Deterioration of concrete sewers

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Abstract:
The corrosion and maintenance of concrete sewers have always been an area of social as well as financial priority. The corrosion of the concrete sewer system is related to biodegradation of concrete which led to formation of sulphuric acid. The sulphuric acid so produced affects the life span of structure by causing expansion which eventually led to collapse of structure as a whole. The damage is further amplified in case of splashing of waste waters in the sewer network as compared to stagnant waters. In order to access the degree of damage an experimental program was carried out. This paper presents the results of degradation depth of concrete subjected to stagnant and flowing condition of sulphuric acid solution (H₂SO₄) made with different the water-cement ratio and concentration of sulphuric acid. For this purpose, concrete cubes with various water-cement ratios were made. These cubes were exposed to sulphuric acid solution of pH 1, 2, 3 and 4. The results revealed that surrounding conditions play one the important role in deciding the erosion depth in addition to water cement ratio. From the experiment it was also affirmed that erosion depth depends on the concentration of the acidic solution.

1. Introduction:
Biodegradation is a process of disintegration of materials due to the creation of various living organisms which degrades the material eventually [1]. Biodegradation of the concrete sewers produces biogenic sulphuric acid inside the sewer networks. This acid produced causes huge loss to country in terms of economy, as millions of dollars are spent every year for restoration and rehabilitation purpose. Also, 20% of the global destruction of concrete constructions in sewer networks is because of sulfate attacks [2]. In the early stage, it causes the dissolution of calcium silicate hydrate (CSH) by erosion and the formation of expansive products. In the latter stage, it causes cracking which finally alters the strength causing the ultimate failure. [3-8]. The problem of concrete corrosion is hazardous to the older pipe network system. The renewal cost associated with the sewer corrosion is 42 billion dollars in the USA [9], 300 million dollars in Australia [10], 100 million euro in Germany [11], 85 million pounds in the UK [2,12], and 4 million pounds in Belgium [13] of the annual total cost.

Lot of literature is available concerning sulphuric acid attack in sewer networks. Some researchers have worked on the effect of design parameters [14], while some have focused on the usage of different cement [15], some incorporated admixtures in their mix design, and others have focused on the acid concentration [16-17]. Every researcher has valid proof to prove their work. Also, many researchers have worked on how the flow velocity affects corrosion [18]. Yet, again it is not clear whether the flowing velocity increases or decreases the corrosion process all together. Therefore, in order to address above issues extensive laboratory investigations were performed. For this purpose, concrete with various water cement ratios were made using Ordinary Portland cement and were subjected to sulphuric acid solution of various concentrations in flowing and in stagnant condition.
2. **Materials and Proportions:** Ordinary Portland Cement was used for making the concrete cubes. Details of mix are enlisted in table 1.

| Cement | Fine Aggregate | Coarse Aggregate | Name |
|--------|----------------|------------------|------|
| 1      | 1.60           | 2.61             | M1   |
| 1      | 1.68           | 2.75             | M2   |
| 1      | 1.77           | 2.89             | M3   |

3. **Preparation of concrete specimens:** Concrete cubes were prepared in 150×150 × 150 mm cube molds. The cubes were prepared as per table 1.

4. **Sulphuric acid baths:** For the sulphuric acid bath, eight HDPE tanks were made. Four tanks were kept for stagnant condition & the other four for flowing condition. For tanks made for flowing condition motor with a pumping system having a velocity of 0.95 m/sec. Sulphuric acid of various pH 1,2,3 and 4 were made by mixing deionized water with undiluted acid. The pH of the tank was monitored everyday by using digital pH meter and to maintain the required concentration undiluted sulphuric acid was added as when required.

5. **Test procedure:** Having casted the samples, they were demolded after 24 hours. The demolded cubes were then subjected to curing in normal water for 28 days according to IS:456-2000. After curing phase was over the samples were air-dried for 12 hours. After air drying, the samples were put in an oven at a temperature of about 105°C for achieving constant weight and thereafter cooled at room temperature for 6 hrs. before putting them in the tanks containing sulphuric acid solutions of concentrations. After subjecting the samples to acid attack erosion depth was monitored. For taking measurements, the cubes were taken out from the tanks, dried at room temperature for 12 hrs. and then put in an oven at 105°C and dried till constant weight was maintained and allowing them to cool at room temperature for 6 hrs. Finally, brushing was done with a wire brush to remove the loose corrosion products from the specimen. The erosion depth was then measured as:

\[ Erosion\ Depth: \ D_o - D_f \]

where \( D_o \) = Original Depth of concrete cube.

\( D_f \) =Final depth due to acid attack.

6. **Results & Discussion:**

6.1 **Effect of water cement ratio:** Erosion depth for various mixes is shown in the ‘figure.1’. In the figure mix M1 in flowing condition is first to gets degraded tailed by M2 and M3. The rationale behind such reaction is the ample source of cement available for reaction in case of mixture with low water cement ratio. Also, because of the low water cement ratio in case of M1 all the reaction takes place on the surface portion without infiltrating into the pore of the concrete. Conversely, for stagnant condition a layer of gypsum formed due to reaction between the \( \text{H}_2\text{SO}_4 \) and cement paste that gets deposited on the facade. This gypsum principates and hence clogging of pores takes place. The clogging of pores is more for more water cement ratio. This clogging of pores is beneficial as it prevents the underlying concrete from further attack and hence concrete in stagnant conditions suffers from less loss as compared to flowing conditions.
Figure 1. Erosion depths of various concrete mix in pH (a) 1 (b) 2 (c) 3 (d) 4.

6.2 Effect of surrounding conditions: ‘Figure. 2’ (a) and (b) represents concrete cube in both flowing and stagnant condition subjected to the attack. As seen from the figure in case of the flowing surroundings white powdered is very less visible on the surface. This while powder is mainly gypsum the chief corrosion product. This gypsum gets washed away in case of flowing surroundings without being precipitated or less precipitation takes place in case of flowing condition as the velocity of water carries this layer with it. Also, in case of flowing surroundings the surface of the cube were rough in texture While in case of concrete subjected to stagnant environment as shown in ‘figure.2’ (b) a dense layer of gypsum is clearly visible. This is because there is no moment of the water. The surface texture in case of stagnant condition was powdery with a smooth touch.
Figure 2. Reaction product on the concrete cube in sulphuric acid (a) Flowing condition (b) Stagnant condition.

6.3 Effect of acid concentration: The effect of acid concentration is shown in ‘figure 3’. As seen in the figure the maximum degradation has been observed in pH below 3. The rationale behind this is that when the solution become too acidic there is surge in the quantity of hydrogen and sulphate ions which is responsible for faster reaction and dissolution of calcium silicate hydrate. That is why the degradation is maximum in pH 1 and least in pH 4. Also, when the low acidic solution combines with the flowing conditions, degradation takes place rapidly because of the exposure of new concrete layers. The results depicted by our experiments also agree with the same.
Figure 3. Effect of acid concentration on flowing and stagnant surroundings for (a) M1 (b) M2 (c) M3.

7. Conclusions:

From the experimental analysis following conclusions can be drawn:

1. For concrete having low water cement ratio the difference between erosion depth is small for both surrounding conditions. This difference however increases as the water cement ratio increases.
2. The rate of damage is more in case of flowing surrounding as compared to stagnant surrounding and it varies linearly with the time.
3. Acid concentration plays important role in deciding the degradation of the samples. From the experiments it was observed that the level of degradation was more at pH below 3.

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