Effects of surface washing on the mitigation of concrete corrosion under sewer conditions

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A B S T R A C T

This study systematically investigated the potential of mitigating sulfide induced sewer concrete corrosion by surface washing. Washing interrupted the corrosion activity of concrete coupons by increasing the surface pH and decreasing the H_2S uptake rates (SUR). The SUR recovered to the level prior to washing within 60–140 days. The slowest recovery rate was from the most severely corroded coupon. However, no significant difference was observed for concrete mass loss of the washed and unwashed coupons after 54 months. The results suggest that frequent washing at short intervals of a few months might be needed to control corrosion over a long term.

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1. Introduction

Urban sewer networks collect and transport domestic and industrial wastewater (sewage) to centralized facilities for treatment prior to discharge of the treated effluent into receiving waters. In industrialised countries, the establishment of sewer networks has been achieved through continuous public investment for more than a century. However, the deterioration of sewer concrete pipes, caused by sulfide induced concrete corrosion, is a major economic and infrastructure burden in many countries [1]. It shortens the service life of sewer pipes and results in expensive replacement of prematurely failed structures. For example, the estimated corrosion caused cost in wastewater catchment infrastructure per year is around $20 billion in the USA [1]. As such, the development of effective technologies to mitigate corrosion is imperative for extending the service life of sewer pipes and reducing the huge annual maintenance expense.

Sulfide is produced within the anaerobic regions of the sewer, mainly in the fully filled pressure pipes [2,3]. During the pumping of sewage from a pressure pipe to a gravity pipe, the sulfide is partially released into the sewer atmosphere of the gravity pipe [4]. In the presence of oxygen, gaseous H_2S is taken up by the moist concrete surface exposed to gas phase and there it is oxidized to sulfate and other sulfur species by sulfur oxidizing bacteria (SOB) [5,6]. The acid formed during sulfide oxidation will react with alkaline compounds in the concrete and form corrosion products [7]. This process causes decreased concrete surface pH (from 12–13 to below 1–2), loss of concrete mass, cracking and weakened sewer structure [6,8]. A corrosion layer develops on the concrete surface that is largely gypsum, this has a soft texture and can be several mm in thickness. Severe corrosion will eventually result in the structural collapse of the sewer network.

To achieve effective corrosion control, various technologies have been developed. These technologies mitigate the corrosion through either preventing the build up of sulfide in the liquid phase or by preventing the concrete surface from H_2S attack [9–14]. In particular, one treatment is to directly remove the corrosion layer by washing the concrete surface. This is considered a cost efficient approach and hence is of great interest to water utilities [15]. However, surprisingly there has been no comprehensive evaluation on the effectiveness of surface washing for the purpose of mitigating concrete corrosion.

Currently, there is disagreement on whether the formed concrete corrosion layer accelerates or slows the corrosion process

[16–18]. It is proposed that the thick corrosion layer acts as a barrier that slows the sulfuric acid attack onto the intact concrete surface, and consequently it is suggested that the removal of the corrosion layer would accelerate the corrosion activity [16,18]. In contrast it is argued that the flushing of the concrete pipe with sewage removes the corrosion layer and this disturbs and removes the low pH environment of the sulfur oxidizing bacteria [15,17,19]. Therefore, there are contradictory theories of the effect that surface washing may have on the corrosion processes and it is not clear whether washing would mitigate the corrosion activity.

It is indicated that gentle flushing is not a successful control measure. Two early studies flushed concrete samples with wastewater for a few seconds and repeated it 1–3 times daily or weekly [15,19]. This immediately increased the concrete surface pH, although, this returned to its low level found prior to flushing, in a few hours. Likely the gentle flushing only removed soluble components (e.g. acid) but not the corrosion layer containing the acid-generating microbes. They measured the surface pH and indirectly measured the corrosion rates from the polarization resistance. It was postulated that heavy and frequent washing is necessary to effectively reduce corrosion rates (in terms of producing high surface pH) [15,19]. A more recent study washed concrete pipes using a hose and a brush, but this only temporarily reduced the corrosion activity (measured as sulfide oxidation rate). In just 10 days the sulfide oxidizing rate was seen to increase and by 30–40 days this had reached the pre-washing level [20]. In this study the bioactive layer would have been removed from concrete surface, although the effect on corrosion activity was only measured through the sulfide oxidation rates [20]. A comprehensive and systematic study evaluating the effect of high pressure washing on the concrete surface pH, sulfide oxidation rate and concrete loss in the long term is required to delineate the overall impacts of surface washing for mitigating sewer corrosion.

The aim of this study was to assess the effectivity of high pressure washing on controlling corrosion of concrete in corrosive sewer environment. To simulate the concrete exposure condition in real sewers, concrete coupons were exposed to the gas phase of laboratory chambers with controlled levels of relative humidity, temperature and H_2S concentration. After being exposed in the chamber for specified periods, the coupons with various corrosion levels were washed using a high pressure washer with water. The sulfide oxidation activities of the coupons were measured and concrete losses of washed and unwashed concrete coupons were compared in a long term study of over 4.5 years. The experiment enabled a comprehensive understanding and evaluation of the effect of washing on corrosion control.

2. Materials and methods

2.1. Concrete coupons

Two types of concrete coupons, i.e. fresh and pre-corroded concrete coupons, were prepared and established into the laboratory corrosion chambers as described [6]. To briefly explain, the fresh concrete coupons were cut from a newly manufactured spun cast standard reinforced concrete sewer pipe, which has 1.2 m internal diameter and a standard strength of load class 2 (HUMES, Australia). The concrete had a minimum of 400 kg m^{-3} cementitious content and 45–50% aggregate content by volume. The standard sewer pipes are suitable for most sewer systems. The pre-corroded concrete coupons were cut from reinforced concrete that previously served as a sewer wall for 70 years from Sydney Water Corporation, Australia. The dimensions of each coupon were approximately 100 mm (length) × 70 mm (width) × 70 mm (thickness). After cutting, the coupons were washed in fresh water

and then dried at 60 °C for 3 days to achieve similar and stable initial water content.

The internal surface of the sewer pipe, was designed as the coupon surface to be exposed to H_2S. After cutting, the coupons were embedded in epoxy (FGI R180 epoxy & H180 hardener) in specially designed stainless steel frames. Each frame containing one fresh and one pre-corroded coupon and forms a concrete coupon pair (Fig. 2). The stainless steel frame provided a reference point for determining the change in thickness due to corrosion. The coupons were exposed to the gas phase of corrosion chambers as described in Section 2.2.

2.2. Corrosion chambers and exposure conditions

Four identical corrosion chambers were constructed of glass panels of 4 mm thickness to achieve a controlled environment simulating that of real sewers and the detailed description is made elsewhere [6,21]. Briefly, the dimensions of the chambers were 550 mm (length) × 450 mm (width) × 250 mm (height). The conditions in the chambers were controlled at four H_2S levels (i.e. 5 ppm, 10 ppm, 25 ppm and 50 ppm) with the gas-phase temperatures at about 25 °C and the relative humidity level at 100%. Each chamber contained 2.5 L domestic sewage (characteristics of sewage was reported in Table S1 in Supplementary Information) collected from a local sewer pumping station which was replaced every fortnight. Coupons were exposed to the gas phase of the chambers with the exposure surface facing downwards about 110 mm above the sewage. This arrangement simulates the crown area of sewer pipe, a region that is highly susceptible to corrosion [16].

To control the H_2S gaseous concentrations inside the chamber at the specified level, Na_2S solution was pumped (Bio-chem fluidics, model: 120SP2440-4TV) into a plastic container partially filled with hydrochloric acid (16%). The H_2S concentrations were monitored using a H_2S gas detector (OdaLog Type 2, App-Tek International Pty Ltd, Brendale, Australia) with a range between 0 and 200 ppm. A programmable logic controller was applied to monitor the H_2S concentration and to trigger the pump for Na_2S addition to maintain the H_2S concentration at the specified level. The chambers were stored in a cabinet and the temperature of the sewage was controlled by recirculating temperature controlled water through glass tubes submerged in the sewage. Through this way, the relative humidity was controlled at 100% for all the chambers.

2.3. A test to monitor the corrosion recovery after high pressure washing

This test investigated the recovery of corrosion activity of corroding concrete coupons after the high pressure washing. The coupons used were from the 5 ppm (F5 and P5, namely the fresh and pre-corroded coupon respectively) and 50 ppm (F50 and P50, namely the fresh and pre-corroded coupon respectively) H_2S level chambers exposed to 100% relative humidity and 25 °C for 45 months. In this test the H_2S uptake rate (SUR, a previously proven indicator of corrosion activity [22]), sulfur species in the corrosion layers and surface pH were measured (see details in Section 2.5).

The washing was carried out on the coupon exposure surface using a high pressure washer (Karcher K 5.20 M, 12 MPa). Each coupon surface was washed by 4–8 L of deionized water. H_2S uptake tests and surface pH measurements were carried out immediately before and after the high pressure washing, as described in Section 2.5.1 and 2.5.2, respectively. The washed coupons were returned to the original exposure chamber for re-exposure. This was followed by weekly measurements of SUR for 1–4 weeks, and monthly measurements of SUR for 1–6 months untill the H_2S