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Comparative Evaluation of Poly Urethane and Poly Vinyl Chloride in Lining Concrete Sewer Pipes for Preventing Biological Corrosion

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ABSTRACT: Corrosion makes huge economic and ecologic damage all over the world. Biologic corrosion of sewer pipes is considered as a serious limitation in economic perspectives. To prevent biologic corrosive damage, lining techniques can be applied by materials and aggregate resistant to bacteria attack in sewer pipes. The role of bacteria is that they convert Sulfur compounds into Sulfuric Acid which causes highly corrosion. In this study, some concrete samples were lined using polymeric materials called poly urethane (PU) and poly vinyl chloride (PVC) and the role of these linings was compared in terms of improving durability and resistance of concrete samples in acidic environment. The experimental results indicated that, after a 3-month period, in comparison with PVC, poly urethane showed better durability and resistance in acidic aggressive environment. Furthermore, having made strong bonds with concrete surface, PU lining minimized the penetration of acidic solution [generated by sewage fermentation in sewer pipes] toward the concrete body.

Key words: Biological corrosion, Poly urethane (PU), Poly vinyl chloride (PVC), Concrete sewer pipes

INTRODUCTION

Wastewater treatment plant and Sewage network is one of the most important infrastructure that has been a significant growth in cities during the past century. (Karbassi and Pazoki, 2015) Sewage network imposes huge cost to the cities. For example, the worth of sewage network of USA and Australia are respectively a trillion and 100 billion dollars. Corrosion and cracking of the sewage pipe network can impose a lot of cost to the country. For example, only in USA, nearly 14 billion dollars cost annually in order to repair and replace sewage pipes caused by corrosion. The costs will increase by aging of sewage pipe network.

Population growth and urbanization cause the increasing of wastewater pipelines and also increasing in repairs and modernization of the pipelines. The use of cement in the structure and pipes is due to its many advantages such as relatively low cost and high flexibility. These materials have both advantages and disadvantages like other materials.

Corrosion is not exclusive to metals, but mineral and organic materials, plastics, and even concrete body are exposed to corrosion. So, during the design, those factors considered to which concrete blocks have to be exposed during long years is appeared essential. Due to H_2S gas production in sewage, corrosion of sewer concrete pipes is one of the substantial problems causing low efficiency and productivity of sewer networks (Rosato, 2008). The corrosion process in sewer concrete pipes is such that first of all, sulfur compounds in swage are restored to be sulfided by non-aerial bacteria. During this process, the level of non-soluble is absorbed by moisture in the empty ceiling of sewer pipe. Then they are oxidized by aerial bacterial and produced sulfuric acid at the top of the pipe. The resulted sulfuric acid causes calcium compounds in concrete to be solved and leads to the corrosion of top and wall of the sewer pipe little by little. Under this condition, top of the pipe is destroyed and, after a period, it is fallen (De Muynck and De Belie, 2007; De Belie et al., 2004; Monteny et al., 2000). Biological corrosion is made by material changes due to activation of biological live bacteria. Microbial metabolites lead to the corrosion in concrete sewer pipes. This corrosion could be happened some Millimeter annually (Fiertak and Tomal, 2013). For the first time in Los Angeles, Olmsted and Hamlin did some researches on corrosion of concrete sewer pipes. They claimed that lots of materials such as Sulfuric Acid results in corrosion (Vollersten et al., 2008). A bacterium

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called *Thiobacillus Concretivorous* was known a main factor in corrosion of sewer pipes. That bacterium then was changed to *Thiobacillus thioxidans* and then *Acidithibacillus thiooxidans* (Little and Staehle, 2001). Biological wastewater treatment processes is sensitive on pH and temperature but has serious drawbacks like corrosion.(Pazoki and Dalaei, 2016, Pazoki et al., 2010, Takdastan and Pazoki, 2011).

Subsequently fungi was reported as principal factor in corrosion process (Little and Staehle, 2001). Minimum lifetime of concrete sewer pipe is 30 years. In terms of high biological corrosion, these pipes will be severely destroyed and loss their efficiency which lead to too much ecologic and economic damages. Corrosion of concrete pipes is not repairable. Replacing is too difficult and also money-consuming, too. These problems highlight the importance of prevention from corrosion in sewer pipes. Due to chemical and biological activations such as decreasing of pH level and high turbulence, Hydrogen Sulfide gas is created at top of the waste water. This gas reacts with oxygen and results in producing Sulfur compounds. These compounds settle out in pips. The role of bacteria is that they convert these Sulfur compound into Sulfuric Acid which causes highly corrosion (Monteny et al., 2001; De Belie et al., 1998; Kaempfer and Berndt, 1998). In various industries concrete structures are extremely vulnerable against sulfuric Acid created by industrial and biological process (Yamanaka et al., 2002). Early researchers hadn't found any clear reason for production of Sulfuric Acid from acid till Parker's studies approved that the main factor involved in converting of Sulfur into Sulfuric Acid is bacteria (Soroushian et al., 2010).

Corrosion of concrete sewer pipe is done based on following reaction (Attiogbe and Rizkalla, 1988):

$$Ca(OH)_2 + H_2SO_4 \rightarrow CaSo_4.2H_2O \quad (1)$$

$$CaSiO_2.2H_2O + H_2SO_4 \rightarrow CaSO_4 + Si(OH)_4 + H_2O \quad (2)$$

$$3CaO.Al_2O_3.12H_2O + 3(CaSO_4.2H_2O) + 14H_2O \rightarrow 3CaO.Al_2O_3.3CaSO_4.32H_2O \quad (3)$$

The product of this procedure is a kind of gypsum which is eventuated in expansion and also make the concrete fractured. If these gypsums haven't been removed from the concrete, the wall of pipes will be slowly corroded (Monteny et al., 2000). There are two ways to increase lifetime of concrete structures against corrosion. One is applying different materials and artificial coverage resistant against biological corrosion and the other is using Pesticides to prevent from growing bacteria which produce sulfuric acid (Bassuoni and Nehdi, 2007). PU and PVC are two thermoplastic materials in the world which include significant and valuable features such as various usages in industry, high chemical resistant and also low price. All those specifications result in using these two materials as lining in concrete sewer pipes (Ameer, 2013).

Main goal of this research is to study the effect of PU and PVC lining. It has assessed and compared effect of each in preventing from biological corrosion of sewer pipes.

The main purpose of this article is to point out the lining effects of PU and PVC on the amount of corrosion of concrete structures (especially concrete pipes), also their resistance in various time conditions and the percentage of acid concentration in environment have been investigated.

The results of this study help to prevent from large biological corrosion of concrete structures in sewage collection network and also refrain from large costs.

MATERIALS & METHODS

In this study, the concrete cube samples with dimensions of 100 mm (length), 100 mm (width) and 100 mm (thickness) have been used to measure corrosion rate. The reason that cubic samples are taken into account is that the rate of corrosion in each dimension is equal and the difference in dimensions does not have any effect on the accuracy. As it is shown in table 1, the type of cement which has been used, is Portland cement type I. About 60 percent of its compounds consists crushed stone, crystalline silica (quartz) and gravel. The amount of water is also about 50 percent and the rest of the percentage is related to other materials in cement. After making the samples, they have been washed with clean water (fresh water) on account of surface contamination to be removed and they do not interfere in the amount of corrosion. Washed samples are taken into oven at 60 °c for three days until the amount of its water become similar to initial steady state. Tap water of Tehran has been used in this section.

Table 1 shows the design of mixing concrete applied in biologic corrosion experiments to concrete, for a sample with the volume of one cubic meter. Specified compressive strength and the density of cement were respectively about 220 kg/cm^2 and 2357.5 kg/cm^3.

Acidic environment of sewage in the laboratory was modulating as accelerated condition to assess its effects on control and lining the concrete samples in the least time (3 months). It is necessary to keep acidic concentrations and temperatures of the environments

Table 1. Design of mixing concrete applied in biologic corrosion experiments to concrete

	W/C	W	C	S	G	F_c	γ
Unit	0	Kg	kg	Kg	kg	Kg/cm^2	Kg/m^3
M^2	0.5	162.5	325	1425	445	220	2357.5

constant (about 25°C); so, stabilizing of acidic concentration of environment titration technique is used and for stabilizing temperature, heating equilibrium of environment and solution is used. Before determining the acidic concentration of the solutions, the standard Na-OH solution (0.1 ml) had to be prepared.

The amount of acid concentration in wastewater is simulated in the laboratory and its effect on concrete samples has been investigated. It is essential that acid concentration to be constant during the test. The constant concentration of acid is provided by nitration method.

In order to create the desirable acidity concentration, 0.1 molar solution of NAOH has been used. Sodium hydroxide, as a solid and in solution, looses strength on exposure and its concentration needs to be determined or standardized by titration, using a hydrocholoric acid (HCl) solution of a known concentration (0.1 M). The constant temperature is due to a balance between the lab environment and the solution. And the time needed to keep the temperature and acidity concentration level to this experiment was three months. In this study, 9 concrete cubic samples have been tested which three of them were control samples and three of them were samples with PU lining and three of them were samples with PVC lining. All these 9 samples are investigated in different acidity concentration for three month at 25 °C. The concentrations which have been used were 1, 2.5 and 5 percent, that are investigated in the followings.

In order to measure corrosion, weighting techniques with 0.1 gr accuracy have been used. Each time before weighting, samples were washed with pressurized water, so that the corroded materials could be removed from the surface and then the samples have been in an oven at 60°c for three days, and then have been weighted. The amount of mass difference with initial samples shows the amount of corrosion. Timing of the weighting experiments depends on acidic concentration and time passed from beginning of the experiments; thus, in each phase, the titration procedure was done in order to stabilize concentration.

RESULTS & DISCUSSION

Since the selected research design in this study was based on direct laboratory observation, by statistical analysis, the relationship between the tested variables and corrosion was determined.

In this kind of calculations, the kind of relationship between the considered function (in this case, proportion of corroded mass in primary and second mass of samples) is determined by tested variables such as time, environmental pH, properties of comprising aggregate of pipe shell, kind of protective lining, etc. Results of such analysis usually leads to equations, in which corrosion level of designs and applicable prototype conditions can be estimated without performing laboratory works, then the effect extent of each variable on corrosion level can be evaluated by one variable regression. In all the analyzed cases, the corrosion level depended on time and acid concentration in the environment in concordance with concordance with ordinary engineering perception. In other words, doing experiments was based upon a technique for modulating natural condition in sewer pipes. Therefore, generalizing the results of observations into real (prototype) conditions can be reasonable. Three samples as control, PVC lined, and PU lined were compared.

Fig. 1 shows the corrosion percentage for the control sample, in which two variables of time and pH (acid concentration in environment) are reasonable and their effects on corrosion level are shown. Corrosion percentage (Δcp) is the mass destroyed during an assumed time period in an environment with an assumed acidic concentration to primary mass of sample.

The effect of two variable (time and environment acid concentration) on the percentage of control sample's corrosion are illustrated in figs 1, 2 and 3. The time period of investigation has been three months. Corrosion rate occurs slowly due to the low concentration of environment acid (1 percent) and the amount of corrosion increase up to the 22nd day and after that its upward trend has been stopped and it is due to the decrease in the effect of acid concentration. After the 22nd day, even some part of the mass, lost due to water penetration into the cement and also not discharging water during the drying process, is compensated. After the 60th day, the amount of corrosion is 0.5 percent and the process continues its constant routine. The average of the percentage of corrosion considering the variable time and 1 percent acid concentration is shown in fig. 1.

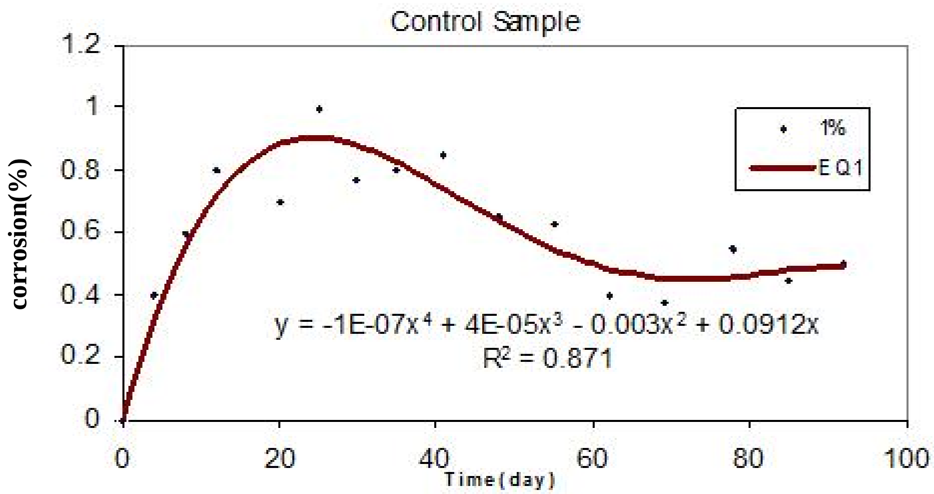

Fig. 1. Processed curve of the control sample in 1% acidity concentration

In figs 2 and 3 that shows the percentage of corrosion based on time in different concentrations (2.5 and 5 percent), that the trend in these figs is different compared with fig. 1. In figs 2 and 3, the percentage of corrosion has increased within 90 days. And only in a few parts the increasing rate of the diagram has declined a little, but on the whole corrosion rate is increased. In acid concentration of 2.5 and 5 percent at the end of 90 days, the corrosion rate is respectively 18 and 74 percent. This case demonstrates that if the concrete samples without any special coating applied in wastewater industry, the impact of pH on them can be increased and also can greatly increase the corrosion. Therefore lining the concrete structures is essential. Each equation of control samples graph is shown in their own figs.

Samples are shown in figs 4 and 5 are with PVC lining and are under the influence of environment acid concentration of 1 and 5 percent. The negative corrosion in figs 4 and 5 is considerable. Since the corrosion criteria is the weight of samples, steady decrease of corrosion can be seen in both samples up to the 20th day. And after the 20th day, the process rate has been slower and in some cases it has been constant. So according to the graphs , it can be deduced that PVC lining on concrete pipes has a huge impact and there is not any sign of corrosion even in acid concentration of 5 percent on 90-day period in laboratory. The estimated equations for each acid concentration percentage of 1 and 5 percent are shown in figure 4 and 5. Also corrosion graph of sample with acid concentration of 2.5 percent has the same trend of graph 4 and 5.

In figs. 7 to 9, the corrosion of pipes with PU lining in acidic concentration of 1, 2.5 and 5 % are shown during 90 days. The corrosion rate in three states have significantly declined compared with figs 1 to 3. And PU lining protects the concrete samples from corrosion successfully. For example, in acid concentration of 5 percent, the maximum corrosion has been achieved at the 80th day which its amount is only 0.06 %, while it is 75 percent in the state of without lining.

Another point about figs 7 to 9 is that the corrosion changes is very low. Due to the changes in acid concentration, great changes are not seen in the corrosion of samples, and even has shown less changes compared to the sample with PVC lining. And it indicates that the stable PU lining has low changes and high resistance due to the acids derived from sewage. In all the discussed graph, the percentage of corrosion of changes rate (formula) can be seen according to the time.

Observations showed that sulfuric acid attack started from concrete surface and the main attack was done at the cement gel. But, the application of alkali, like lime and dolomite, can reduce speed and corrosion level. It is clear that corrosion made by sulfuric acid was related to the combination of hydroxy calcium with acid and production of calcium sulfate in phase 1 and also the combination of this sulfate with calcium aluminates in phase 2. Therefore, it is essential to make the inner wall of sewer concrete pipe resistant to biologic corrosion using possible techniques considering economic and executive aspects. So, by applying polymeric materials using PU, the manufactured concrete samples (10×10×10 cm3) were lined; so, it could be compared with other samples (without lining) in terms of resistance and durability in acidic environments with different concentrations. Accordingly, the results from the experiments related to PU lining after 90 days were represented. Meanwhile, the results from polymeric lining and poly vinyl

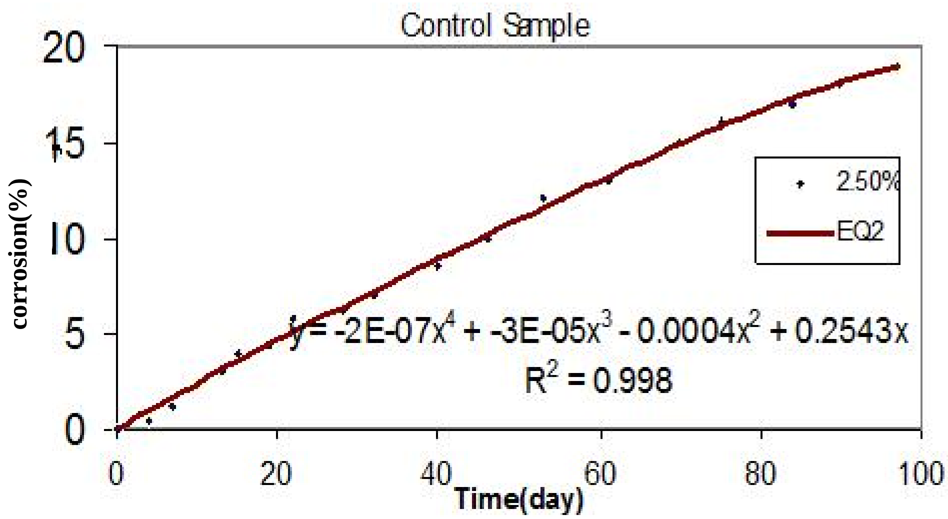

Fig. 2. Processed curve of the control sample in 2.5% acidity concentration

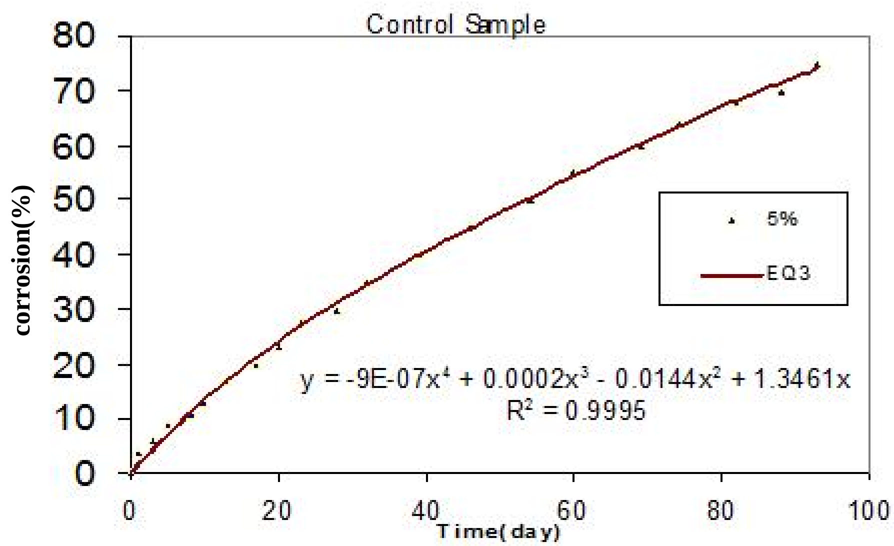

Fig. 3. Processed curve of the control sample in 5% acidity concentration

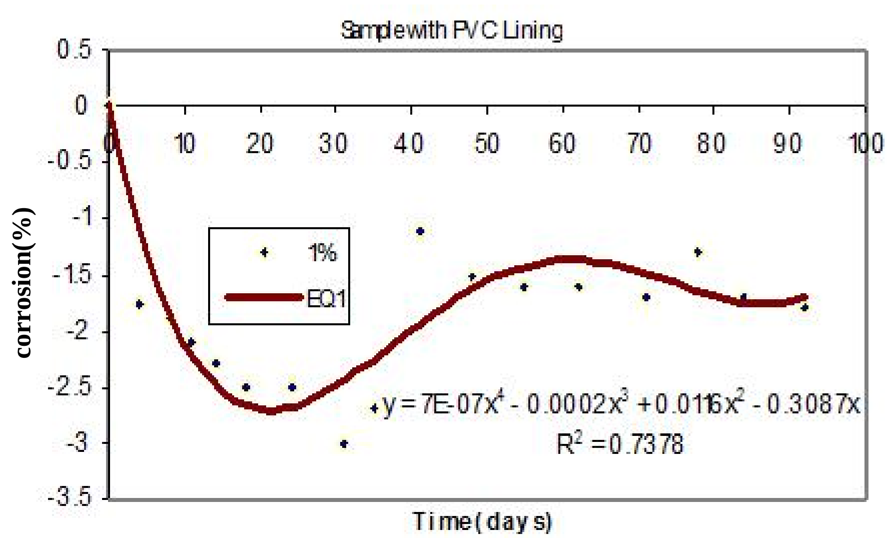

Fig. 4. Processed curve of the PVC lined samples in 1% acidity concentration

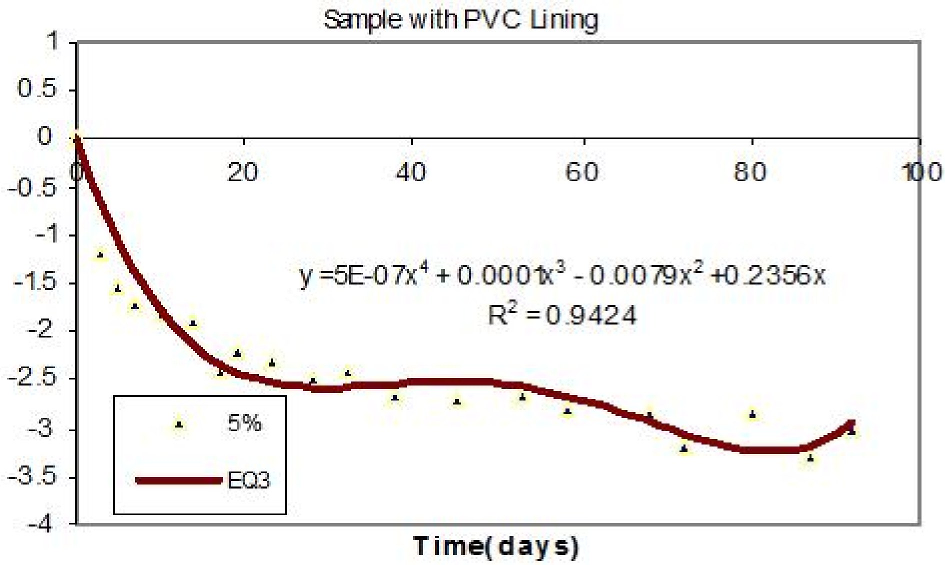

Fig. 5. Processed curve of the PVC lined samples in 5% acidity concentration

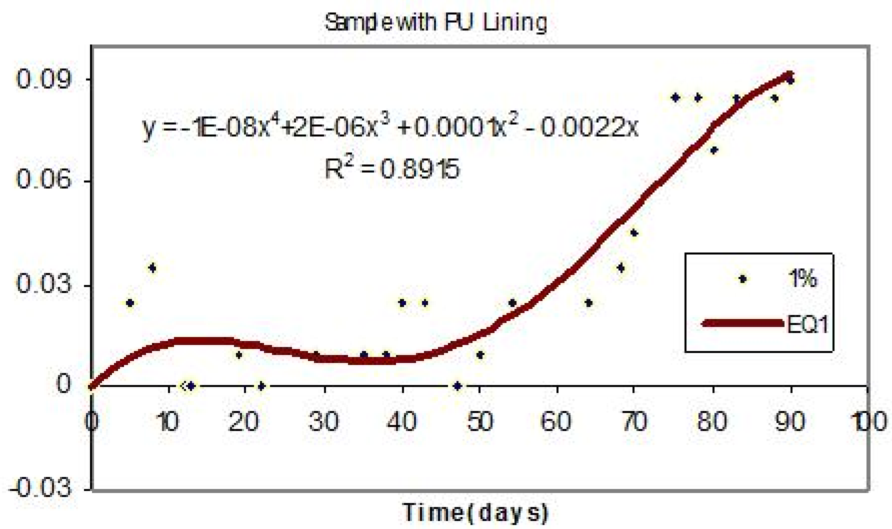

Fig. 6. Processed curve of the PU lined samples in 1% acidity concentration

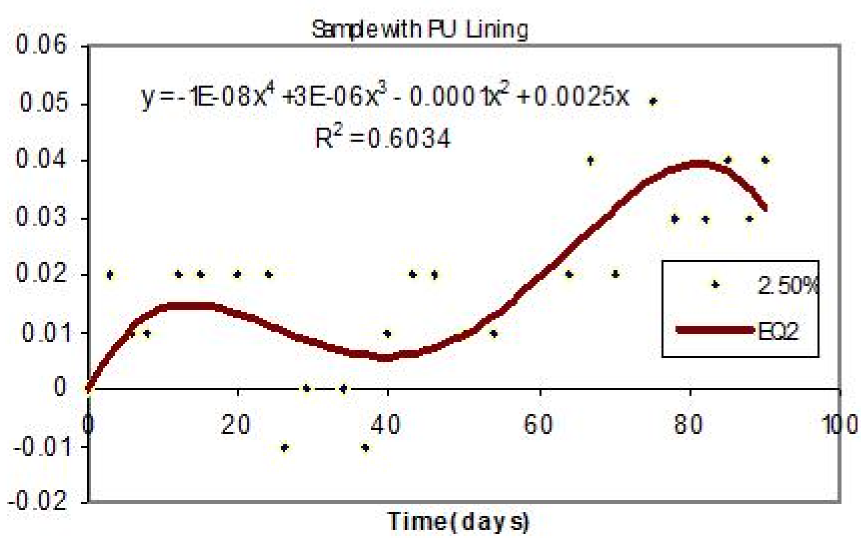

Fig. 7. Processed curve of the PU lined samples in 2.5% acidity concentration

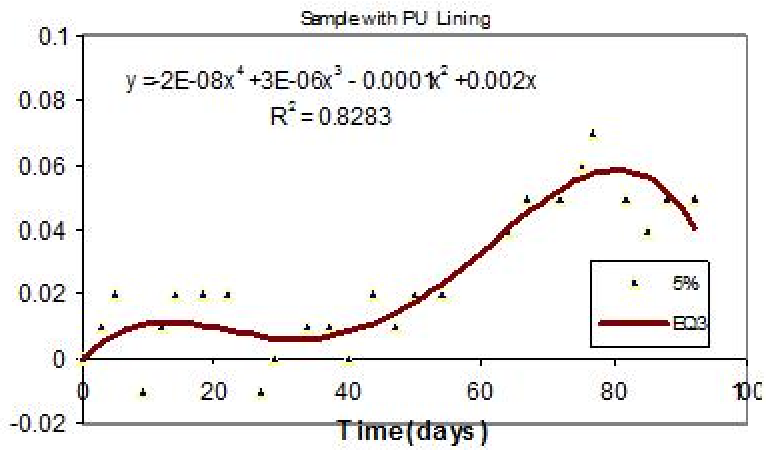

Fig. 8. Processed curve of the PU lined samples in 5% acidity concentration

chloride (PVC) lining were followed for comparing in all aspects. If there were a potential penetration in the surface of the lined sample (such as aspects and corners), the lining would be already tracked from that location and cause corrosion aggression to concrete and lining laminating. Therefore, in using sewer lined concrete pipes, applying technical principles and suitable performance techniques could be essential for preventing the potential weak points for corrosion aggression and lining disruption.

CONCLUSIONS

The corrosion made by sulfuric acid was related to the combination of hydroxy calcium and acid, production of calcium sulfate in phase 1 and also the combination of this sulfate and calcium aluminates in phase 2. Therefore, it is essential to make the inner layer of sewer concrete pipe resistant to biological corrosion using possible techniques considering economical and executive aspects. Furthermore, making strong bonds with concrete surface, PU lining minimized the penetration of acidic solution [generated by sewage fermentation in sewer pipes] toward the concrete body. Considering the curves and their resulted equations, high durability and resistance of the PU lining in corrosive environments compared to other tested linings can be found. Because the technology of applying lining in inner pipe walls needs strong control, we should provide a background for developing this technology and protecting this standard lining procedure. Also, the effect of lining with each lining material should be considered in future studies.

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