Corrosion failure analysis of A L80 oil tube thread

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Abstract. Material properties of L80 oil tube thread were tested by means of chemical composition analysis, hardness testing and metallographic examination. The results showed that the content of chemical compositions and HRC value accorded to API SPEC 5CT requirements. Micro-morphology and corrosion production analysis of inner surface were carried out by SEM, EDS and XRD. The results showed that the corrosion products on thread were dense and mainly consisted of FeCO₃, but there were a large number of microcracks and micropores in it. The main reason of corrosion for thread sample was crevice corrosion which originated from the infiltration of corrosive medium such as high salinity formation water and CO₂ to thread joint.

1. Introduction
Tubes of an oil well began to leak only after six months of use. The specification of these tubes was Φ88.9mm×6.45mm and steel level was L80. All these tubes had not been used before. Through field inspection, it was found that multiple threaded joints were seriously corroded. In order to analyze the corrosion reason of the threaded joints, a sample which was corroded most seriously was taken to lab for failure analysis.

The position of the sample was 400m above the pump outlet top, where the depth was 2640m, the temperature was 83℃, the pressure was 26MPa and the medium was oil containing water. The depth of this well was 3283.9m, normal production was 5,000 barrels/day, content of water was 18.5%, and the volume content of CO₂ was about 1.58%.

2. Experimental methods

2.1 Macro-morphology
Macro-morphology analysis was carried out by observing the corrosion location and macroscopic features, and recorded using a digital camera.

2.2 Metallographic Analysis
Metallurgical structure, grain size and nonmetallic inclusions analysis were carried out according to GB/T 13298, ASTM E45, ASTM E112 respectively. The corrosion pits and cracks on inside and outside surface of specimens were observed at the same time.

2.3 Chemical compositions analysis
Chemical compositions analysis was carried out according to ASTM A751.
2.4 Hardness Testing
HRC testing was carried out according to ASTM E18

2.5 Micro-morphology and corrosion products analysis
Micro-morphology and corrosion production of failure location were analyzed by SEM and EDS, XRD respectively.

2.6 Simulation experiment in laboratory
Simulation experiment was carried out in autoclave to evaluate the corrosion performance of L80 oil tube in on-site environment. The experiment conditions were shown in table 1.

| condition | Temperature (℃) | Content of CO₂ (%) | Total pressure (MPa) | Duration (h) | concentration of Cl⁻ (mg/L) |
|-----------|-----------------|---------------------|----------------------|--------------|-----------------------------|
| value     | 83              | 1.58                | 26                   | 360          | 160844                      |

The static corrosion test was carried out using an autoclave. Before test, the surface of the specimens was polished with grit silicon carbide papers progressively up to 800 grades, then degreased with acetone and rinsed with absolute alcohol, weighted using a precision of 0.1mg, and finally stored in desiccators for use. The simulated test conditions including Cl⁻ concentrations, CO₂ partial pressure, temperature were in accordance with the on-site condition shown in table 1. The solution was deoxygenated by pure nitrogen for 10 hrs. Then, the system was given required the partial pressure of CO₂ and temperature. The total pressure is 26MPa, which was achieved by adding nitrogen. After the test, the corrosion specimens were removed from the autoclave and rinsed with deionized water. Then, the specimens were descaled, rinsed with water and absolute alcohol, dried in nature state and weighted again using a precision of 0.1mg. The corrosion rate was represented by corrosion depth (mm)/corrosion time (per year), i.e. mm/y.

3. Results and discussion

3.1 Macro-morphology
Figure 1 showed that the external thread sample was corroded extremely seriously. The original thread had basically been corroded and could not be made out already. There were obvious corrosion products on eternal thread surface, which intergraded with the matrix very well and could not be peeled off easily.

![Macro-morphology of external thread sample](image)

Figure 1  Macro-morphology of external thread sample

3.2 Metallographic Analysis
Section macro-morphologies of the specimens were shown in Figure 2, which indicated that the inner surface and tube of thread sample were corroded lightly. Figure 2 also showed that the thickness of tube wall which was at the end of the thread was basically not thinned.

Figure 2  Section macro-morphology of specimen (a. tube; b. thread)

Nonmetallic inclusions, metallurgical structure and grain size analysis results were shown in Table 2. The corrosion pits and cracks on inside and outside surface of specimens analysis results were shown in Figure 3 to Figure 4. Corrosion existed on inside, outside and end surface and metallurgical structure around corrosion pits was tempered sorbite. The corrosion pits on external thread surface were deep and there were plenty of cracks at the bottom of it. The inner surface and end surface were corroded lightly and uniformly. Metallurgical structure around local corrosion pits was deformation.

Table 2  Nonmetallic inclusions, metallurgical structure and grain size analysis results

| nonmetallic inclusions | A | B | C | D | metallurgical structure | grain size |
|------------------------|---|---|---|---|--------------------------|-----------|
| thin thick             | 1.0 | 0 | 1.0 | 0 | 0 | 0 | 0.5 | 0 | tempered sorbite | 8.5 level |

Figure 3  Corrosion pits of specimen (a. inner surface; b. outer surface)

Figure 4  Metallurgical structure around corrosion pits (a. inner surface; b. outer surface)
3.3 Chemical compositions analysis
The Chemical compositions analysis result was shown in Table 3, which accorded to API SPEC 5CT requirement.

|         | C   | Si  | Mn  | P   | S   | Cr  | Mo  | Ni  | Cu  |
|---------|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| thread  | 0.17| 0.33| 1.14| 0.018| 0.014| 0.26| 0.021| 0.12| 0.26|
| API SPEC 5CT requirement | ≤ 0.43 | ≤ 0.45 | ≤ 1.9 | ≤ 0.03 | ≤ 0.03 | ≤ 0.25 | ≤ 0.35 |

3.4 Hardness Testing
The hardness testing result was shown in Table 4, which accorded to API SPEC 5CT requirement.

| sample      | HRC value  | API SPEC 5CT requirement |
|-------------|------------|--------------------------|
| thread      | 18.0, 18.5, 19.0 | ≤23                      |

3.5 Micro-morphology and corrosion products analysis
Micro-morphologies analysis results of corrosion surface were shown in Figure 6. The corrosion product on thread was dense, but there were a large number of microcracks and micropores in it.
Elements analysis of corrosion product were carried out by EDS. The results were shown in Table 5, indicating that the main elements of corrosion product on external thread surface were Fe, C, and O.

| Element | C  | O   | Na  | Mg  | Ca  | Fe  | Total |
|---------|----|-----|-----|-----|-----|-----|-------|
| Weight% | 8.80 | 46.68 | 1.17 | 1.74 | 7.27 | 34.34 | 100.00 |
| Atomic% | 16.04 | 63.86 | 1.11 | 1.56 | 3.97 | 13.46 | 100.00 |

To identify the phased formed on samples after corrosion, the specimens surfaces were analyzed by X-ray diffraction. Combined with EDS analysis results, the XRD spectra was demarcated. The results in Figure 7 showed strong peaks for FeCO₃, indicating that FeCO₃ was the main corrosion product.

![XRD spectrum of external thread surface](image)

**Figure 7** XRD spectrum of external thread surface

### 3.6 Simulation experiment

Simulation experiment was carried out according to table 1. Corrosion rate was calculated by the weight-loss. The results were shown in table 6. The average corrosion rate of specimens were 0.0853mm/a. The specimens exhibited uniform corrosion and there was no pitting corrosion on surface.

| material | average corrosion rate (mm/a) | surface morphology |
|----------|------------------------------|--------------------|
| L80      | 0.0853                       | uniform corrosion  |

### 3.7 Comprehensive Analysis of Corrosion

The analysis results of EDS and XRD showed that the main corrosion product on thread was FeCO₃, indicating that the thread had suffered CO₂ corrosion[1-4].

CO₂ corrosion is also hydrogen depolarization corrosion process. H⁺ is deoxidized to H atom first at inclusions, grain boundaries, etc.. Then these H atoms gather into hydrogen. The mechanism of CO₂ corrosion is:

\[
CO_2 + H_2O \rightarrow H_2CO_3 \\
H_2CO_3 \rightarrow H^+ + HCO_3^- 
\]
\[ \text{HCO}_3^- \rightarrow \text{H}^+ + \text{CO}_3^{2-} \]
\[ 2\text{H}^+ + \text{Fe} \rightarrow \text{Fe}^{2+} + \text{H}_2 \]
\[ \text{Fe}^{2+} + \text{CO}_3^{2-} \rightarrow \text{FeCO}_3 \]

The overall reaction equation is:
\[ \text{CO}_2 + \text{H}_2\text{O} + \text{Fe} = \text{FeCO}_3 + \text{H}_2 \]

Thread corrosion was the main feature of thread sample. The original thread had basically been eroded and could not be made out already. But the inner surface and tube of thread sample corroded lightly. The original wall thickness of 6.45mm had been thinned to 3~4mm, which was much higher than the experimental result. Accordingly, the main reason of corrosion for thread sample was crevice corrosion which originated from the infiltration of corrosive medium such as high salinity formation water and \( \text{CO}_2 \) to thread joint.

Crevice corrosion occurs in narrow gap where electrolyte solution exists\(^5\). The gap can be between metal and metal or metal and nonmetal. Crevice corrosion is a form of localized corrosion which is caused by obstruction of medium migration.

The corrosion process involves two stages: (1) inside and outside gap of metal surface take place the same anodic and cathodic reactions; (2) as the reactions going on, corrosion medium inside gap is gradually consumed, while medium outside the gap diffuses slowly to inside. So medium concentration difference between inside and outside increases, which induces the formation of concentration difference cell. The outside forms cathode because of sufficient supply of medium, while the inside forms anode. Metal inside the gap corrodes more quickly, while metal outside the gap is protected.

**4. Conclusions**

Physical and chemical properties were carried out according to relevant standards, the results showed that the content of chemical compositions and HRC value accorded to API SPEC 5CT requirements.

The thread samples had suffered \( \text{CO}_2 \) corrosion. The main reason of corrosion for thread sample was crevice corrosion which originated from the infiltration of corrosive medium such as high salinity formation water and \( \text{CO}_2 \) to thread joint.

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