Failure Analysis of Butane Spherical Tank Flange Cover Crack

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Abstract: In response to the crack failure phenomenon of the lower flange cover of a butane spherical tank in a certain petrochemical company, the failure reason was analyzed through macroscopic observation, material analysis, scanning electron microscopy analysis, metallographic test analysis, impact test analysis, etc. The results show that the fillet weld of the flange cover is a stress concentration area, and after a period of use, the internal stress gradually releases. In addition, the internal dislocations in the grains gather, causing cracks to initiate from within the grains and gradually delay the occurrence of cracks, leading to brittle fracture failure of the flange cover.

1 Introduction

Steel spherical storage tanks are spherical pressure bearing metal containers that hold gases with high pressure or liquefied gases, most of which are flammable and explosive media with high risk. There are four 2000 cubic meter spherical tanks in the mixed butane tank farm of a certain petrochemical company, which were put into use in 2017 and are mainly used to store mixed butane and isobutane. The main corrosion types of butane spherical tank include wet hydrogen sulfide damage, sulfide stress corrosion cracking, atmospheric corrosion, vibration fatigue, etc.

In June 2021, one of the spherical tanks experienced crack failure in the lower flange cover. At present, there are many cases and articles about the cracking failure of the LPG spherical tank body, and most of the literatures have concluded that the failure mechanism of the spherical tank is sulfide stress corrosion cracking through failure analysis. However, because the spherical tank is generally in use, the cracks are polished and eliminated, and no sampling analysis is carried out. However, there are few penetrating cracks on the flange of this type of spherical tank. This article analyzes the failure reasons of the lower flange of the butane spherical tank through a series of experiments, and identifies the failure reasons of the equipment flange, providing suggestions and basis for the safe use of this type of equipment in the future.

2 Material & Methods

The main information and technical parameters of the spherical tank with flange cover failure are shown in Table 1:

<table>
<thead>
<tr>
<th>Product name</th>
<th>Butane spherical tank</th>
</tr>
</thead>
<tbody>
<tr>
<td>Design pressure</td>
<td>2.16MPa</td>
</tr>
<tr>
<td>Design temperature</td>
<td>50/-19℃</td>
</tr>
<tr>
<td>Working medium</td>
<td>butane</td>
</tr>
<tr>
<td>Design date</td>
<td>2015-10-16</td>
</tr>
</tbody>
</table>

In response to the crack failure phenomenon of the lower flange cover of the butane spherical tank, this article analyzed the cause of the failure through macroscopic observation, material analysis, scanning electron microscopy analysis, metallographic test analysis, impact test analysis, etc.

From the macro view of the flange cover in Figure 1 can be found: there are cracks on the inside and outside of the flange cover, the nozzle fillet weld has been cracked, the crack in the inner part of the flange cover extends to the edge of the flange cover, flange cover outside has extended trend.

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3 Results & Discussion

3.1 Material analysis

The chemical composition of the sample was analyzed and tested, determine whether the material of flange cover is normal. The chemical composition test results are shown in Table 2, and (Carbon Ang Low-alloy Steel Forgings For Pressure Vessels) points out the composition of 20MnMo in the standard as a comparison of the chemical composition of the material [1-3].

From the chemical composition test results in Table 2, the chemical composition of flange cover conforms to the regulations of JB4726-2000.

<table>
<thead>
<tr>
<th>Analysis item</th>
<th>Mass fraction (wt%)</th>
<th>The standard requires a quality score (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>C, %</td>
<td>0.188</td>
<td>0.17~0.23</td>
</tr>
<tr>
<td>Si, %</td>
<td>0.248</td>
<td>0.17~0.37</td>
</tr>
<tr>
<td>Mn, %</td>
<td>1.269</td>
<td>1.10~1.40</td>
</tr>
<tr>
<td>P, %</td>
<td>0.0087</td>
<td>≤0.025</td>
</tr>
<tr>
<td>S, %</td>
<td>0.0095</td>
<td>≤0.015</td>
</tr>
<tr>
<td>Cr, %</td>
<td>0.208</td>
<td>≤0.30</td>
</tr>
<tr>
<td>Ni, %</td>
<td>0.135</td>
<td>≤0.30</td>
</tr>
<tr>
<td>Mo, %</td>
<td>0.217</td>
<td>0.20~0.35</td>
</tr>
<tr>
<td>Cu, %</td>
<td>0.182</td>
<td>≤0.25</td>
</tr>
</tbody>
</table>

3.2 Scanning electron microscope analysis

Electron microscope sample was cut at the crack site of flange cover for electron microscope test, the cutting position is shown in Figure 2, the head end of the crack extension direction inside the flange cover was sampled for analysis.

After taking the sample, the extended crack surface of the failure site is opened, as shown in Figure 3.

Electron microscope test was carried out on the red region of the sample section, as shown in Figure 4.

According to the test results of electron microscope, Figure 5 a) and b) are the electron microscope test images in the red area on the left. Figure 6 shows the area on the right.

The area in the yellow box in Figure 5 b) is the area that has not been corroded or oxidized. The fracture morphology is cleavage tongue and river pattern. In Figure 5 a), the red area is the corrosion and oxidation product after crack opening, the more regional corrosion and oxidation products that first fractured, basically cover the fracture morphology.
According to the results of electron microscope test, the morphology of the fracture is consistent with the cleavage fracture characteristics, brittle fracture\(^{4-6}\).  

### 3.3 Metallographic test analysis

![Metallographic test photos](image)

**Figure 7** a) shows the morphology of the original tissue. Figure 7 b) is a metallographic photograph of the crack. According to the results of metallographic test, the crack directly passes through the grain and causes fracture failure, it is a transgranular fracture\(^{7-8}\).

### 3.4 Impact test analysis

The results of the impact test showed that, the standard impact energy of 20MnMo at 10\(^\circ\)C is 34J.  

The spherical can is at room temperature in working condition, under the condition of 3\(^\circ\)C for a short time when stopping and returning materials, from the impact test, the impact energy difference is small\(^{9}\).

### 4 Conclusion

The fillet weld of the flange cover is a stress concentration area, and after a period of use, the internal stress gradually releases. In addition, the internal...
dislocations in the grains gather, causing cracks to initiate from within the grains and gradually delay the occurrence of cracks, leading to brittle fracture failure of the flange cover. According to the above test analysis results, comprehensive analysis of flange cover failure reasons, the following conclusions are drawn:

1. The material of flange cover meets the standard.
2. The failure form of the equipment is transgranular brittle fracture.
3. It is presumed to be delayed welding crack of flange cover initiation, long service in high stress areas, eventually causing it to crack.

The equipment flanges in pressure vessels are the core components of the equipment. During the manufacturing process, welding residual stress should be eliminated in a timely manner through heat treatment and other means. During the regular inspection process of pressure vessels, macroscopic inspection and surface defect detection of such components should be strengthened, and metallographic testing should be supplemented for suspicious components that have problems during the inspection process to avoid situations similar to flange cracking and ensure the safe operation of the device.

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