Failure analysis of exhaust valve bolt of Ultra Supercritical Unit

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Abstract. The exhaust valve bolt of an ultra supercritical unit broke during its service. This paper makes an all-round study on the fracture reason through macro fracture analysis, chemical composition and material analysis, metallographic structure analysis and hardness analysis. The research shows that the bolt is made of 25Cr2MoV, and the main reason for the fracture of the bolt is the insufficient strength caused by low hardness and uneven structure.

1. Introduction
25Cr2MoV steel is a medium carbon heat resistant alloy steel with good comprehensive mechanical properties and high thermal strength [1-2]. 25Cr2MoV steel high temperature bolt is an important fastener for high and low pressure cylinders in thermal power plants, which can operate at 510 ℃ for a long time. The performance of the bolt directly affects the operation safety of the cylinder [3-5]. This paper introduces a case of bolt fracture of steam exhaust valve of power plant unit, and deeply analyzes its failure reason.

There are eight bolts for exhaust valve of an ultra supercritical unit, one of which is broken. The bolt specification is Φ 36mm × 190mm, 25Cr2MoV. As shown in Figure 1, the random number of bolts is #1~#8, and the number of broken bolts is #8. The analysis items include fracture analysis, chemical element spectrum analysis, metallographic analysis and hardness analysis.

2. Methods and Discussion

2.1. Macro fracture analysis
Macro analysis of the fracture surface of the broken bolt #8 is carried out as shown in the figure1. The fracture occurs at the back groove of the bolt, which is the stress concentration part of the bolt; And the bolt is a rigid straight cylinder bolt. Under the tightening state, the elongation deformation of the bolt is concentrated at the thread bottom, and the stress concentration is more obvious.
2.2. Chemical composition analysis
Conduct element analysis on eight bolts with full quantitative metal element analyzer, and the results are shown in Table 1:

![Schematic diagram of broken bolt](image1)

Figure 1. Schematic diagram of broken bolt

It can be seen from Figure 2 that the fracture surface is seriously oxidized, and most of the surfaces are basically straight. The fracture originates from the lower end face and extends from bottom to top. The upper part of the figure is rough and presents a certain angle, which should be the final fracture area. The crack propagation stripes in the propagation and final fracture areas become more and more obvious, and the load on the surface of the bolt after cracking becomes larger and larger; After repeated cleaning with dilute acid, there is still a thick oxide film on the surface of the fracture, and only the morphology of the oxide film can be observed under scanning electron microscope. The original fracture morphology has been damaged by oxidation and corrosion at high temperature for a long time. On the other hand, it shows that the bolt should continue to operate for a long time from crack initiation to fracture, resulting in heavy fracture oxidation.

![Schematic diagram of bolt fracture](image2)

Figure 2. Schematic diagram of bolt fracture
Table 1. Chemical composition analysis results (mass fraction wt%)

| Number | C    | Si   | Mn   | P    | S    | Cr   | Mo   | Ni   |
|--------|------|------|------|------|------|------|------|------|
| #1     | 0.273| 0.331| 0.566| 0.0200| 0.0187| 1.82 | 0.262| 0.0562|
| #2     | 0.256| 0.325| 0.545| 0.0190| 0.0149| 1.80 | 0.254| 0.0552|
| #3     | 0.259| 0.326| 0.549| 0.0183| 0.0172| 1.81 | 0.249| 0.0548|
| #4     | 0.260| 0.328| 0.554| 0.0193| 0.0163| 1.81 | 0.253| 0.0558|
| #5     | 0.268| 0.332| 0.557| 0.0173| 0.0159| 1.84 | 0.257| 0.0585|
| #6     | 0.259| 0.326| 0.545| 0.0180| 0.0148| 1.81 | 0.254| 0.0554|
| #7     | 0.267| 0.329| 0.559| 0.0187| 0.0191| 1.82 | 0.257| 0.0562|
| #8     | 0.247| 0.323| 0.538| 0.0191| 0.0151| 1.79 | 0.252| 0.0545|

| Number | Al   | Co   | Cu   | Nb   | Ti   | V    | W    | Pb   |
|--------|------|------|------|------|------|------|------|------|
| #1     | 0.0081| 0.0165| 0.131| 0.0079| 0.0016| 0.207| <0.0050| 0.0041|
| #2     | 0.0081| 0.0165| 0.129| 0.0081| 0.0016| 0.202| <0.0050| 0.0042|
| #3     | 0.0082| 0.0164| 0.129| 0.0082| 0.0015| 0.203| <0.0050| 0.0041|
| #4     | 0.0086| 0.0170| 0.129| 0.0083| 0.0016| 0.204| <0.0050| 0.0044|
| #5     | 0.0086| 0.0170| 0.131| 0.0083| 0.0016| 0.207| <0.0050| 0.0039|
| #6     | 0.0085| 0.0166| 0.129| 0.0086| 0.0015| 0.205| <0.0050| 0.0034|
| #7     | 0.0085| 0.0173| 0.131| 0.0076| 0.0016| 0.206| <0.0050| 0.0040|
| #8     | 0.0080| 0.0160| 0.127| 0.0080| 0.0015| 0.201| <0.0050| 0.0040|

Through laboratory spectral analysis, the bolt composition is close to the bolt material 25Cr2MoVA in DL/T 439-2018《The technical guide for high-temperature bolt of fossil-fired power plant》, and is within the standard requirements.

2.3. Metallographic structure analysis
Metallographic structure analysis the #1~#8 bolt's cross section is analyzed. The metallographic structure and schematic diagram are as follows:

Table 2. Metallographic structure of each sample

| Number | Sample number | Metallographic structure | Figure number |
|--------|---------------|--------------------------|---------------|
| 1      | #1            | Tempered sorbite         | Figure 2      |
| 2      | #2            | Tempered sorbite         | Figure 3      |
| 3      | #3            | Tempered sorbite         | Figure 4      |
| 4      | #4            | Tempered sorbite         | Figure 5      |
| 5      | #5            | Tempered sorbite         | Figure 6      |
| 6      | #6            | Tempered sorbite         | Figure 7      |
| 7      | #7            | Tempered sorbite + ferrite| Figure 8     |
| 8      | #8            | Tempered sorbite         | Figure 9      |
2.4. **Hardness analysis**
Conduct hardness analysis on metallographic samples with bench hardness tester. The hardness analysis
part is metallographic inspection surface. The test results are shown in the table below:

Table 3. Hardness test results of bolt cross section

| Number | Test component | HBW        | Average |
|--------|----------------|------------|---------|
| 1      | #1             | 218/227/217/225/220 | 221     |
| 2      | #2             | 218/217/225/221/221 | 220     |
| 3      | #3             | 215/216/218/217/216 | 216     |
| 4      | #4             | 223/216/220/221/219 | 219     |
| 5      | #5             | 226/216/217/220/218 | 219     |
| 6      | #6             | 214/219/221/215/218 | 217     |
| 7      | #7             | 217/222/215/224/220 | 220     |
| 8      | #8             | 218/215/219/217/216 | 217     |

According to the analysis results, the Brinell hardness of eight bolts including broken bolts ranges from hbw216 to 221. Referring to the hardness control range HBW248 to 293 of bolt material 25Cr2MoVA in DL/T 439-2018 (The technical guide for high-temperature bolt of fossil-fired power plant), the bolt hardness is lower than the lower limit specified in the standard.

3. Conclusions
1. According to the spectral analysis, the chemical composition of the eight bolts is close to that of the bolt material 25Cr2MoV used in thermal power plant, and within the standard requirements;
2. According to the metallographic structure analysis, the bolt structure is normal and uniformly tempered sorbite, and no abnormal structure is found, but there are more ferrite structures in the bolt structure which number is #7.
3. According to the hardness analysis, referring to the hardness control range hbw248 ~ 293 of bolt material 25Cr2MoVA in DL / T 439-2018 (The technical guide for high-temperature bolt of fossil-fired power plant), the bolt hardness value is low.
4. According to the fracture analysis, the fracture occurs at the common stress concentration part of the bolt, and the fracture feature is brittle fracture; There is serious oxidation corrosion on the surface, indicating that the cracking lasts for a long time.

To sum up the test results, the fracture of the bolt is related to its insufficient strength. The main reasons for the insufficient strength are the low hardness value of the bolt and the non-uniformity of the structure; Under the action of high temperature and large tightening force, the stress concentration parts such as tool withdrawal groove will bear large load. The bolt is a rigid straight cylinder bolt, which greatly increases the possibility of becoming a crack initiation area; The crack initiation and propagation lasts for a period of time, and the load acting on the bolt increases with the reduction of the bearing area, resulting in fracture. If the metal supervision can be strengthened in this process, the hidden dangers can be found and eliminated in time.

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