Study on typical failure of metal parts in circuit breaker

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Abstract. On the base of accident investigation of metal parts failure in circuit breaker in recent years, reasons of material defects in metal parts, i.e. material composition, mechanical properties, microstructure and inclusion defects, were summarized in this paper. In the end, the corresponding control measures were proposed.

1.Introduction

With the rapid development of economy and the ever increasing demand for electricity, the construction of power facilities are speeding up in recent years. Service stability of main power equipment plays an important role in reliable operation of power network, such as transformer, circuit breaker and so on[1,2]. By reason of hundreds of repeated stress during divide-shut operation, the circuit breaker were easily vulnerable to metal components failure[3-5].

In this paper, the failure causes of metal parts in circuit breaker were thoroughly investigated including connecting lever and transmission main shaft, in order to provide technical support for operational maintenance and technical supervision.

2.Experimental section

All the failed circuit samples were collected from transformer substation in service. The tensile property test was conducted on an electronic universal testing machine (Suns). The morphologies and structures of the samples were analyzed by metallurgical microscopy (Zeiss microscope) and field emission scanning electron microscope (FE-SEM). FESEM characterization and inclusion composition characterization was performed on a JSM-7600F.

3.RESULTS AND DISCUSSION

3.1 Connecting lever

Several circuit breaker in various 110kV substations broke down successively in 2013. Preliminary check of these failure equipments indicated that all the connecting levers cracked with apparent rust layers covering the surface. The disabled circuit breakers were type LW36-126 which had been put into service in 2006.

3.1.1 Visual inspection

The samplings were screened according to the severity of surface surface corrosion. As is shown in Figure 1 and Figure 2, the connecting levers of No.508 circuit breaker and No.510 circuit breaker suffered the most severe corrosion. According to the data measured on the field, the thickness of both ends of connecting lever was 12 mm. However, the corrosion layer thickness of No.508 circuit breaker already reached 4 mm which is one-third of the total thickness.Meanwhile randomly distributed corrosion pittings were also observed on the cover plate of connecting lever.In addition, the corrosion layer thickness of the other No.510 circuit breaker was 3 mm.

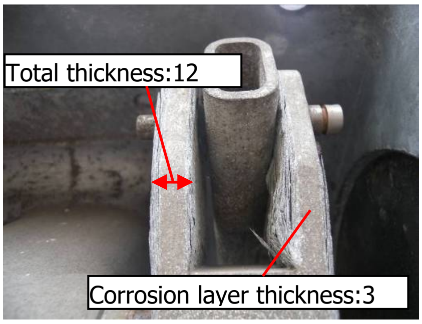


Figure 1. Macroscopic picture of No.508 connecting lever.

Figure 2. Macroscopic picture of No.510 connecting lever.

3.1.2 Composition and microstructure analysis

The chemical element analysis results of connecting lever were shown in Table 1. As seen the composition matched the standard requirements of GB/T 4437.1-2015.

Table 1. Chemical element analysis results.

Element	Content/ %	Standard requirement/%
Al	92.65	Remain
Zn	5.16	5.00～7.00
Cu	1.71	1.40～2.00
Mn	0.21	0.20～0.60
Fe	0.35	0～0.50
Cr	0.13	0.10～0.25

The microstructure analysis of connecting lever indicated that the matrix was after machining process which with bulky second phase scattering around. It is displayed in the Figure 3. Under normal circumstances, the delivery conditions for the surface condition of 7A04 aluminum alloy is heat-treated. However, the defective product has not been heat-treated or conducted well.

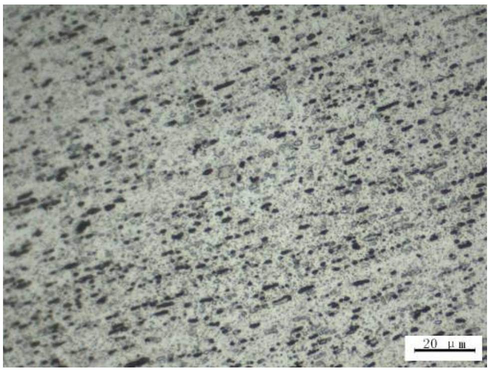


Figure 3. Microstructure picture of connecting lever

3.1.3 Exfoliation corrosion and mechanical property analysis
The exfoliation corrosion test was conducted according to GB/T 22639. The EXCO standard solution which containing sodium chloride (4.0mol/L), nitrate (0.5mol/L) and nitric acid (0.1mol/L) was applied. As time went on, corrosion degree of surface continued to develop into severe stratification from pittings on the surface.

The mechanical properties of original and treated sheets of connecting lever were analyzed, respectively. The tensile strength of original sheet was 591 MPa. However, the tensile strength of samples with soak time of 6 hour, 24 hour and 48 hour was 513 MPa, 482 MPa and 436 MPa, respectively. It is obvious that the mechanical property dropped dramatically after soaking treatment.

3.1.4 Failure analysis
The 7A04 aluminum alloy used in circuit breaker was rolling formed. The grains stretched along the rolling direction during forming process which allowing the intercrystalline corrosion developed into peeling corrosion along the direction of rolling plane. The 7A04 aluminum alloy possessed native denudation sensitivity which was determined by its composition. In order to improve the antistrip performance, overaging and regression re-aging treatment were usually applied. Due to the strict requirements of these heat treatment process in terms of heat preservation temperature and holding time, manufacturers often obtained unqualified products which easily leading to exfoliation corrosion.

3.2 Vertical links
Some circuit breaker in 110kV substations once broke down in July, 2013. The cracked circuit breaker was type LW36-126 with vertical links which was composed of 1Cr18Ni9 stainless steel. Expanded examinations aimed at the same batch revealed that 51 vertical links had similar defects. However, there were spreading cracks in 3 of these samples.

3.2.1 Visual inspection and physico-chemical tests
The vertical link bended near the thread joint and cracked right at the thread root. As is shown in Figure 1, on sign of oxidation corrosion was observed in the fracture.

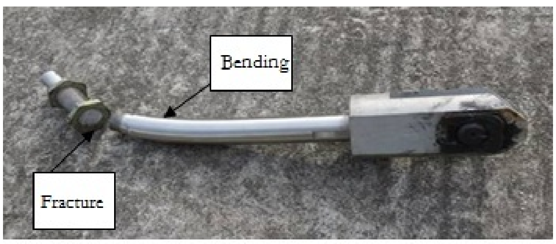


Figure 4. Macrograph of cracked vertical link.

The metallographic observation result indicated that the matrix structure of hoop were composed of ferrite, pearlite and bulky ribbon inclusions. The metallograph was shown in Figure 5. Corresponding chemical composition analysis result indicated that the cracked vertical link meets the standard requirements of GB/T 1220-2007.

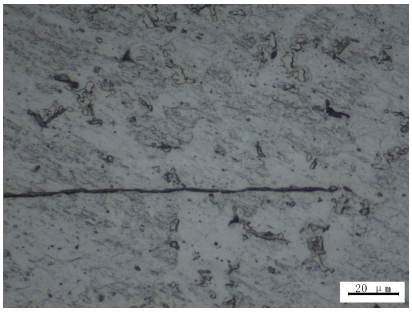


Figure 5. Metallographic structure of hoop.

The mechanical properties test illustrated that the tensile strength, yield strength and elongation was 592 MPa, 163 MPa and 48.7%, respectively. However, according to the standard requirement of GB/T 1220-2007, the yield strength of 1Cr18Ni9 stainless steel should be no less than 205 MPa. The sample was considered as an unqualified product.

3.2.2 Fracture analysis

Fracture morphology analysis showed that the fracture comprised of three parts: semi-arc fatigue crack source, smooth crack propagation extent and ultimate fracture region, as is displayed in Figure 6. Distinct fatigue striations were also found in further FE-SEM analysis which also declaring the feature of fatigue-broken, as showed in Figure 7.

Figure 6. Macrograph of vertical link fracture.

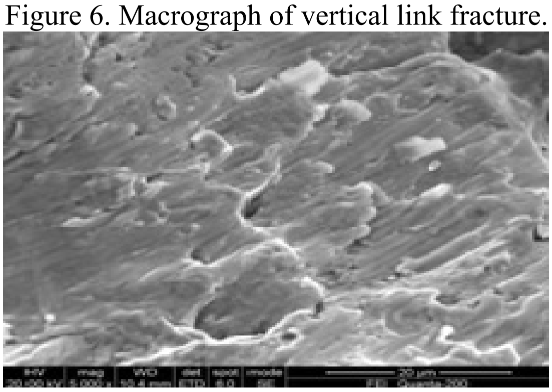
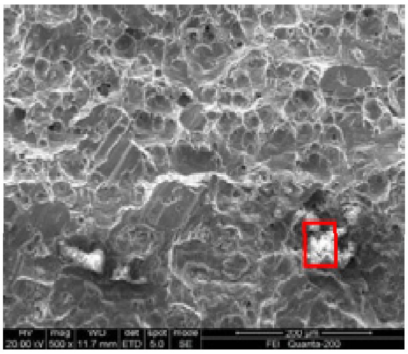


Figure 7. FE-SEM picture of fatigue striations.

Electron dispersive spectrum (EDS) of fracture indicated that there were inclusions mainly containing Zn and O randomly scattered around which may be residual deoxidizer during smelting process of link.Corrsponding data was displayed in Figure 7.



E	At%
CK	13.36
OK	55.69
SK	05.09
ZnK	21.93

Figure 8. FE-SEM and EDS results of fracture.

The microstructure picture of cracked link was showed in Figure 7. There were many large second phase particles distributed on austenitic matrix. The EDS analysis results indicated that the second phase were mainly composed of Fe and Cr, as seen in Figure 8. The microstructure of link seemed quite abnormal that Cr was enriched in massive large second phase. In addition, the sample exhibited comparatively large magnetism which further verified the sample was not fully austenitized.

3.2.3 Failure analysis

The manufacturer only examined the composition of 1Cr18Ni9 stainless steel leaving the microstructure analysis out. No solid solution was performed to most of the product unless there were special requirements. Hence, insufficiency of solid solution and inhomogeneity of structure rendering the 1Cr18Ni9 stainless steels were not suitable while used as main load bearing rotating components.

4.CONCLUSIONS

In consideration of above discussions, the production process of connecting levers and vertical links in circuit breaker and corresponding necessary testing should be paid attention to. Failure analysis conclusion and treatment measures were proposed as follows.

a) The reason of connecting lever peeling corrosion could be attributed to the unqualified heat treatment aging. The cracked connecting lever should be replaced by new one after anodic oxidation treatment. The thickness of oxide film should be no less than 15 μm.

b) The rupture of vertical link was mainly caused by insufficiency of solid solution and inhomogeneity of structure. Solution treatment was indispensable for 1Cr18Ni9 stainless steel while used as main load bearing rotating components. Otherwise, the 1Cr17Ni2 stainless steel should be a better choice instead of 1Cr18Ni9 stainless steel.

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