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Inspection Results and Impact Load History of Vertical Split Rim Wheels

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Summary

Thirty-five wheels with vertical split rim (VSR) or broken flange failures were recently visually inspected and evaluated for impact load history by Transportation Technology Center, Inc. (TTCI) and a group of wheel experts, as part of the Association of American Railroads' (AAR) Strategic Research Initiatives (SRI) Program to prevent wheel failures. The Federal Railroad Administration (FRA) has since provided cooperative funding for additional analysis and testing of these wheels, to be reported in future FRA reports and *Technology Digests*.

The wheels showed much diversity with respect to manufacturing method, diameter, design, and wear. The most consistent aspect of the broken wheels was the radial depth of the failure origin below the tread surface (0.1 inch to 0.25 inch in all cases). Most of the wheels had visible shells in the immediate vicinity of the failure origin, and 16 of the wheels had exceeded 90,000 pounds impact load prior to removal from service.

Results from the 2011 SRI evaluation of 35 broken wheels agreed well with a 2008 evaluation of 71 VSR and broken flange wheels,[1] with the exceptions that in the current study the wheels were typically newer and had less wheel tread hollowing.

Further analysis planned for the VSR and broken flange wheels includes optical microscopy evaluation and axial residual stress testing. Shallow subsurface horizontal cracks are being investigated with radiography and scanning electron microscopy. TTCI will attempt to create a VSR wheel under controlled conditions using a service worn wheel with a preexisting horizontal crack to explore the relationship between shallow horizontal cracks and the VSR failure mode.

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INTRODUCTION

This *Technology Digest* (TD) describes the results of visual inspections and analysis of impact loads from wheels that failed in service due to VSR or broken flange. This work was conducted as part of the AAR's SRI to prevent wheel failures. The FRA has since provided cooperative funding for additional analysis and testing of these wheels, which will be reported in future FRA reports and TDs.

BACKGROUND

TTCI requested and received a total of 29 VSR wheels and six broken flange wheels from three different railroads to analyze the fracture surfaces and conduct laboratory tests. VSR and broken flange wheels are thought to be the result of related failure modes. Figure 1 shows photos of a VSR wheel and a broken flange wheel.

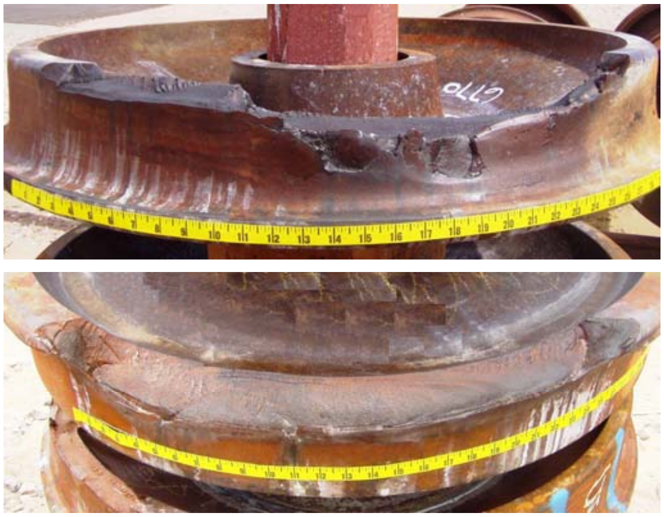

Figure 1. Wheels with VSR (Top) and Broken Flange (Bottom)

Basic data was collected from the wheels regarding manufacturer, manufacture date, bearing locking plate date, car number from which the wheelset was removed, removal date, and rim thickness. Next, wheel profiles were recorded for each wheel and analyzed for flange height, flange thickness, and tread hollow. After TTCI completed the initial inspection, a group of wheel experts was convened to visually inspect each wheel tread surface for evidence of shelling and spalling and determine the failure origin location based on any low-cycle fatigue "beach marks" that developed during failure.

Results of a similar exercise were reported in 2008.[1] At that time, 71 VSR and broken flange wheelsets were evaluated. The 2008 study showed the following:

- VSR typically occurs between 1 inch and 2.75 inches from the front rim face.
- VSR failures progress in "jumps"—not classical fatigue and not a single fracture.
- The origin of the VSR is typically near a tread defect such as a shell or spall, but not always.
- VSRs can be found in wheels with a wide variety of diameters, designs, wear (rim thickness, flange thickness, and tread hollow), manufacturing methods, and can occur under many different car types and car gross tonnage ratings.
- Ten years was the most common service life for VSR wheels (manufacture date to failure date).
- Most VSR wheels have elevated levels of impact load prior to failure. However, more than half were below condemning limits, and about 15 percent showed no notable impact loads.

INSPECTION

Thirty-one of the broken wheels inspected by TTCI were cast and four were forged. All of the wheels were AAR Class C. The wheelsets were removed from a variety of car types including 11 covered hoppers, nine coal hoppers or gondolas, five boxcars, four stack cars, three flat cars, and two tank cars. The gross tonnage ratings of the single unit cars were as follows: 16 cars at 110 tons, 14 cars at 100 tons, and one car at 70 tons. Single-wear wheel designs outnumbered double-wear designs by 24 to 11. Any wheelset in which the bearing locking plate date was more than a few months newer than the wheel manufacturing date was assumed to have been reprofiled at least once. Using this methodology, it was determined that 18 of the broken wheels had been reprofiled, and 12 were in their initial life cycle. Bearing locking plate dates were not available for the remainder of the wheelsets. Median time from manufacture to failure was 5.4 years, with a maximum of 18.0 years and a minimum of 8 months. Median time from bearing locking plate date to failure was 2.3 years, with a maximum of 10.6 years and a minimum of 8 months.

Rim thickness of the VSR wheels ranged from 0.88 inch to 1.94 inch, with a median rim thickness of 1.31 inch. Rim thickness of the broken flange wheels ranged from 1.0 inch to 1.19 inch, with a median rim thickness of 1.13 inch. Although rim thickness generally did not correlate with the maximum impact load of the wheel prior to failure, all four wheels with maximum impact loads less than 60,000 pounds had relatively thin rims (1.125 inches or thinner).

One VSR wheel was found to have a severe 0.234 inch hollow tread as the apparent result of sustained contact between the tread surface and the brake head. Figure 2 shows a cross section of this wheel. Six of the other broken wheels inspected had tread hollow ranging from 0.0195 inch to 0.117 inch.

Flange thickness of the broken wheels ranged from 1.01 inches to 1.38 inches, with a median of 1.25 inches. The VSR wheel with the brake head wear had a flange that was 0.33-inch thinner than its mate. For all of the other wheelsets inspected, the broken wheel and mate wheel had similar flange thicknesses typically within 0.1 inch. Flange height of the broken wheels ranged from 1.01 inches to 1.48 inches with a median of 1.18 inches. Flange height differences between the broken wheel and its mate were typically less than 0.05 inch and never more than 0.15 inch. Flange thickness, flange height, and tread hollow were similar between the broken flange wheels and the VSR wheels.

Figure 2. Cross Section from an Unusual VSR Wheel Showing Wear Groves in the Tread and Flange from Apparent Contact with the Brake Head

The location of the origin of the failure was determined by visually examining the failure surface. VSR and broken flange wheels usually exhibit faint markings on the failure surface that show the direction in which the crack propagated. By tracing these marks backwards, an origin point was established for each broken wheel. The radial depth of the origin point was then established relative to the existing tread surface, and the axial location was established relative to either the front rim face or the back of the flange. Origin radial depths were similar for both VSR and broken flange wheels and ranged from 0.10 inch to 0.25 inch below the tread surface, with a median value of 0.17 inch. Figure 3 shows a histogram of the origin radial depth relative to the worn tread surface. For VSR wheels, axial locations of the origin ranged from 1.25 inches to 2.60 inches from the front rim face, with a median value of 2.10 inches. For broken flange wheels, axial locations of the origin ranged from 3.00 inches to 3.75 inches from the front rim face, with a median value of 3.25 inches.

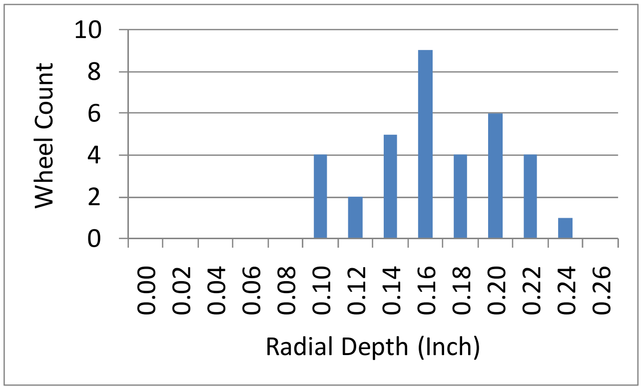

Figure 3. Histogram of Failure Origin Radial Depths

Figure 4 shows the axial and radial locations of the failure origins. The radial dimensions of this figure have been referenced to brand new wheel profiles by incorporating the origin radial depth below the worn tread surface and the tread wear as determined by the difference in the measured rim thickness from the nominal rim thickness. Although the origins are at a consistent radial depth from the worn tread surface, the radial depth varies considerably when referencing the new wheel tread surface. This is an indication that broken wheels are not typically the result of microstructures such as bainite or martensite that can inadvertently be formed near the tread surface from the quenching operation during the manufacturing heat treatment.

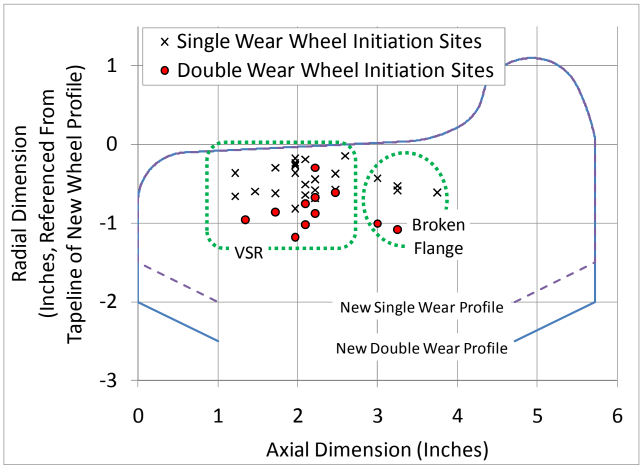

Figure 4. Origin Locations Relative to New Wheel Profiles – Note: This Figure Does Not Indicate the Radial Depth Relative to the Worn Wheel Tread Surface

Shells were noted on the tread surface in close proximity to the origin point for 23 of 29 VSR wheels and all six broken flange wheels. Usually, when tread damage is the result of a wheel sliding event, martensite is present on the tread surface. Etching the tread surface near the shells of the broken wheels did not reveal any martensite, implying that the shells were not the result of a wheel sliding event. Rolling contact fatigue and thermal mechanical shelling are the likely causes.

IMPACT LOADS

The wheel impact load detector (WILD) data history from each broken wheel was queried from Inte*RRIS*®. Figure 5 contains a histogram of the highest impact load for each broken wheel up to and including the official failure date. For some wheels, the failure may have occurred prior to passing a WILD site; and therefore, the impact load would indicate the conditions after the failure rather than the conditions immediately prior to failure. Sixteen of the broken wheels analyzed had exceeded the AAR condemning limit of 90,000 pounds impact load prior to removal.

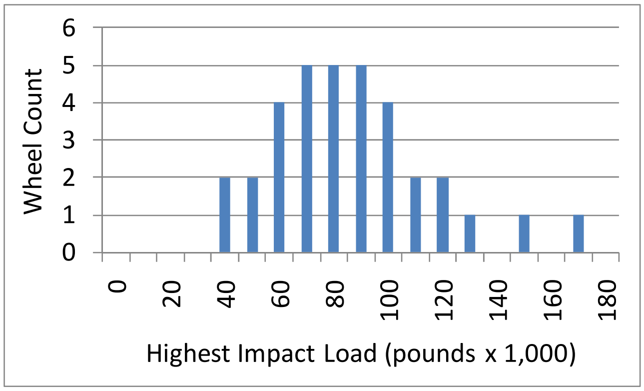

Figure 5. Histogram of WILD Data

Another way to analyze WILD data is by calculating "kip days." A kip is a unit of force equal to 1,000 pounds. The kip day calculation is a way to identify wheels that have been producing noncondemnable impact loads for a long time. A wheel begins accumulating kip days the first time it exceeds 30,000 pounds dynamic load (i.e., maximum impact load minus average load). Each day thereafter, the highest impact load (in kips) experienced by that wheel is added to the kip days total for the wheel. For example, a wheel with a maximum impact load of 70,000 pounds would have a daily accumulation of 70 kip days. The kip days total for a wheel is set back to zero when the wheelset is changed. One railroad has suggested that 11,000 kip days could used as a limit. A wheel with a 65,000-pound maximum impact load would accumulate 11,000 kip days in just less than 6 months. Figure 6 shows that if an 11,000 kip day removal criteria was used as well as the current 90,000-pound impact load limit, 24 of the 35 broken wheels would have been condemnable based on WILD readings.

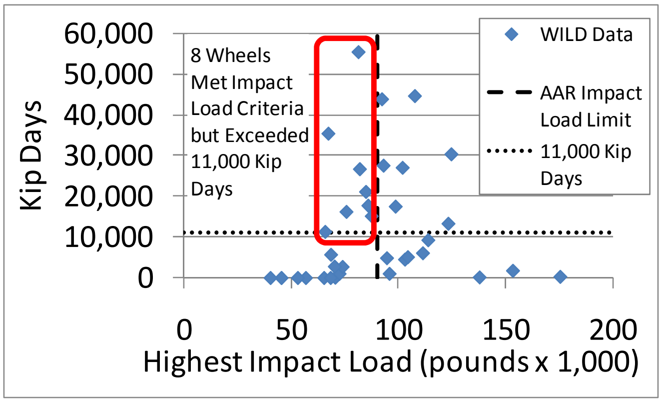

Figure 6. Kip Days and Highest Impact Loads

The kip days calculation is one way to monitor the overall damage sustained by a wheel rather than just the maximum impact load produced. Because different cars move different distances per month, the kip days criteria could give similar values for a car that had traveled 50,000 miles with 65 kip impacts and a car that had traveled 1,000 miles with 65 kip impacts. A distance-based parameter may be more effective than a time-based parameter at identifying wheels sustaining a large number of cycles of impact load. A kip miles criteria could be used to evaluate wheels once suitable data collection and storage of individual car mileage becomes available. Such a database is expected from Railinc in 2011.

CONCLUSIONS

Inspection and analysis of WILD data from 35 VSR and broken flange wheels showed the following:

- The wheels were very diverse with respect to many parameters including manufacturing method, diameter, design, and wear.
- Origins of the VSR or broken flange were consistently between 0.1 inch and 0.25 inch below the worn tread surface.
- Most wheels (29 out of 35) had visible shells in the immediate vicinity of the failure origin.
- About half (16 out of 35) wheels had exceeded 90,000 pounds impact load prior to removal from service.
  - An additional eight wheels exceeded 11,000 kip days prior to removal from service.
- Results from this evaluation of 35 broken wheels agreed well with a previous evaluation of 71 broken wheels[1] with two exceptions:
  - Typical age of the wheel (from manufacture to failure) was much shorter (5.4 years compared to 10 years in the previous study).
  - Wheel tread hollowing was less prevalent in the current study.

FUTURE WORK

An optical microscopy evaluation of the areas around the fracture surfaces and axial residual stress testing are both underway. Shallow subsurface horizontal cracks are being investigated with radiography and scanning electron microscopy. TTCI will attempt to create a VSR wheel under controlled conditions using a service worn wheel with a preexisting horizontal crack to explore the relationship between shallow horizontal cracks and the VSR failure mode.

ACKNOWLEDGEMENTS

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REFERENCES

1. Dick, M., et al. 2008. "Characterization of Vertical Split Rim Failures," Presentation to BNSF Wheel Shelling and Failure Study Group, Topeka, Kansas.