Fracture failure analysis of flange connecting bolt

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Abstract. The fracture failure causes of flange connecting bolt were analyzed by chemical composition, tensile test, optical microscope and scanning electron microscope analysis. The results show that the carbon content of bolt doesn’t meet the requirements of relevant standards. Stress corrosion cracking is the main reason of bolt fracture.

1. Introduction
Fracture of flange connecting bolt resulted in fire and explosion accident of supercritical ethylene pipeline. To prevent similar accidents, the causes of flange connecting bolt failure should be revealed.

In the past, some researchers investigated the fracture failure causes of different bolts. Moshayedi et al. [1] investigated the fracture property and reasons of worm gear connecting bolts of refueling machines of a nuclear power plant. The results showed that the reverse temper embrittlement occurred in these bolts during the service. Li et al. [2] investigated the repetitive failures of Cr-Mo-V steel bolts of 325 MW steam turbine units in a thermal power plant. The results showed that the main fracture reason was a big gap between the bolt and bolt hole and surface decarburization and local stress concentration accelerated the fracture. Hedayat et al. [3] proposed three methods referred to as MTD1, MTD2 and MTD3 as appropriate failure criteria for bolt fracture prediction in shear when threads were excluded from the shear plane. Gong et al. [4] studied the premature fracture failure causes of TP321 stainless steel anchor bolts used in an indoor seawater booster pump of a nuclear power plant. The results showed that the stress corrosion cracking from chlorides induced by splashing of the seawater during routine maintenance of the pump was the main reason of anchor bolt premature fracture. Gao et al. [5] studied the failure causes of the bolt connections by fractographic analysis and theoretical analysis. Kong et al. [6] analyzed the fracture failure mode and cause of U-shaped bolt. The results showed that the U-shaped bolt’ failure was related with densely distributed surface micro cracks, surface decarburization appearance, small dimension, and low strength of material. Wen et al. [7] developed the numerical finite element models of bolted gusset plate and coped beam connections. The results provide insight on block shear failure mechanism. Elliott et al. [8] investigated the behaviour and strength of structural steel bolted connections whose failure modes involve shear yielding and/or fracture.

In this paper, the fracture failure causes of the flange connecting bolt were analyzed.

2. Sample and Experimental
As shown in Fig. 1, the sample is a M24 flange connecting bolt. The bolt has completely broken. The bolt has a dim color, which indicates that the bolt was burnt by fire at the accident site.
The hardness of bolts was tested according to GB/T 231.1-2009 < Metallic materials-Brillel hardness test-Part 1: Test method>. Bolts were sampled according to GB/T 2975-1998 < Steel and steel products-Location and preparation of test pieces for mechanical testing >. The size of the tensile test specimen is shown in Fig. 2. The standard spacing of sample is 25 mm, the length of parallel section is 30 mm, and the thread of clamping end is M8. According to GB/T 228-2002 < Metallic materials-tensile testing at ambient temperature>, the tensile test was carried out at room temperature.

3. Results and Discussions

3.1. Chemical composition analysis
According to GB/T 20123-2006 <Steel and iron-Determination of total carbon and sulfur content Infrared absorption method after combustion in an induction furnace (Routine method) > and GB/T 11170-2008 < Stainless steel-Determination of multi-element contents-Spark discharge atomic emission spectrometric method (Routine method) >, chemical composition of bolt was analyzed. The chemical composition of flange connecting bolt is shown in Table 1. The original documents provided by the valve factory show that the material grade of the bolt is ASTM A193-B8 < Standard specification for alloy-steel and stainless steel bolting materials for high-temperature service >. From the table, we can see that the carbon content of bolt sample exceeds the standard, and the Cr content is lower than ASTM A193 standard.

| Element                  | C    | S    | Si    | Mn    | P    | Cr    | Ni    |
|--------------------------|------|------|-------|-------|------|-------|-------|
| Flange connecting bolt   | 0.10 | 0.007| 0.43  | 1.29  | 0.03 | 17.00 | 8.12  |
| ASTM A193-B8             | ≤0.08| ≤0.03| ≤1.00 | ≤2.00 | ≤0.045| 18.0-20.0| 8.0-11.0|

3.2. Tensile properties analysis
The tensile properties of 3 flange connecting bolt samples are shown in Table 2. The test results show that the mechanical properties of flange connecting bolt meet the requirements of ASTM A193-B8.
Table 2 Tensile properties of flange connecting bolt

| Sample      | Yield strength (MPa) | Tensile strength (MPa) | Elongation (%) | Reduction (%) |
|-------------|----------------------|------------------------|----------------|---------------|
| No. 1       | 828                  | 908                    | 19             | 35            |
| No. 2       | 818                  | 921                    | 30             | 64            |
| No. 3       | 831                  | 936                    | 36             | 51            |
| ASTM A193-B8| 795                  | 550                    | ≥15            | ≥35           |

3.3. Hardness analysis

The Brinell hardness values of the center for flange connecting bolt are shown in Table 3. The average value of Brinell hardness (HBW) is about 295. It can be seen that the hardness of the bolt meets the requirements.

Table 3 Brinell hardness values of flange connecting bolt

| Points                          | 1 | 2 | 3 | Average value |
|---------------------------------|---|---|---|---------------|
| Flange connecting bolt          | 291| 296| 298| 295           |
| ASTM A193-B8                    |   |   |   | ≤321          |

3.4. Metallographic microstructure analysis

The metallographic microstructure of the flange connecting bolt is shown in Fig. 3. The grade of grain size is 12. It can be seen from the figure that there are parallel needles in the grain, which is the deformed martensite phase, and white carbides precipitate at the grain boundary.

Figure 3. Metallographic microstructure of the flange connecting bolt.

The metallographic microstructure of the bolt crack is shown in Fig. 4. It can be seen that the crack is obviously intergranular propagation and the crack tip is bifurcated.

Figure 4. Metallographic microstructure of the bolt crack.
3.5. **SEM Micromorphology analysis**

The SEM morphology of fracture surface of the flange connecting bolt is shown in Fig. 5. Fig. 5(a) and 5(b) are fracture edge and fracture center morphology, respectively. It can be seen that the fracture surface is obviously intergranular fracture. From fig. 5(b), it can also be seen that there is a glacial intergranular fracture.

![SEM morphology of the flange connecting bolt](image)

Figure 5. SEM morphology of the flange connecting bolt.

4. **Conclusion**

The carbon content of the flange connecting bolt exceeds the requirements of relevant standards. There are a lot of carbides precipitated on the grain boundary. The reason of bolt fracture is stress corrosion cracking.

**References**

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