Fracture analysis of casting connector for power grid equipments

JunWang*, ChaoFeng, YiXie, HuLian, YiLong, DengkeLi, WeikeLiu and KejianOuyang

State Grid Hunan Electric Power Company Limited Research Institute, Changsha 410007, China
*Corresponding author’s e-mail:676459812@qq.com

Abstract. Various failures of casting connector were discussed here. In order to analyze the failure reasons of different samples, a series of tests were carried out, such as macro check, metallographic observation and X-ray penetration method. It turned out that the material defect, casting defect and improper heat process are assigned to be the main reason, respectively. In addition, the corresponding countermeasures were also proposed to improve the quality of power grid equipments.

1. Introduction
In recent years, with the rapid development of electric power construction, power grid casting connectors were widely used. As the structure of the casting is relatively simple and almost no threshold for the manufactures, product qualities were not granted. Due to the insufficient attention on product quality control, coupled with the defects generated in the manufacturing process of material selection, casting and heat treatment, defective critical equipment casting structures enter the grid and came into service. Because of the above situation, a large number of casting failure and fracture accidents occurred which is extremely detrimental to the safe and economic operation of power grid.

In this paper, the fault of casting connector caused by material, casting process and heat treatment is studied. In combination with consulting design, macro inspection and metallographic observation, the failure reason were found and the corresponding measures concerning about construction acceptance and operational maintenance were also put forward.

2. Experimental Section
The failed casting connectors for power grid equipment were collected from transformer substation in service. Themorphologies and structures of the samples were analyzed by metallurgical microscopy (Zeiss microscope). The X-ray detection was conducted via digital radiographic imaging system (GE corporation).

3. Results and Discussion
3.1. Material defect
In April 2013, the fork of one switch universal joint in some 110kV substation broke, as shown in figure 1. The design material of fork is ZG35 which equivalent to the ZG270-500. According to the report of the staff of the power supply company, the broken universal joint fork is a newly replaced...
spare part which broke during the debugging of the isolating switch. It was found that the carbon content of the actual material of the fractured universal fork was only 0.17% which only meets the carbon content standard of ZG200-400. Therefore, the main reason for the fracture of universal joint fork is that the material is lower than the design requirements and cracks has already emerged on the surface.

![Figure 1. Fracture morphology of universal joint.](image1)

The metallographic structure of the fractured universal joint fork was pearlite and ferrite, displayed in Figure 2. And the pearlite content in the sample was significantly lower than that of the ZG35 universal joint fork which compared as contrast sample (as shown in Figure 3). This indicated that the carbon content of failure sample was too low which was consistent with the results of component analysis. ZG35 steel belongs to carbon steel castings which is equivalent to ZG270-500 according to standard GB/T 11352-2009. Carbon is the most important element of material strengthening in these steels. Generally the carbon content of ZG35 steel is 0.32-0.39%, while the actual carbon content of the fractured universal fork is only 0.17% which is far below the standard requirements.

![Figure 2. Metallographic structure of fractured universal joint fork.](image2)

![Figure 3. Metallographic structure of the contrast universal joint fork sample.](image3)

3.2. Casting defect
In May 2012, the GW35 switch vertical connecting rod hoop broke during the maintenance of some 500kV substation. The hoop design material is die-cast aluminium YL112. The fracture is located in the middle of the hoop with a relatively even fracture. It exhibited a typical brittle fracture feature with no trace of plastic deformation around it. At the same time, there are typical casting defect pores on the fracture which is shown in Figure 4. There are many pores in the metallographic microstructure of failed hoop, as shown in Figure 5. The pores have a large size up to 1251μm with many loose tissues scattering around the pores.
Further X-ray inspection revealed that the fracture hoop was not dense in structure and there were many dark shadows in the X-ray film (as shown in Figure 6) which indicating poor casting quality. If the supplier changes the casting method and adopts steel mold for casting, the organization of the hoop is very dense and there is almost no shadow in the X-ray film (as shown in Figure 7). This indicated that high quality products could be obtained as long as the casting process was well controlled.

According to the standard requirements of DL/T 768.5-2002, the important parts (mechanical loading parts) of the casting aluminium parts of power grid fittings are not allowed to have defects such as porosity, sand hole, slag hole and so on. However, the macroscopic examination and metallographic analysis results revealed that there are many defects in the failure hoop including pores and porosity. The existence of pores and porosity would likely to cause local stress concentration and become the crack source of material fracture. It will significantly reduce the bearing capacity of casting and eventually lead to the fracture of hoop.

3.3. Heat treatment
In November 2013, some wire clip with the mode of TL-300 broke in the process of punching. The wire clip was produced by sand casting being T4 heat treated which the designed material is ZL101. The T-shaped wire clip was clamped in the front end of the drainage plate, and the fracture was brittle fracture without obvious plastic deformation trace. Meanwhile, its surface was smooth, flat and free of pores and other defects, as shown in Figure 8. The metallographic structure of fractured wire clip is alpha aluminium-based solid solution and acicular Al-Si eutectic structure, as is shown in Figure 9. However, the metallographic structure of ZL101A after solid solution and aging heat treatment should be the combination of alpha aluminium-based solid solution and granular eutectic structure. Obviously the microstructure of this wire clamp is not qualified.

After being heat treated, Al-Si eutectic crystals exhibit the characteristics of granular distribution. In this way, the mechanical properties of alloys, especially the plasticity could be greatly improved. However, the structure of the failed wire clip is aluminium matrix and acicular Al-Si eutectic structure which is not heat treated. The aluminium-silicon eutectic structure of the wire clip is relatively thick which seriously weakening the continuity of the aluminium-base solid solution. It is likely subjected to stress concentration which reducing the mechanical properties of the alloy, especially the reduction of its plasticity. In the case of wire clip without heat treatment, it is easy to break under comparatively
high impact due to big brittleness. Therefore, the main reason for the fracture of TL-300 wire clip is the unqualified structure and big brittleness which resulted from being not heat treated.

4. Conclusions
According to the failure analysis in recent years, there are three main types of defects in grid casting connector including material defect, casting defect and heat treatment.

In order to improve the health condition of power grid equipment, it is necessary to strengthen the technical supervision of the metal parts of the equipment. For one thing, casting manufacturers should improve technology and strengthen quality management to avoid unqualified products being supplied. For another, the power grid construction and operation and maintenance units should also strengthen the inspection of equipment entering the network and the acceptance work in the construction stage, so as to minimize the operation of equipment with defects.

Acknowledgments
Authors wishing to acknowledge assistance or encouragement from colleagues, special work by technical staff or financial support from organizations should do so in an unnumbered Acknowledgments section immediately following the last numbered section of the paper.

References
[1] Zhao, J., Xu L., Wang S.Q., Liu J. (2011) Experimental study on austenite stability of electric power energy saving fittings. Foundry Technol., 32:328-331.
[2] Chen, Q.Y., Wang L.F., Ma H., Cai X.H., Gao Y.B., Shui T., Wang Q. (2019) Study on bulging mechanism and preventive measures of tension clamp in long-term service. Electric Eng., 12:44-45.
[3] Huang J.L., Lin J.F., Wei P.C. (2019) Discussion on prevention measures for the corrosion fracture of the tension clamp in the large diameter conductor. Guangxi Electric Power, 42:66-70.
[4] Wang J.G., Jiang W.D., Luo H.J., Li Q.Q. (2019) Numerical simulation of welding residual stress of 1050 aluminum strain clamp. Hot Working Technol., 48:212-219.
[5] HU J.Z., Luo H.J., Zhang J., Zhou Y.T., Zou J.W. (2019) Analysis and prevention of outlet casing clamp cracking of transformer. Zhejiang Electric Power, 38:114-118.
[6] Lv X., Zhu L.J., (2018) Cause analysis and treatment measures of line breakage accident caused by T-clamps on transmission lines. Electric Eng., 7:65-69.