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Concrete Sewer Pipe Corrosion Induced by Sulphuric Acid Environment

Anna Romanova, Mojtaba Mahmoodian, Upul Chandrasekara, Morteza A. Alani

Abstract—Corrosion of concrete sewer pipes induced by sulphuric acid attack is a recognised problem worldwide, which is not only an attribute of countries with hot climate conditions as thought before. The significance of this problem is by far only realised when the pipe collapses causing surface flooding and other severe consequences. To change the existing post-reactive attitude of managing companies, easy to use and robust models are required to be developed which currently lack reliable data to be correctly calibrated. This paper focuses on laboratory experiments of establishing concrete pipe corrosion rate by submerging samples in to 0.5pH sulphuric acid solution for 56 days under 10°C, 20°C and 30°C temperature regimes. The result showed that at very early stage of the corrosion process the samples gained overall mass, at 30°C the corrosion progressed quicker than for other temperature regimes, however with time the corrosion level for 10°C and 20°C regimes tended towards those at 30°C. Overall, at these conditions the corrosion rates of 10 mm/year, 13,5 mm/year and 17 mm/year were observed.

Keywords—Sewer pipes, concrete corrosion, sulphuric acid, concrete coupons, corrosion rate.

I. INTRODUCTION

CONCRETE sewer pipe structural vulnerability is dominantly addressed by the Microbially Induced Concrete Corrosion (MICC) which is dictate by the presence and high activity of the sulphuric acid in the air phase, pipe wall and crown surfaces.

The replacement and rehabilitation costs spend on dealing with corrosion problem of concrete sewer pipes sum up to annual costs of \$36 billion in USA [1], \$300 million in Australia [2], €100 million in Germany [3], £85 million in UK [4] and [5] and £4 million in Belgium [6], which is a constantly growing threat in aging pipe sewer network.

As known the MICC goes through a three step chemical process, the sulphate contained in the wastewater is converted into sulphide, further the sulphide is released into the air phase in gas form, where the hydrogen sulphide is oxidised on moist surfaces to sulphuric acid [7]-[9].

To understand the process of concrete corrosion the accelerated experiments with the use of sulphuric acid have been undertaken. Experiments carried out previously, known to the authors investigated: the concrete samples being exposed to sulphuric acid solution of 2-3pH over 72 days,

where a corrosion rate of 0.82mm was observed [10] and [11]. In research carried out by [12] subsequent steps of sample immersion and drying, combined with mechanical abrasion, were applied to simulate events occurring in sewer systems. Both chemical and microbiological tests showed that the aggregate type had the largest effect on degradation. To simulate sulphuric acid attack, three cylinders of each concrete type were subjected to 10 attack cycles consisting of an alternated immersion in a 0.5% sulphuric acid solution (initial pH 0.9–1.0), drying by air and brushing. Furthermore, in other research, the corrosion level was estimated on concrete samples exposed for 64 days in 0.5%, 0.2% and 0.05% of sulphuric acid solution, where corrosion rates of 2.19mm/year, 0.76mm/year and 0.18mm/year were observed [13] and [14].

The purpose of this paper is to assess the establishment of the corrosion process on concrete samples exposed to environments of sulphuric acid solution with different temperature regimes, which has not been investigated previously. The output of this study can help to calibrate a range of models predicting deterioration of concrete sewers as well as their service life and supplement reliability analysis of corrosion affected pipelines [15] and [16].

II. EXPERIMENTAL SETUP

Experiments were conducted in a fully controlled environmental chamber located in Engineering Laboratory at the University of Greenwich.

A. Tanks and Temperature

The chamber hosted three 500L HDPE tanks where two of them were curing tanks and could autonomously control the fluid temperature inside them. Each of the tanks had a further 120L HDPE container, which was submerged by 2/3 into the fluid contained by 500L tank. This was done to create a thermal bath type effect and control a constant temperature of the solution in 120L containers. To avoid any fluctuation or displacement of the containers they were attached to the sides of the tanks by the use of L-type brackets. Three tanks: Tank 1, Tank 2 and Tank 3 maintained a constant temperature of solution located in containers of 10°C, 20°C and 30°C, respectively. The temperatures were chosen to represent the common range of effluent temperatures found in sewer pipes at different climate conditions. The temperature of Tank 1 was controlled by the environmental chamber which was set to deliver 10°C at a humidity level of 70%. Tank 2 and 3 temperatures were controlled autonomously by heating elements.

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B. Sulphuric Acid Solution

To achieve accelerated corrosion effect in short time, the diluted sulphuric acid solution of 0.5pH was chosen for the experiments. Sulphuric acid of 95% was mixed with de-ionised water at a ratio of 8.91ml of H₂SO₄ to 1L of H₂O. Each of the containers was filled with 60L of diluted acid solution, where the levels were constantly maintained to compensate for absorption and evaporation. The last took place mainly in Tank 2 and 3 due to the difference in temperatures of the environmental chamber and the temperatures supported by curing tanks.

C. Cube Samples

A total number of 45 cubes, cut out from brand-new circular concrete pipe were used in these experiments. Each cube had a measurement of 100x100x100mm and was cut with diamond-blade rotating saw, however as the process of cutting a circular pipe is very challenging and labour consuming a tolerance of 10% in each side measurement of the cube was allowed for. A number of 15 cubes were fully submerged into 0.5 pH solution of sulphuric acid in each of the containers in Tanks 1, 2 and 3. Further they were extracted at different points in time and assessed using different techniques to account for the corrosion level. Fig. 1 demonstrates a setup of tanks, containers and cubes located in the environmental chamber.



Fig. 1 Experimental set up of cubes being submerged into diluted sulphuric acid

III. METHODOLOGY

Before emersion into sulphuric acid solution each cube was dried in the industrial oven at 100°C for 24h. After the oven, the cube was left to cool for 2h at room temperature of 20°C. Further, the cube physical measurement of width, length and height were taken and their mass was recorded on weights (OHAUS I-10) which had a tolerance of 2g. The above data was further used to calculate the bulk density of the samples. Furthermore, the sample surface pH measurements were taken by the use of phenolphthalein to record any changes before and after emersion. Moreover, a photogrammetry technique was used to recreate sample 3D structure before and after emersion and quantify the corrosion rate.

Each individual cube was numbered, immersed into sulphuric acid solution and ejected at 7, 14, 28, 42 and 56

days, in quantities of three from each tank. After ejection each cube was washed using tap water and gently brushed to remove any flocks. Further, they were placed in to the oven for another 24h at 100Co. After which the cubes were left to cool down for 2h and only then the physical measurements together with surface pH and photo tests were recorded.

A high resolution camera (Nikon D3200 SLR with 18-15 VR Lens) was used, where for each cube a picture at 45° angle to the top plane focusing on plane side was taken. These pictures were used to digitally estimate the roughness of the cube as a standard deviation of cube height from the edge-to-edge plane. In this study the calculated roughness was assumed to represent the level of corrosion. For each cube the corrosion depth was calculated as a difference of cube roughness before and after immersion.

It should be noted that in these experiments the bottom plane of the cube (as the cube rested on the bottom plane when was inserted into the container with acid solution) was the least affected by the corrosion, however is accounted for in the physical measurements.

IV. RESULTS

The result of this study are summarised in Table I, where column 1 identifies the tank number (ABI are ‘all cubes before immersion’ and AAI are ‘all cubes after immersion’), followed by the number of days the cube was submerged in the solution and associated cube numbers. Column 4 shows the average of three cube’s mass after exposure into acid solution, followed by mass loss compared to original mass values and bulk density after exposure. Last column shows the corrosion level obtained from the digital photo-tests (Fig. 2 shows one cube side before immersion and three cubes ejected from acid solution at different days).

TABLE I
CUBE MASS, MASS LOSS, DENSITY AND CORROSION LEVEL

| Tank | Days | Cube | Mass (g) | Mass loss (%) | Density (g/cm ³) | Corrosion (mm) |
|------|------|------------|----------|---------------|------------------------------|----------------|
| ABI | - | All | 2446 | 0.00 | 2385 | 0 |
| 1 | 0 | - | 2488 | 0.00 | 2396 | 0 |
| | 7 | 1, 2, 3 | 2499 | 0.59 | 2445 | 0.13 |
| | 14 | 4, 5, 6 | 2498 | 1.90 | 2368 | 0.18 |
| | 28 | 7, 8, 9 | 2412 | 1.01 | 2348 | 0.43 |
| | 42 | 10, 11, 12 | 2394 | -1.07 | 2268 | 0.85 |
| | 56 | 13, 14, 15 | 2372 | -2.23 | 2248 | 1.52 |
| 2 | 0 | - | 2429 | 0.00 | 2378 | 0 |
| | 7 | 19, 20, 21 | 2445 | 0.08 | 2392 | 0.23 |
| | 14 | 22, 23, 24 | 2443 | 2.43 | 2409 | 0.41 |
| | 28 | 25, 26, 27 | 2400 | -0.79 | 2310 | 0.90 |
| | 42 | 28, 29, 30 | 2335 | -1.30 | 2274 | 1.42 |
| | 56 | 31, 32, 33 | 2317 | -2.82 | 2264 | 2.07 |
| 3 | 0 | - | 2421 | 0.00 | 2380 | 0 |
| | 7 | 37, 38, 39 | 2428 | 2.12 | 2445 | 0.27 |
| | 14 | 40, 41, 42 | 2426 | 3.38 | 2436 | 0.52 |
| | 28 | 43, 44, 45 | 2378 | -1.18 | 2322 | 1.12 |
| | 42 | 46, 47, 48 | 2333 | -3.62 | 2217 | 1.80 |
| | 56 | 49, 50, 51 | 2325 | -3.51 | 2193 | 2.61 |
| AAI | - | All | 2400 | -0.33 | 2328 | 0.95 |

Before immersion into acid, on average, cube mass was 2446g, density was calculated as 2385g/cm^3 and surface roughness at the top plane was 0.75mm. After ejection in 7, 14, 28, 42 and 56 days these values, on average over all cubes were measured as 2400g, 2328g/cm^3 and with mass loss of 0.33% and corrosion depth of 0.95mm. As expected, the mass loss as well as corrosion depth tends to increase exponentially with time, however at early stages of corrosion process few interesting behaviours were recorded.



Fig. 2 Cube sample 22 before immersion (a), cube samples 44 after 28 days (b), cube sample 47 after 42 days (c) and cube sample 49 after 56 days of immersion (d)

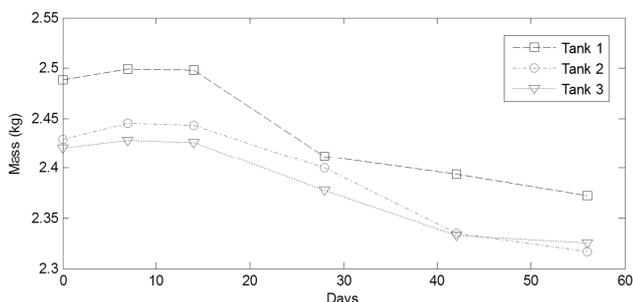


Fig. 3 Average mass of the cubes extracted at different days compared over three temperature regimes of sulphuric acid solution

At all temperature regimes, in the early stage of the experiments, at 7 and 14 days, when the corrosion process just begins to establish, an increase in overall mass of the cubes was observed (Fig. 3), similar finding was noted by [14]. On visual inspection, cube samples showed soft and hard white formations – gypsum and ettringite, however in the process of cube rinsing most of them were washed away. The fact that the cube mass was higher than before the immersion could be explained by the ability of concrete to absorb the acid via micro-pores where the formation of gypsum and ettringite also rapidly accelerates as the surrounding environment is constantly acidic. Phenomenon of ettringite formation was also reported in previous works; however, no data on change in mass was mentioned. Further, as expected, for measurement taken at 28, 42 and 56 days the mass of all samples in all containers decreased, where for tanks with temperatures of 20°C and 30°C the mass loss was higher than for tank with 10°C. The mass loss analysis for each individual group at

three tanks showed that cubes in Tank 3 had the largest mass proportional gain in percentage in first 14 days, up to 2.45%, and then the largest loss in 56 days with 3.51%.

The increase in overall mass of the cubes proportionally affected the increase in bulk density for cubes examined at 7 and 14 days. Finding presented in Fig. 3 should be examined further and it is suggested that the cube samples should be subjected to systematic compression tests, as due to this chemical reaction their compressive strength and hence the durability may increase. For measurements after 14 days the density values decreased as expected. At days 42 and 56 the density value of cubes ejected from tank with temperature of 30°C was considerably lower than for the other two, which were similar.

The corrosion depth calculated from the photographic tests is shown in Fig. 4. For all temperature regimes at early stage of the experiment the corrosion depth increased by 0.22-0.45mm. Further, the discrepancy in corrosion depth increased between different temperature regimes. At 30°C, after 7 days, the corrosion process established quicker and continued to rapidly grow. For 10°C and 20°C the corrosion seemed to establish slower, however at 56 days the level of corrosion was tending towards corrosion observed in tank with 30°C solution, which was 1.52mm, 2.07mm and 2.61mm, respectively. Overall, at these three temperature regimes, if the corrosion rates were to progress linearly after 56 days, they would represent corrosion rates of 10mm/year, 13.5mm/year and 17mm/year, respectively. It is proposed that with time the same depth of corrosion will be observed in all tanks despite the temperature regime, however to validate the above assumption it is required to carry out experiment for a longer period of time.

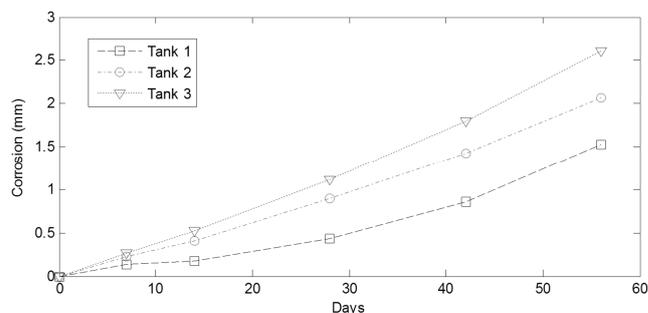


Fig. 4 Average corrosion depth of the cubes extracted at different days compared over three temperature regimes of sulphuric acid solution

Interestingly that the leap between the cubes corrosion depth doubled in periods from 28 days to 42 days and then further between 42 days to 56 days which could be visibly assessed. Examples of such can we seen in Fig. 5.

Fig. 6 presents the average results of cube's mass, density, mass loss and corrosion depth for all temperature regimes, where the mass, density and mass loss increase in 0-14 days and further decline, whereas the corrosion depth increases with time from day one.

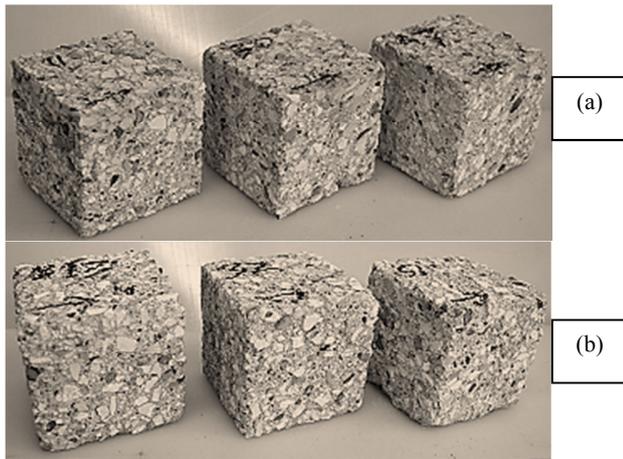


Fig. 5 Cube samples 11, 30 and 47 (left to right) after 42 days immersion into 0.5 pH sulphuric acid solution and temperatures of 10°C, 20°C and 30°C, respectively (a) and cube samples 13, 32 and 51 (left to right) after 56 days immersion into 0.5 pH sulphuric acid solution and temperatures of 10°C, 20°C and 30°C, respectively (b)

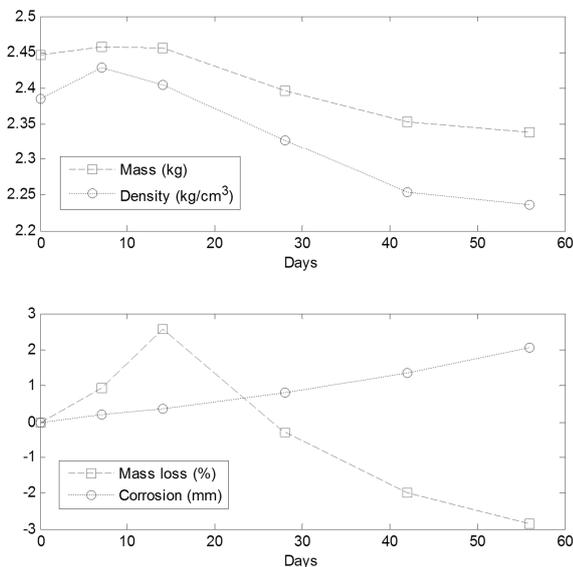


Fig. 6 Average mass, density, mass loss and corrosion level of the cubes extracted at different days from the sulphuric acid solution

V. CONCLUSIONS

The above paper reports on a laboratory based experiments, where the concrete 100mm cube samples cut out from a circular pipe were fully submerged in a diluted sulphuric acid solution of 0.5 pH, for a number of 56 days, in three different temperature regimes, 10°C, 20°C and 30°C. The main research findings are listed below:

- 1) At very early stage of the corrosion process concrete mass and density increase;
- 2) Corrosion establishes quicker in the presence of higher temperature;
- 3) With time corrosion seems to reach the same level for all temperature regimes.

Further to this study each cube's compressive strength will be reviewed as well as the cube 3D photogrammetry analysis

and 3D Laser analysis will be carried out and results compared.

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