Evaluate the Possibility of Cracking Pipe on Water Supply Network under the Age of Pipe

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Abstract: Minimizing water loss in water supply networks is one of the objectives for protecting water resources. Currently, the large amount of water loss is mainly due to leakage of the pipeline network. The leaking of pipe can be caused by incorrect construction, impacted by external forces, or corroded pipe material and aging. Therefore, to control and predict the cracking area on pipe, it is necessary to collect data about pipe conditions, approve the solution of technology improvement and define the ability of pipe capacity from setting up to the first preparing time. This paper will demonstrate how to evaluate corrosion pipe under the age of pipe and the impact level of internal pressure pipe at different times, and will put forward solution of effective leaking management on water supply network.

Key words: The age of pipe, material of water pipe, water environment, leaking, cracking pipe.

Nomenclature

| Symbol | Description |
|--------|-------------|
| $\rho_s$ | soil resistivity |
| pH | soil acidic or alkaline nature |
| A | final pitting rate constant, mm/year |
| B | pitting depth scaling constant, mm |
| C | corrosion rate inhibition factor, year$^{-1}$ |
| D | diameter pipe, mm |
| K,Kn, n | constant |
| n | related to soil redox potential |
| T | exposure time, year |
| P | static pressure, bar |
| L | length of corrosion pit, mm |
| Q | flow out pipe |
| R | wide of corrosion pit, mm |
| $S_T$ | thickness of pipeline, mm |
| S | depth of corrosion pit, mm |
| $\Delta S$ | thickness residual pipeline, mm |
| t- | increasing pressure time, s |

1. Introduction

A crack on the pipe in the water supply network shows that the pipe cannot be used longer and should be repaired or replaced. If the pipe is not timely treated, it will cause large amounts of leaking water at high pressure in pipe. In addition, it also increases the risk of external contaminants at a low pressure in pipe [1]. It entails not only economic losses to the water company, but also the potential risk to the health of consumers [2]. Thus, it is necessary to analyze the causes of these cracks and make plans to minimize and manage them effectively. The lifespan of water supply pipe as recommended by the manufacturer is at least 50 years in normal working conditions. However, the fact is that some pipes do not reach this minimum lifespan [3]. Ignored errors, due to construction techniques or materials’ defects resulting in earlier damages, can be classified into two main categories, the load acting on the pipe and the corrosion process [4]. Also, when the thickness of pipe was reduced to a certain level, the influence of the load in this position will be much larger and increase the risk of cracking pipe. Thus, the pipe is cracked due to the different load effect from time to time, which should be taken into consideration. In this paper, experimental models are used to determine the influence of the load on the defects of
different sizes. These defects are assumed shapes correlated with the corrosion pits appearing on the material surface after operation periods. Lastly, the degree of capacity load is proposed for different defects. Experimental results are also the basis to build management of cracking solution for pipes in water distribution systems.

Materials of pipes commonly used in water supply network can be divided into 2 main categories, metal and nonmetal. Metal materials, such as gray cast iron, cast iron and steel, are characterized by low brittle damage but high bearing strength [5]. So they are often used in the transmission pipelines. Recently, plastic materials are more popular for distribution pipes (with smaller diameter than transmission pipe), especially for convenient HDPE pipes during construction as well as operation management. Therefore, HDPE pipe with 110 mm diameter and 5.3 mm thickness are selected in this research.

2. Evaluate Material Corrosion Rate under the Operation Pipe Time

The defects on the material surface are due to the impact of soil around pipes and working conditions inside them [4]. By experiments model and statistical methods, the research has suggested the mathematical formulas determined the corrosion depth as shown in Table 1. The results were published earlier in 1969, analyzing the causes of appearing pits from electrode corrosion and the solution proposed the equations defining the depth of the outer surface corrosion of metal pipes, but the author has not reviewed cases from the aspect on environmental impact of material inside the pipes [5], and put on forward to calculate corrosion rate belong to pipe age. They focused on analyzing the factors of the wet season in a year and chemical and physical reactive process of material; the formula used many constants so they are converted to suit research area when applied. Rajani’s method in 2000 was further analyzed with both corrosive elements from outside and inside the pipe, based on two-phrase corrosion models, a rapid corrosive growth and a slow linear growth of pit.

The results of this research [3] indicated that the given depth of corrosion developed rapidly in the early stages but later the speed had slowed down. Kucera showed that the corrosion rate had been rising gradually with the pipe age. The appliance of D110 pipe with wall thickness 5.3 mm (Fig. 1) shows that the expected pipe age is calculated using the Kucera method (26 years), which is greater than the Rajani method (12.6 years); and considering the same depth value, the speeds of corrosion occurring at the moment also are different. Thus, traces of corrosion depth can be determined by the work time of the pipes, and what method should be applied will depend on the actual area.

| Formula | Reference |
|---------|-----------|
| $S = K_c Z^2$ where $Z = \left[ \frac{(10 - pH R)}{\rho_s} \right] a$ | [6] |
| $S = K T^n$ and $S_f = n K T^{(n-1)}$ | [5] |
| $S = a T + b \left(1 - e^{-c t}\right)$ and $S_f = a + b c \times e^{-c t}$ | [3] |

Table 1: The formula for calculating the depth of corrosion follows the exposure time.

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- $S$—depth of corrosion pit, mm
- $K_c$—Constant
- $Z$—coefficient
- $pH$—soil acidic or alkaline nature
- $T$—exposure time, year
- $\rho_s$—soil resistivity

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Water supply system has its own characteristics. They have internal pressures which vary continuously according to real time [8]. Therefore, when considering the lifespan of water pipe, the authors cannot ignore the influence of water pressure in the pipe. Experiments are performed to observe the influence of pressures inside the pipe on the outside defects, which are in the shape of ellipsoid.

3. Experimental Models about Bearing Limited of Corrosion Pit

The model is set up as shown in Fig. 2. It has 1 m HDPE pipe D110 produced by Thieu Nien Tien Phong Plastic Company [9], with wall thickness of 5.3 mm and accessory: valve, pipe, pressure meter P (0\text{–}25 \text{ bars}). Equipment to create pressure by hand T-50K-P number PAT No. 1559537 is produced by KYOWA company in Japan country, with a limited measure of 0\text{–}50 \text{ bars}.

Air valve is located in the highest position on the pipeline to ensure that no air exists in the pipe test. Q valve is used to discharge flow quickly out of the pipe after the appearance of pressure damage to reduce the possibility of the material deformation. Two top pipes are covered by flange, perforated on the flange for connection with the valve and the equipment T-50K-P. Four experiments were conducted for four points', external corrosion of pipes with corresponding depth of 90\%, 70\%, 50\% and 30\% of wall thickness of original pipe respectively.

Pipelines are divided into five equal sections and marked to create defect ellipsoid as shown in Fig. 2. After each defect is failed, this is fixed by the clamp saddled, and then continues to experiment with the next defect. Based on the theory of plastic deformation and destruction of materials, shape defects are assumed to have the elliptical with dimensions as shown in Table 2. The $S \times L \times R \ (\text{mm})$ represents depth $\times$ length $\times$ width traces of corrosion elliptical, and $\Delta S$ is the remaining thickness of the water supply pipes.
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Table 2  Corrosion pits size on the wall HDPE pipe D110.

| No | D110 | S (mm) | L (mm) | R (mm) | ΔS (mm) |
|----|------|--------|--------|--------|---------|
| 1  | 90%  | 4.8    | 47.7   | 9.5    | 0.5     |
| 2  | 70%  | 3.7    | 37.1   | 7.4    | 1.6     |
| 3  | 50%  | 2.7    | 26.5   | 5.3    | 2.7     |
| 4  | 30%  | 1.6    | 15.9   | 3.2    | 3.7     |

D110-90%

| P(bar) | 0   | 5   | 10  | 12.5 | 15  |
|--------|-----|-----|-----|------|-----|
| t(s)   | 0   | 20  | 34  | 42   | 99  |

The shape of defect on wall pipe is damaged due to increasing static pressure process.

Fig. 3  The results of experiment No. 1 on the HDPE pipe D110-90%.

Water is pumped into the pipe, ensuring no air inside. The first experiment was conducted with a corrosion point with a depth of 90% wall thickness pipe and a length of 10 times depth and width ellipse R = 2S. Using the device to increase pressure in the pipes from 0 bars to 15 bars during 99 seconds is failed completely (Fig. 3).

Observation showed that when the pressure reaches 10 bars, the defect starts to deform, contentedly increasing the size, and tends to stretch protruding pipe. The whole pipe also deformed when the load time increased. However, because the material has high elasticity HDPE (800-1,100 MPa), pipe sections back to its original shapes after releasing the pressure. When repeating the experiment with the smaller defect size, the results showed the pressure of value destruction increased from 15 bars to 22.5 bars with load time from 0-160 seconds (Fig. 4).

The graph in Fig. 4 shows that the time for the damage of defect D110-30% is shorter than those in the previous two cases. This phenomenon is caused by all defect points, conducting on the same pipe. The elastic limit of the material decreased through each experiment so it led to faster fatigue occurring on fourth defect. Although the total time decreased, the static pressure damage value on the elliptical cross section remains the highest of the four experiments (Fig. 5); this result shows that the failure of pressure value depends on the thickness of the wall remaining on the pipe and other than the dependent deformation of the material before.
4. Evaluate the Possibility of Cracking Pipe on Water Supply Systems

Management of cracking pipe not only contributes to the reducing costs of the water company but also saves natural resources which are increasingly scarce today. Based on the above results, the researchers suggested quantitative methods of cracking location on the water supply network as follows:

- The risk of cracking pipe is high at locations with high corrosion rate and large impact loads.
- Location with normal load conditions but corrosive environment or vice versa is a high-risk crack area.
- The water pressure in the pipe oscillating at average levels and average corrosion rate is able to crack an inadequate pipe.
- Corroded pipes with a low or moderate water pressure on the system are less easily to crack a pipe.

The different diameters have different bearing values; it depends on the mechanical properties of each material. The degree of corrosion will be assessed on the remaining thickness of the pipe at the time of calculation.

5. Conclusion

Researches from 1969 to 2000 determined the general rule, which is that the corrosion depth depends on the age of pipe. The developing processes of corrosion pit on the pipe are different, and it depends on the soil conditions around the pipe as well as materials that pipe used in water supply system. By means of experimental method, the results showed the influence of the static pressure on the defects is not dependent on the previous deformation of the material. Thus, as for HDPE pipe with a diameter of 110 mm and a thickness of 5.3 mm, it is failed at pressure value from 15 bars to 22.5 bars.

Operation conditions and soil environment of the pipe are very diverse. In order to evaluate the influence of these factors to the pipeline, a survey with detailed parameters related to hydrogeology, chemical and physical properties of the water inside the pipe under working time should be carried out. Therefore, this study was conducted setting the premise for the evaluation of an easier cracked by quantifying the life and encompassing the area pipes or occurring high pressure fluctuations. Future researches will expand on the working pressure limits for different types of water supply pipes.

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