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Cost analysis of pipes for application in sewage systems

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ABSTRACT

The work described in this study is a preliminary effort to identify the most cost effective pipe material for application in sewage collection networks. Firstly, cylindrical concretes coated by epoxy (Ep), polyurethane (PU), and combination of epoxy and sodium silicate (Ep–SS) were tested to investigate coatings ability to protect concrete samples against corrosion. Secondly, the price of the cured concrete (CC) pipe by designed coatings was compared to that of a new concrete network. Economic analysis was then carried out to compare the prices of the CC and double wall corrugated high-density polyethylene (DWC-HDPE) pipes. The outcomes revealed that the designed coating materials were able to lengthen the concrete pipes service life. They acted as a barrier against the aggressive environment, and were able to reduce the corrosion rate in the piping system. By using the designed coatings, it was at least 1.5 times more economical compared to replacing it with new pipes. The CC pipes have been found to be more cost effective than DWC-HDPE pipes for pipes diameter larger than 600 mm. A computer program was provided based on the developed mathematical models which could aid engineers in nominating the proper pipe for optimum cost saving and performance.

1. Introduction

Concrete, asbestos, iron, plastic, etc. pipe materials are being used for sewer networks. Due to its compatibility with the environment, huge material resources, cost effectiveness, more resistive and strength, concrete has been the most widely construction material [1] used in sewers, treatment plants, and open channels. However, concrete suffers from deterioration and rapid degradation of concrete structures has been reported in wastewater facilities. This degradation is due to the acidic environments mostly generated by bacterial activities [2].

Abrasion-resistant interior to withstand scouring action of wastewater carrying gritty materials, durability for long life, adequate strength to resist failure or deformation under loads, and impervious walls to prevent leakage are physical characteristics essential for sewer pipes. Besides, resistance of pipe material to chemical attacks (e.g. corrosion) is important enough to be considered in selecting the proper pipe material. Fig. 1a shows an example of load deformation, while Fig. 1b demonstrates the corrosion attack captured by a CCTV placed in a sewage network in Malaysia.

Corrosion deterioration has long-term effect on environment, economy, and society [3,4]. The evaluation of current and future corrosion damage of concrete pipes in sewer networks during their service life has become imperative for engineers which results as aging decrement of the network. Thus, shortens their remaining service life, requires funding for repair or replacement. Due to the high cost and the difficulty of repairing the deteriorated parts, it is required that the material should be long lasting [5]. Hence, economical and effective techniques are needed to prevent or control corrosion deteriorations in particular areas of sewers especially where H_2S generation is common. The rate of hydrogen sulfide generation in sewers depends on sewage parameters such as pH, temperature, and turbulence, and so forth [6]. Over the time (usually, about 5–30 years), dissolved sulfates in water penetrates the hardened concrete and causes deterioration [7]. The cracks initiated at the concrete surface by chemical reaction of sulfates, propagate into the concrete core which lead to an increase in diffusivity, permeability, and porosity of concrete structure [1,8,9]. Control technologies that can be used to overcome this issue include using acid resistant materials, using chemical or biological treatments, and optimizing the sewer hydraulic design [1,4,10].

To protect concrete structures from physical, chemical, or biological degradation and increase their durability, high performance protective surface coating materials can be used. The coatings can stay in contact with concrete and provide long-term effective protection under severe condition with low maintenance costs [11,12]. Sulfuric acid is one of the main substances produced in corrosion process. In order to predict the service life of CC

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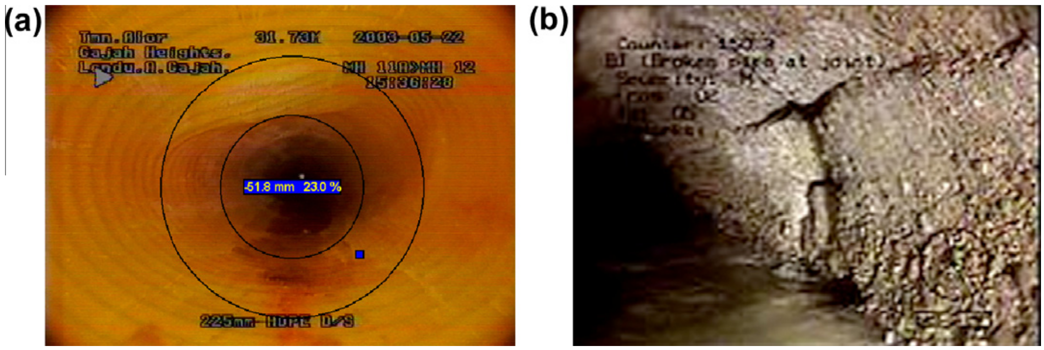

Fig. 1. (a) Deformation of DWC-HDPE pipe under external loads, and (b) corrosion of concrete pipe under chemical attack (cases in sewage network captured by CCTV, Malaysia).

structures, it is important to determine the value of sulfuric acid absorption into the CC. Previous researchers have worked on the quality of organic coating materials (e.g. chlorinated rubbers, acrylic, polymer, epoxy, and polyurethane) to protect the concrete surface against corrosion [12–15]. They used cubic and cylindrical concrete samples coated by coating materials to conduct lab experiments using accelerated test. Visual inspection, weight changes, etc., were employed to investigate the coating deteriorations. Their results pointed out that Ep and PU materials provide better performance, less absorption rate, and more resistance to corrosion.

Sodium silicate (SS) as an inorganic coating material is very useful material that can improve the concrete surface properties such as abrasion resistance, chemical durability, hardness, and permeability [16,17]. In addition, it is reported that silicates form as a gel is similar to the form of alkali silicate reactions which fills the concrete pores (pore blocking) by swelling. When applied to well-cured concrete that is dry and absorptive, silicate solution will provide reduced dusting and improved density of the concrete surface which can decrease the permeability of concrete [16,17].

DWC-HDPE pipe in contrast, has become a popular alternative nowadays because it is chemically resistive, durable, easy to handle, and flexible. It also entails low piping cost, and offers an acceptable service life. As an important part of sewer construction costs, initial price of pipes is another considerable category in selecting the type of pipe material for use in sewer network. Undoubtedly, due to fluctuating prices of DWC-HDPE pipe, selecting the type of pipe material is always a challenge task.

This study focused on finding a cost effective pipe materials to be used in a sewer system. In doing so, objectives can be summarized as follows: (i) to investigate the efficiency of coating materials on concrete samples which can withstand the aggressive environment, (ii) to calculate the cost of coatings based on their ability to extend concrete service life, (iii) to compare the price of CC and DWC-HDPE pipes in various diameters. In addition, a computer program according to the developed mathematical models was provided to assist municipals in selecting a proper pipe based on desired variables.

2. Materials and methods

2.1. Materials

The cylindrical concrete samples which represent the concrete pipe with a water per cement (w/c) ratio of 0.36 [18], cement content of 350 kg/m^3, Portland cement type V, were used to conduct tests under laboratory condition. The cylindrical concrete is 10 cm in diameter and 20 cm in height.

Two types of organic coating materials and one inorganic coating material were selected as follows:

(1) Ep (NP Solvent Coating industrial supply, grey color, ρ = 1.5 g/cm^3, US$16/kg, ratio of wet/dry weight (Vs) = 1.06).
(2) PU (NP Solvent Coating industrial supply, white color, ρ = 1.35 g/cm^3, US$27/kg, Vs = 1.07).
(3) Ep–SS (SS: R & M chemicals, gel form, 70%, ρ = 1.13 g/cm^3, US$12/kg, Vs = 1.04).

2.2. Methods

Before the coating was applied, the concrete surface preparation was conducted according to ASTM C811-98 standard [19] using water pressure and wire brusher to remove any sort of dirt. Ep and PU were applied (100 μm thickness) on concrete samples with utmost care to cover all surfaces thoroughly without any defect following the supplier recommendations and left in the lab temperature to be completely dry.

The accelerated method, identified as a rapid test [20], is one of the most widely used tests to investigate the chemical resistance of CC. This method can be performed in two ways [21]; i.e. using specimens with large surface area per volume ratio or increasing the aggressive solution (e.g. sulfuric acid) concentration. Monteny et al. [21] proposed to keep the pH of the solution at a certain level (by titration) for accelerated method using sulfuric acid. In addition, the worst condition in the sewer systems is due to sulfuric acid produced by bacteria when the pH reaches the value of less than one, which is approximately similar to the concentration of 1–3% sulfuric acid solution [22].

The CC samples were then weighed (W_p) by a digital balance having a precision of ±0.001. The samples were placed in closed containers (half immersion) filled by 2% and 10% sulfuric acid solution. During the test, the pH of solution was monitored using the Thermo Electron Corporation 3-star portable pH meter to provide a constant condition. The high power magnifying glass 30x LED lighted was also used to visually inspect the samples for the corrosion signs (coating failure types, e.g. blistering, cracking, or flaking [23]). The failures were picked as indicator to evaluate the experimental results to determine the service life of designed coatings. The time of first failure on coated samples immersed in 10% sulfuric acid solution was recorded.

The time taken for a CC to fail after corrosion initiation is related to the thickness of coating material (L_t), the liquid absorption by coating, and the contact time with the liquid. After the designed test period (30-day), samples were taken out of the containers, washed by water, and the damaged parts were removed. According to Lin and Vipulanantan [20], the estimation of the weight changes of the CC structure exposed to aggressive environment is a significant parameter to predict the service life of coating material. When the samples were completely dry, the samples were then