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Experimental Study on Damage Characteristics of Corroded Steel pipe Based on Acoustic Emission Technology

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Abstract **Original Research Article**

The corrosion damage of steel pipe is mainly characterized by crack initiation and local wrinkling. One of the effective methods to evaluate the damage degree of steel pipe is to find out the law of crack initiation. The research object of this test was Q235 steel pipe specimen with diameter of 700mm, wall thickness of 5mm and height of 260mm. Acoustic emission technology was used to conduct real-time axial compression detection on corroded steel pipe specimens. The relationship between acoustic parameters (cumulative ringing number and amplitude) and the damage degree of steel pipe specimens was established, and the crack propagation law and crack initiation load of steel pipe after corrosion damage were obtained. By analyzing the different characteristics of the relationship between the displacement of loading point and acoustic parameters, the general position of steel pipe damage was detected and the exact value P of crack initiation load was determined. The experimental results provide a basis for further research on the damage mechanism of steel tube specimens. The test results provide a certain basis for further research on the damage mechanism of steel pipe specimens.

Keywords: Steel Pipe; Corrosion damage; Acoustic Emission Technology; Cracking load.

0. INTRODUCTION

With the rapid development of economic construction, oil and natural gas energy is widely used, and the safety of the buried pipeline as its main transportation medium is particularly important. In fact, the buried pipeline in service needs to pass through a variety of complex external environments, which will cause a certain degree of corrosion damage to the steel pipe [1-3]. Therefore, an important index to evaluate the damage degree of the steel pipe is the initiation toughness [4-6]. Its accuracy depends on the crack initiation load value. In addition to high accuracy and reliability, acoustic emission (AE) technology can be used to determine the cracking load of buried pipelines, and can also distinguish the internal and external damage of the pipe wall. According to the analysis and evaluation of the corrosion detection data, the manager can formulate an economic and reasonable maintenance plan, save the repair cost, determine the safe operation conditions and remaining life of the pipeline in the future, and ensure the long-term safe and economic operation of the pipeline, which is of great positive significance.

At present, there were few experimental studies on the exact crack initiation load value of steel pipes after damage, and many research objectives were to detect the damage degree of steel pipes [7-9]. Jiang [10] proposed two major methods, local method and overall method, to detect the damage of concrete-filled steel tubular structures, but this technical method was greatly affected by the surrounding environment. Liu [11] adopted the ultrasonic guided wave nondestructive testing method to test the damage of pipes. This method can quickly detect the corrosion damage of steel pipes in a long distance, in a large range and at a low cost. However, it can not obtain the exact value of crack initiation load after steel pipe damage. Therefore, in order to accurately analyze the change of crack damage and crack initiation load of steel pipe, it is urgent to find a method that can not only analyze the general location of corrosion damage, but also obtain the exact value of crack initiation load. In recent years, many scholars have used acoustic emission technology to detect some materials [12, 13]. For example, Wang [14] located the damage of civil structures based on AE technology. Tu [15] analyzed and obtained the crack initiation law of wood beams by studying the change law of acoustic emission parameters during loading and the evolution of surface strain information in the crack zone. The results show that AE technology can detect the internal micro damage of materials before macro deformation.

Based on the above discussion, acoustic emission technology was used in this study to detect the damage of corroded steel pipe specimens under axial compression load. Through the analysis of cumulative ringing number and amplitude value in acoustic parameters, the final damage degree of steel pipe specimens and the determined crack initiation load value were obtained.

1. MATERIALS AND METHODS

1.1 Test materials and equipment

Three Q235 steel pipe specimens with the diameter of 700 mm, the wall thickness of 5 mm and the height of 260 mm were used in this test. The test equipment included PS-305D electrochemical corrosion instrument, with an output current range of 0-3A and an accuracy of 0.01A; As well as loading machine and DS5-8A acoustic emission acquisition instrument. The test materials and equipment are shown in Fig 1.

Fig 1: Test materials and equipment

1.2 Steel pipe corrosion

Take Q235 steel pipe as the test object, the corrosion area is from the bottom to the height of 145mm. The two poles of the power supply were connected to the steel pipe and copper sheet respectively, and then put into the prepared NaCl solution to start the electrochemical corrosion test, as shown in Fig 2. There was no obvious change in the solution at the beginning of the corrosion test, and the solution gradually turned reddish brown the next day. At this time, the steel pipe began to be corroded. After three days, the color of the solution deepened further, and at the same time, impurities began to be generated in the corrosion area and adsorbed on the steel pipe surface. On the fifth day of corrosion, the steel pipe surface was covered with green impurities. During the corrosion process, some parts near the copper strip were seriously corroded and fell off in a large area. The corroded steel pipe is shown in Fig 3.

Fig 2: Steel pipe corrosion

Fig 3: Corroded steel pipe

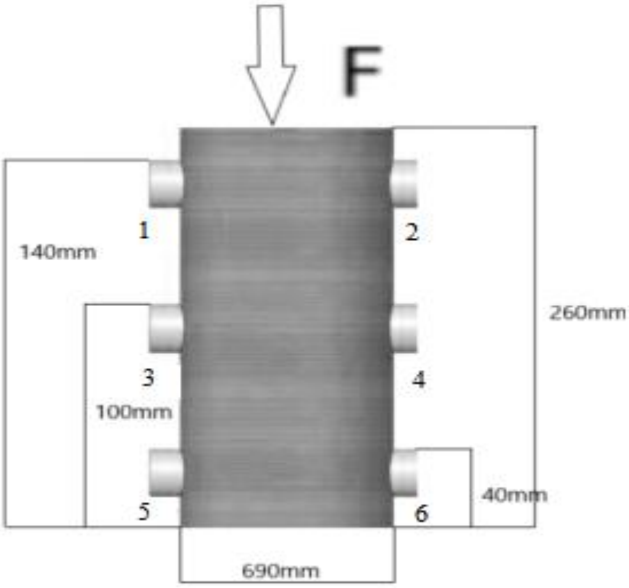

Fig 4: Position diagram of acoustic emission sensors

1.3 Arrangement of acoustic emission sensors

A total of 6 acoustic emission sensors are arranged on the surface of the steel pipe. In order to ensure the contrast and accuracy of the experimental data, the acoustic emission sensors need to be fixed at the same position on the opposite side of the steel pipe, as shown in Fig 4. And the specific location parameters are shown in Table 1. The channel threshold value of the acoustic emission instrument is 20 mV, and the frequency range of the sensor is 50-400 kHz.

Table 1: Location of acoustic emission sensor and steel pipe

Sensor	Height (mm)	Angle (°)	Radius (mm)
1	40	0	345
2	40	180	345
3	100	0	345
4	100	180	345
5	140	0	345
6	140	180	345

1.4 Loading design

The schematic diagram of the test loading device is shown in Fig 5. After ensuring that the sensor is connected to the acoustic emission device correctly, the loading system is started to use the steel pipe for a certain amount of pre-loading, which is intended to reduce the frictional noise generated between the loading machine and the steel pipe, so as not to cause the acoustic emission to collect too much noise to affect the test results, as shown in Fig 6. During formal loading, the loading device is loaded by displacement control, and the rate is kept at 0.2mm/s. Finally, the data of load, ringing count and displacement of loading point with time are recorded by computer. The loaded steel pipe is shown in Fig 7.

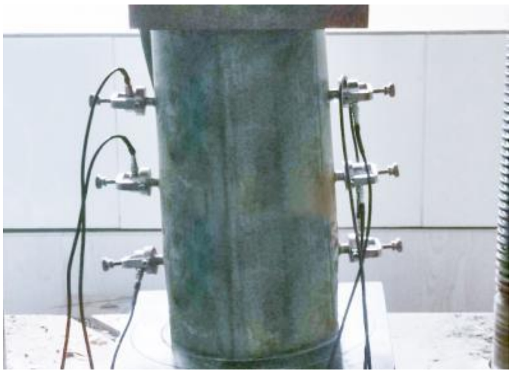

Fig 6: Steel pipe pre-loading

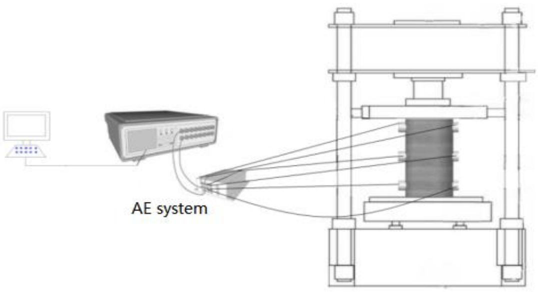

Fig 5: Test device specimen diagram

Fig 7: Loaded steel pipe

2 RESULTS AND ANALYSIS

2.1 Data analysis of acoustic emission parameters

The relationships between loading time, load (P), loading point displacement (δ) and cumulative ringing count and acoustic emission signal amplitude during the whole loading process are shown in Fig 8 and 9. In the loading test, cracks were observed on the surface of the pipe at 109s, so the pipe may have cracked before 109s. From Fig 8, it can be seen that the cumulative acoustic emission ringing count had a large trend before and after crack generation, which can be roughly divided into 3 stages: Resilience phase, cracking stage and crack extension stage. When the time before 11s (loading point displacement $\delta < 0.15$mm), the cumulative ringing count was very low and in a slow growth state (cumulative ringing count < 25000), the load-loading point displacement curve at this stage can be approximated as a vertical straight line. This situation indicates that the steel pipe had not cracked and was in the elastic stage. From Fig.9, it can be obtained that when the time was 11s (loading point displacement $\delta = 0.15$), the amplitude of acoustic emission signal appeared the first maximum (maximum amplitude = 4300 mV), and the load at the point of the change trend was large (P = 38500 N). The phenomenon indicates that the pipe began to sprout microcrack inside the steel pipe, and the steel pipe began to crack. With the increase of time and load, the loading point displacement began to show a non-linear relationship, and gradually declined. The deformation of the test piece with the time change growth was more obvious. At this time the steel pipe was in the yielding stage, acoustic emission signal amplitude reached a peak (10000mV), and the cumulative ring count curve at this stage of the rising trend was more obvious, indicating that the crack inside the steel pipe was increasing. Until the time reached 120s, there are obvious cracks on the steel pipe surface.

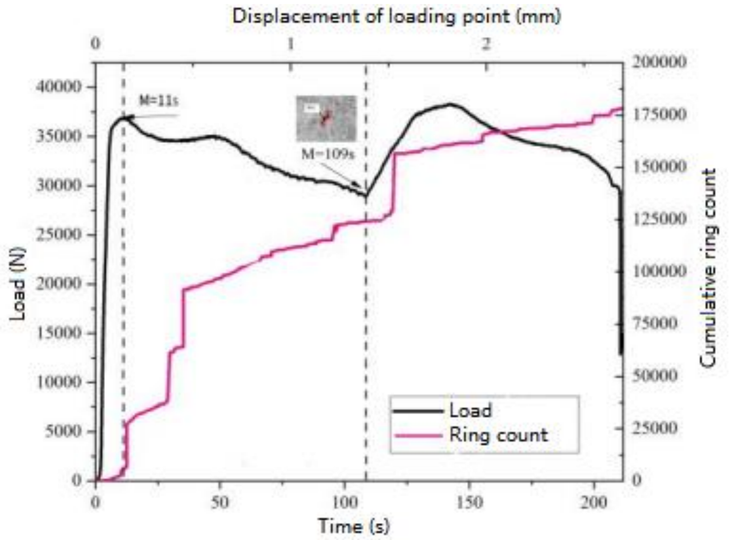

Fig 8: Cumulative ringing count graph

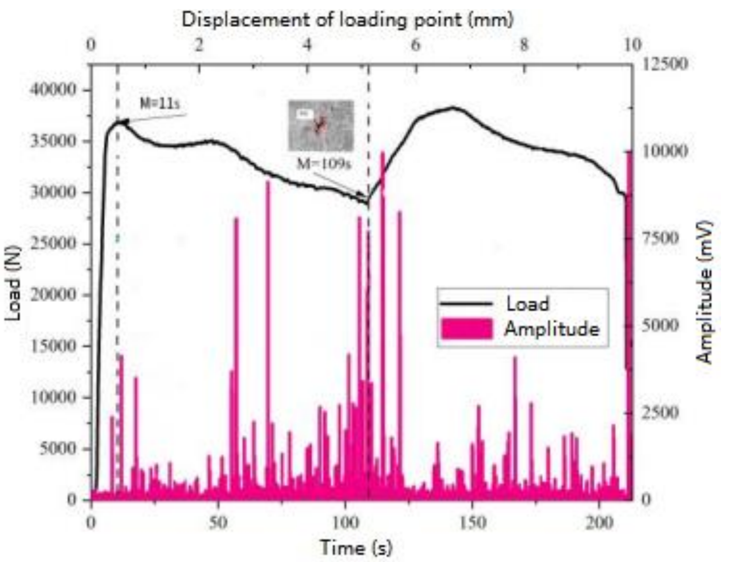

Fig 9: Magnitude histogram

In the acoustic emission equipment for steel pipe detection test, energy refers to an impact acoustic emission amplitude value of the integral value of the duration, to reflect the relative energy and strength of the steel pipe during the test. According to Fig 10, it can be obtained that the energy collected by the sensors in the range of channel number 1 to 4 ranges from 395,000 to 485,000 (mV*ms), while the energy collected by sensors number 5 to 6 ranges from 175,000 to 205,000 (mV*ms). From the perspective of energy analysis, it can be initially presumed that the corrosion is more serious near the No.1 to No.4 sensor area. And during the test, one of the copper pieces of the electrochemical corrosion power supply was placed near the No.3 sensor, so the corrosion area near this sensor was the greatest, and the most energy was released. The No.3 sensor collected the most energy, which was consistent with what the histogram shew. The effective voltage value (RMS) is the square root mean value of the acoustic emission signal during the sampling time, which is used for continuous acoustic emission activity and can effectively reflect the degree of material loss. From Fig 11, it can be seen that cumulative effective voltage value range for No.1 to No.4 sensor is 34000-65000 mV, and for No.5 to No.6 sensor is 9000-16000 mV. According to this, it can be indicated that the damage is more serious in the No.1 to 4 region. Because the effective voltage value of the No.3 channel is greater than the other channels, it can be concluded that the severity of corrosion damage in No.3 area is the largest. And then according to the above energy analysis of each channel, it can be proved that the corrosion damage degree of steel pipe can be judged by acoustic emission signal parameters.

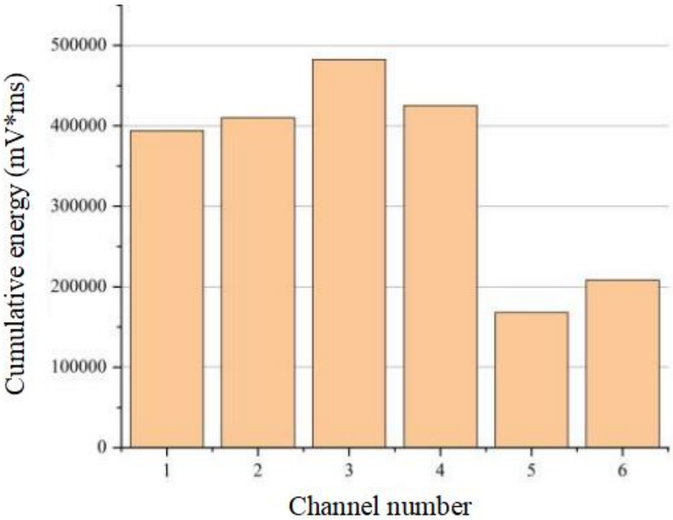

Fig 10: Accumulated energy

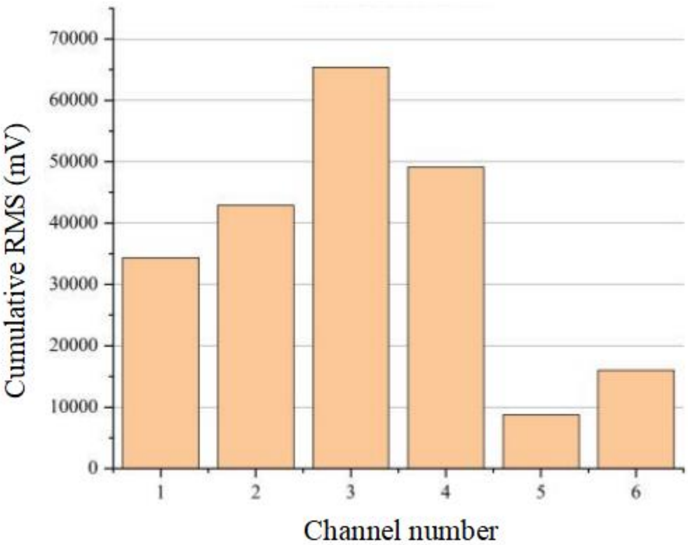

Fig 11: Cumulative RMS voltage

2.2 Determination of cracking load

In the process of steel pipe cracking, the amplitude and cumulative ringing count change more obviously than other ae signal parameters, so the relationship diagram of acoustic emission amplitude and cumulative ringing count with the displacement of steel pipe loading point is used to determine the crack initiation load P. Due to the bending deformation of the steel pipe during the loading process, the strain energy stored in the steel pipe can be quickly transformed into elastic wave and released from the crack initiation position. The acoustic signal monitored by the acoustic emission sensor has a sudden change, which is embodied in the sharp rise of acoustic emission amplitude signal, reaching the peak of this stage, and the cumulative ringing count also has a sudden change.

Therefore, it is reliable and realistic to use the above acoustic emission signal parameters to determine the crack initiation load. It can be seen from Fig 8 and 9 that prior to the loading point displacement was 0.15mm, the amplitude presents a relatively stable state, indicating that the steel pipe was in the elastic stage and no microcracks occurred inside the steel pipe. However, when the loading point displacement exceeded 0.15mm, the amplitude peaks, and the trend of the cumulative ringing count and the loading point displacement curve changed sharply. According to Figure 12, when the time was 11s (amplitude =80000 mV), the amplitude-arrival time curve had a great trend change, which was consistent with the change rule in Fig 8 and 9, indicating that steel pipe started to crack at this point. Therefore, it can be determined that the representative value of steel pipe crack initiation load is 38.5kN.

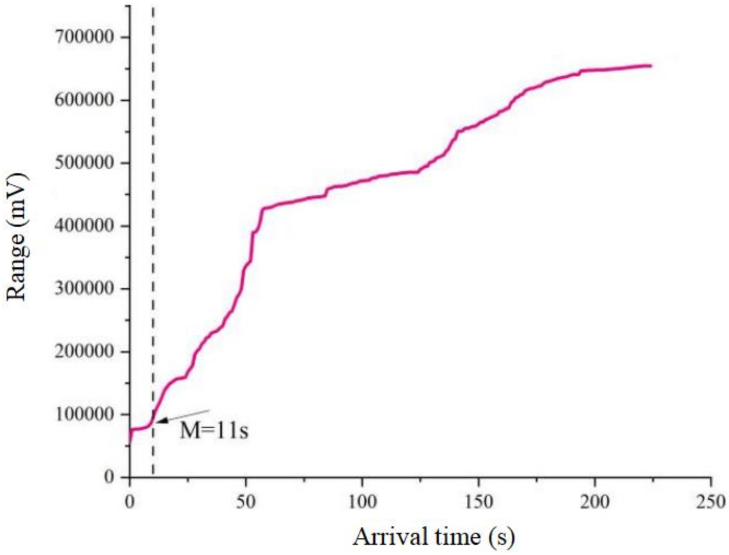

Fig 12: Range-Arrival time

3. CONCLUSION

The axial pressure test was conducted on the corroded steel pipe using acoustic emission technology. And the acoustic emission amplitude and cumulative ring count were studied and analyzed during the loading process of the steel pipe, and the test phenomena and results were summarized, and the following conclusions were obtained.

1. Acoustic emission technology was used to detect pipes. By analyzing the energy and effective voltage values corresponding to different channel numbers, damage conditions in different areas of steel pipes can be distinguished and specific locations of different damage degrees of steel pipes can be detected.
2. By analyzing the acoustic emission parameters, the steel pipe damage process can be divided into three stages: elastic stage, crack initiation stage and crack expansion stage. The exact value of the initiation load P can be determined by studying the acoustic emission signal parameters.
3. Acoustic emission technology can monitor pipeline damage in real time, and measure the crack initiation load of pipeline with accuracy and reliability, which is of great significance to the preventive protection of pipeline transportation

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REFERENCES

1. Fan, J. F., Liu, M., & Zhang, X. C. (2019) Influenc e factors of the corrosion behavior of Q235B steel pipeline. *China Petroleum Machinery*, 47(02), 130-135.
2. Miao, J. M., & Wang, Q. (2013) Study on corrosio n failure risk assessment method for urban buried g as steel pipeline. China Safety Science Journal, 23(07), 49-54.
3. Tian, X. Y. (2012). Study on the factors affecting o il and tubing corrosion of n80 steel pipe used inoilfi

eld. *Science Technology and Engineering*, 12(16), 3962-3964.

4. Nie, Y, T. (2017). Determination of initial fracture toughness of concrete and its application. Journal o f Hebei University of Technology.
5. Zhao, Z. F., Song, L. L., & Zhou, H. G. (2014) Det ermination method of initial cracking load for dam and wet-screenef concrete. *Journal of Zhejiang Uni versity of Technology*, 42(4), 355-358.
6. Huang, D. H., & Song, Y. P. (2000). On relationshi p between initial fracture toughness and fracture to ughness of concrete. *Journal of Hydroelectric Engi neering*, (1), 92-100.
7. Chen, M., Chen, X. Z., & Chen, G. Y. (2018) Ultrasonic wave testing on damage condition of concrete filled steel pipe under axial loading. Journal of Northeastern University (Natural Science), 39(10), 1458-1462.
8. He, X. B. (2017) The research on application of date fusion in steel pipe damage identification system. Ningxia University.
9. Xie, Y., Zhu, Y. D., & Zeng, G. Y. (2010). On testing methods of the amorphous alloy sensor array for steel pipe defects. *Chinese Journal of Scientific Instrument*, 5-8.
10. Jiang, S. F., Xu, P. Y., & Chen, W. (2003) Damage detection methods of concrete filled steel tubular (CFST) structures. *Journal of Harbin Institute of Technology*, 204-04.
11. Liu, F. (2010). Experimental study on damage detection in pipes using ultrasonic guided wave technique. Jinan University.
12. Xiong, L. M., Xing, X. F., & Lin, L. Y. (2020). Effects of high-field-intensity microwave treatment on macroscopic cracks in mongolian scotch pine. *Chinese Journal of Wood Science and Technology*, 34(6), 1-4.
13. Yang, X. J., Que, Z. L., & Sun, Y. F. (2014). Mode-I interlaminar fracture toughness of CFRP reinforced wood composites. *Journal of Northwest Forestry University*, 29(4), 23-28.
14. Wang, G. H. (2020). A review of structural damage localization methods based on acoustic emission technology. *Engineering and Construction*, 34(6), 1115-1118.
15. Tu, J. C., Zhao, D., & Zhao, J. (2020). Experimental study for determining method of cracking load of wooden beams with LT crack. *Journal of Forestry Engineering*, 5(3), 149-154.