Fracture failure analysis of high-speed shaft

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Abstract. The fracture failure causes of a high-speed shaft in a hoisting gearbox were analyzed based on the optical microscope and scanning electron microscope analysis. The results show that the fracture failure cause of the high-speed shaft is fatigue. Surface defects, such as machining tool marks and folded cracks, are the source of fatigue fracture under stress.

1. Introduction

During the loading and unloading of a portal crane, the high-speed shaft of the hoisting gearbox suddenly broke, causing the damage of the adjacent rod teeth. In order to avoid similar accidents, it is necessary to systematically analyze the causes of fracture of high-speed shaft.

There are many cases of shaft failure. Zangeneh et al. [1] investigated the fracture failure causes of an agitator shaft made of 304L stainless steel in a large vessel. The results showed that the main reasons for the failure of the shaft were the insufficient radius of the fillet and the label defect during processing. Bi et al. [2] investigated the fracture causes of a speed reducer shaft for driving sluice gate in a nuclear power plant. The results showed that the hydrogen embrittlement and tempering embrittlement during heat treatment and carburizing were the direct reasons of the speed reducer shaft fracture. Domazet et al. [3] investigated the failure reasons of two overhead crane shafts. The results showed that the fracture failure was caused by rotating bending load at the stress concentration point. Shi et al. [4] investigated the fracture failure mechanism of a supporting shaft in a rotary kiln. The results showed that the failure mechanism was fatigue caused by fretting wear between shaft and sleeve. Zhu et al. [5] studied the failure causes of a railway wheel shaft for power locomotive. The result showed that the failure of the wheel shaft was caused by fretting fatigue. Li et al. [6] studied the failure causes of an isometric polygonal shaft of a coal mine reducer. The result showed that the main cause of the fracture was the large eccentricity between the hub hole and shaft. Ni et al. [7] studied the premature fracture failure reason of a pump shaft used in a nuclear power plant. The results showed that the main causes of failure were the triple stress concentration caused by small transition arc radius, inclusion aggregation and surface defects. Zhao et al. [8] studied the root cause and failure mode of a drive shaft used in a vehicle. The result showed that the dominant mechanism of drive shaft failure was fatigue.

In this paper, the fracture failure analysis of a high-speed shaft was carried out. The chemical composition, metallographic and SEM micromorphology of the shaft were analyzed.

2. Macroscopic morphology

The macroscopic morphology of the high-speed shaft of a hoisting gearbox is shown in Fig. 1. The fracture position is at the withdrawal groove with variable cross section, as shown by the arrow in the figure. The section is perpendicular to the axis. The machined surface at the corner transition is very...
rough, and deep machined tool marks can be seen visually. The material of the high-speed shaft is 20CrMnTi.

![Fracture location](image)

Figure 1. Macroscopic morphology of the high-speed shaft.

The macroscopic morphology of fracture surface is shown in Fig. 2. It can be seen that the whole fracture has no obvious plastic deformation and the fracture is even. There are strong friction marks on the fracture surface. The (a) zone has bright color and is the source of fatigue. The (b) zone is smooth and fatigue extension zone. The (c) zone is transient breaking area.

![Macroscopic morphology of fracture surface](image)

Figure 2. Macroscopic morphology of fracture surface.

3. Results and Discussions

3.1. Chemical composition analysis

The chemical composition of high-speed shaft is shown in Table 1. The chemical composition of high-speed shaft is compared with 20CrMnTi steel referring to GB/T 3077-1999 < Alloy structure steels >. The results show that all element contents of high-speed shaft meet the standard requirements.

| Element | C     | Si    | Mn    | Cr    | Ti    |
|---------|-------|-------|-------|-------|-------|
| High-speed shaft | 0.22  | 0.27  | 0.95  | 1.03  | 0.061 |
| 20CrMnTi (GB/T 3077-1999) | 0.17-0.23 | 0.17-0.37 | 0.80-1.10 | 1.00-1.30 | 0.04-0.10 |

3.2. Metallographic microstructure analysis

The metallographic microstructure of the fracture is shown in Fig. 3. The carburized layer can be seen in the outer circle, as shown in Fig. 3(a). The microstructure of the carburized layer is high carbon martensite and a small amount of retained austenite, as shown in Fig. 3(b). The microstructure of the non-carburized layer is low carbon martensite and bainite, as shown in Fig. 3(c).
The micromorphology of different chamfers is shown in Fig. 4. Different shapes of folding and tool marks can be seen.

3.3. SEM Micromorphology analysis

The SEM morphology of the fracture surface is shown in Fig. 5. The SEM morphology of the fatigue extension zone is shown in Fig. 5(a) and (b). The fatigue striation can be seen in the figure. The SEM
morphology of the transient breaking area is shown in Fig. 5(c) and (d). The cleavage of the fan-shaped dimples can be seen.

Figure 5. SEM morphology of fracture surface.

4. Conclusion
The results of chemical composition analysis show that the components of the material meet the requirements of 20CrMnTi steel in relevant standards. Fracture macroscopical examination and scanning electron microscopic analysis show that the fracture failure cause of the high-speed shaft is fatigue. Machining tool marks and surface defects of folded cracks will lead to stress concentration in the region, and become the source of fatigue fracture under stress.

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