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Corrosion induced fatigue failure of railway wheels

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A B S T R A C T

Two AAR class B rolled wheels for locomotives failed after about two years of service. The fracture surfaces of the failed railway wheels were examined. The examination showed that there were corrosion pits on the back plate surface of the failed wheels. All of the fracture originated from corrosion pits at the wheel plate surface and fatigue propagated to a length and then expanded rapidly by cleavage. Fatigue specimens cut from the wheel plate were corroded with different time duration in an artificial corrosion environment to simulate the corrosion states of the wheels. The fatigue properties of the un-corroded specimens and the specimens corroded with different times were tested in air. Finite element method (FEM) and Sines' criterion were used to evaluate the safety of the wheels. The results showed that the wheel plates without corrosion pits exhibited an excellent resistance to failure. The corrosion pits could promote the initiation of fatigue cracks and drastically lower the fatigue limits of corroded specimens. The real root cause of the failure of the subject wheels was due to the corrosion pits at the wheel plate surfaces. A critical depth of the corrosion pit on the wheel plate 300 μm was recommended. Protection of the wheel plate was important to ensure the safety of wheels and the rust prevention oil was recommended to be applied on the wheel plate regularly.

1. Introduction

Railway wheels are one of the most critical components in a railway vehicle and bear cyclic complex loading system [1,2]. Wear and fatigue are the main failure mode of railway wheels [3–6]. Unlike the slow deterioration process of wear, fatigue would result in abrupt fractures of wheels which might cause serious consequences. Fatigue could occur anywhere in the wheel due to the wheel design, the axle load, the train speed and internal or surface defects etc. Therefore accurate evaluation and prediction of the fatigue performance for wheels are important issues. Moreover, experience with exiting wheels has indicated that also corrosion is a key problem that must be addressed if the structure reliability of the wheel needs to be maintained. It is almost impossible to suppress corrosion especially when the maintenance costs need to be managed within acceptable limits. Many investigations showed that prior corrosion, especially localized corrosion can degrade the fatigue resistance of metals [7–9].

In this article, a failed wheel with fatigue cracks initiated from a corrosion pit has been studied. During service, the wheels suffer fatigue loading all the time, but suffer corrosion not all the time. During non-operating period, corrosion may develop, but fatigue would not. The effects of prior corrosion on the fatigue limit of the wheel steel were investigated here. However the synergetic effect of both corrosion and cyclic loads [10–12] were not considered. Fatigue properties of the wheels with and without corrosion damage were assessed by FEM.

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2. Examination of failed wheel

A few rolled wheels for locomotives made in accordance with Association of American Railroads (AAR) class B standard [13] failed after about two years of service. The composition (in weight percent) of the wheels was C 0.63, Si 0.87, Mn 0.80, S 0.014, P 0.010, Cr 0.17, Ni 0.011, Cu 0.028 and balanced Fe. The diameter of the wheel (at taping line) was 1066 mm (42 in.). Visual examination, scanning electron microscope (SEM) examination and metallographic examination of two wheels were performed.

One of the failed wheels (No. 1) as received is shown in Fig. 1. Inspection of the wheel reveals a fatigue crack extended through most of the plate. The extent of fatigue crack is highlighted with the black arrows. Outside the fatigue crack frontier there is the fracture surface caused by abrupt break of the wheel. For more detail, fatigue crack appeared to originate from a surface discontinuity most likely a corrosion pit in the back plate surface and the plate appeared to contain a few more pits, as shown in Fig. 2. The distance from the fatigue crack origin to the center of the wheel is 353 mm.

The section with the corrosion pit which fatigue crack may be originated from was examined using SEM after the rust was removed from the crack surface using 3.6 g/L hexamethylenetetramine + 50% hydrochloric acid aqueous solution. The examination showed fatigue crack originated from a corrosion pit, see Fig. 3. The maximum depth of the pit is 0.8 mm, the length of the pit is about 4.0 mm, as shown in Fig. 3(a). The half width of the pit is about 1.0 mm, as shown in Fig. 3(b). So the shape of the pit is like a semi ellipsoid. The fatigue fracture surface outside the corrosion pit is quasi-cleavage, as shown in Fig. 3(c), and no fatigue striations can be found.

The fracture surface around the fatigue crack frontier (rectangular box zone in Fig. 1) is shown in Fig. 4. There is an obvious boundary between the fatigue crack and the fracture surface caused by abrupt break of the wheel, as shown in Fig. 4(a). The fatigue crack surface is quasi-cleavage and the fracture surface caused by abrupt break is typical cleavage, as shown in Fig. 4(b).

Metallographic specimens with dimensions of about 20 mm × 20 mm × 20 mm close to the fatigue crack origin were removed from the wheel plate using the wire-electrode cutting method. The cross section of the wheel plate were mounted, polished, and examined using the Clemex Vision System. Examination of the specimens revealed more corrosion pits in the back plate surface, as shown in Fig. 5(a). However, no obvious corrosion could be observed in the front plate surface, as shown in Fig. 5(b).

The specimens cut from the fatigue crack origin were etched with 3% Nital to reveal the microstructure. The examination showed a typical pearlitic microstructure as would be expected, see Fig. 6. No obvious fatigue cracks initiated at other corrosion pits was observed.

The morphology of the back plate surface is shown in Fig. 7. Fig. 7(a) shows the surface morphology near the fatigue crack origin. The 3-dimension morphology of the surface was measured using a ContourGT-X3 optical metrology, as shown in Fig. 7(b). The average roughness of the surface was 28 μm and the maximum depth of the corrosion pits was 220 μm. The status of corrosion on the back plate surface was not uniform. In some areas, no obvious corrosion could be found except shot peening indentations, as shown in Fig. 7(c). The 3-dimension morphology of the surface is shown in Fig. 7(d). The average roughness of the surface was 14 μm and the maximum depth of the shot peening indentations was 81 μm.

The other failed wheel (No. 2) as received is shown in Fig. 8. Inspections of the fracture surfaces reveal two fatigue crack surfaces, shown as Fig. 8(a). The fatigue crack surfaces are labeled as fatigue crack surface A and fatigue crack surface B. Fatigue crack surface A extended through almost half of the plate along the circumferential direction and fatigue crack surface B is like a semi ellipse, as shown in Fig. 8(b) and (c). The lengths of the short semi axis and the long semi axis of the semi elliptical crack B were 10 mm and 51 mm respectively. Fatigue crack surface A and B had a crack origin, i. e. fatigue crack origin A and B, respectively. The distances from the fatigue crack origin A and B to the center of the wheel were 377 mm and 338 mm respectively.

The morphology of fatigue crack origin A is shown in Fig. 9. The fatigue crack appears to originate from the plate surface, as shown in Fig. 9(a). The SEM morphology of fatigue crack origin A from the fracture surface direction is shown in Fig. 9(b). Fatigue crack origin A is a corrosion pit with the maximum depth about 0.4 mm and the length about 2.0 mm. In Fig. 9(c), the half width of the pit was about 1.0 mm. So the pit is a shallow-wide type. But the boundary of the pit is not as sharp as the pit shown in Fig. 3.

The morphology of fatigue crack origin B is shown in Fig. 10. The fatigue crack appears to originate from a surface discontinuity like a corrosion pit. Around the fatigue crack origin A, some other surface discontinuities were found, as shown in Fig. 10(a). The SEM

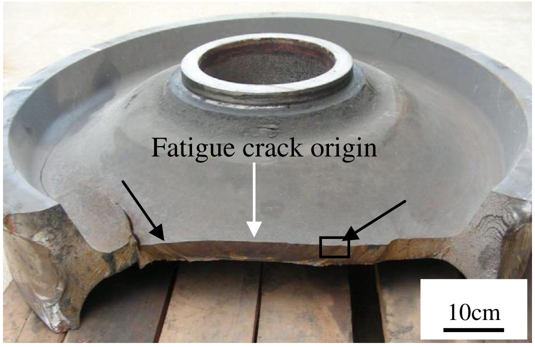

Fig. 1. The failed wheel No. 1 as received.