Fracture analysis for reasons of bellows with braided hose

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Abstract. The fracture of metal braided hose around bellows were found in working condition. Then, the macroscopic analysis, fracture analysis, metallographic analysis and chemical composition analysis were performed separately by using Scanning Electron Microscope (SEM), Energy Dispersive Spectrometer (EDS) and other equipment. The causes of the damage in the braided hose are studied in this paper. The results show that the pitting corrosion and stress corrosion caused by chloride ion are the major factors of wire breakage. In follow, the preventive measures for such accidents for this fracture accidents are put forward.

1. Introduction
Metal bellows have been used in vary diameter transfer systems to dissipate and absorb vibration that would coursing damages to rigid equipment [1]. Due to flexibility without high bending loads, the bellows often have as thinner wall thickness as possible, this makes the bellows vulnerable to external physical force like it striking the sharp corner of a solid structure or a tool striking the bellows. However, surrounding the bellows with a braided, flex metal hoses can provide protection against that disadvantages [2]. Widely application of bellows with braided hoses made of austenitic stainless steel showing that, under circumstances involving complicated external forces, high stresses, high operating temperature and strong corrosive medium, it often fails and causes large losses [3-4]. most of failure forms are stress corrosion, pitting and intergranular corrosion among which about 80% are stress corrosion caused by Cl- [5-7].

16 bellows with braided hoses had been used in hydraulic oil transfer system among which 7 bellows were observed distinguish damages occurred. This paper analyzed the damaged bellows by using metallographic microscope, scanning electron microscope (SEM) and energy spectrum analyzer (EDS). Finally, the reasons of damages were determined, and the causes of damages were discussed, which can provide an important reference to prevent damages of these bellows.

2. Materials and methods
2.1. Macroscopic analysis
According to damage appearance, we classified these damaged bellows as partly broken in the middle area of the hose and wholly broken of the hose. The typical sample of former has a scattered fracture whose wires of outer hose had been pulled out partially (shown in Figure 1), while the typical sample of latter has a relatively neat fracture whose wires of outer hose had been pulled out completely (shown in Figure 2). Due to the loss of restriction imposed by outer hose, distinguish bending deformation occurred on the bellows of both broken types of which the wholly broken hose one has more severe bending. Reddish brown rust has been observed on hoses of both types.
2.2. Microscopic analysis
When the fracture surface of these broken hoses was observed under SEM, it was found that the surface morphology and fracture morphology of each hose wire are similar. We can see lots of obvious rust layer covered on the surface of the hose as shown in Figure 3. After cleaning with descaling solution, the covered rust disappeared, and the surface of the hose became clean with rough pits on (shown in Figure 4).

2.3. Chemical composition analysis
Analyzing chemical composition of this rust by EDS, energy spectrum as shown in Figure 5. We can see that besides the main elements Fe, Cr and Ni, O (19.05%) and Cl (5.27%) and other elements were found. It means that the corrosive oxide related to chlorine occurred on the hose.
to get a better corrosion resistance, we can take hose made of 0Cr18Ni9 into account instead of that made of 1Cr18Ni9.

Table 1. Chemical compositions comparison (wt.%).

| Object | C   | S    | P    | Cr   | Ni   | Ti | Mn | Si | Cu | Mo |
|--------|-----|------|------|------|------|----|----|----|----|----|
| Sample 1 | 0.12 | 0.021 | 0.027 | 16.94 | 7.92 | 0.01 | 1.31 | 0.53 | 0.39 | 0.2 |
| Sample 2 | 0.12 | 0.02 | 0.026 | 17.23 | 8.04 | 0.01 | 1.37 | 0.53 | 0.39 | 0.2 |
| 1Cr18Ni9 | ≤0.15 | ≤0.03 | ≤0.045 | 17-19 | 8.0-10.0 | / | ≤2.00 | ≤1.00 | / | / |
| 0Cr18Ni9 | ≤0.08 | ≤0.03 | ≤0.045 | 17-19 | 8.0-11.0 | / | ≤2.00 | ≤1.00 | / | / |

2.4. Metallographic analysis
Metallographic analysis was performed on the sample of fractured hose, and many branch-like cracks were found on the cross section of wire, which are branched from the surface into the inside (see Figure 6). This is a typical characteristic crack of austenitic stainless steel under chloridoid environment. It can be seen from the figure that the crack originated from the corrosion pit on the surface and developed into the inside of the wire. From the Figure 7 we can see that the composition of the hose is austenite, granular carbide and a small amount of ferrite.

![Figure 6. Crack branch path of fractured hose.](image1)

![Figure 7. Metallographic analysis of hose.](image2)

2.5. Fractography analysis
It is found that there are three types of fracture after the fractography analysis of the wire with SEM: oblique fracture plane, flat fracture plane and necking fracture.

Oblique fracture plane is shown in Figure 8, there are some white products covering on the one side of the fracture plane which similar to the rust layered covered on the surface of the hose. Analyzed chemical composition of this products by EDS, we found that besides the main component element Fe, Cr and Ni, it also contains elements such as O and Cl, indicating that it is a corrosion product of chlorine. The other side of the fracture plane appeared as dimpling fracture surface (shown in Figure 9). The fracture process of oblique fracture plane consists of two parts, in the beginning the crack growth slowly causing effective bearing area decrease, and then to a critical point that rest part of materials unable to bear load, the hose suddenly breaks, in which plastic deformation is usually involved.

Flat fracture plane is shown in Figure 10, There are no obvious deformation and shrinkage on the periphery, which means that the wire breaks suddenly. The fracture surface was covered with more corrosion products, and the fracture pattern can be seen in some areas (the lower left edge of the wire) as shown in Figure 11. Flat fracture plane means suddenly fracture occurred in the process of fracture.

Necking fracture is shown in Figure 12, there are obvious even shrinkage around the periphery of the fracture surface, also with various degrees of scratch around the periphery. It can be seen that the periphery of the wire is dimple fracture, as shown in Figure 13, which means plastic strain emerged in the process of fracture.
3. Discussions

The bellows has little stiffness in the axial direction, causing axial elongation when subject to internal pressure. The hose is the main part bearing tension of the bellows installed in the pressure pipe, and at the same time hose acts as a sheath for the bellows. Bellows reinforced with hose can provide easily bending and deformation to compensate the thermal expansion of the pipe system. Due to the loss or partly loss of reinforcement provided by hose, the bellows spring off instantly, and twisted or deformed.

According to the fractography analysis of the hose, there are mainly three morphological characteristics of the fracture: oblique fracture plane, flat fracture plane and necking fracture. These fractures usually mean tensile fracture behavior. From the oblique and flat fracture plane, we found that there are white corrosion products and corrosion patterns on the fracture surface, and there are also a large number of white corrosion products on the surface of the hose. Chemical analysis results showed that corrosion products mainly contain O and Cl. It means that, firstly, the chloride ion in the environment causes pitting corrosion and stress corrosion on the surface of hose, then breakage occurs.
in the wire of the hose, resulting in reduction in the effective load-bearing area of the hose wire, when load-bearing area is small enough to withstand tension that come from the internal pressure of the pipe system, the hose breaks down and the bellows twisted or deformed.

Observed the bellows where the fracture did not happen under SEM, it found that although the metal hose did not break, there were already a lot of corrosion products and micro cracks in the hose. These micro cracks could further expand and eventually cause the metal hose to crack as time go on. Although at present only one hose breaks on one device, pitting corrosion and stress corrosion fractures caused by atmospheric ions cannot be avoided, and this problem is bound to occur in other hoses over time. In order to eliminate these risks, we should inspect the bellows periodically, replace the defective bellows in time, and pay attention to the treatment of the environment around the bellows or cover anti-corrosion coat on hose to reduce the possibility of corrosion.

Metallographic analysis showed that no metallurgical defects, such as inclusions and segregation, were observed in the hose wire itself. Chemical composition analysis showed that the material of the hose is 1Cr18Ni9. For the purpose of improving the corrosion resistance without changing other properties, we can choose hose made of 0Cr18Ni9 to reinforce bellows instead of that made of 1Cr18Ni9, for the reason of that steel have better corrosion resistance.

4. Conclusions
Failure of the bellows due to pitting corrosion occurred on the surface of braided hose, causing reduction of effective load-bearing area of the hose wire. When tension along axial direction of the bellows exceeds the limit of the effective load-bearing area of the hose wire, the wire broken gradually and have developing three fracture morphology, oblique fracture plane, flat fracture plane and necking fracture.

To prevent devastating failure of bellows, we suggest:
(1) Choose hose made of 0Cr18Ni9 to reinforce bellows instead of that made of 1Cr18Ni9, which could increase carbon content of material of hose without changing other properties, for the reason of that steel have better corrosion resistance with more carbon content.
(2) Inspect the bellows periodically, and replace the metal hoses in time when there is a small amount of breakage in the bellows to avoid failures.
(3) Improve the environment of bellows installed or to cover surface of the hose with anti-corrosion coat to prevent pitting corrosion occurs.

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