Effect of hydrogen sulphide emissions on cement mortar specimens

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Idriss, A.F., Negi, S.C., Jofriet, J.C. and Hayward, G.L. 2001. **Effect of hydrogen sulphide emissions on cement mortar specimens**. Canadian Biosystems Engineering/Le génie des biosystèmes au Canada **43**: 5.23-5.28. The most corrosive agent that leads to the rapid deterioration of concrete floors in barns with underground manure storage tanks is hydrogen sulphide, which is generated from anaerobic fermentation of manure. One of the objectives of the research on corrosion in livestock buildings at the University of Guelph was to compare the corrosion resistance of different cement mortar specimens under long term exposure to hydrogen sulphide. Six treatments were tested in the laboratory using the impressed voltage technique, including Portland cement Type 10 with 0.45 water-cementing material ratio (W/C) (PC45), Portland cement Type 10 with 0.55 W/C (PC55), sulphate resistant Portland cement Type 50 (SRC) with 0.45 W/C, Portland cement with fibre mesh (FMC) with 0.45 W/C, silica fume cement (SFC) with W/C 0.35, and specimens containing Portland cement Type 10 (0.45 W/C) coated with linseed oil (PCL). The results of this study revealed that test specimens made with 8% silica fume cement replacements (SFC) performed best and similar Portland cement mortar specimens with a water-cement ratio of 0.55 (PC55) poorest. The other four treatments (PC45, SRC, FMC and PCL), all with water-cement ratios of 0.45, were less effective in preventing corrosion than treatment SFC. **Keywords:** concrete, corrosion, hydrogen sulphide, livestock buildings, slats, water-cement ratio.

Le sulfure d'hydrogène généré lors de la fermentation anaérobie du fumier est le produit le plus corrosif qui entraîne la détérioration rapide des planchers de béton des bâtiments d'élevage avec un réservoir à fumier au sous-sol. Un des objectifs de cette recherche sur la corrosion des bâtiments d'élevage à l'université de Guelph était de comparer la résistance à la corrosion de différents échantillons de mortier de ciment en contact avec du sulfure d'hydrogène durant une période prolongée. La technique de la tension imposée fut utilisée pour tester 6 traitements en laboratoire, dont du ciment Portland type 10 avec un ratio eau/ciment (W/C) de 0.45 (PC45), du ciment Portland type 10 avec W/C de 0.55 (PC55), du ciment Portland type 50 résistant aux sulfates avec W/C de 0.45 (SRC), du ciment Portland avec un treillis de fibre (FMC) avec W/C de 0.45, du ciment Portland contenant de la fumée de silice avec W/C de 0.35 (SFC), et des échantillons contenant du ciment Portland type 10 (W/C=0.45) enrobé d'huile de lin (PCL). Les résultats de cette étude ont montré que les échantillons contenant 8% de fumée de silice (SFC) s'étaient le mieux comportés, alors que ceux contenant du ciment de Portland avec un ratio de 0.55 (PC55) avaient été les moins résistants. Les autres 4 traitements (PC45, SRC, FMC et PCL), qui avaient tous un ratio eau/ciment de 0.45, furent moins efficaces que le traitement SFC pour prévenir la corrosion. **Mots clés**: béton, corrosion, sulfure d'hydrogène, bâtiments d'élevage, lattes, ratio eau-ciment.

INTRODUCTION

Reinforced concrete is one of the most durable construction materials used extensively in the construction of animal housing, especially in floors and underground tanks used to store liquid manure. However, the temporary storage of manure underneath the barn floor in swine, dairy, and beef housings can create an environment that is quite corrosive to concrete, causing premature rusting of reinforcement and direct corrosion of the concrete. In some instances, slatted floors have deteriorated to the point of requiring replacement in less than five years (MacKinnon 1994).

The corrosion of reinforced concrete structures is a serious problem where it comes in contact with chlorides. As a result, much research and many studies have dealt with the deterioration of reinforced concrete in marine environments, waste water collection and treatment facilities, bridges, parking garages, and underground structures. However, the deterioration of reinforced concrete in animal buildings has not received much attention. Therefore, little is known about the seriousness of this problem and few solutions have been provided.

The deterioration of the concrete in animal buildings, such as in slatted floors, may lead to reduced safety or even collapse. The failure of a floor can cause serious injuries to animals and/or persons. Replacing or maintaining floors that have corroded is expensive. The deterioration of the walls of liquid manure tanks might lead to leakage of manure or even failure of the tank and result in the pollution of groundwater.

The floor of a barn is often made of slotted precast reinforced concrete slabs. The upper side of the floor is subjected to faeces and urine, and the underside is subjected to the gaseous environment that exists above the liquid manure. As a result of anaerobic fermentation of the manure, hydrogen sulphide, ammonia, methane, acetic acid, water vapour, and carbon dioxide are generated. The most corrosive agent that leads to the rapid deterioration of concrete floors in barns is hydrogen sulphide (H_2S), which also attacks concrete in sewers and wastewater treatment plants. The H_2S dissolves in moisture films on the exposed concrete surfaces where it undergoes oxidation by aerobic bacteria to sulphuric acid, commonly referred to as biogenic sulphuric acid attack (De Belie et al. 2000). In addition, the H_2S attacks concrete directly by reacting with the calcium hydroxide in a set cement to form calcium bisulphide (Frénay and Zilverberg 1993).

The objective of this research was to compare the corrosion resistance of six different cement mortar specimens exposed to hydrogen sulphide for a period of one year.

BACKGROUND

The septicity in the manure storage system results from the activity of bacteria under anaerobic conditions. Bacteria will reduce sulphur-containing organic compounds and sulphates to form sulphides. A small amount of reduced sulphur is assimilated by the bacteria, but almost all is released into the environment as sulphide ions, mostly as free hydrogen sulphide (H_2S) depending on the pH of the environment (Boon 1992). In the absence of oxygen, hydrogen sulphide is initially formed by the action of *proteolytic* bacteria on the organic compounds of sulphur.

The proportions of H_2S, HS^-, and S^{2-} are significantly affected by the pH of the solution and will also be slightly affected by its temperature and ionic strength (Boon 1992). Hydrogen sulphide production in most cases is not the first step of anaerobic biodegradation. The sulphate reducing bacteria (SRB) are not able to metabolise the contaminants of the fresh manure. However, bacteria from the digestive systems can convert the original organic compounds into lactic acid, which has been found to be one of the common substrates used by the hydrogen sulphide producing bacteria (Jobbágy et al. 1994). Equation 1 shows the stochiometry of sulphate reducing strain using lactic acid as a carbon source.

$$CH_3CHOHCOOH + 0.43\ H_2SO_4 + 0.067\ NH_3$$
$$\xrightarrow{\textit{Desulfovibriod desulfuricans}} 0.33\ CH_{1.4}N_{0.2}O_{0.4} +$$
$$0.96\ CH_3COOH + 0.43\ H_2S + 0.7\ CO_2 + 0.94\ H_2O \qquad (1)$$

Most of the sulphate reducing bacteria are unable to use acetic acid as a carbon source, but there are several exceptions such as *Desulfotomaculum acetoxidans*. An acetic acid based H_2S - production is illustrated by Eq. 2 (Jobbágy et al. 1994).

$$CH_3COOH + SO_4^{2-} \xrightarrow{\textit{Sulphater reducers}} H_2S + 2HCO_3^- \qquad (2)$$

Hydrogen sulphide developed during decomposition of organic substances is transformed into sulphate by aerobic *Thiobacilli* bacteria, *Beggiatoa* and *Thiotrix* species, as well as purple and sometimes green *Chromatium* and *Corobium* species (Jobbágy et al. 1994; Zhu et al. 1994; Alekseev et al. 1993; Heuer and Kaskens 1993; Sand et al. 1986). Oxidation of H_2S occurs in several stages as:

$$2H_2S + O_2 \xrightarrow{\textit{green sulphur bacteria}} 2H_2O + 2S + 528j \qquad (3)$$

$$S_2 + 3O_2 + 2H_2O \xrightarrow{\textit{purple sulphur bacteria}} 2H_2SO_4 + 1231j \qquad (4)$$

The sulphuric acid in Eq. 4 is of course very corrosive to concrete and probably the major cause of concrete corrosion in animal housing and liquid manure tanks.

In addition to the obvious acid damage, the sulphate ions attack concrete directly by reacting with calcium ions to form gypsum:

$$2H_2O + Ca^{2+} + SO_4^{2-} \rightarrow CaSO_4 \cdot 2H_2O \qquad (5)$$

and with calcium aluminum hydrate to form ettringite. The gypsum formation results in a 124% volume increase and the ettringite formation results in a 227% volume increase. Both of these processes result in sufficient stress to cause cracking and disintegration of the concrete.

Hydrogen sulphide also attacks both concrete and reinforcing steel directly. It reacts with lime to produce a soluble product:

$$Ca(OH)_2 + 2H_2S \rightarrow Ca(HS)_2 + 2H_2O \qquad (6)$$

When it reaches the reinforcing steel through cracks produced by the sulphate attack or by external mechanical stresses, ferrous sulphide is formed. Water and oxygen, also migrating through the cracks, forms iron oxides and hydroxides. These corrosion products also expand in volume, further cracking the concrete.

EXPERIMENTAL DESIGN

Treatments

Six materials that are typically used in the construction of animal housing buildings or in other areas of concrete construction were studied. In all cases, cement mortar specimens were used to accelerate the corrosion process. The test was divided into two sets of experiments, one not exposed to H_2S, the other exposed to H_2S for one year. Three replicates from each treatment were tested in each set.

Portland cement type 10 (PC45) Portland Cement (Type 10) is the most commonly used cement in concrete. This material is considered the control treatment in the study. For durability, a water-cementing material (W/C) ratio of 0.45 is recommended for class A exposure, such as exposure to de-icing chemicals (CSA 1994). Concrete used in barn floors, under floor manure tanks, and other parts in contact with manure is exposed to an environment equivalent to exposure condition A in CSA A23.1 warranting the use of a W/C ratio of 0.45. Super plastizier (0.125 L/100 kg cement) was used to increase the workability of the mortar and facilitate its moulding. The weight ratio of cement, sand (natural sand with particle sizes ranging from 0.075 to 2 mm), and water used in the mix design of specimens was 1 to 2 to 0.45.

Sulphate resisting cement type 50 (SRC) Sulphate resisting cement (Type 50) is commonly used in concrete subjected to the attack of sulphates. A water-cementing material ratio of 0.45 and super plastisizers were used as for the PC45 specimens and the amount of super plastisizer and the weight ratios of cement, sand, and water were also the same as PC45.

Silica fume cement (SFC) In this treatment, 8% of the cement was replaced by silica fume to improve both the mechanical characteristics and durability. A water-cementing material ratio of 0.35 was used in the SFC mortar. This is possible because part of the cement is replaced by silica fume which does not need hydration water since it has no cementious properties. Super plastizier (1.00 L/100 kg) was used to increase the workability of the mortar and to facilitate its moulding. The weight ratio of cement, silica fume, sand, and water was 0.92 to 0.08 to 2 to 0.35.

Fibre mesh added to PC45 (FMC) This treatment is the same as PC45 except that polypropylene fibre mesh (0.9 kg/m^3) was added to the cement mix. The fibres reduce shrinkage cracks which lower the integrity of the concrete. Also, this type of fibre actively fights microbial growth, which may lead to early deterioration of concrete from sulphuric acid. The Microban "B" additive in Fibermesh fibres is a cell wall penetrant that disrupts the metabolic function of thin walled micro organisms, thereby helping to control them.

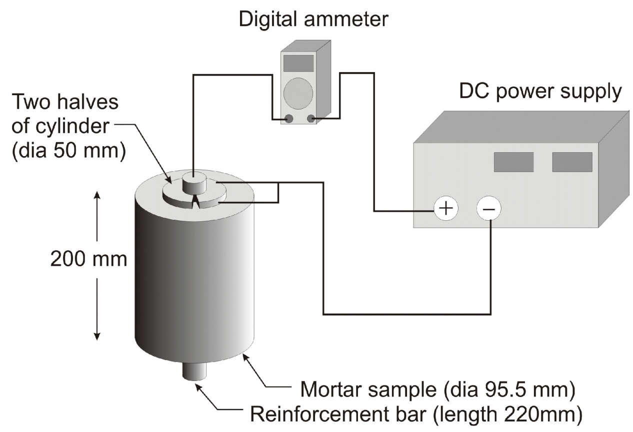

Fig. 1. Schematic diagram of impressed voltage test.

PC45 coated with linseed oil (PCL) PC 45 specimens were given an external coating of linseed oil diluted in diesel fuel (50% by volume). This method of protection has been used for many years to protect concrete in bridges and other road structures from corrosion. Some contractors in Ontario use this method of protection on floors in swine barns. The weight ratio of cement, sand, and water used in the mix design of specimens was 1 to 2 to 0.45.

Portland cement type 10 (PC55) Portland Cement Type 10 with a W/C ratio of 0.55 and no super plastisizer was used for this treatment. The purpose of this treatment was to demonstrate again that concrete with a commonly used W/C ratio of 0.55 in the construction of agricultural structures has inferior durability. The weight ratio of cement, sand, and water used in the mix design of specimens was 1 to 2 to 0.55.

Specimen preparation

All specimens were cylindrical in shape with a 11.3 mm diameter reinforcing rod in the centre of the cylinder. The cylinder was 95.5 mm in diameter and 200 mm long. The deformed reinforcing rod (yield strength = 400 MPa) was 220 mm long. A sheet steel electrode consisting of two half 50 mm diameter cylinders separated by 2 mm was also cast in the mortar cylinders to serve as an external cathode (Fig. 1).

A plastic mould was designed and fabricated to prepare the specimens. The mould was comprised of four elements: the outer frame, two cylinder halves (electrode jackets), base, and upper template to hold the components together. The mortar was placed in the test mould in three equal layers where each layer was compacted 25 times using a 16-mm steel rod, 600 mm long. The mould was disassembled one day after casting the specimens. All specimens were cured for 28 days, and they were kept in plastic bags partly filled with water to ensure 100 % RH.

Exposure to hydrogen sulphide environment

Three Plexiglas containers (450 x 350 x 250 mm) were used to expose the specimens to H_2S. Each Plexiglas box contained six specimens, one from each of the treatments. The specimens were subjected to a daily dosage of 2000 ppm of hydrogen sulphide, which was prepared with 250 mL of sodium sulphide of 0.1 mol/L concentration and 80 mL of hydrochloric acid of 1 normality. The containers were drained daily of H_2S and a new solution was used to prepare H_2S to simulate the agitation process, which takes place on an intermittent basis. The specimens were exposed to H_2S for one year before testing.

Randomised complete block design (RCBD) was used in this study because it is simple and reduces the experimental error (Kuehl 1994). The mortar specimens were grouped into blocks of six specimens, one from each treatment, such that each block was subjected to the same H_2S dosage. Thus, any differences in the mortar response caused by a possible variation in H_2S concentration could be associated with the blocks.

Corrosion measurement

Corrosion measurement techniques are used in the evaluation of existing structures or for studying the performance of the reinforcement in concrete under controlled conditions in the laboratory. The impressed voltage technique, which was used in this study, is an accelerated corrosion testing technique for a qualitative comparison of concretes (Al-Tayyib and Khan 1991). This technique was used by Khder and Idriss (1995) to study the performance of silica fume concrete exposed to chlorides. In this technique, the embedded reinforcement in concrete is made anodic with respect to an external electrode serving as cathode by applying a constant positive potential to the system from a direct current (DC) source. The variation of the current with time is recorded. A sharp rise in the current, caused by change in the electrical resistivity of the specimen, indicates the onset of corrosion and the specimen usually cracks thereafter. The test apparatus and the dimensions of the specimen are shown in Fig. 1.

An electrical DC power supply of 40 V was used. The current readings under the constant voltage were recorded every 15 min. The current rose until it reached a maximum value and then declined until a longitudinal crack developed along the length of the cylindrical specimen. The internal pressure due to the accumulation of corrosion products, such as rust and hydrated ferric oxide, causes circumferential (hoop) tension which results in cracking of the specimen. The time taken to develop the longitudinal crack in the mortar specimen was recorded as T_c. The amount of electricity required for cracking, Q_c, was obtained by graphical integration of the current-time curve. A realistic measure of the durability of a specimen is the value of Q_c multiplied by T_c. The reciprocal of the product Q_cT_c is known as the susceptibility to corrosion, STC. The behaviour of the treatments due to corrosion of the reinforcement was compared on the basis of the electrical current variation, T_c, and STC.

RESULTS and DISCUSSION

Non exposed specimens

Effect of the treatment on current variation The current variations recorded for the non exposed specimens are presented in Figs. 2 and 3 (note the time scale difference). The maximum current recorded for each treatment is shown in Table 1. The PC55 had the maximum current of 3.11 A while the SFC had the lowest at 1.39 A.

The current at the beginning of the experiment, Fig. 2, was virtually the same for all treatments. The differences in current among the treatments were greater in the first hour of testing than for the remaining period of the test. The current increase is a result of reduction in the electrical resistivity of the specimens.

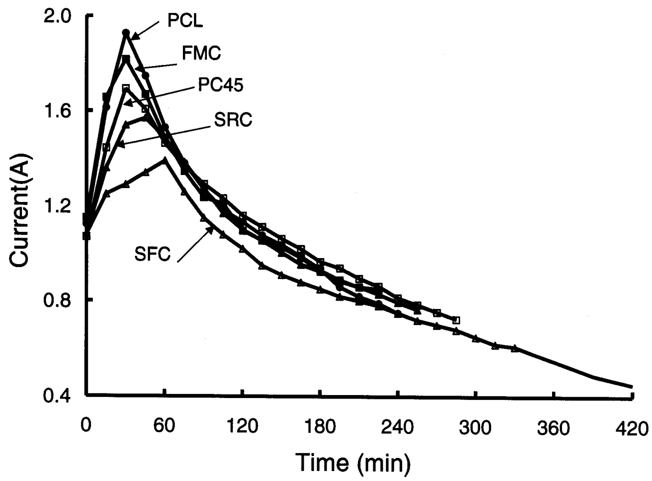

Fig. 2. Current variation for specimens not exposed to H_2S except for PC55.

The ionization of the pore water in the specimens due to the applied potential difference was probably the reason for the reduction in the electrical resistivity. The applied voltage ionized the pore water to OH^- and H^+, where H^+ was attracted to the negative pole forming H_2, and OH^- was attracted to the positive pole, the steel bar embedded in the specimens. The movement of negative hydroxyl and positive hydrogen ions created an internal current, which was another reason for the increase in the recorded current. However, the OH^- ions react with the reinforcement steel forming corrosion products, such as rust and hydrated ferric oxide, which are not as conductive as the original steel bar.

$$Fe^{2+} + 2OH^- = Fe(OH)_2 \tag{7}$$

After one hour for treatment SFC and half-hour for treatments PC45, PCL, FMC, and SRC, the corrosion products would have covered most of the reinforcement bar and increased the electrical resistance of the specimen. Consequently, the current declined beyond these points in time for the aforementioned treatments.

Treatment SFC recorded the lowest current at the beginning of the experiment (Fig. 2) because the addition of silica fume

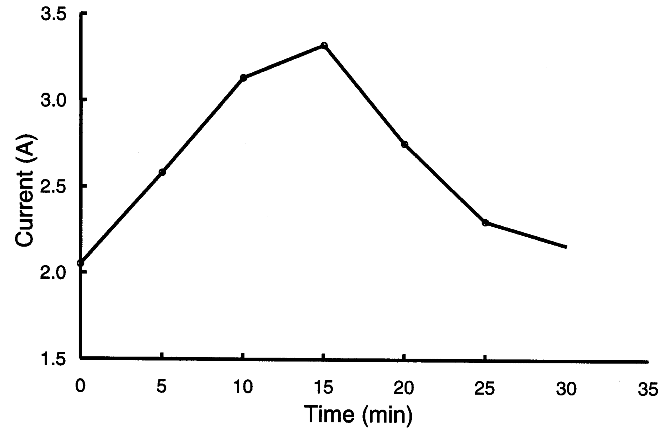

Fig. 3. Current variation for PC55 specimens not exposed to H_2S.

increases the electrical resistivity (Vennsland and Gjrov 1991). The PC55 specimens had the highest recorded current because the high water content reduced the electrical resistance. For the treatments with a 0.45 W/C ratio, linseed oil coated specimens (PCL) had the highest current, while the SRC specimens had the lowest. It seems that the diluted linseed oil was absorbed by the mortar reducing its electrical resistance.

In the PC55 treatment the current rose to its peak after 15 min and declined gradually until failure. Failure was signified by the occurrence of a longitudinal crack in the mortar specimen. Figure 3 shows the current variation for PC55. The current variation followed the same bell-shaped curve, as for the other treatments, for the same reasons mentioned previously.

Effect of treatments on failure time The corrosion products of steel have a bigger volume than the original material. The increase in volume will produce internal pressure, which will cause the cracking of the specimen due to circumferential tension. Therefore, it was expected that the fibre mesh mortar would show the second best corrosion resistance, after SFC, due to increase in the tensile strength provided by the fibres. On the contrary, the experiments revealed that the fibre mesh did not have the maximum T_c. A visual inspection of the fibre specimens (FMC) from inside, showed that the steel bar suffered from heavy corrosion unlike the other specimens of 0.45 W/C ratio (PC45, SRC, PCL). The impressed voltage test is accompanied by an increase in temperature, the external surface temperature of the specimen was about 45°C, which could be the main reason for the early failure of the fibres. As such the damaged fibres acted as micro cracks and allowed easier pore water movement in the specimen. The SFC treatment had the highest value of T_c because the application of silica fume increased the electrical resistivity, as such the corrosion process would not proceed as fast as the other treatments. Table 1 shows the T_c for the six treatments.

Effect of treatment on STC Table 1 also shows the susceptibility to corrosion, STC, in $\mu A^{-1} min^{-2}$, for the specimens not exposed to H_2S. The SFC treatment had the lowest STC while the PC55 treatment had the highest. It was expected that the fibre mesh mortar would show better resistance because of the fibres. On

Table 1. Impressed voltage test results for mortar specimens not exposed to hydrogen sulphide.

Parameters	Treatments					
	PC45	SRC	FMC	PCL	PC55	SFC
Maximum current (A)	1.69	1.57	1.81	1.93	3.11	1.39
Failure time, T_c (min)	285	255	225	240	35	420
Charge, Q_c (A min)	167	150	144	151	130	185
Susceptibility to corrosion, STC (μA^{-1} min^{-2})	21	26.2	30.8	27.6	219	12.9

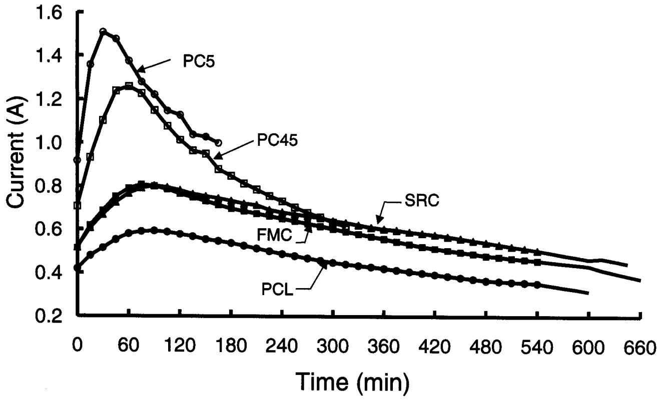

Fig. 4. Current variation for specimens exposed to H_2S except for SFC.

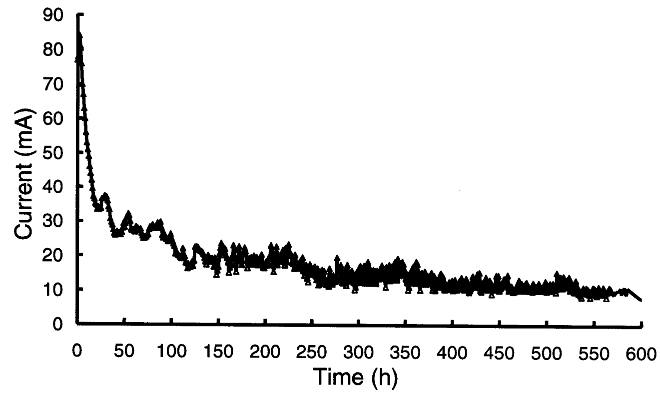

Fig. 5. Current variation for SFC specimens exposed to H_2S.

the contrary, the experiments revealed that the fibre mesh had the maximum STC because T_c was small in comparison to the other treatments with 0.45 W/C ratio.

Specimens exposed to H_2S

Effect of the treatment on current variation The current variation recorded by the impressed voltage technique for the exposed specimens is presented in Fig. 4 for PC45, SRC, FMC, PCL, and PC55, and in Fig. 5 for the SFC treatment because of the difference in time scale. The maximum current for each treatment is shown in Table 2. Treatment PC55 had the maximum current of 1.48 A while the SFC specimens had the lowest current of 0.084 A. The current at the start of the experiment could be categorised into three groups. The first group consisted of PC45 and PC55, in which the starting currents of 0.71 and 0.93 A were recorded (Fig. 4). The second group consisted of treatments SRC, FMC, and PCL with starting currents ranging from 0.42 to 0.52A (Fig. 4). The third was SFC, which had the lowest current of 84 mA at the beginning of the experiment (Fig. 5).

The current variation curves for the specimens of treatments PC45, SRC, FMC, PCL, and PC55 had a bell shape, similar to the non-exposed ones. The maximum current for treatments PCL, FMC, and SRC was recorded after 1.5 h, and for PC45 and PC55 after 1 h and 0.5 h, respectively. Then the current decreased until failure occurred. The explanation of the differences between treatments is similar to those for the non-exposed specimens discussed earlier. Figure 4 indicates that the treatments SRC, FMC, and PCL exhibit about the same performance when exposed to H_2S and they performed better than PC45 and PC55.

Figure 5 shows that the specimens of the silica fume cement (SFC) exhibited much lower currents which rose to a peak after 1 h and then declined until failure. The current-time variation was not smooth and current fluctuations were recorded. The current was relatively small in comparison to the other treatments and could vary considerably due to small changes in water content or temperature. The ohmmeter had high impedance and was sensitive to these changes in the current.

Effect of treatment on failure time Table 2 shows the T_c for each treatment. Treatment SFC performed best and failed after 600 h of testing, while PC55 failed earliest after 165 min. The PC45 control specimen also performed poorly and failed after 315 min. Treatments SRC, FMC, and PCL had approximately similar values of T_c between 600 and 660 min.

Effect of treatment on STC Table 2 also shows the susceptibility to corrosion, STC in $A^{-1}min^{-2}$, for the specimens exposed to H_2S. The SFC treatment had the lowest STC of $86.3x10^{-12}$ $A^{-1}min^{-2}$, while the PC55 treatment had the highest of $62.5x10^{-6}$ $A^{-1}min^{-2}$. Treatments FMC and SRC had nearly the same value of $7.9x10^{-6}$ $A^{-1}min^{-2}$ and treatment PCL about double that value, almost $16x10^{-6}$ $A^{-1}min^{-2}$. The control treatment, PC45, performed second poorest with a STC value of about $22x10^{-6}$ $A^{-1}min^{-2}$. Based on the STC values, all treatments except PC55 performed better than the control, PC45. Treatment SFC had the best resistance to H_2S followed by FMC and SRC while PC55 had the worst.

Another indicator that can be used for comparing the performances of the different treatments due to exposure to H_2S is Q_c, the amount of electricity required to cause specimen failure. Q_c is the integration of current with time and a high value of Q_c indicates superior performance against corrosion. Tables 1 and 2 show the values of Q_c for

Table 2. Impressed voltage test results for mortar specimens exposed to hydrogen sulphide.

Parameters	Treatments					
	PC45	SRC	FMC	PCL	PC55	SFC
Maximum current (A)	1.26	0.80	0.81	0.59	1.48	0.084
Failure time, T_c (min)	315	645	660	600	165	36,000
Charge, Q_c (A min)	146	202	196	119	108	322,000
Susceptibility to corrosion, STC (μA^{-1} min^{-2})	22.2	7.89	7.87	15.9	62.5	$86.3x10^{-6}$

the non-exposed and exposed specimens respectively. Q_c for treatments PC45, PCL, and PC55 decreased after the exposure to H_2S, whereas Q_c for treatments SRC, FMC, and SFC increased. The treatments which showed increase in Q_c after the exposure period are more resistant to H_2S than the treatments with decreased Q_c. For the non-exposed specimens, the ranking from best to poorest performance is SFC, PC45, PCL, SRC, FMC, and PC55; for the exposed specimens, the order is SFC, SRC, FMC, PC45, PCL, and PC55. The Q_c indicator confirms that the silica fume cement provides the best protection against corrosion due to H_2S and that the high W/C ratio of treatment PC55 is unsatisfactory. It also shows that the linseed oil treatment (PCL) is not a long-term solution.

Statistical analyses of the susceptibility to corrosion results included a multiple comparison with the best (MCB), a multiple comparison with the control (MCC), and a pairwise comparison of treatment means using the least significant difference (LSD) procedure at 0.05 level of significance. The MCB analysis was used to select the set of treatments or the single treatment that provides the best result. MCC analysis was carried out to determine if there was a difference between a treatment and the control (PC45). The LSD analysis was used to check if the treatments were significantly different with respect to the susceptibility to corrosion.

The MCB analysis showed that the best subset included treatments SRC, FMC, PCL, and SFC, but not treatments PC45 and PC55. From the MCC procedure it was concluded that all treatments were different from the control treatment. The results of the LSD test revealed that SFC is the best treatment, followed by FMC, SRC, and PCL in descending order. Treatments PC45 and PC55 were not part of the best subset according to the MCB test.

CONCLUSIONS

In the test where specimens were not exposed to H_2S, silica fume cement (SFC) specimens with a W/C ratio of 0.35 exhibited the lowest susceptibility to corrosion while the Portland cement specimens with a W/C ratio of 0.55 (PC55) had the highest. Although it was expected that the fibre mesh mortar (FMC) would show very good corrosion resistance, due to superior tensile strength from the fibre reinforcement, compared to the other treatments with water-cement ratios of 0.45, it did not. On the contrary, the experiments revealed that the fibre mesh had the maximum STC because T_c was small in comparison to the other treatments with 0.45 W/C ratio.

For the tests in which specimens were exposed to H_2S for one year, the mortar specimens made with 8% silica fume cement replacements (SFC) performed best and failed after 600 h of testing, while Portland cement mortar specimens with a water-cement ratio of 0.55 (PC55) failed earliest after only 165 min. The amount of electricity required to cause failure, Q_c for treatments PC45, PCL, PC55 decreased after the exposure to H_2S, whereas Q_c for SRC, FMC, and SFC increased. The treatments, which showed an increase in Q_c after the exposure period, are more resistant to H_2S than the treatments with decreased Q_c. The statistical analysis for susceptibility to corrosion showed that the best subset of treatments includes SFC, FMC, SRC, and PCL in descending order. All treatments provided results for susceptibility to corrosion that were statistically different from each other, including the control treatment PC45.

ACKNOWLEDGEMENT

The authors thank the Ontario Ministry of Agriculture, Food and Rural Affairs for supporting the work described in the paper.

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