

Study on Breakage Cause of Copper Pipe

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Abstract. Copper pipe was widely used in the pipeline of seawater system. Comprehensive characteristics of pipe were analysed. Pressure and velocity were selected as representations of primary static and dynamic characteristics of the pipeline; the breakage reason of water supply pipe was studied through flow field simulation analysis and pipeline metallographic analysis. There was a phenomenon of excessive flow velocity and obvious erosion corrosion in bending pipe; the result showed that erosion corrosion is the direct cause of pipeline breakage. By improving the copper pipe manufacturing press, increasing the pipeline size and bending radius can effectively prevent pipeline damage.

1.Introduction

In order to improve the corrosion resistance of ship pipeline, copper pipe is widely used in the pipeline of seawater system, especially TP2 pipe. As shown in table 1, TP2 pipe has good corrosion resistance. Compared with 316L stainless steel pipe, TP2 has good antifouling performance and prevents sea life growth. Therefore, many systems on board, such as sanitary water system, ballast water system, all use TP2 pipes.

However, when there is a large amount of corrosion in the pipe of the seawater system, the system leakage will cause the ship to fail to operate normally. So the safety of the pipeline is of vital importance.

Table 1 Corrosion rate of different materials in seawater(mm/a)

Material	Flow, continuous oxygen supply	Flow, non-continuous oxygen supply
10#	1.933	1.587
LF21	2.341	1.887
TP2	0.014	0.012
316L	0.013	0.011

In addition to the metallographic results, mechanical properties and surface treatment of copper pipes, the medium environment and water quality conditions of copper pipes are also the main factors influencing corrosion. The corrosion tendency of copper pipe is also different with the water quality of different chemical components.

One of the ships had just sailed when a serious corrosion occurred in the pipeline of its seawater system, resulting in leakage of the pipeline. The leakage pipeline is shown in Fig 1, and the pipeline structure is shown in Fig 2.



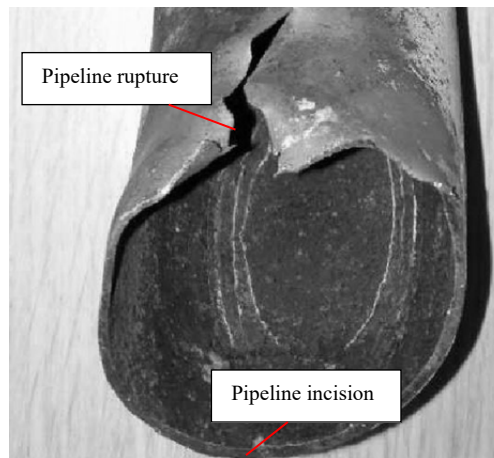


Fig 1 Diagrammatic of leakage pipeline

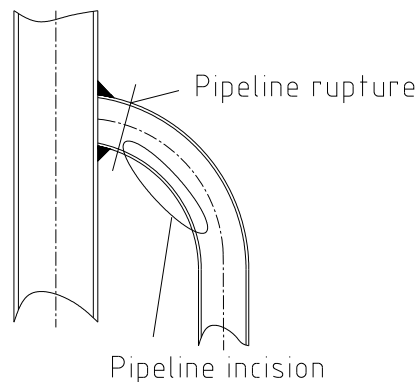


Fig 2 Structure diagrammatic of leakage pipeline

2. Pipeline design

The wall thickness of seawater pipeline is related to the design pressure, pipe outer diameter, pipe material, pipe welding coefficient and other parameters. In general, the wall thickness of pipe material is designed according to formula 1.

$$\delta = \alpha \left(\frac{PD}{2[\sigma]e + [\sigma]} \right) \quad (1)$$

- α was pipe negative tolerance correction factor.
- P was the pipeline design pressure.
- D was the pipe outer diameter.
- $[\sigma]$ was the allowable pipe stress, $[\sigma] = 55(\text{N/mm}^2)$.
- e was the pipe welding coefficient.

When P was 3.0MPa, the pipe outer diameter was 70mm, δ was 1.8mm. 1.8mm was the safe wall thickness of the pipe. Considering the design allowance and corrosion allowance, the design wall thickness was 2.5mm, which meets the design requirements.

Considering the effect of pipe alternating stress, the Coffin formula and fatigue curve F·Langer formula of material is taken as the basis, the formula of fatigue life is derived.

$$N = \left[\frac{E}{4(S_a - \sigma_{-1})} \ln \frac{100}{100 - Z} \right]^2 \quad (2)$$

- S_a was the virtual stress amplitude.
- E was the elastic modulus of material.
- Z was the percentage reduction of area.

- σ_{-1} was the ultimate fatigue strength of the material.
- N was the number of cycles before destruction.

The cycles of TP2 pipe under pressure of 0~3MPa are 10573 times, which meet the requirements of alternating pressure.

3. Analysis

The meshes of the whole computational domain were divided by ANSYS ICEM software. The meshes were unstructured tetrahedron meshes. The single layer meshes on the wall were controlled between of 30-300. The unsteady simulation of the unstructured meshes mentioned above was carried out by CFD software Fluent. The boundary adjustment of the pipe wall was set as the wall boundary condition. As seen in Fig 3.

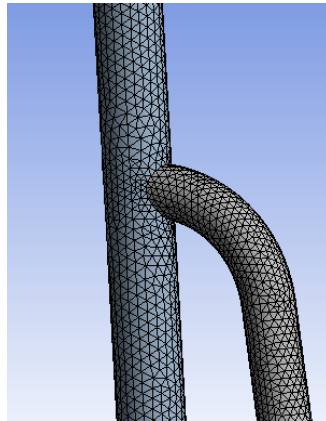


Fig 3 Schematic mesh diagram of water supply pipe

3.1 Flowrate characteristic analysis

Pressure and velocity were selected as representations of primary static and dynamic characteristics of the pipeline. A 3MPa pressure difference between the two sides of the pipeline was given as the original input, Fig 4~Fig 5 were different performances of pressure and velocity when the same simulation condition.

3.1.1 Influences by pressure

The rated different pressure 3MPa was given between the two sides of the pipeline. The trends of pressure are almost consistent in the elbow area. It is shown that the pressure concentration of the pipeline is mainly on the in-charge road, and there is no obvious stress concentration on the inside of the bend. As seen in Fig 4.

Considering that there is not much difference in pressure in different places, the pressure in the pipeline is even, there is no obvious stress concentration at the bend. Therefore, stress is not the cause of pipeline damage.

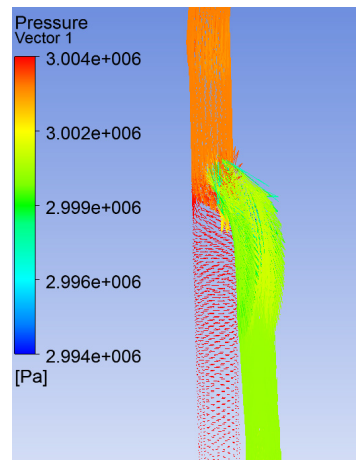


Fig 4 Diagrammatic of pipeline pressure vector

3.1.2 Influences by velocity

Fig 5 shows the flow velocity cloud diagram of the pipe. The maximum velocity of flow in the pipe is concentrated on the inside of the bend, and the maximum velocity is 3.257m/s. The velocity distribution of pipeline is very different.

Considering that the flow rate is too high to cause erosion and corrosion of the pipe, the local velocity concentration of the bent may probably lead to the breakage of the pipe.

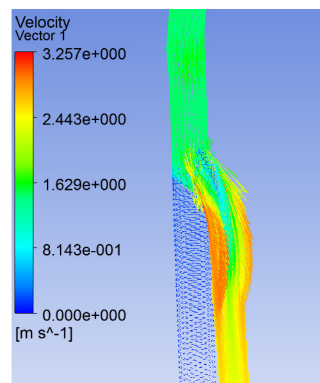


Fig 5 Diagrammatic of pipeline velocity vector

3.2 Metallographic Analysis

3.2.1 SEM Analysis

1) Appearance of fracture

The pipeline fracture was analyzed by scanning electron microscope (SEM). The SEM analysis showed that some of the fractures surfaced were badly worn, and some of the fractures were simple characteristics. The energy spectrum of the region is shown in Fig 6, which mainly contains C, O and Cu, and it also contains corrosive elements such as S and Cl.

Fig 7 shows the diagrammatic of pipeline fracture energy spectrum. The chemical composition analysis results are shown in table 2. The chemical composition of pipeline fracture meets the standard requirements. Therefore, the damage of pipeline is not caused by uneven material composition.

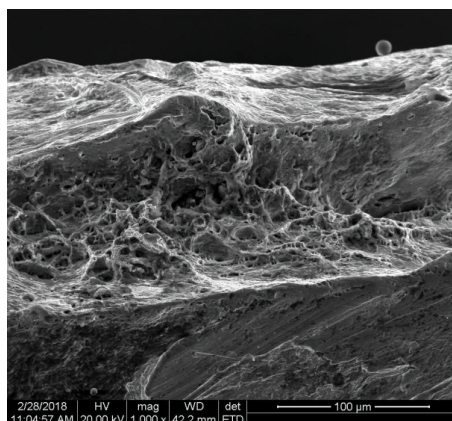


Fig 6 Diagrammatic of pipeline fracture topography

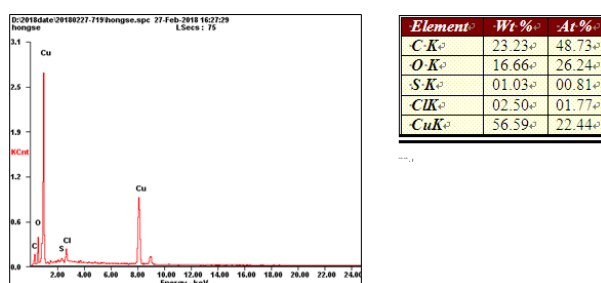


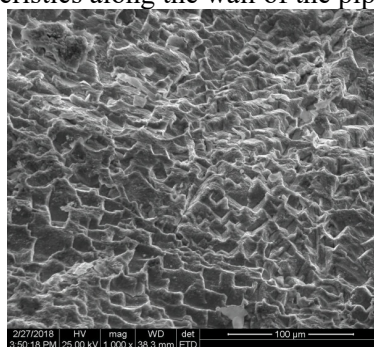
Fig 7 Diagrammatic of pipeline fracture energy spectrum

Table 2 Chemical composition analysis results(Wt%)

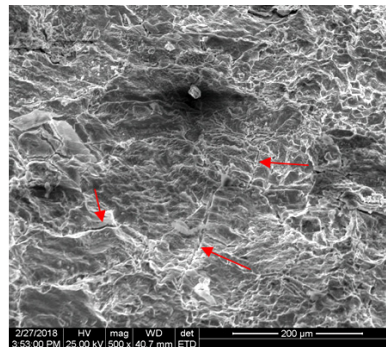
Chemical content	Cu+Ag	P
Exemplar pipeline	99.96	0.040
Standard request	≥99.9	0.015~0.0414

2) Normal inner wall appearance

The pipe wall at the undamaged place was analyzed by scanning electron microscope, as shown in Fig 8. Fig 8 a) shows that the obvious corrosion pit characteristics on the surface of the pipe, and Fig 8 b) shows that the corrosion characteristics along the wall of the pipe along the crystal.



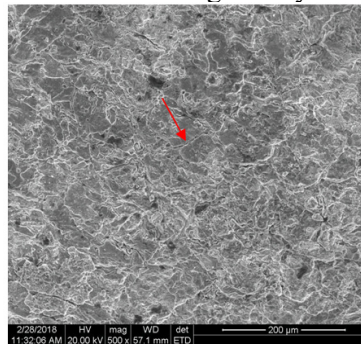
a)



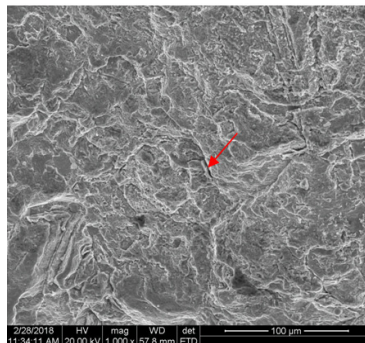
b)

Fig 8 Pipeline inner wall topography

When the inner wall is enlarged, as shown in Fig 9, the obvious corrosion crack characteristics along the crystal can be seen, and there is also corrosion on the surface of the grain. Even if the normal inner wall appearance, there is obvious corrosion along the crystal.



a)



b)

Fig 9 Enlarged profile of pipeline inner wall

3) The appearance of the inner wall of the damaged part

As shown in Fig 10, the characteristics of parallel stripes and corrosion pits can be observed by observing the inner wall of the pipe wall of the damaged part. Pipeline corrosion is probably the cause of pipeline damage.

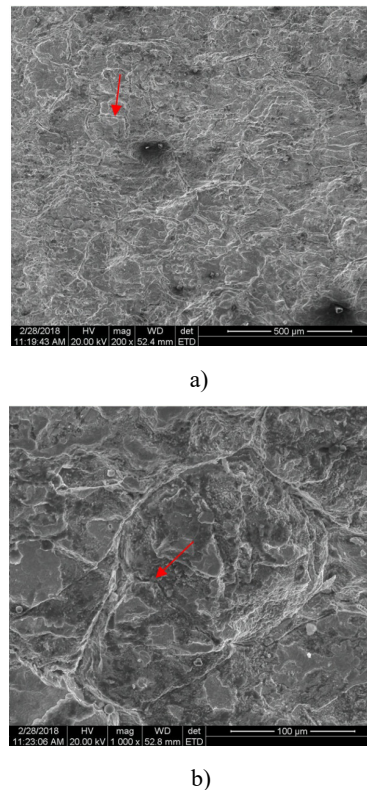


Fig 10 Enlarged profile of pipeline inner wall

3.2.2 Metallographic Analysis

The microstructure of the region larger than the thickness of 2mm is twinning α , the outer wall is straight and the inner wall is uneven, has corrosion characteristics. As shown in Fig 11. The microstructure of the thinned area is twinning α , the outer wall is also straight and the inner wall is uneven, has corrosion characteristics. As shown in Fig 12. The thickness of the wall near the fracture surface is the most obvious. The microstructure structure is twinning α . The grain is coarse and the outer wall is straight, has corrosion characteristics. As shown in Fig 13. The deformation at the fracture surface is obvious, the grain is elongated and there is a slip line.

There is no obvious abnormality in the ectotheca section. The inner wall is thinned. The thinnest part of the fissure is about 0.5mm. The rupture is characterized by deformation. The microstructure is dimpled. Therefore, the failure of pipe section belongs to the plastic fracture caused by wall thickness thinning.

The pipe is supplied with seawater, and the inner wall of the pipe contains corrosive elements such as S and Cl. The characteristics between the normal inner wall appearance and the appearance of the inner wall of the damaged part are basically the same. Both the intergranular corrosion characteristics are obvious and the inner grain is also corroded. So the thinning is caused by corrosion, and the thinning is most obvious at the rupture.

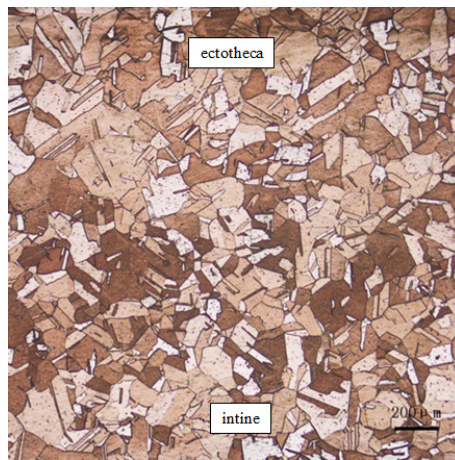


Fig 11 Thick wall tissue(50×)

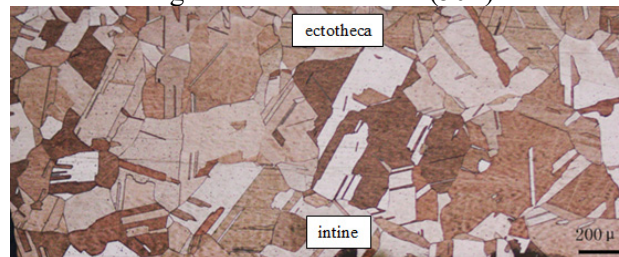


Fig 12 Thinning regional wall tissue(50×)



Fig 13 Thinning regional wall tissue(10×)

The corrosion thinning of the inner wall is located on the inner side of the curved section of the bend pipe, which is characterized by gradual thinning, and is located on the surface of facing the water. It is also a place where the direction of the flow changes, and there are more complicated flow fields such as turbulence. This caused the area to be scoured more than any other part of the seawater. The results of flow field simulation are consistent with those mentioned above.

The microscopic characteristics of erosion corrosion of copper pipes are generally obvious, which is consistent with the metallographic analysis of intergranular corrosion. Therefore, erosion corrosion is the direct cause of pipeline breakage.

3.3 Improvement measure

In the design of pipes, the diameter and bending radius of the pipe should be increased as much as possible, the concentration of velocity at the bend should be reduced as much as possible, and the erosion corrosion should be alleviated.

4. Conclusions

Generally some understandings are obtained for analysing of the pipe.

- It is recommended to enlarge the diameter of pipeline.

- It is recommended to enlarge the bending radius.
 - The chemical composition and structure uniformity of the pipeline are very important to the corrosion resistance of the pipeline.
 - The pressure of control system can reduce the stress of the pipeline and increase the service life of the pipe.
- Some experimental work was carried out and the conclusions above were well verified.

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