Fracture failure analysis of an escalator driving chain

Facai Ren¹, Xiaochang Liu¹, Xiao Liang¹ and Xinghua Wu¹
¹Shanghai Institute of Special Equipment Inspection and Technical Research, Shanghai 200062, PR China
Corresponding author e-mail: caifaren@163.com

Abstract. The fracture failure causes of an escalator driving chain were analyzed by the optical microscope and scanning electron microscope analysis. The surface decarbonization of the driving chain plate can be observed. From the macro and micro analysis of the fracture surface, the fracture of the driving chain is caused by fatigue.

1. Introduction
An escalator suddenly turns to the opposite direction during operation, which causes some passengers to be injured. Through the investigation of the accident scene, it was found that the driving chain of escalator was broken. As a key component of escalator and automatic sidewalk, the driving chain will lead to the separation of driving device and load once the chain is broken, which will lead to reversal accident. Therefore, the cause of driving chain failure should be revealed.

Papadopoulou et al. [1] investigated the failure cause of the in-service fractured steel pins of a chain assembly installed in a continuous cold drawing machine. The results showed that the pins failed due to multiple-origin rotating bending fatigue under low applied load. Idapalapati et al. [2] studied the failure cause of a metal chain link with stud during an anchoring operation of a ship. The results showed that the improper flash welding and heat treatment, which resulted in localised carbide segregations and embrittlement, were the main cause of the chain link failure. Al-Fadhalah et al. [3] investigated the failure causes of chain links that occurred during towing operation of heavy-weight army vehicles. The results showed that high cyclic loading, weld defects and improper post-weld heat treatment were the major causes of chain failure. Kim et al. [4] investigated the effect of chain installation condition on stress distribution. The results showed that the initial position of the chain that was installed in the hook influenced the state of stress. Zhao et al. [5] analyzed the fracture surface morphology of chain link crack by scanning electron microscopy and established the accurate virtual prototype model of excavator. Ren et al. [6] investigated the nonlinear uncertainty and actuator saturation characteristics with respect to the issue of reducing the load of a wind turbine drive train.

In this paper, the failure analysis of an escalator driving chain rupture accident was carried out. The material properties and failure causes of an escalator driving chain were analyzed.

2. Macroscopic morphology
As shown in Fig. 1, the sample is a 20A-2 double row escalator driving chain. The pitch is 31.75 mm and the width is about 83.2 mm (pin length). Fracture occurs at the bend of the middle part of the chain plate of four composite transition joints, and there is no abnormal mechanical damage around them. The outer diameter of pin shaft contacted with the direct surface of transition chain plate hole is about 9.47 mm, and the outer diameter of intermediate chain plate is about 9.03 mm after wear. The
outer diameter of pin shaft contacted with chain plate is about 8.95 mm after wear, and the outer
diameter of pin shaft contacted with sleeve is about 9.34 mm after wear.

![Fracture Escalator Driving Chain](image1)

**Figure 1.** The fracture escalator driving chain.

The fracture morphology of the transition chain plate is shown in Fig. 2. The chain plate thickness
is about 3.9 mm and width is about 30 mm. It can be seen that the shape of the four transition chains is
basically the same, and both have the same bending angle. Fractures of the four transition chains are
distributed along the corner of the arc bending angle, as indicated by the arrow in the figure. The four
fracture surfaces are silver-gray, with different areas of thickness, and the fracture propulsive pattern
on each fracture surface shows that the crack extends inward from the surface of bending angle.

The lower part of the fracture of No. ② chain plate is relatively thin, but the crystalline shape is
still visible. Small steps are visible at the left edge, while the upper part of the fracture is relatively
rough, indicating that the fracture is also a pre-cracking at the lower part of the left.

![Macroscopic Morphology of the Transition Chain Plate](image2)

**Figure 2.** Macroscopic morphology of the transition chain plate.

3. Results and Discussions

3.1. Chemical composition analysis

The chemical composition of No. ④ chain plate is shown in Table 1. The chemical composition of
chain plate is compared with 40Mn steel referring to GB/T 699-1999 < Quality carbon structural
steels >. The results show that all element contents meet standard requirements.

| Element     | C   | S     | Si | Mn    | P  | Cr | Ni | Cu |
|-------------|-----|-------|----|-------|----|----|----|----|
| Chain plate | 0.41 | 0.01  | 0.21 | 0.84  | 0.015 | 0.11 | 0.042 | 0.094 |
| 40Mn(GB/T 699-1999) | 0.37-0.44 | ≤0.02 | 0.17-0.37 | 0.70-1.00 | ≤0.025 | ≤0.25 | ≤0.30 | ≤0.25 |
3.2. Metallographic microstructure analysis
The metallographic microstructure of the No. ② chain plate is shown in Fig. 3. The morphology of the fracture initiation region is shown in Fig. 3(a). On the left side is the outer direction below the fracture surface, and the phenomenon of carbon depletion can be seen. The depth of carbon depletion layer measured by metallographic method is about 22 um. The structure is sorbite and ferrite which keeps martensite orientation. On the top of the graph is the surface of the fracture initial zone, and no oxidation and abnormal decarbonization are observed. The morphology of the bending zone on the other side is shown in Fig. 3(b). On the right is the corner surface. As indicated by the arrow, there is a small crack about 0.03mm deep. As can be seen from the figure, decarbonization occurs in the surface layer. The morphology of the surface tissue of the peripheral surface is shown in Fig. 3(c). The surface structure on the top is sorbite and ferrite, and the subsurface structure is sorbite and very small amount of ferrite. Metallographic measurements show that the depth of the depletion and decarbonization layer is about 8 um. As shown in Fig. 3(d), the structure of the chain plate central zone are sorbite, a small amount of bainite and a very small mount of ferrite.

Figure 3. Metallographic microstructure of the No. ② chain plate.

3.3. SEM Micromorphology analysis
The SEM morphology of the No. ② chain plate is shown in Fig. 4.

The morphology at low magnification of the initial zone at the corner edge of the fracture is shown in Fig. 4(a). It can be seen that there are many small steps on the edge and the section is relatively flat, which indicates that the multi-source initiation cracking under stress concentration effect. The morphology of the edge region at high magnification is shown in Fig. 4(b). On the lower side of the figure is the outer surface of the corner. It can be seen that the cracking is related to the wrinkle fringes. The cross section is quasi-cleavage and has the phenomenon of extrusion. Parallel distribution of fatigue striations can be seen in the quasi-cleavage pattern in the extended region, as shown in Fig. 4(c). On the other side of the symmetrical zone, dimples are visible, partially torn and eventually broken, as shown in Fig. 4(d).
4. Conclusion
The material of the escalator driving chain plate is 40Mn. The surface decarburization is observed with varying degrees. The fracture cause of the driving chain is the fatigue fracture caused by the bending stress concentration effect of the transition chain plate.

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