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Analysis of Vertical Split Rim Wheels

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Summary

TTCI invited Class I railroads to send suspected vertical split rim (VSR) wheels for in-depth analysis. With 14 wheelsets obtained, TTCI evaluated the wheels visually, ultrasonically, and metallographically to determine whether new insights into these failures could be identified.

Eight of the 14 broken wheels were determined to be VSR or vertical split flange (VSF); the remainder failed by different mechanisms. Approximately 80 percent of the VSR/VSF wheels were manufactured more than 10 years before failure and experienced a large amount of fatigue. Almost all of the VSR wheels and their mate wheels contained multiple subsurface fatigue cracks. Wheels tested for chemical composition met the requirements of AAR M-107/M-208. Six of 14 wheels examined for microcleanliness did not meet the requirements of the AAR standard requirements of this AAR standard.

Subsurface fatigue cracks are surmised to be the cause of VSR or VSF defects, and they are rare defects in railway wheels. Repeated applications of contact stresses can cause subsurface fatigue cracks to form in wheels. These subsurface cracks, sometimes referred to as delamination, can develop near the depth of the maximum shear stress, approximately 0.19 inch. During continued rolling along the track, multiple subsurface cracks can form and grow, both circumferentially and laterally. In some cases, subsurface cracks form in a vertical orientation. Such cracks may also grow and eventually fracture, creating a vertical split rim.

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INTRODUCTION

TTCI invited Class I railroads to send suspected VSR wheels for in-depth analysis. In total, 14 wheelsets were obtained. TTCI evaluated the wheels visually, ultrasonically, and metallographically to determine whether new insights into these failures could be identified. This *Technology Digest* provides a summary of the data collected in this investigation. For the complete set of data, see AAR Research Report R-1020.[1]

BACKGROUND

Many wheel failures and replacements due to tread damage are caused by surface initiated cracks and by subsurface initiated cracks. Vertical split rim (VSR) or vertical split flange (VSF) defects are surmised to be caused by subsurface fatigue cracks and are rare defects in railway wheels.

Repeated applications of contact stresses can cause subsurface fatigue cracks to form in wheels. These subsurface cracks, sometimes referred to as delamination, can develop near the depth of the maximum shear stress of approximately 0.19 inch. During continued rolling of a wheel along the track, multiple subsurface cracks can form and grow, both circumferentially and laterally. In some cases, subsurface cracks form in a vertical orientation. Such cracks may also grow and eventually fracture, creating a vertical split rim.

INVESTIGATION METHODS

Visual Inspection

TTCI inspectors gave each wheel a thorough visual examination and recorded all of the manufacturer information. An identification number was assigned to each wheel, with the broken wheel assigned an odd number, and its mate the next higher even number.

Ultrasonic Evaluation

To detect subsurface cracks, inspectors performed ultrasonic testing on each wheel tread, using a 5 MHz, zero degree transducer. The size and position of each indication was recorded.

Chemical Analysis

The chemical composition of 13 of the wheels was analyzed by glow discharge optical emission spectroscopy. These samples were removed adjacent to the microcleanliness samples.

Microcleanliness

Inclusions reduce steel's mechanical properties. To assess the cleanliness of the steel on the microscopic level, AAR M-107/M-208 specifies maximum levels for voids and inclusions. Samples from 14 wheels, not all of which were VSR wheels, were extracted from locations shown by white boxes in Figure 1. Three samples were examined across the tread, beginning about 0.43 inch from the front rim face. The depth of the examined surfaces was approximately 0.19 inch below the tread surface, since this is the typical depth of the maximum shear stress. The usual requirement for microcleanliness per AAR M-107/M-208 is six samples taken from a depth of 0.50 inch. The void and inclusion contents are evaluated at 100× magnification in each sample.

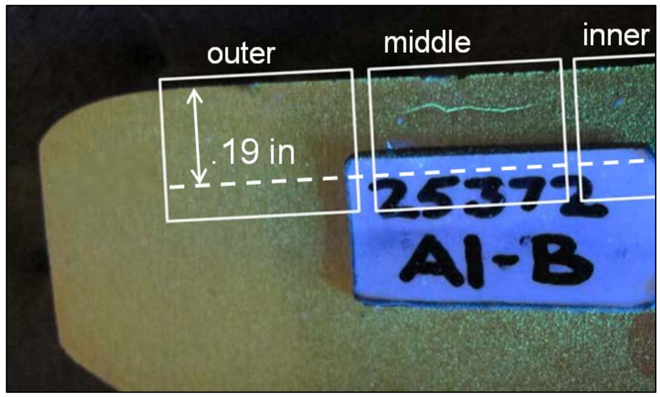

Figure 1. Microcleanliness Sample Locations

Microstructural Analysis

Some of the samples were ground, polished and etched to reveal microstructural details. Subsurface cracks were also examined with this method.

RESULTS

Nine of the 14 wheelsets contained VSRs as listed in Table 1. The number of miles on the wheelsets was not available, but car type and wheel position were provided.

Table 1. VSR Wheel Information

Wheel ID	Service months	Wheel Diameter (in.)	No. of Subsurface Cracks in VSR Wheel	No. of Subsurface Cracks in Mate Wheel
V1	136	36	21	19
V3	147	36	19	21
V7	47	36	6	9
V11	42	36	0	12
V13	135	36	9	6
V15	180	33	7	0
V21	92	36	5	7
V23	141	36	12	12
V27	304	28	1	0

Visual Examination

Most of the VSR wheelsets showed light to moderate surface damage in the form of shelling. Some wheels with subsurface cracks and VSRs can show very little surface damage, while others may have extensive damage. Wheelset V23/V24 exhibited the largest amount of surface cracking. Wheelset V19/V20 showed severe shelling, and was removed for high impact, but did not contain a VSR. Most of the mate wheels had a similar amount of surface damage as the VSR wheels.

Fracture surfaces of the VSR wheels were examined; one of these is shown in Figure 2. All but one of the fracture surfaces (Wheel V27) show evidence of fatigue, indicating that the crack grew for a period of time before final fracture.

Figure 2. Fracture Surface of Wheel V7

Chemical Analysis

All of the 13 samples met the chemical requirements of AAR M-107/M-208.

Ultrasonic Evaluation

Maps of subsurface crack locations and positions are provided for each wheelset in the referenced AAR research report.[1] In addition to the lateral and circumferential positions, the crack depths are shown, represented by the color scale on each map. Table 1 lists the number of subsurface cracks found in the VSR/VSF and mate wheels.

All but one of the VSR/VSF wheels contained subsurface cracks; most also had subsurface cracks in the mate wheels. This is logical as both wheels generally experienced the same loading, but in different lateral positions.

Microcleanliness

The microcleanliness results for the 14 examined wheelsets is graphed in Figures 3 and 4. These represent VSR/VSF wheels, as well as wheels with other failure modes. The dotted horizontal lines indicate the current maximum limit, and the dashed lines represent the pre-2008 maximum limit.

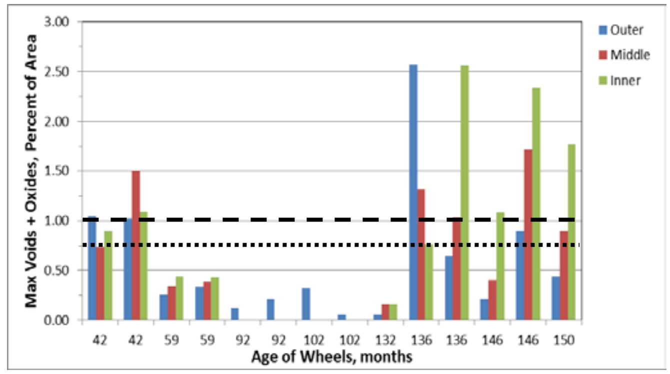

Figure 3. Maximum Void + Oxide Contents in Microcleanliness Samples

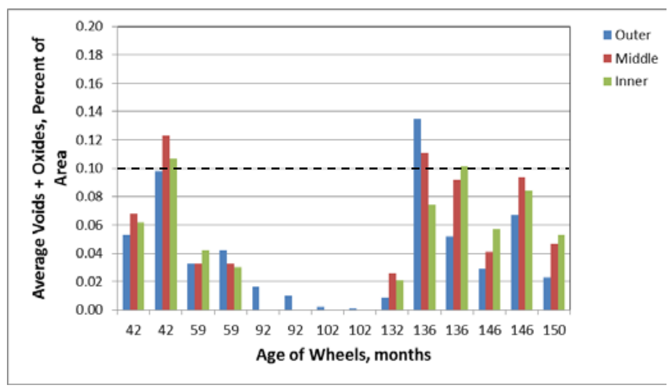

Figure 4. Average Void + Oxide Contents in Microcleanliness Samples

In all the samples, the maximum sulfide level was below the maximum allowable level. The maximum voids + oxides values in Figure 3 showed strong variation, both between the wheels and in the samples across the tread. Four of the wheels contained samples greater than 1.0 percent, and the highest value was 2.6 percent.

The average void + oxide values plotted in Figure 4 showed less variation as well as two samples above the maximum limit. The microcleanliness values were statistically analyzed by wheel age, sample position, and inclusion type. Statistical differences were found between some of the wheels, including wheels of similar age.

A previous study of VSR/VSF wheels was conducted by TTCI in 2010. In that investigation, 30 VSR/VSF wheels were analyzed for microcleanliness. Only two of them exceeded the maximum allowable oxide + void content. Steel cleanliness is very important, whether on a microscopic scale or on a larger scale, but in generaldoes not seem to be the primary factor in vertical split rim failures.

Microstructure

Five VSR wheels and their mate wheels were sectioned for metallographic analysis (see AAR Research Report R-1022[1] for the complete set of pictures). Figure 5 shows a subsurface fatigue crack in Wheel V8. The light brown to gray color immediately surrounding the crack is martensite, thought to be formed when one side of the crack slides across the other side during rolling. Localized heating around the crack is then rapidly cooled by the large thermal mass of the wheel, forming untempered martensite. Martensite forms around some subsurface cracks, but is not visible around others.

Figure 5. Subsurface Crack with Untempered Martensite in Wheel V8

CONCLUSIONS

Repeated applications of contact stresses can cause subsurface fatigue cracks to form in wheels. During continued rolling of wheel along the track, multiple subsurface cracks can form and grow (both circumferentially and laterally). In some cases, subsurface cracks form in a vertical orientation. Such cracks may also grow and eventually fracture, creating a vertical split rim or VSR. All but one of the VSR wheels showed evidence of fatigue. The formation mechanism is very complex and there is currently no model to accurately predict when a VSR will form.

The 13 samples tested met the chemical requirements of AAR M-107/M-208. However, there is little data available for chemical composition of VSR wheels for comparison.

Seven of the nine VSR wheelsets evaluated had more than 10 years in service. In most of the VSR wheelsets, both the broken wheels and the mate wheels contained multiple subsurface cracks.

Six of the 14 wheels examined for microcleanliness did not meet the requirements of AAR M-107/M-208. There was no statistical difference among the different wheels or in samples from the same wheel. While steel cleanliness is very important, it does not seem to be the primary factor in vertical split rim failures.

TTCI will continue to analyze vertical split rim wheels and will provide updated information on these types of failures.

Reference

1. Jones, Kerry and Matt DeGeorge. October 2017. "Analysis of Vertical Split Rim Wheels" Research Report R-1022. Association of American Railroads, Transportation Technology Center, Inc., Pueblo, Colorado.