreased the rate of deterioration. This observation is probably true only in areas where the aggregate is subject to corrosion by acids such as in Southern Ontario where a large percentage of concrete aggregates consists of limestone.
5. The boiled linseed oil treatment (no. 4) delayed commencement of deterioration about 2 wk. However, after about 6 wk the rate of scaling was about the same as that of the control specimens. The usefulness of this coating for farm silos must be considered marginal and of short-term nature.
6. The impregnation of concrete with a polystyrene polymer (nos. 5 and 20) delayed the acid attack considerably. After breakdown of the surface finish, the rate of scaling was still less than 50% of that of unprotected concrete. This relatively inexpensive treatment would provide short-term protection, and would probably have to be repeated every 3 - 5 yr to provide effective, continuous protection.
7. In the tests, all water-based coatings (nos. 15, 22, 23, 26 and 32) softened. Bubbling and peeling usually resulted. However, the treatment using an acrylic elastomer coating over a primer showed no loss of weight. This suggests that this type of treatment might be a useful alternative if a suitable primer is used to prevent loss of bond with the concrete. This coating is very flexible (ASTM D2370 elongation ranges from 120% at -18°C to 360% at 38°C), a necessary property for stave silo coatings.
8. The impregnation with sulphur (no. 34) reduced the rate of scaling. This test, although of short duration, showed deterioration to be about 1/5 of that of unprotected concrete. However, for the relatively low water-cement ratio concrete used, the penetration was not very deep (about 3 - 4 mm) and it may be expected, therefore, that the rate of scaling would be equal to that of unprotected concrete after the sulphur im-

Figure 2. Specimens of test no. 5 after completion of testing.

Figure 3. Specimens of test no. 4 after completion of testing.
coating. One of the most important factors to be considered is cost. However, because it is not practical to obtain reliable cost data unless a quotation is obtained for a specific job, this factor was not considered by the author.

Another consideration relates to the ease of application of the coating. This may determine whether the coating can be applied by the silo owner or whether an application specialist must be employed. The epoxy, butyl elastomer and urethane resin coatings require closely controlled application conditions and a thoroughly dry concrete surface at time of application. Most epoxy and butyl elastomer coatings are two component packages which must be mixed in the correct proportions at time of application. During application, harmful fumes are released by some coatings. In these cases, special equipment may be required to ventilate the inside of the silo or otherwise protect the applicator.

In farm silos other properties than durability may be important. They are (a) toughness and abrasion resistance, especially where unloading equipment is guided by the silo wall; (b) flexibility of coating where large movements can be expected such as at vertical joints of stave silos; and (c) adhesion to the concrete. Epoxy and urethane coatings are outstanding in their toughness and abrasion resistance but are also quite brittle. The elastomer coatings are far more flexible but less tough. Epoxy coatings adhere to concrete very well; urethane coatings also adhere well provided extreme care is taken in surface preparation.

Finally, the suitability of any coating for the inside of farm silos used to store animal feed must be assessed and approved by the appropriate regulatory body. It was not possible to obtain such assurance from all coating manufacturers although the intended use of the coating was clearly stated in the initial enquiry. In any case, some coating products, such as epoxy, are marketed by a large number of manufacturers. The complexity of polymer chemistry leads to a wide variety of different products. Approval of one particular epoxy coating does not necessarily imply that all epoxy coatings are suitable for application to animal food containers. Thus, the fact that a particular coating was tested in this research project and found to be satisfactory does not guarantee suitability as a coating for silo application.

It should be pointed out that the rates of scaling in Tables III and IV can be viewed only comparatively. The rate of deterioration of a silo wall made of concrete with a water-concrete ratio of 0.5 will most likely be much smaller than that found in the tests.

**Further Considerations**

Other factors than durability must be taken into account in the selection of a silo coating. Pregenerated concrete had disappeared. Thus, the protection provided using this treatment would be about equivalent to impregnation with the polystyrene polymer, but more costly.

All coatings of non-water-based epoxy, liquid urethane resin and butyl elastomer behaved equally well in the tests. With the exception of the butyl elastomer coating, one coat appeared to be adequate protection for the 30-wk test period.

**Summary**

Farm silos for the storage of silage are subject to corrosion by silage juice. Large concrete silos may deteriorate very fast if the concrete is of inferior quality. Even good concrete will, in time, deteriorate and the useful life of a silo will be shortened drastically.

Various solutions for combating acid corrosion have been examined by test and
the results have been used to provide
guidance in selecting the best alternative. A
number of coatings performed very well and
a selection of the best could not be made on
the basis of resistance to acid attack alone.
Further selection would have to be made by
the user on the basis of cost and on the
suitability for a particular application. To
aid in the latter, some additional properties
of coatings have been mentioned.

In conclusion, it should be noted that the
rates of scaling from the test can be viewed
only comparatively and bear no relationship
to the rate of scaling that will actually occur
in a silo. The rate of deterioration of a silo
wall made of concrete with a water-concrete
ratio of 0.5 will most likely be much smaller
than that found in the tests.

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