TTCI TRANSPORTATION TECHNOLOGY CENTER, INC. TECHNOLOGY DIGEST

APRIL 2021

TD21-005

The research described was performed by Transportation Technology Center, Inc., a wholly owned subsidiary of the Association of American Railroads.

High Performance Wheel Test 2 Update

Kerry Jones and Matt DeGeorge

Key Findings:

- Rotating beam fatigue tests were completed for all steels in the HPW2 test and used to determine endurance limits that ranged from 45 ksi to 85 ksi.
- Two additional test wheelsets at FAST have been removed after subsurface fatigue cracks were detected. To date, seven out of 80 HPW2 wheels have been removed from the FAST train due to subsurface cracks. No wheels have been removed for other causes.
- HPW2 wheels have accumulated an average of 60,000 miles at FAST since testing began in 2017.

Transportation Technology Center, Inc. (TTCI) has been conducting two long-term high performance wheel (HPW) tests under the Association of American Railroads' (AAR) Strategic Research Initiatives program on Wheel Performance and Integrity.

As previously reported,[1] the wheels in the first HPW test (HPW1) have been running on a western U.S. railroad since 2009, but are currently accumulating very few miles. No test wheels have been removed since the publication of the previous interim report.[1] The second HPW test, designated HPW2, began in 2016 to evaluate current state-of-the-art wheel steels. Eleven manufacturers have participated in this test with a total of 14 wheel steels. HPW2 consists of laboratory testing, on-track testing, and revenue service testing phases. Laboratory test results and the initiation of on-track testing are discussed in a previous publication.[2]

Rotating beam fatigue tests are used to determine the theoretical endurance limit of a material, the stress below which the material can experience infinite cycles without fatigue failure. TTCI researchers performed these tests on each of the HPW2 steels and determined endurance.

The HPW2 wheels have accumulated an average of 60,000 miles at the Facility for Accelerated Service Testing (FAST), Pueblo, CO. Normalized values of flange width wear and tread wear showed similar values compared to previous measurements. Subsurface fatigue cracks were detected in two additional test wheelsets, bringing the total to seven. No wheels have been removed for other causes, though several wheels are nearing the AAR wear limit for flange width.

Revenue service testing began during summer 2020, with six suppliers participating. Wheels from six suppliers are currently accumulating miles.

HPW2 FATIGUE TESTS

In a rotating beam fatigue test, one end of the sample is fixed, while a known load is applied to the other end. This load bends the specimen as it rotates, giving a complete stress reversal, or a stress ratio of R = -1, each revolution. The rotating beam fatigue tests are performed with a series of decreasing loads, running these samples to failure or 10,000,000 cycles; whichever occurs first. Plotting the calculated stress (S) against the number of cycles (N) on a $\log_{10}$ scale creates an *S-N* curve. Figure 1 shows a generic *S-N* curve. The stress at which the curve becomes horizontal is known as the endurance limit. The material could theoretically withstand stresses below this limit for an infinite amount of time.

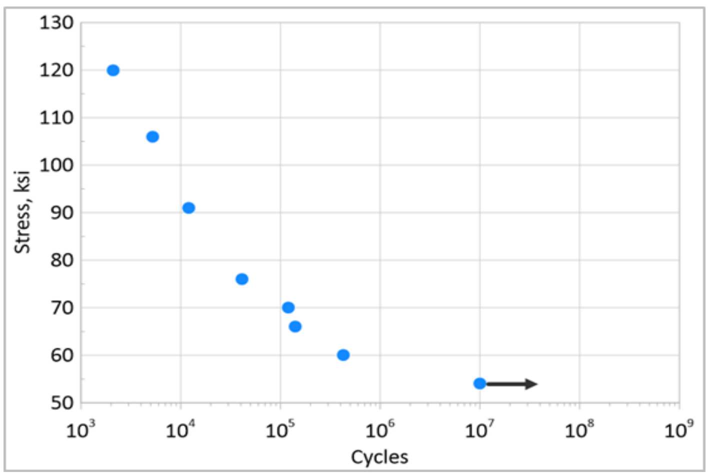

Figure 1. Generic *S-N* curve for steel

TTCI researchers performed rotating beam fatigue tests for eight of the 14 HPW2 steels in 2019 and completed tests for the remaining six suppliers in 2020. All samples were extracted from the wheels in the circumferential orientation, with 16 to 18 specimens used for each wheel steel. At least two specimens were tested at each load.

Figure 2 indicates the approximate endurance limits, ranging from 45 ksi to 85 ksi, for all suppliers. The endurance limit by itself is not an indicator of performance but must be considered in conjunction with other mechanical properties. The experimental endurance limits will be compared to performance at FAST and during the revenue service portions of the test.

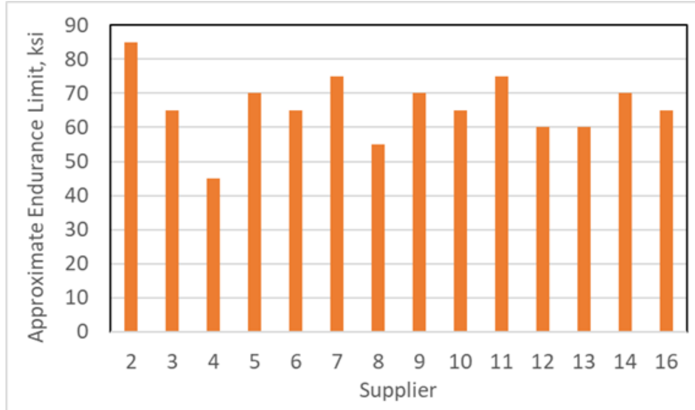

Figure 2. Endurance limits for the HPW2 wheel steels

HPW2 ON-TRACK TESTING AT FAST

Forty test wheelsets with nominal 36-inch diameter wheels are installed under 10 cars at FAST. The cars are loaded to their 110-ton capacity. The test wheelsets have an average mileage of 60,000 miles.

TREAD CONDITION

The tread condition has not changed appreciably since the previous interim report.[1] About half of the wheels show surface-initiated cracking, also known as rolling contact fatigue (RCF) cracking. This is generally not a problem if the wear rate is similar to the crack formation rate. However, if enough material along these cracks breaks out, high impacts can result.

WEAR

For HPW2, the flange width wear and tread wear, both normalized by mileage, are the measured parameters. Wear is measured by comparing wheel profiles over time, aligning them, then calculating the difference in various parameters. Flange width is measured as the distance from the flange back to a point on the flange root radius. Tread wear is determined by evaluating the flange height relative to the worn tread surface.

Figures 3 and 4 show the average flange width wear and tread wear for the HPW2 wheels at FAST, respectively. The flange width and tread wear rates have changed little from the previous HPW2 reporting.[1] Wheels from Suppliers 4, 12, and 13 showed the highest wear rates for both measurements. These had lower hardness than wheels that currently show less wear.

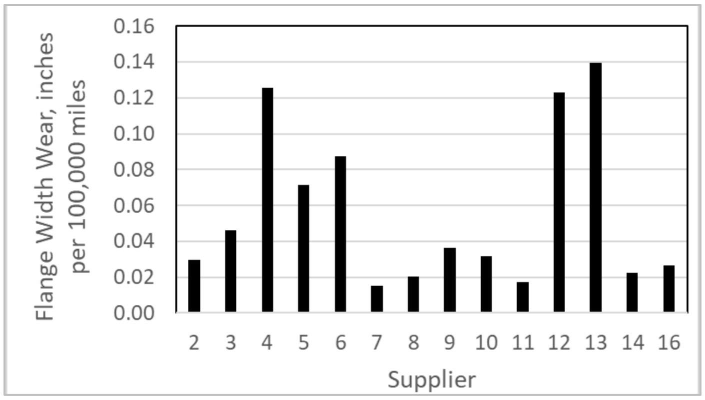

Figure 3. Normalized flange width wear for HPW2 wheels at FAST

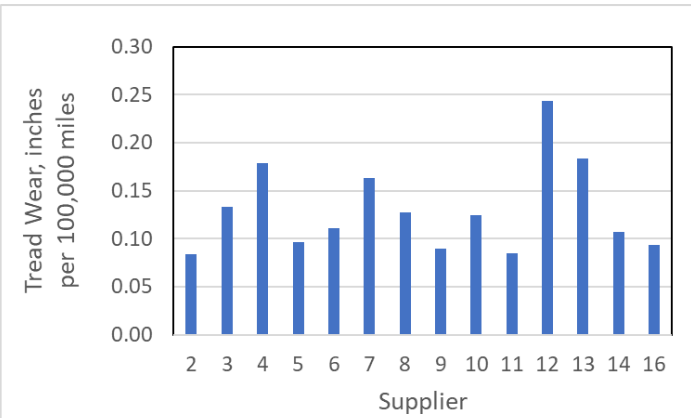

Figure 4. Normalized tread wear for HPW2 wheels at FAST

Three wheelsets are nearing the AAR wear limit for flange width. When these wheelsets reach that limit, they will be removed and replaced with another test wheelset. No wheelsets have been removed for high impacts.

SUBSURFACE FATIGUE CRACKS

A manual ultrasonic scan is performed on the test wheels at FAST semi-annually—once in the spring and once in the fall. Subsurface fatigue cracks were detected in two additional wheelsets prompting their removal and bringing the total number of cracked HPW2 wheels to seven out of 80. Table 1 lists key dimensions of these subsurface cracks. All subsurface cracks listed were found beneath the tread of the wheel at an average distance from the front rim face between 1.25 and 2.4 inches.

The subsurface cracks in wheel 5 were detected in June 2019. Both wheels were ultrasonically scanned before installation and after 8,000 miles. No indications were found either time.

Table 1. Average dimensions of UT indications in cracked wheels

ID	Supplier	Indications	Avg. Length (in.)	Avg. Width (in.)	Avg. Depth (in.)	Miles at Removal
1	5	8	2.20	0.50	0.22	28,600
2	5	1	24.00	0.40	0.30	17,300
3	7	2	8.00	0.20	0.16	25,300
4	3	Continuous	---	0.16	0.13– 0.34	15,500
5	13	15	6.00	0.50	0.27–0.30	22,700
6	5	1	1.30	0.80	0.54	31,800
7	7	Continuous	---	0.25	0.23	23,600

After an additional 14,700 miles, 15 indications were detected. This means these cracks formed and developed quickly, though some are propagating much more slowly. The longest indication in this wheel measured 13.0 inches in the circumferential direction. There were three other indications greater than 11.0 inches. Combined, the indications covered 80 percent of the circumference. Several of the cracks were extracted for examination. Figure 5 shows one of the subsurface cracks.

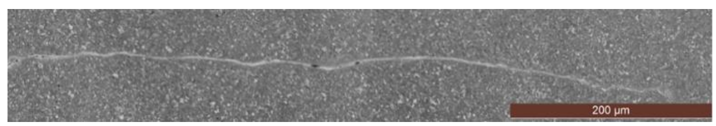

Figure 5. Subsurface fatigue crack in wheel 5

Extraction of wide crack bands is relatively basic, but extraction of narrow subsurface crack bands is difficult due to the non-continuous nature of the cracks. Repeated cutting or milling is usually necessary to completely open the crack, leaving very little crack surface for analysis. This was the case with cracked wheels 3 and 4. For this reason, there are no plans to conduct destructive evaluation of cracked wheel 7. Cracked wheel 6 stands out due to the depth of the crack. Most subsurface fatigue cracks that develop shells or vertical split rims form approximately 0.15 to 0.35 inch below the tread surface. Deeper forming cracks could develop into a shattered rim or another type of defect.

Subsurface fatigue cracks greater than 0.40 inch wide will continue to be extracted for further examination.

HPW2 REVENUE SERVICE TEST

Due to current health-related shutdowns and travel restrictions in many countries, several HPW2 suppliers experienced delays in producing and shipping their test wheels. The revenue service test began in the summer of 2020. Currently, six suppliers have test wheels accumulating mileage. Each supplier submitted approximately 50 wheel plates for testing.

Approximately 100 sets of AAR Class C wheels are slated to be tracked and monitored for comparison to the high performance wheels. The test wheels are being installed under grain cars and inspections will be conducted (visual, tread profile, and ultrasonic) as business and travel conditions allow. Given the current conditions, it may not be possible to examine each wheel on a regular basis.

References

1. Jones, Kerry, and M. DeGeorge. June 2020. "High Performance Wheel Tests Update." *Technology Digest* TD20-011. AAR/TTCI Pueblo, CO.
2. Cummings, Scott. September 2009. "Initiation of the Revenue Service Test of High Performance Wheels." *Technology Digest* TD09-025. AAR/TTCI, Pueblo, CO.
3. Cummings, Scott. November 2012. "High Performance Wheel Test: 223,000-mile Interim Results." *Technology Digest* TD12-024. AAR/TTCI, Pueblo, CO.
4. Robles Hernández, Francisco, S. Cummings, S. Kalay, and D. Stone. September 2009. "Properties and Microstructure of High Performance Wheels." *WEAR 271*(1), Florence, Italy.
5. Jones, Kerry. October 2015. "Interim Report: Comparison of AAR Class C and High-Performance Wheels." *Technology Digest* TD15-032. AAR/TTCI Pueblo, CO.
6. Jones, Kerry and M. DeGeorge. September 2018. "High-Performance Wheels: 320,000 Mile Update." *Technology Digest* TD18-021. AAR/TTCI Pueblo, CO.
7. Jones, Kerry, M. De George, and T. Cong. September 2018. "High-Performance Wheels: Laboratory Testing and Initiation of On-Track Testing." *Technology Digest* TD18-022. AAR/TTCI, Pueblo, CO.

For comments or questions about this publication, contact Kerry_Jones@aar.com