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Fracture analysis and countermeasures of the grid switch castings

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Abstract. Based on the detection technology of direct reading spectrum, metallographic microscope and X-ray, the defects of the grid switch castings were analyzed. The four main forms of casting fracture were summarized as poor physical and chemical properties, material misuse, casting defects and designing defects. In order to strengthen the quality control of the source of the product, it was proposed to carry out targeted network inspection in the two stages of material arrival and infrastructure acceptance.

1 Introduction

Castings have been widely promoted and widely used in power grid systems[1-2]. In recent years, with the rapid development of power construction, the use of grid switch castings has increased. Due to the relatively simple structure of castings, lower entry barriers for industry, extensive production models, insufficient attention to product quality control, and the existence of some low-level manufacturing units, a large number of fault accidents occur when casting connection defects enter the power grid, affecting the safe and economic operation of the power grid. Based on the failure cases, the defects of grid switch castings were classified and analyzed to provide a reference for their entry into the network and for infrastructure acceptance in this paper.

2 Physical and chemical properties

Fig. 1. Fracture morphology of the flange.

The GW16 switch vertical connecting rod flange broken during maintenance of a 220kV substation. The design material of this flange was die-cast aluminum alloy YL112. The flange broke in the middle. The fracture was flush and did not have any plastic deformation, which was a typical brittle fracture feature, as shown in Figure 1.

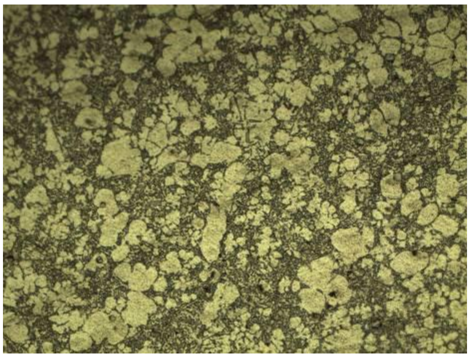

Fig. 2. Metallographic structure of thin walls of the flange.

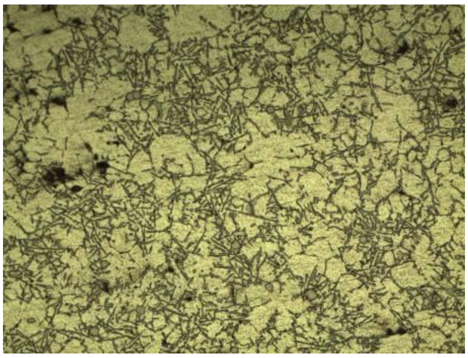

Fig. 3. Metallographic structure of thick walls of the flange.

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The metallurgical microscope was used to analyze the microstructure of the failed flange, and the areas with thin and thick flange walls were observed respectively. Figure 2 showed the structure of thin walls, including white petal-like α solid solution, fine Si-Al eutectic and small bulk Al2Cu phase. The structure was relatively uniform, which was a typical YL112 structure. Figure 3 showed the structure at the wall thickness, including α solid solution and needle-like Si-Al eutectic structure. Previous studies have shown that the Si-Al eutectic structure is hard and brittle, and its large needle-like distribution breaks the continuity of the matrix, which easily causes stress concentration at the interface between the matrix and the eutectic structure, thereby reducing the mechanical properties of the alloy, especially the reduction of plasticity[3]. Different thickness regions had different microstructures, which may be related to different cooling rates in the die casting process. The thin wall had a fast cooling rate, and the structure was fine and uniform. Compared with the thin wall, the cooling speed was slower at the wall thickness, which led to the appearance of needle-like Si-Al eutectic structure.

Table 1. Components of the flange.

Element	Content/%	Standard/%
Si	8.0	7.5-9.5
Fe	0.86	≤1.20
Cu	3.2	3.0-4.0
Mn	0.28	≤0.50
Mg	0.22	≤0.30
Ni	0.35	≤0.50
Zn	0.76	≤1.20
Sn	0.07	≤0.10
Pb	0.08	≤0.10

As illustrated in Table 1, the chemical composition of the flange was also tested. The component content of Si, Fe, Cu, Mn, Mg, Zn was 8.0%, 0.86%, 3.2%, 0.28%, 0.22% and 0.76, respectively.

Samples were taken at the middle and end of the flange for tensile tests, and their tensile strengths were 184 MPa and 337 MPa, respectively. By consulting relevant research data, the design strength of YL112 at room temperature should be 330MPa. According to the technical requirements of GB / T9438-2013 aluminum alloy castings, the sample tensile strength of the I and II castings with important bearing capacity should not be less than 75% of the design strength value[4]. Using the above standard calculation, the strength of the middle wall thickness of the hoop was about 55% of the design strength, which was unacceptable. It was confirmed that the performance of the wall-thickness part having the needle-like Si-Al eutectic structure was degraded.

3 Material misuse

In an 110kV substation, a universal joint fork of the 5X14 switch broke during replacement and debugging, as shown in Figure 4. The joint fork design material was ZG270-500. For comparative analysis, a qualified universal joint fork of the same material and model was also provided.

By direct reading spectrum analysis, the C content of the fractured universal joint fork was 0.17wt.%. According to GB / T11352-2009 Standard for Casting Carbon Steel Parts for General Engineering [4], the C content of ZG270-500 material was 0.32-0.39%. The C content of the fracture universal joint fork was in the range of the

Fig. 4. Fracture morphology of the universal joint fork.

standard low-strength grade ZG200-400, which did not meet the ZG270-500 material requirements. Since C was the most important strengthening element of cast carbon steel parts, a decrease in the C content would lead to a reduction in the proportion of pearlite structure in carbon steel parts and a decrease in the strength of the material.

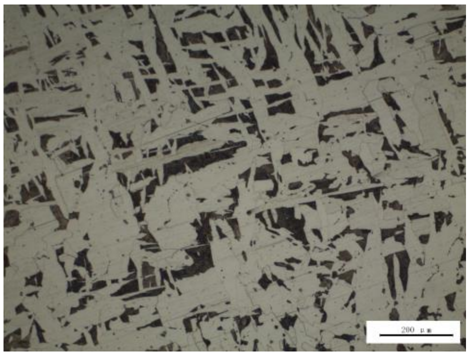

Fig. 5. Metallographic structure of fracture universal joint fork.

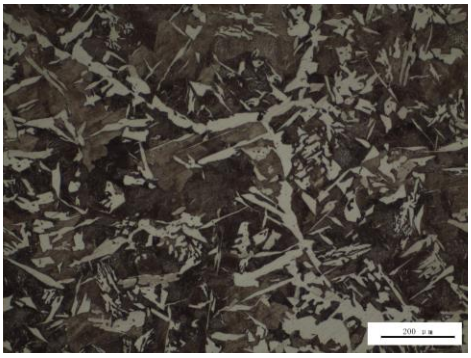

Fig. 6. Metallographic structure of comparative sample.

Metallographic analysis was performed on the fractured universal joint fork and the comparative sample using a metallographic microscope. The metallographic structures of the fractured sample and the comparative sample were both pearlite and ferrite, as shown in Figure 5 and Figure 6, respectively. Comparing these two figures, it could be found that the pearlite content in the tissue of the fractured sample was significantly lower than that of the control sample, which was consistent with the conclusion of the C content detected by direct reading spectrum. It was further confirmed that the actual use of the fractured universal joint fork was the low-strength grade ZG200-400, which was a typical material misuse.

Table 2. Components of the universal joint fork.

Element	Content/%	Standard/%
C	0.16	⩽0.20
Si	0.35	⩽0.50
Mn	0.62	⩽0.80
S	0.02	⩽0.04
P	0.02	⩽0.04

The chemical composition of the universal joint fork was displayed in Table 2. The component content of C, Si, Mn, S, P was 0.16%, 0.35%, 0.62%, 0.02% and 0.02%, respectively.

4 Casting defects and design defect

The GW4 switch terminal block in a 110kV substation was broken. The design material of this terminal block was die-cast aluminum alloy ZL102.The fracture position was at the clamping position of the terminal block bolt, and the fracture was a brittle fracture without plastic deformation, as shown in Figure 7.

Samples were taken from the assembly of the failed terminal block for macro observation and penetration inspection, and it was found that there were porosity defects in the cast aluminum parts, as shown in Figure 8.The pores will form a stress concentration in the local area, which will become a crack source for the terminal block to break, and reduce the bearing capacity of the casting.According to the requirements of DL / T768.5-2002 Quality Aluminium Parts for Electric Power Hardware Manufacturing [5], defects such as looseness, porosity, slag holes, etc.were not allowed in important parts such as the mechanical load of cast aluminum parts of power grids.The terminal block cast aluminum quality was unqualified.

Fig. 7. Fracture morphology of the terminal block.

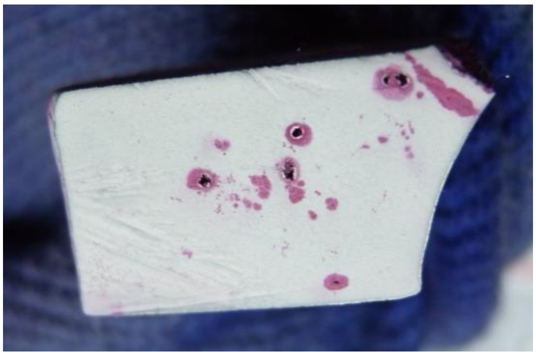

Fig. 8. Pores morphology of the terminal block casting.

Further measurement of the wall thickness at the break of the terminal block found that the thinnest part was less than 3mm. It was more important that this part bears the moment of the bolt and the conductive rod, which was an important part of the component. Compared with other manufacturers' products of the same type, the minimum wall thickness of this part was required to reach 6mm. The literature had reported that the cast aluminum parts fractured due to the thickness of the stress point at 5mm [6]. It showed that the insufficient design thickness of the terminal block bolt clamping was another major cause of fracture.

5 Conclusion and countermeasures

1) From the failure analysis in recent years, the defects of the power grid switch castings mainly included four types of poor physical and chemical properties, material misuse, casting defects and designing defects.

2) In order to improve the health status of power grid switch equipment, it is necessary to strengthen the

network access detection of the metal parts and move forward to the technical supervision point. On the one hand, casting manufacturers should improve technology, strengthen quality management, and prevent unqualified products from leaving the factory. On the other hand, power grid construction and operation and maintenance units have strengthened the equipment's network detection and acceptance work to avoid the maximum commissioning of defective equipment.

Acknowledgments

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