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Analysis on the Failure Causes of the Collapsed Tubing in an Oil Well

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Abstract

Due to the influence of multiple factors such as internal and external formation and mechanical pressure, medium corrosion and construction operation environment, a tubing collapse failure occurred in an oil well. In order to determine the failure cause of the tubing, physical and chemical tests and mechanical properties analysis were carried out on the failed tubing sample and the intact tubing. The results show that the chemical composition, ultrasonic and magnetic particle inspection, metallographic test, Charpy impact energy and external pressure mechanical property test of the failed tubing all meet the requirements of API Spec 5CT-2021 standard, but the yield strength of the failed tubing does not meet the requirements of API Spec 5CT-2021 standard. Through the analysis of the working conditions, it can be seen that the anti-extrusion strength of the tubing collapse does not meet the API 5C3 anti-extrusion strength standard. The failure type of the well tubing is tubing collapse caused by large internal and external pressure difference.

Keywords

Tubing, Failure Analysis, Collapse, Complex Working Conditions

1. Introduction

Tubing is the main equipment in the development and production of oil and gas fields. It is the second largest type of oil pipe after tubing and casing. After the tubing is put into the wellbore, it can complete a variety of downhole operations such as acid fracturing, fracturing and production [1], which is widely used in the development of oil and gas fields. During the service period, the tubing should not only bear complex alternating loads, but also be affected by the corrosion of various media in the working environment [2]. Affected by complex loads and harsh working environment, tubing is prone to corrosion, fracture and other failures. In recent years, relevant scholars at home and abroad have carried out relevant research on the failure of tubing. Li Meng [3] established a finite element model of tubing with defects to study the influence of different load conditions on tubing failure. M. Javidi [4] conducted a comparative analysis of the chemical composition, mechanical strength, charpy impact and microstructure of the intact tubing and the failed tubing. Ghadeer Mubarak [5] used optical microscopy, X-ray diffraction (XRD), combined with weight loss and characterization methods to study the failed tubing. Al-Jaroudi, SS [6] was used for metallographic evaluation of the tubing, and the corrosion products were identified by photometric and potential analysis combined with X-ray diffraction.

With the deep development of oil and gas resources, the working conditions of oil and gas wells are becoming increasingly harsh and complex, and tubing failure accidents occur frequently. Once a failure occurs, it may cause casualties, environmental pollution, waste wells, stop drilling, and drop wells. It not only causes huge economic losses, but also seriously endangers public safety and social stability [7] [8]. Therefore, this paper takes an oil well as an example to study the failure mechanism of tubing. Firstly, the working conditions of the failed tubing are analyzed. Secondly, the physical and chemical tests and mechanical properties of the failed tubing and the intact tubing are tested and compared. Then determine the cause of tubing collapse failure, which can prevent the occurrence of collapse tubing failure accidents.

2. Overview of Collapse Failure

The drilling depth of an oil well is 6750 m, and the lining pipe body is TP110SS type oil pipe. The type of oil pipe is Φ88.90 × 12.90 mm. The depth at which the tubing string collapse occurred is 4252.33 m, and the morphology of the tubing body flattening deformation is shown in **Figure 1**.

The tubing of an oil well has been destroyed, and it has successively carried out complex working conditions such as setting, sealing inspection, acidification construction, drainage, shut-in, operation of CQ-CPV valve, well killing, and string pulling out [9] [10] [11]. In the process of setting and checking, the changes of oil pressure and casing pressure are shown in **Figure 2**. The oil pressure is finally stabilized at 28.47 MPa and the casing pressure is 14.9 MPa. In the process of acidizing construction, the construction curve is shown in **Figure 3**, and the total amount of acidizing fluid injected into the wellbore is 1258.51 m^3. The maximum pump pressure is 123.7 MPa and the minimum is 102.3 MPa. The highest casing pressure is 45.3 MPa, and the lowest is 41.5 MPa. The maximum displacement is 7.23 m^3/min, and the minimum is 3.0 m^3/min.

After the completion of acidification, during the process of drainage and shut-in, the cumulative drainage is 1749.5 m^3, and the values of oil pressure and casing pressure are also constantly changing. The final oil pressure is 0 MPa and the casing pressure is 3.0 MPa. Then, the well killing and CQ-CPV back-off and plugging valve pressure test were carried out. The plugging valve pressure test

Figure 1. Crushed tubing in an oil well.

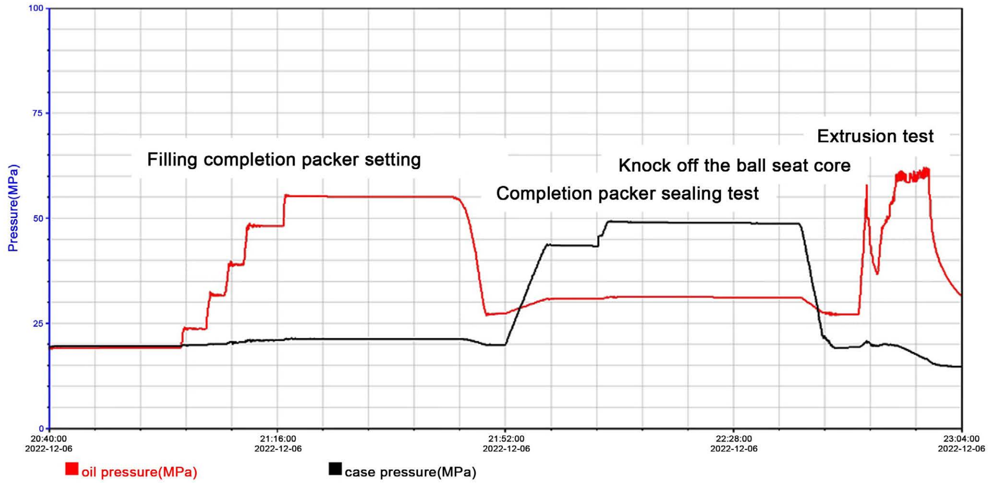

Figure 2. The change of oil pressure and casing pressure in the process of setting and sealing test.

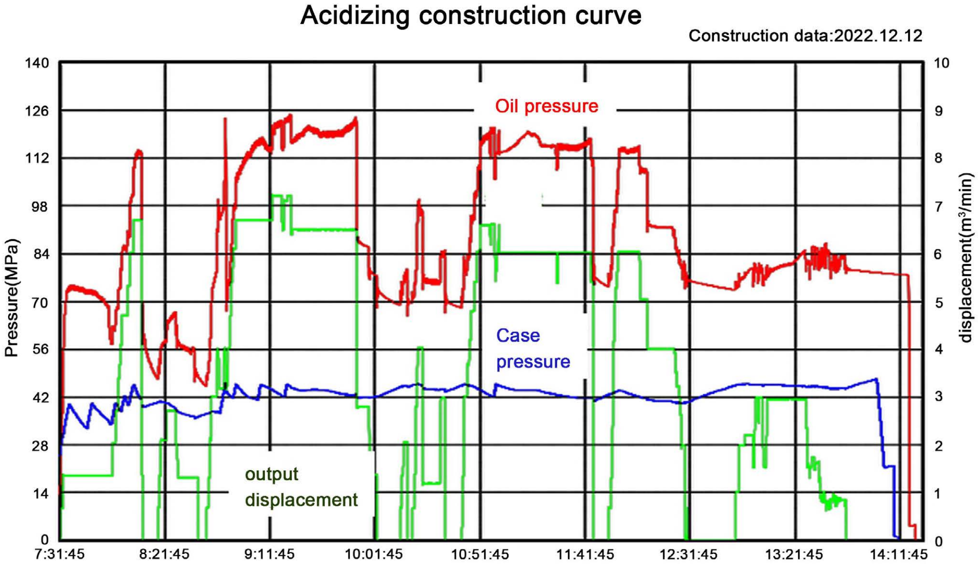

Figure 3. Acidizing construction curve.

was qualified and the wellbore drainage pressure test was carried out. There was no abnormality in the open well observation outlet. The string is pulled out as shown in **Figure 4**. From the 444th root of the tubing, it is found that the tubing body is flattened and deformed, corresponding to a depth of 4252.33 m. The RD valve rupture disc is not broken, and the circulation hole is normal. The CQ-CPV valve controller rupture disc is not broken, and the tool is normal.

3. Physicochemical Test

3.1. Chemical Composition Analysis

According to the API Spec 5CT-2021 standard and the requirements of the supply technical agreement, the chemical composition analysis of the materials of the failed tubing body and the intact tubing was carried out [12] [13]. The results are shown in **Table 1**. It can be seen from **Table 1** that the chemical composition of the failed tubing and the intact tubing material meets the requirements.

3.2. Ultrasonic and Magnetic Particle Testing

In order to further verify whether there are cracks and excessive defects on the surface of the failed tubing, fluorescent magnetic powder and ultrasonic flaw detection [14] [15] were used to detect the collapsed tubing and the intact tubing respectively, as shown in **Figure 5**, **Figure 6**. The test results show that cracks and over-standard defects are not found on the surface of the extruded tubing and the intact tubing.

3.3. Metallographic Test

Metallographic examination was carried out on the failed tubing and the intact tubing [16] and the test results were compared. The macroscopic morphology of local corrosion on the inner wall of the tubing was observed. There was local pitting corrosion on the inner surface of half of the inner wall of the intact tubing. There is only less pitting corrosion on the inner wall of the collapsing tubing, as shown in **Figure 7** and **Figure 8**. At the same time, the depth of the corrosion pit was measured, and the corrosion depth of the inner wall was detected by a stereomicroscope. It was found that the spot was higher than the inner wall surface, and the cone was protruding, as shown in **Figure 9**. The analysis shows that the pitting corrosion does not reduce the wall thickness of the tube.

Figure 4. Outlet pipe, RD valve, CQ-CPV valve.

Table 1. Chemical composition of failed tubing and intact tubing (mass fraction).

Sample composition	C	Si	Mn	P	S	Cr	Mo	Ni	Cu
Failed tubing	0.23	0.25	0.47	0.0087	0.0026	0.91	0.76	0.027	0.044
Intact tubing	0.24	0.26	0.47	0.0090	0.0025	0.91	0.76	0.028	0.044
API Spec 5CT	≤0.35	/	≤1.20	≤0.020	≤0.005	0.40 - 1.50	0.25 - 1.00	≤0.99	/
Supply technical agreement	≤0.35	/	≤1.20	≤0.015	≤0.003	0.10 - 1.60	0.20 - 1.20	/	/

Figure 5. Ultrasonic flaw detection.

Figure 6. Magnetic particle testing.

Figure 7. Macroscopic morphology of local corrosion on the inner wall of intact tubing.

Figure 8. Macroscopic morphology of local corrosion on the inner wall of extruded tubing.

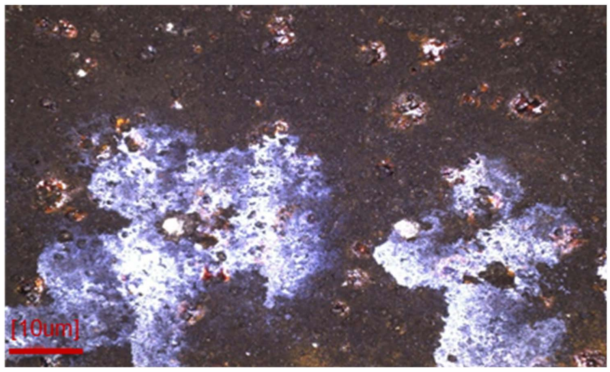

Figure 9. Measurement of corrosion pit depth.

The grain size and inclusions of the extruded and intact tubing were detected, as shown in Table 2. The metallographic analysis results show that the grain size and inclusions of the extruded and intact tubing meet the relevant requirements of API Spec 5CT-2021 and PTS-020501-01-2018.

4. Mechanical Property Test

4.1. Tensile Mechanical Properties

The longitudinal tensile performance test was carried out on the failed tubing body and the intact tubing body [17]. The test was carried out according to the API Spec 5CT-2021 standard. The test results are shown in Table 3. It can be seen from the test results that the yield strength of one sample (704 < standard value 758MPa), and the other samples and mechanical properties meet the requirements of API Spec 5CT-2021 standard and supply technical agreement. The average yield strength of the intact tubing material is less than the standard value of 758 MPa, and the average tensile strength is less than the standard value of 793 MPa.

4.2. Charpy Impact Energy Test

According to API 5CT-2021 standard, the longitudinal impact energy and shear areawere tested along the longitudinal sampling on the failed tubing body and

Table 2. Metallographic analysis results.

Sample number	Non-metallic inclusion									Tissue	Grain size (level)
	A		B		C		D		The sum of inclusions		
	Thin	Thick	Thin	Thick	Thin	Thick	Thin	Thick			
Failed tubing	0.5	0	0.5	0	0	0	1.0	0	2.0	Sround	10.0
Intact tubing	0.5	0	0.5	0	0	0	0.5	0	1.5	Sround	10.0

API Spec 5CT-2021stipulation: Grain size ≥ 6; PTS-020501-01-2018stipulation: A/B/C/D the thick inclusions are < 2 level, the thin inclusions are < 2.5 level, and the sum of all kinds of inclusions is < 8 level.

Table 3. Test results of longitudinal tensile properties of extruded tubing and intact tubing.

Sample		Yield strength (0.7%eul) (mpa)	Tensile strength (mpa)	Percentage elongation after fracture (%)
Numbering	Width × wall thickness × gauge length (mm)			
Failed tubing (portrait)	19 × 6.45 × 50	789	838	20
		759	828	21
		759	822	22
		704	816	20
	Mean value	753	826	21
Intact tubing (portrait)	19 × 6.45 × 50	720	779	23
		736	794	24
		734	788	25
		736	796	24
	Mean value	732	789	24
API spec 5ct-2021		758 ~ 828	≥793	≥12
Provisions of supply technical agreement		758 ~ 828	≥793	/

the intact tubing body. The test results are shown in Table 4. It can be seen from the test results that the longitudinal impact energy and shear area of the crushed and intact tubing meet the requirements of API 5CT-2021 and the procurement technical specification.

4.3. External Pressure Test of Pipe Body

The external pressure testwas carried out on the intact tubing body, and the external pressure of 57.9, 93.3, and 105.6 MPa load steps was applied to the tubing body. The test is carried out according to API 5C2 standard, and the test results are shown in Table 5.

From the test results, it can be seen that when the applied external pressure test value is lower than the minimum guarantee value of 93.3 MPa specified in API 5C2 standard, the intact tubing does not collapse. When the external pressure test value is greater than the minimum guarantee value of 93.3 MPa

Table 4. Charpy impact test results of extruded tubing and intact tubing.

Sample			Absorbed energy			Mean value	Percent shear fracture (%)			Mean value
Numbering	Specification (mm)	Notch shape								
Failed tubing	5 × 10 × 55 (portrait)	V	85	85	87	86	100	100	100	100
Intact tubing			95	98	91	95	100	100	100	100

API spec 5ct-2021specify full-size specimens: ≥41j; shear area ≥ 75%; Pts-020501-01-2020purchasing technical specifications provisions: ≥80j.

Table 5. External pressure test of intact tubing.

Load step	External pressure (MPa)	Dwell time	Anti-collapse test phenomenon of tubing
1	57.9	10	No collapse failure occurred.
2	93.3	10	No collapse failure occurred.
3	105.6	/	Crushing failure

specified in API 5C2 standard, the tubing collapse failure occurs, as shown in Figure 10.

The collapsing strength of the intact tubing and the collapsing tubing was evaluated according to the measured geometric dimensions and mechanical properties of the material. The test was carried out according to the API standard. The experimental results are shown in Table 6. It can be seen from the test results that the anti-collapse strength results of the intact tubing calculated according to the measured geometric dimensions and mechanical properties of the material are consistent with the full-scale test results of the physical object, both of which meet the minimum values specified by the API. The collapsing strength of the downhole collapsing tubing is evaluated according to the measured geometric size and mechanical properties of the material to meet the minimum requirements of the API.

5. Failure Cause Analysis

The physical and chemical properties of the failed tubing body and the intact tubing were tested and analyzed. The results showed that the failed tubing body was TP110SS tubing, and the chemical composition, ultrasonic magnetic particle inspection and metallographic test of the material met the requirements of API Spec 5CT-2021 standard. During the mechanical property test of the failed tubing, the yield strength of one sample in the tensile mechanical test is 704 MPa, which is lower than the standard value of 758 MPa, and the remaining mechanical property test results meet the requirements of API Spec 5CT-2021 standard.

When operating the CPV valve, the maximum pressure difference between the inside and outside of the tube is 88.5 MPa; according to the calculation formula of API 5C3 anti-extrusion strength, after the packer is set up, the anti-extrusion strength of the string collapse (4252.33 m) is reduced from 93.3 MPa to 84.69 MPa, which is less than the external pressure of 88.5 MPa, and there is a

Figure 10. Collapse failure of intact tubing.

Table 6. Tubing collapsing strength analysis.

Maximum d/t (standard size ratio)	Average wall thickness (mm)	Average outside diameter (mm)	Ovality (%)	Wall thickness nonuniformity (%)	Residual stress (mpa)	Yield minimum value (mpa)	Section number
Intact tubing (according to the collapse morphology in the middle of the tubing to collapse the choice of section 5 geometry size)							
13.49	6.59	88.93	0.38	5.16	−140.5	720	5
Plastic collapse compressive strength (mpa)				Kt ultimate collapse strength (mpa)			
93.1				97.7			
Extrusion strength of collapsing tubing (evaluation)							
12.5	7.14	89.32	0.45	9.1	−140.5	705	/
Plastic collapse compressive strength (mpa)				Ktultimate collapse strength (mpa)			
103.5				104.76			

1) According to API standard, the minimum value of anti-extrusion is 93.3 MPa; 2) The measured geometric dimensions and the calculated collapsing strength of the mechanical properties of the material are greater than the API specified value. 3) According to the minimum mean of the measured wall thickness of the extruded tubing and the minimum yield strength of the measured material (704 MPa); 4) The maximum roundness and wall thickness unevenness, maximum average outer diameter and residual stress of the intact tubing were measured, and the collapse strength of the collapsed tubing was evaluated.

risk of collapse. By calculating the three-axis safety factor of the string during the operation of the CPV valve, it can be seen that the minimum safety factor of the string is 0.966, located at 3374 m; the safety factor of the tubing collapse is 0.997, and there is a risk of collapse.

6. Conclusions

Based on the problem of collapse failure of an oil well tubing after setting, sealing inspection, acidification and other construction, this paper proposes a failure analysis method for physical and chemical tests and mechanical performance tests of failed tubing and intact tubing. Firstly, the chemical composition, ultrasonic domain magnetic particle inspection and metallographic experiment were analyzed. Secondly, tensile mechanics, Charpy impact and external pressure test analysis of pipe body are carried out. Finally, the failure mechanism of tubing is studied by comparing the test results of intact tubing and failed tubing, and the failure reason of tubing collapse is determined.

Through the analysis of the results of the oil well failure oil management test and mechanical performance test, it is concluded that the tubing of the oil well has the risk of collapse. Therefore, for the study of tubing failure mechanism, the method proposed in this paper can be used to determine the cause of tubing collapse failure.

Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

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