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Broken Wheel Inspections

Daniel Stone,* Harry Tournay, and Scott Cummings

Summary

This *Technology Digest* describes an inspection of 24 wheelsets with broken wheels conducted by Transportation Technology Center, Inc. at a wheel shop in Canada. The inspection was completed to gather data to increase the industry's state of knowledge regarding broken wheels. This work was conducted as part of the Association of American Railroads' Strategic Research Initiatives program.

Findings from the inspection are as follows:

- Vertical split rim (VSR) was the dominant failure mode (71%) of the inspected wheels.
- Designs of the broken wheels included single wear, double wear, cast, forged, and a variety of diameters.
- Broken wheels and their mate wheels tend to have more hollow wear than the general population of wheels, though this may simply be a natural consequence of the age of the broken wheels.
- Failure geometry does not appear to be strongly related to rim thickness.
- Six of the twelve broken wheels for which historical wheel impact load detector data was found exceeded a 90,000-pounds impact load prior to failure.
- VSRs are initiated by brittle fractures from tread surface defects.
- The roles of impact loading and residual stress in causing VSRs are not well understood.

Other failure modes observed were vertical split flange, cracked wheel, and a combination of shattered rim and VSR. The lateral defect location of VSR wheels did not show any correlation to the mate wheel flange thickness.

Four wheels with VSRs were sectioned and de-rusted for fracture analysis. All of the fractures showed initiation from either a rolling contact fatigue initiated shell or spall defect. The depth of initiation on all wheels was approximately 0.1-inch deep crack at the bottom of the shell or spall. Fracture then occurred in a brittle manner. VSRs may be triggered by impacts. However, the appearance of VSR failures has occurred after heat-treated wheels were adopted as the standard, which may indicate that the residual stresses associated with heat-treated wheels play a part in the formation of VSRs. Additional research should be conducted to determine the subsurface axial residual stresses in the wheel rim.

*Hunter Holiday Consulting, Inc.

INTRODUCTION AND BACKGROUND

In October 2008, Transportation Technology Center, Inc. (TTCI) conducted an inspection of 24 wheelsets with broken wheels at a wheel shop in Canada. The inspection was done to gather data to increase the industry's state of knowledge regarding broken wheels, which are a significant problem. Wheels with broken rims (Federal Railroad Administration accident code E61C) were the official cause of 53 train accidents over a three-year period (2005-2007) in the United Sates and Canada. Broken rims, including VSR and shattered rim defects, were the highest ranking wheel related accident cause during that period of time based on a severity index incorporating the frequency and cost of accidents.

INSPECTION PROCEDURE

Basic information was recorded at the Canadian wheel shop based on each wheel's hub stamping including manufacturer, design (e.g., CH-36), class (e.g., Class C), serial number, and manufacture date. The date on the bearing locking plate was recorded for an estimate of the most recent truing of the wheelset. The handwritten markings on the wheel plates related to the wheelset removal from service were recorded where they were still decipherable (some wheelsets had been stationed outdoors for more than 18 months between the time they were removed from service and the inspection). The handwritten markings included the following information: date removed from service, why made code, car number, and location of wheel in car (e.g., L2).

Next, the type of defect causing the broken wheel and the dimensions associated with the defect were noted in terms of circumferential length, axial (or lateral) width, and radial depth. The rim thickness was measured with a wheel gage. The wheel profile of the broken wheel and its mate wheel were measured with a Miniprof™ wheel profilometer. Photos were taken of each broken wheel, and any other general observations were recorded.

Following the inspection, historical wheel impact load detector (WILD) readings were queried from the broken wheels. Wheel tread hollow and flange thicknesses were calculated based on the wheel profiles. The type of car was determined based on the car number.

RESULTS

The failure mode of the majority of broken wheels inspected was VSR, as Figure 1 shows. Other failure modes observed were vertical split flange (VSF), as Figure 2 shows, and cracked wheel and a combination of shattered rim and VSR, as Figure 3 shows. Table 1 contains a listing of the failure modes and wheel designs of the inspected wheelsets. Wheel designs included single wear, double wear, cast, forged, and a variety of diameters.

Figure 1. Vertical Split Rim

Figure 2. Vertical Split Flange

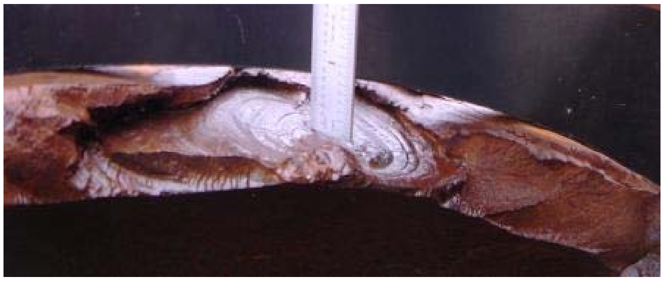

Figure 3. Radial Depth Measurement of a Wheel with Combination Shattered Rim and Vertical Split Rim

Table 1. Failure Mode and Wheel Design

Failure Mode	Count by Wheel Design							Total	Percent
	E28	CJ33	J33	CJ36	CH36	H36	CB38		
VSR	1	2	2	4	5	1	2	17	71%
VSF	0	1	0	1	0	0	0	2	8%
Shattered Rim / VSR	0	1	0	1	1	0	0	3	13%
Cracked Wheel	0	0	0	2	0	0	0	2	8%

The tread hollow of the broken wheels and their mate wheels was compared to the tread hollow of a random survey of 6,628 wheels,[1] as Figure 4 shows. It appears that the broken wheels and their mate wheels had more hollow wear than the comparison group of wheels. This is consistent with an earlier analysis of tread profiles of VSR wheels.[2] This may be a natural consequence of the age of the tread of the broken wheels (time elapsed between the bearing locking plate date and the removal from service date), as Figure 5 shows. The hollow wear rates of the broken wheels and their mate wheels show much scatter in Figure 6.

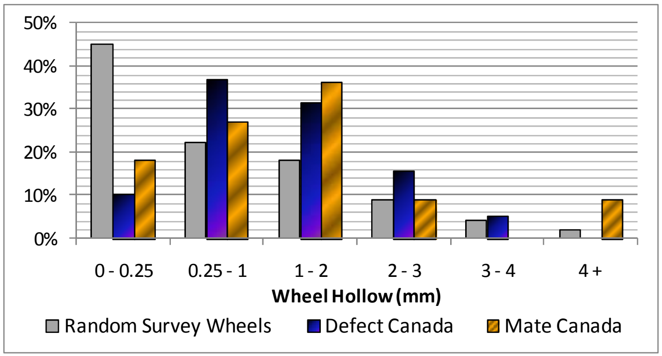

Figure 4. Wheel Hollow Wear

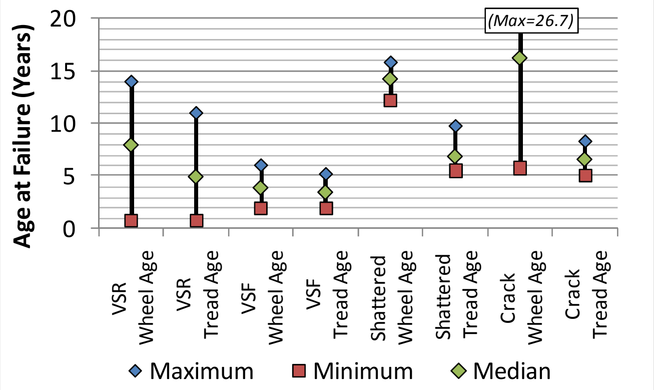

Figure 5. Ages of the Broken Wheels

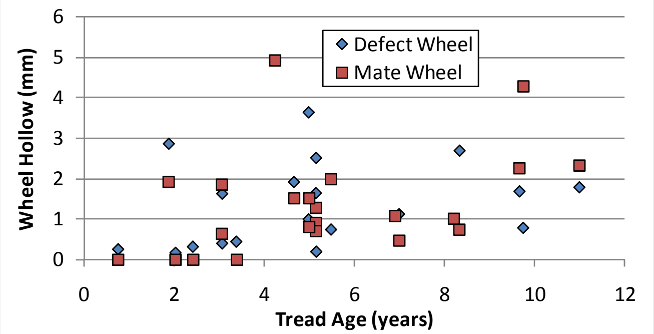

Figure 6. Wheel Hollow versus Tread Age

The radial depths of the three shattered rim defects were measured in inches to be 0.875, 0.875, and 0.625. The lateral defect location of VSR wheels did not show any correlation to the mate wheel flange thickness.

Failure geometry did not appear to be strongly related to rim thickness, as Figures 7 and 8 show. Figure 8 shows that most VSR failures occurred outboard of the tapeline. This is also where wheel shelling is most prevalent.[3] Six of the twelve broken wheels for which historical WILD data was found exceeded a 90,000-pound impact load prior to failure. The other six broken wheels did not exceed a 73,000-pound impact load prior to failure. Table 2 shows the car types of the broken wheels.

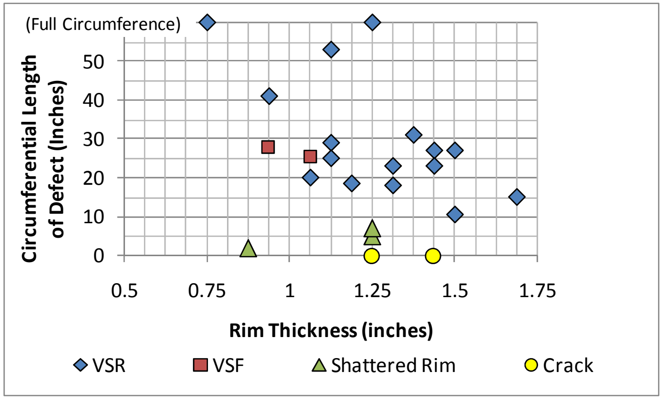

Figure 7. Circumferential Length of Defects versus Rim Thickness

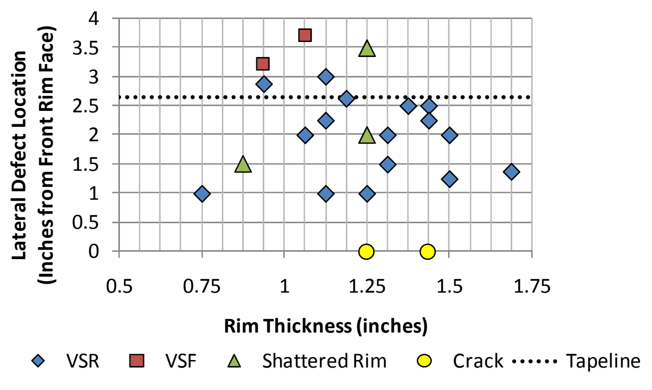

Figure 8. Lateral Defect Location versus Rim Thickness

Table 2. Car Types of Broken Wheels

Failure Mode	Count by Car Type								
	Autorack	Box	Bulkhead Flat	Center-Beam Flat	Coal Gondola	Covered Hopper	Stack	Tank	Unknown
VSR	1	2	0	1	1	2	4	2	4
VSF	0	0	0	0	1	0	1	0	0
Shattered Rim / VSR	0	0	2	0	1	0	0	0	0
Cracked Wheel	0	0	0	0	0	0	0	1	1

ANALYSIS

Four wheels with VSRs were sectioned and de-rusted for fracture analysis. All of the fractures showed initiation from either a rolling contact fatigue initiated shell or spall defect. The depth of initiation on all wheels was approximately 0.1-inch-deep crack at the bottom of the shell or spall. Fracture then occurred in a brittle manner that formed the large area of the VSR, as Figure 9 shows. Because the formation of the VSR is by the process of brittle fracture and the depth of the initiating crack is known, the stress necessary to cause fracture may be calculated from the following equation:

$$\sigma_{fracture} = K_{IC} / 1.12\sqrt{\pi a}$$

Where: $\sigma_{fracture}$ = fracture stress

K_{IC} = AAR Class C wheel fracture toughness (39,000 psi$\sqrt{\text{in}}$)

a = depth of the initiating crack (0.12 inch)

Substituting these values into the equation gives a fracture stress of 56,700 psi. Using a simple bending formula, σ=Mc/I, the relationship between rim thickness, lateral distance between crack and contact patch (moment arm), and fracture load for a 0.12-inch-deep crack is shown in Figure 10.

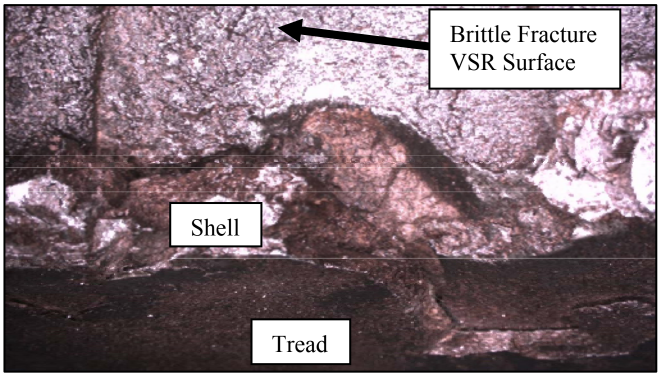

Figure 9. Fracture Surface of Vertical Split Rim

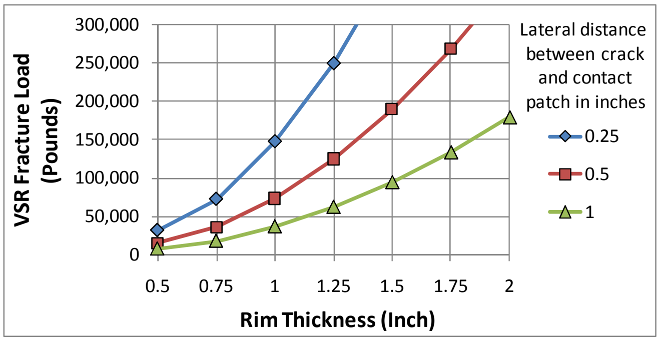

Figure 10. Calculated Effects of Rim Thickness and Contact Position on VSR Fracture Load for a 0.12-inch-deep Crack

Before the BNSF study group, Berge proposed that the stress necessary to propagate a VSR is the result of a bending stress on the crack induced by a load on the outer edge of the tread.[4] He calculated average fracture loads of 95,000 to 110,000 pounds.

While this calculation suggests that VSRs may be triggered by impacts, the role of residual stress is unknown. The appearance of VSR failures has occurred after heat-treated wheels were adopted as the standard, which may indicate that the residual stresses associated with heat-treated wheels play a part in the formation of VSRs.

CONCLUSIONS AND RECOMMENDATIONS

VSR was the dominant failure mode of the inspected wheels, and because of this, the VSR failure mode deserves further study. Failure geometry (size and location) does not appear to be strongly related to rim thickness, but hollow wear and impact loads appear to be contributing factors in the formation of broken wheels. The broken wheels were not limited to a specific wheel design or manufacturing process.

Because the role of residual stress in causing VSRs is not well understood, additional research should be conducted to determine the subsurface axial residual stresses in the wheel rim. This should be conducted on a number of wheels removed from revenue service with varying degrees of wear and rim thickness because the normal deformations associated with rolling contact can change the residual stresses.

REFERENCE

1. Sawley, K. and N. Parker. 1998. "North American Wheel-Profile Survey." *Technology Digest* TD-98-003, Association of American Railroads, Transportation Technology Center, Inc., Pueblo, Colorado.
2. Stone D., J. Elkins, and J. Kristan. 2004. "Effect of Wheel Loading on the Occurrence Of Vertical Split Rim Wheel Failures." *IMECHE2004-59049*.
3. Cummings, S. and D. Lauro. 2008. "Inspections of Tread Damaged Wheelsets." RTDF2008-74009, *Proceedings of 2008 Fall Conference of the ASME Rail Transportation Division*, Chicago, Illinois.
4. Berge, S. 2001. *Presentation to the BNSF Wheel Study Group*, Topeka, Kansas.