Hydrostatic Test and Simulation Verification of Pipeline with Carbon Fiber Repair

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Abstract. We specially designed a hydraulic blasting test for the repair capability of carbon fiber composite materials on pipelines containing defects. In the water pressure test, the location of the pipeline pressure rupture did not appear in the repair area, and the amount of pipeline deformation in the repair area was small. A finite element simulation of the compression process was carried out. After simulation verification, it was found that the ultimate pressures of the two were basically the same, and in the limit state, the stress value of the carbon fiber composite material in the repair area did not exceed its tensile failure strength. It is concluded that carbon fiber composite materials can effectively repair pipeline defects and restore the pressure bearing capacity of the defects.

1. Introduction
In recent years, the mileage of China's oil and gas pipelines has continued to increase, and a pipeline transportation network that "traverses east and west and runs north and south" has been initially formed. However, with the increasing use time of oil and gas pipelines and the complex and changeable surrounding environment of the laying area[1], many pipelines have formed various pipeline defects such as mechanical damage or metal corrosion. The existence of these defects will seriously affect the operation safety of oil and gas pipelines, leading to the occurrence of leaks and bursts[2]. Therefore, it is particularly important to take appropriate and effective measures to repair the defects of the pipe body and prevent accidents. The defects of the tube body include: welding tumor scars, shells, fixtures, glass fiber reinforcement, carbon fiber reinforcement, etc. [3], carbon fiber sheet reinforcement technology[4], because its uninterrupted transportation, corrosion resistance, and convenient construction have gradually become a new reinforcement technology is widely used in home and abroad. In this article, we use a combination of hydraulic testing and finite element simulation to test the pressure bearing capacity of carbon fiber composite materials to strengthen defective pipelines, and analyze the effect of reinforcement on the repair of carbon fiber composite materials[5-6]. Providing a reference for the application of technology in actual engineering.

2. Hydrostatic test
Since the defects repaired by the current reinforcement technology can only be non-tensile defects, under normal circumstances, it is not recommended to repair the tensile defects caused by fatigue damage, but it is recommended to directly replace the pipe fittings. We choose mechanical defects that
are easy to process for hydraulic testing (Q235 as a test material for steel tubes. Basic mechanical performance data: yield strength is 235 MPa, tensile strength is 428 MPa, elastic modulus is 203 GPa, Poisson's ratio is 0.3. Pipeline, the length is 6 meters, the specification is 4268 mm). In the test pipe section, as shown in Figure 1, we handled a circumferential mechanical cutting defect (the circumferential length and width of the defect were 58.2 mm and 1 mm, the depth was 4.6 mm, and 0.7 m from the pipe end).

We polished the processed mechanical defects. The depth and length of the pipeline defect were measured again, and then we cleaned the defect surface to ensure smoothness, filled the defect with putty and applied the adhesive. According to the allowable stress design composite repair thickness method of the pipeline [7], we use carbon fiber composite materials (PerpeWrap® ST85 bidirectional carbon fiber composite material repair system, its axial design stress is 382 MPa, hoop design stress is 740 MPa) for hydraulic test Pipeline defects were repaired. It is calculated that the number of circumferential repair layers of the defective pipe section is 5 layers, the axial repair layer number is 1 layer, and the repair length is 300 mm. Before testing, weld both ends of the test pipe with welding plugs. As shown in Figure 2, pressurize the water injection pipeline from the repaired position at the designed distal head, and install a pressure gauge at the outlet of the pipeline pressure pump to monitor the pressure change during the pipeline pressurization process.

After the experiment started, as the pressure continued to rise, when the pressure was about 14 MPa, the swell began to appear in the middle of the test tube; when the pressure continued to increase, the degree of swell increased, and when the pressure reached the peak, about 15.2 MPa, the swell was the most serious. The value shows a downward trend. When the pressure was 14.9 MPa, the pipeline started to crack in the most swollen area, and the crack expanded in the axial direction; when the expansion passed through the bulging area, the direction of crack growth changes at the boundary between the bulging and the uninflated. The deflection angle was about 45°, and continued to expand until the crack was stopped. The bulging and rupture positions of the hydraulic test pipeline were shown in Figure 3. The cracking position of the pipeline did not occur in the pipeline defect repair area,
and the deformation amount of the pipeline in the defect repair area was very small during the entire pressurization process.

![Figure 3: Bulging and rupture of the test pipeline](image)

**3. Simulation verification**

In order to further study the stress response of the pipeline defect repair in the pressurization process, the finite element method was used to simulate the pressurization process of the test pipeline. Since the test pipeline, the defect and the repair area are symmetrical[8], we selected the built One-half of the finite element model of the pipeline, defected and repaired area is analyzed. As shown in Figure 4, we chose C3D8R, the geometric dimensions, mechanical properties of the pipeline and carbon fiber materials were exactly the same as the hydraulic test unit.

![Figure 4: The finite element model diagram of the hydraulic test](image)

We loaded the finite element model and observed the stress changes of the pipe body and the repair material in the pipeline defect repair area and the pressure bearing capacity under the limit state. As the internal pressure continues to increase, the stress in the defect repair area of the pipeline is significantly lower than that in other areas. At the junction of the repair area and the unrepaired area, there was a stress transition area of half the pipe diameter. When pressurized to the limit state of 16 MPa, the Mises stress condition of the test pipeline was shown in Figure 5. It can be seen from the figure that the amount of deformation of the pipeline repair area is significantly smaller than that of the unrepaired area due to the constraints of the carbon fiber composite material. At the same time, in the limit state, the Mises stress value of the pipe in the unrepaired area reached 400 MPa, far exceeding the yield strength of the pipe 235 MPa, close to the tensile strength of the pipe 428MPa; and the Mises stress of the pipeline in the repair area has just exceeded the yield strength of 240 ~ 290 MPa, and the stress value of the carbon fiber composite material in the repair area did not exceed its design stress.
As shown in Figure 6, the limit state diagram of the circumferential stress cloud test pipeline can be concluded that when the internal pressure was limited, the circumferential stress of the carbon fiber material protected by the pipeline in the repair area is significantly lower than that of the pipeline in the unrepaired area. The average hoop stress of the pipeline in the repair area was about 300 MPa, and the maximum value was about 380 MPa, which is mainly due to the stress concentration at the defect. At the same time, the hoop stress of the carbon fiber composite material was about 200 MPa, which was much lower than its design pressure of 740 MPa. At this time, the hoop stress of the pipeline in the unrepaired area had reached 426 MPa, which is almost equal to the tensile strength of the pipeline.

Comparative analysis of hydraulic test and finite element simulation shows that during the hydraulic test, we monitored that the highest pressure in the pipeline reached 15.2 MPa, and the location of the crack was in the unrepaired area, located in the middle of the pipe section. In the finite element simulation, the area of the pipeline was not repaired first, and the tensile strength was reached. At this time, the pressure in the pipeline was 16 MPa. It can be seen that the carbon fiber materials in the pipeline and repair area have reached their respective failure stresses, and the experimental results are basically consistent with the simulation results.

4. Conclusion

We have passed hydraulic tests and finite element simulation to verify that carbon fiber composite materials can effectively repair pipeline defects, and the repaired pipeline has basically recovered its pressure bearing capacity. However, in actual engineering, the defect type, defect size, defect location and on-site repair situation of the pipeline will affect the final repair effect of the carbon fiber composite material.

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