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TESTS TO CREATE BROKEN RIMS IN RAILROAD WHEELS

SUMMARY

Though relatively rare, broken wheel failures are of concern to the railroad industry due to potential safety implications and expense. Vertical split rim (VSR) cracks usually propagate to the front rim fillet, but can sometimes propagate to the back rim fillet, resulting in a broken flange. Figure 1 shows an example of a VSR failure.

Figure 1. Vertical Split Wheel Rim

The FRA Office of Research, Development, and Technology and the Association of American Railroads (AAR) support research conducted by Transportation Technology Center, Inc. (TTCI) on the root cause of wheel-related accidents. The purpose of project was to improve wheel performance by gaining a solid understanding of the root causes of broken wheel rims and flanges.

Previous work on this project improved the confidence in a working theory about the root cause of VSR failures in railroad wheels. However, two attempts to replicate the VSR failure mode under controlled conditions in the laboratory were unsuccessful after approximately 7 million load cycles at wheel/rail loads as high as 90,000 lbs. Post-test destructive evaluation of the wheels revealed large horizontal cracks with short vertical crack branches. The horizontal cracks were found at a typical radial depth of 0.15 inch – nearly the same radial depth as the VSR crack origins identified during wheel inspections. Analysis showed that the cracks propagated in a transgranular fashion, indicating that material weakness was not a primary cause for the crack development in these two wheels. More research is needed to better understand VSRs and to assess the best potential mitigation methods.

VSRs are thought to be the result of tread damage on the wheel surface in the form of a shell or spall that initiates cracking in the rim and produces impact loads when it comes in contact with the rail. If the crack propagates vertically into an area of tensile residual stress in the wheel rim, further crack growth is encouraged until a portion of the rim breaks free from the wheel.

BACKGROUND

Wheel rims typically break in modes (VSRs) or shattered rims. A VSR is a crack approximately parallel to the bearing end cap, and a shattered rim is a crack usually found parallel to the tread surface. The shattered rim failure mode has been well researched, and AAR has instituted changes necessary to reduce the occurrence of this type of failure, including improved ultrasonic inspection of wheels and the use of impact load detectors. The current work is focused on VSR and broken flange failure modes that have not been reported outside North America. These related failure modes are the result of cracks in the wheel rim oriented vertically (parallel to the back of the flange). The cracks appear to grow in bursts rather than classical fatigue or from a single fracture.

One previous attempt to create a VSR under controlled conditions is described in the literature [1]. A drop hammer machine was used to deliver loads in excess of 200,000 lbs to a service-worn wheel that had developed shelling on the tread. The test could not produce a VSR failure in the wheel and was halted after 30,000 impact events.

OBJECTIVES

The purpose of the project was to identify measures for improving wheel performance by gaining a solid understanding of the root causes of broken wheel rims and flanges.

METHODS

An existing rolling load machine was modified in an attempt to create a VSR in the laboratory.

This machine longitudinally cycled a short piece of rail (approximately 3 feet long) back-and-forth under a stationary wheel. The machine was modified to allow fine lateral position control for a service-worn wheel and to increase the maximum wheel/rail vertical contact force to 90,000 lbs.

Two service-worn wheels originally mounted on the same wheelset as VSR wheels were selected for testing. Ultrasonic testing had shown these wheels to have a large subsurface horizontal crack. The wheels were installed on the test machine so that the field side edge of the horizontal crack was approximately in the center of the contact patch between the wheel and rail. The wheels were scanned daily with a handheld ultrasonic testing device, and the crack area was estimated by noting the edges of the horizontal crack.

RESULTS

For the first wheel, the vertical load was set to 60,000 lbs at the beginning of the test. After 4.5 million load cycles, the load was increased by 10,000 lbs approximately every million load cycles until the maximum load rating for the machine was achieved. The test was intended to force the horizontal crack to turn vertically. Instead, the horizontal crack expanded in area early in the test and then stopped growing until the vertical load was increased. The initial area of the crack was 1.4 square inches and grew to 3.4 square inches. After 6.8 million load cycles, the test was stopped because the machine could no longer cycle the rail. The combination of a large contact force and radial runout from wear and deformation on the wheel surface created too much resistance.

The second test wheel with a 4.3-square-inch, pre-existing horizontal crack was installed on the test machine. The vertical load was initially set to 50,000 lbs and increased by 10,000 lbs approximately every million load cycles up to the machine maximum. After 7.4 million load cycles, the machine experienced a failure in one of the support posts, and the test was stopped. The crack area in the wheel did not change appreciably during this test.

Following the tests on the rolling load machine, each wheel was sectioned, and the cracks were viewed under a microscope. Horizontal cracks were found at a typical radial depth of 0.15 inch – similar to the radial depth of the VSR crack origins identified during wheel inspections. Multiple, short vertical branches were found stemming from the main horizontal cracks. Figure 2 shows the longest vertical branch, about 350 μm at the end of a horizontal crack.

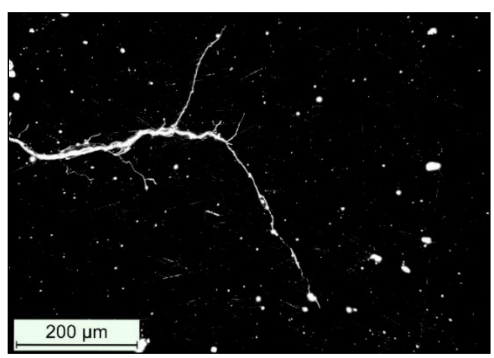

Figure 2. Dark Field Optical Microscopy Shows a Horizontal Crack with Multiple Vertical Branches

The crack propagation paths of selected cracked specimens from the rolling load test wheels were further investigated using a scanning electron microscope (SEM). Understanding the propagation path of a crack can help define the relative influence of high stress levels and localized material weaknesses. The polished samples were etched with a saturated solution of picric acid to show the microstructure, including the boundaries between prior austenite grains. The horizontal cracks and the vertical crack branches examined in the samples removed from the two wheels that failed to develop VSR cracks all showed crack propagation through the middle of the grains (transgranular) rather than between prior austenite grain boundaries (intergranular). This was a strong indication that high stress levels were the main driving force in the crack propagation of these two wheels. If the cracks had followed prior austenite grain boundaries, it would have indicated that material weakness played a large role in the crack development. Figure 3 shows a typical example of a crack in one of the test wheels as viewed through the SEM.

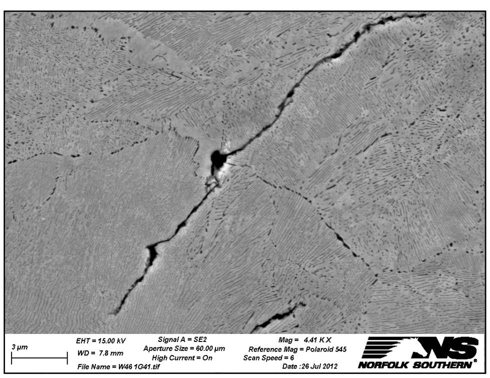

Figure 3. Transgranular Crack Propagation

CONCLUSIONS

Two service worn wheels with large, naturally occurring, subsurface horizontal cracks were cycled on a rolling load test machine at wheel/rail forces as high as 90,000 lbs in an attempt to create a VSR wheel under controlled conditions. In each case, the test machine failed after about 7 million load cycles and the test was stopped. Neither test wheel developed a VSR crack, although post-test destructive evaluation revealed short vertical crack branches in both wheels. SEM analysis showed that the cracks propagated in a transgranular fashion, indicating that material weakness was not a primary cause for the crack development in these two wheels.

FUTURE ACTION

Additional research is needed for VSRs. The relationship between the number of load cycles and VSR crack size is not well understood, including the influence of parameters such as load magnitude, impact, ambient temperature, and lateral position of the contact patch on the wheel tread.

REFERENCES

1. Lonsdale, C., Rusin, T., and Hay, T. (March 2009). Research to Understand the Effects of Wheel Impact Loads on Wheel Stress Levels. *Proc. ASME JRC Conf.* JRC2009-63026.

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KEYWORDS

Wheel, broken rim, vertical split rim