Analysis and Research on the Cause of Wind Turbine Blade Bolt Fracture

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Abstract. In 2019, inspection personnel of a wind farm went to the tower and found that a total of 6 bolts of blades in the hub of a wind turbine had broken and failed. In order to find out the cause of fracture, the bolt fracture was comprehensively detected and analyzed by means of appearance morphology analysis, chemical composition analysis, mechanical properties testing, microstructure testing and fracture micro-area analysis. The results show that the main reasons for the bolt fracture are as follows: under the action of the bolt’s constantly changing and repeated wind load impact and the alternating load caused by blade rotation during the operation of the fan, the crack source is formed along the bottom of the thread with serious stress concentration and expands in fatigue mode until the whole fracture fails.

1. Introduction

In 2019, inspection personnel of a wind power generation company inspected the tower and found that a total of 6 bolts of blades in the hub of a fan had broken and failed. In order to find out the cause of bolt fracture, the method of macroscopic morphology analysis, chemical composition analysis, mechanical properties detection, microstructure detection and fracture micro area analysis were carried out on the bolt. There is one broken bolt in total for incoming sample analysis, and the detailed information is shown in Table 1.

| Sample number | The sample description | specifications | The material | level |
|---------------|------------------------|----------------|--------------|-------|
| /             | Wind turbine blade bolts | M30×550mm     | 35CrMo       | 10.9 on the Richter scale |
2. Test method for fracture study of blade - paddle bearing connection bolts

The macroscopic morphology of the fractured blade bolts was observed to judge whether there were mechanical damage and original defects, and the reasons for cracking were further analyzed by combining other test methods. Scanning electron microscope (SEM) was used to analyze the fracture morphology of the blade bolt to determine its fracture mode and mechanism. According to the requirements of GB/T 4336-2016 Determination of Multi-element Content in Carbon Steel and Medium-low alloy Steel by Spark Source discharge Atomic emission Spectrometry (Conventional Method), the samples of broken blade bolts were analyzed by SPECZROMAXx bench direct reading spectrometer to determine whether the chemical composition meets the standard requirements. According to the requirements of GB/T 13298-2015 Metallographic Microstructure Examination Method, Axio Obser ALM metallographic microscope was used to test the microstructure of blade bolt samples to determine whether the metallographic microstructure was normal. According to the requirements of GB/T 229-2007 Charpy pendulum Impact Test Method for Metallic Materials, low-temperature impact testing machine is used to conduct -20°C impact test on incoming bolt samples to determine whether the impact toughness meets the standard requirements. According to the requirements of GB/T 4340.1-2009 Vickers Hardness Test for Metallic Materials part 1: Test Method, sample bolts were sampled and hardness test was carried out on tuKON2500-6 Automatic Vickers hardness tester to determine whether the material hardness meets the standard requirements. According to the requirements of GB/T 228.1-2010 Tensile test for Metallic materials part 1: Test Method at room temperature, sample bolts were sampled and tensile test was carried out on CMT5305 electronic universal testing machine at room temperature to determine whether the material yield strength, tensile strength and elongation after fracture meet the standard requirements.

3. Test results and discussion

3.1 Macroscopic morphology observation and analysis

The macroscopic morphology of the broken blade bolt was examined. The high-strength bolt was M30×550mm, grade 10.9 double-headed stud, and the overall appearance of the bolt was dark black. The bolt was fractured at the base of the second thread of the bolt from the flexible rod, which was in the stress concentration area of the whole bolt. In addition, the screw part had obvious plastic bending deformation. The fracture initiation zone, crack propagation zone and transient fracture zone on the bolt fracture surface can be clearly identified[1]. Fracture did not see the plastic deformation, rough, the cross section in light grey color, no obvious corrosion product and fracture local area exists obvious mechanical wear trace[2], but can still be observed in the cross section shows obvious multi-source fatigue fracture characteristics, crack extension area can be observed clearly "the beach" fatigue stripe, as shown in figure 1.

![figure 1 Macromorphology of fractured blade bolts](image-url)
3.2 Observation and analysis of fracture microarea

Scanning electron microscope (SEM) was used to detect the fracture of blade bolt[3]. The microscopic characteristic morphology of the fracture is shown in Figure 2. Due to serious mechanical damage, no typical characteristics were observed in the fracture initiation area. However, clear fatigue striations can be observed in the extension zone[4], which has typical characteristics of fatigue crack propagation of quenched and tempered steel.

![figure 2 SEM morphology of fracture extension zone of blade bolt](image)

3.3 Chemical composition detection and analysis

Chemical composition test was carried out on blade bolt samples, and the test data were shown in Table 2. The results show that the contents of elements in bolt are in accordance with the requirements of 35CrMo steel in GB/T 3077-2015 Alloy Structural Steel.

| Detecting element | C  | Si  | Mn  | Cr  | Ni  | Mo  | P   | S   |
|-------------------|----|-----|-----|-----|-----|-----|-----|-----|
| The measured values | 0.35 | 0.23 | 0.56 | 0.93 | 0.01 | 0.19 | 0.010 | 0.004 |
| GB / T 3077 - 2015 | 0.32 | 0.17 | 0.40 | 0.80 | ≤ | 0.15 | ≤ | ≤ |
|                  | ~  | ~   | ~   | ~   | 0.30 | ~   | 0.030 | 0.030 |

3.4 Microstructure detection and analysis

The fractured blade bolt was sampled near the fracture point for metallographic microstructure detection, as shown in Figure 3. It can be seen that the microstructure of bolt thread and matrix are fine tempered and tempered soxaustenite with equiaxed uniform distribution[5], and there is no obvious decarburization layer at the top and bottom of screw thread. No obvious inclusions and other defects were found in the tissue, and the status of the tissue was basically normal.
3.5 Mechanical properties testing and analysis

The mechanical properties of blade bolt samples were tested, and the test results were shown in Table 3 and Table 4. It can be seen that the vickers hardness value of bolts, low temperature (-20°C) impact toughness[6], specified non-proportional extension stress of 0.2%, tensile strength and elongation at fracture all meet the standard requirements.

| The test items         | Vickers hardness /HV30 | Low temperature shock absorption energy (-20°C) AKV /J |
|------------------------|------------------------|-------------------------------------------------------|
| The blade bolt          | 365                    | 38                                                   |
|                        | 363                    | 39                                                   |
|                        | 364                    | 36                                                   |
| The average            | 364                    | 38                                                   |
| GB/T 3098.1-2010       | 320 ~ 380              | ≥27                                                  |

| The test items                                      | Specify a stress of 0.2% of non-proportional extension (MPa) | Tensile strength (Mpa) | Elongation after fracture (%) |
|-----------------------------------------------------|--------------------------------------------------------------|------------------------|--------------------------------|
| Connecting bolts of fan blade and variable propeller bearing | 948                                                           | 1060                   | 15                             |
| Standard requirement                                  | ≥940                                                          | ≥1040                  | ≥9                             |
4. Conclusion
According to the fracture morphology analysis, the blade bolt was fractured at the base of the second thread of the bolt from the flexible rod, and the fracture showed typical fatigue fracture characteristics, and the fracture was originated from the stress concentration at the bottom of the thread tooth.

The microstructure analysis shows that the screw thread and matrix are fine tempered soxhaustne with equiaxed uniform distribution, and there is no obvious decarburization layer at the top and bottom of the screw thread.

From the analysis of mechanical properties, the hardness, strength, toughness and other mechanical properties of the blade bolt meet the standard requirements.

From the analysis of stress state, the blade bolts mainly bear tensile, shear, bending and other static stresses during the operation of the fan, as well as the alternating loads caused by the constantly changing wind load impact and blade rotation, and their stress situation is extremely complex. It is easy to form a crack source along the bottom of the second thread from the flexible rod of the bolt with obvious stress concentration under bad working conditions and expand in the form of fatigue.

Comprehensive the above analysis, the main reason for the blade bolt fracture of the bolt in the operation process of changing, repeated impact of wind load and the effects of the alternating load blade rotation, along the severe stress concentration of thread form ascend a crack source and extension in fatigue, until the whole fracture failure.

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