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High-Performance Wheels: Laboratory Testing and Initiation of On-Track Testing

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Summary

Transportation Technology Center, Inc. (TTCI) initiated a long-term test in 2016 to evaluate advanced wheel steels. This test is named High-Performance Wheel Test 2, or HPW2, and laboratory data on the wheels has been collected and analyzed at the Transportation Technology Center (TTC) in Pueblo, CO. The first High-Performance Wheel test (HPW1) is still active in revenue service. The second, HPW2, is comprised of three parts: laboratory testing, durability testing, and revenue service testing. This *Technology Digest* covers the laboratory testing and the initial stages of the durability testing at TTC.

Fourteen different wheel steels representing 11 different manufacturers were submitted for the test. For each steel type, a supplier submitted three unmounted wheels for laboratory testing and four wheelsets for on-track testing. The wheelsets consisted of 36-inch wheels, K axles, and K bearings. Results refer only to randomly generated supplier numbers. Actual supplier names are kept confidential.

Each steel was evaluated for the following properties: tensile strength, yield strength, fracture toughness, microstructure, and microcleanliness. Tensile strength, yield strength, and fracture toughness values fell within expected ranges. Thirteen of the steels had pearlitic microstructures, while one had a microstructure of bainite and pearlite. The microcleanliness tests were performed at multiple depths down to approximately 0.80 inch below the tread surface. These values showed relatively minor variations over the range, but two HPWs and two older Class C wheels showed higher values of discontinuities.

The durability test at the Facility for Accelerated Service Testing (FAST) at TTC in Pueblo, CO, is used to evaluate wheel performance for at least 20,000 miles before revenue service testing begins. This part of the test began in September 2017. Two to three wheelsets of each steel were randomly distributed among 10 open hopper cars, each loaded to approximately 286,000 pounds. All wheelsets were ultrasonically inspected before the durability testing and showed no subsurface indications.

The wheelsets have accumulated an average of 14,000 miles so far. No ultrasonic indications have been detected in the wheels. After each FAST season, the wheels will undergo thorough visual and ultrasonic inspections. Visual inspections will also occur during FAST operations.

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INTRODUCTION

In 2016, TTCI began a long-term test to evaluate advanced wheel steels. This test is named High-Performance Wheel Test 2, or HPW2; it expands on the investigation of the first High-Performance Wheel test (HPW1). HPW2 consists of three parts: laboratory testing, durability testing, and revenue service testing. This *Technology Digest* covers the laboratory testing and the initial stages of the durability testing at TTC.

Fourteen different wheel steels representing 11 different manufacturers were submitted for the test. For each steel type, a supplier submitted three unmounted wheels and four wheelsets. The wheelsets consisted of 36-inch wheels, K axles, and K bearings. Results refer only to randomly generated supplier numbers. Actual supplier names are kept confidential.

LABORATORY TESTING METHODS

Mechanical Testing

Mechanical testing consisted of tensile testing at room temperature and 1,000°F, as well as fracture toughness at room temperature. A total of four tensile samples and two fracture toughness samples were extracted from each wheel type. Each sample was extracted from the locations specified in AAR M-107/M-208. The testing was performed by an independent laboratory.

In addition to the HPW2 steels, two Class C wheels were tested as a control, designated C-1 and C-2. They were produced by two different manufacturers in 2014 and were tested in as-manufactured condition.

Microcleanliness

Microcleanliness is a standard test per AAR M-107/M-208. The test requires six samples to be cut from around the circumference, then the specimens are mounted and polished. At a magnification of 100×, image analysis software analyzes more than 200 fields on each sample to determine the quantity of voids, oxides, and sulfides present. These values are given as area or volume fraction of discontinuities. In this work, the voids, oxides, and sulfides were combined into one generic discontinuity. The gray level threshold for discontinuity detection was lowered from 179 to 160, to allow for metallurgical differences and responses to the polishing process. This means that the microcleanliness values in this study may be slightly lower than using the standard test.

For this study, TTCI cut one sample from each wheel steel, but analyzed multiple surfaces from near

the tread surface to a depth of approximately 0.80 in, in 0.035-0.050-inch increments. Between 15 and 20 surfaces were analyzed for each steel type. Figure 1 shows this with a wheel cross-section and planes that represent example test surfaces.

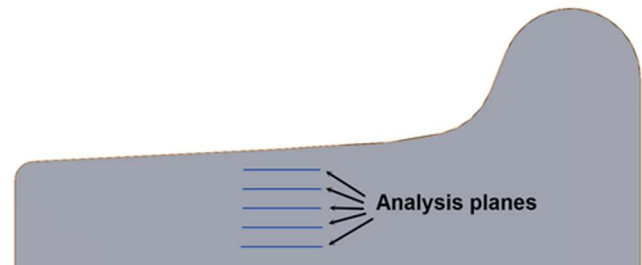


Figure 1. Examples of microcleanliness analysis planes (most removed for clarity).

Photomicrographs from a microcleanliness analysis are shown in Figure 2a and 2b. The first image shows the initial surface, including at least one void and multiple inclusions. The second image shows the discontinuities in red, as flagged by the software. As previously mentioned, combining the discontinuities into one type means that results will not be directly comparable to the standard AAR test.

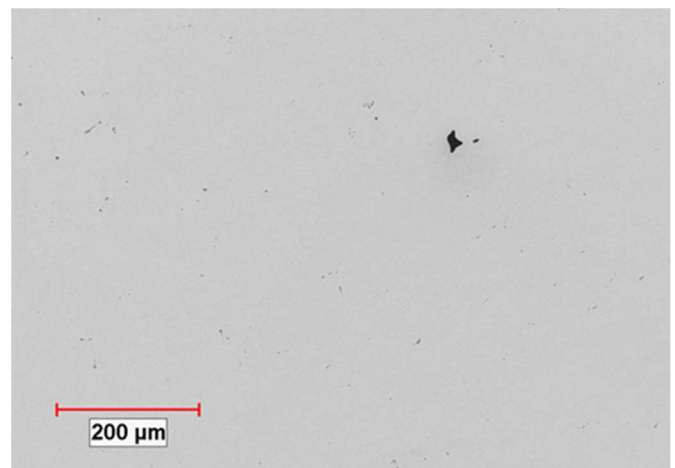


Figure 2a. Micrograph is grayscale image of a field from microcleanliness analysis.

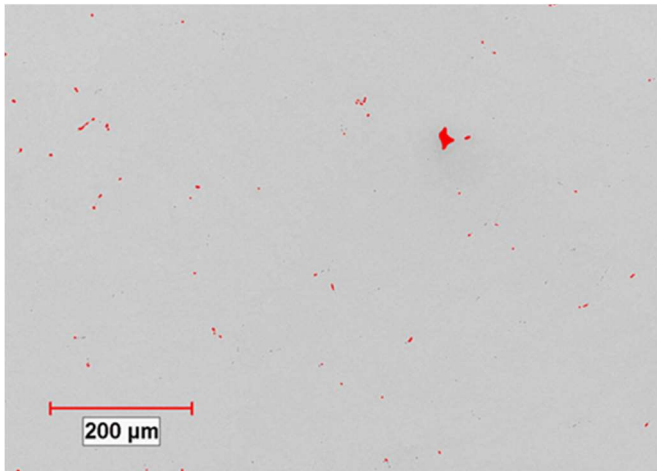


Figure 2a. This micrograph from the analysis shows the same field with discontinuities colored red.

Mechanical Testing Results

Figures 3 and 4, respectively, show the room temperature ultimate tensile strength (UTS) and the ratio of UTS/YS for each of the 12 steels.

Several of the samples had properties that did not meet all the tensile or yield requirements of AAR M-107/M-208. These differences were less than 5 percent below the required values.

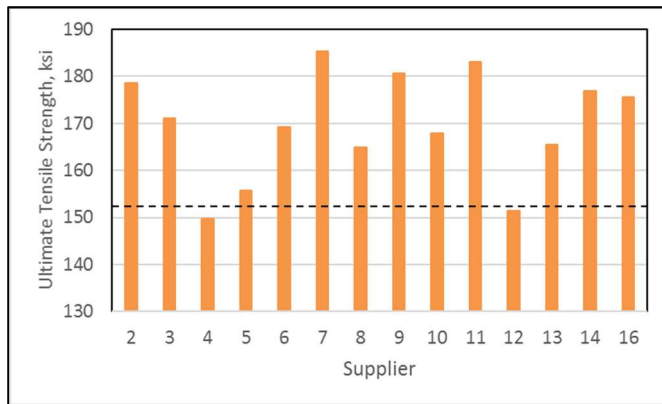


Figure 3. Room temperature ultimate tensile strengths of HPW2 steels. Dotted line represents minimum AAR requirement.

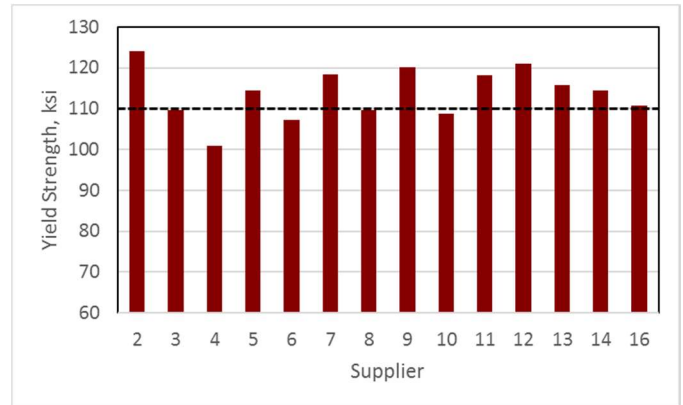


Figure 4. Room temperature yield strengths of HPW2 wheels. Dotted line represents minimum AAR requirement.

Another property of interest is the ratio of UTS to YS. This ratio is a measure of a steel’s strain hardening ability. Higher values should undergo more strain hardening before fracture. Figure 5 shows a plot of this ratio for the HPW2 wheels. Values for this ratio ranged from 1.25 to 1.59.

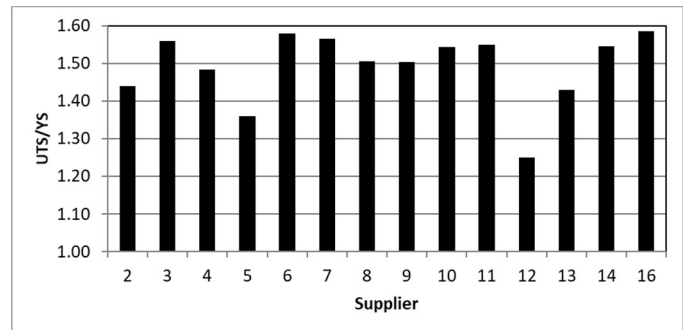


Figure 5. UTS/YS ratios of HPW2 steels

Fracture toughness

Two room temperature fracture toughness samples were removed from the rim of each wheel steel per AAR M-107/M-208.¹ The results are summarized in Figure 6, and varied from 38-52 ksi√in. All values were greater than the required value of 35 ksi√in for Class D wheels, shown by the dotted line.

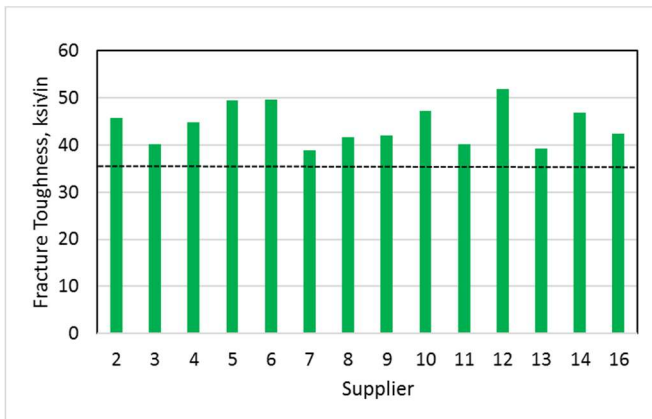


Figure 6. Room temperature fracture toughness of the HPW2 steels.

Microcleanliness results

The microcleanliness results for the HPW2 wheels and the two Class C wheels are shown in Figure 7. The volume fraction of discontinuities for the HPW2 wheels generally formed a range of values from approximately 0.035 percent to 0.100 percent. Two of the HPWs and the two older Class C wheels were considerably higher.

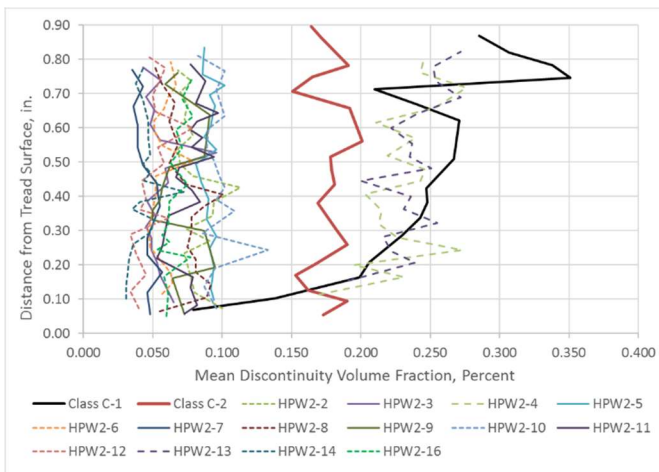


Figure 7. Microcleanliness values of HPW2 steels and two types of Class C wheels.

Some variability was observed during the microcleanliness mapping. Several steels developed black pits, which the image analysis software counted as discontinuities. This gave higher inclusion area fractions

and inclusion counts. Modification of the polishing and cleaning processes provided consistent results.

DURABILITY TEST AT FAST

The durability test is used to evaluate wheel performance for at least 20,000 miles before they begin revenue service testing. Two to three wheelsets of each steel were randomly distributed between 10 open hopper cars, each loaded to approximately 286,000 pounds.

Before the durability test began in September 2017, ultrasonic testing was performed on each wheel, to ensure no subsurface cracks or other indications were present.

The wheelsets have accumulated an average of 14,000 miles so far. After each FAST season, the wheels undergo thorough visual and ultrasonic inspections. One ultrasonic indication has been found so far and it will be closely monitored. Visual inspections are also performed intermittently during FAST operations. No shelling or excessive surface initiated cracking has been observed. Wheels from some manufacturers show greater amounts of wear, but nothing approaches condemnable limits as of this writing.

CONCLUSIONS

Tensile strengths, yield strengths, and fracture toughness for HPW2 fell within expected ranges. The HPW2 microcleanliness values showed only minor variations from near the tread surface to a depth of approximately 0.80 inches. These values were generally much lower than those of the two Class C wheel type tested. One ultrasonic indication has been detected so far in the durability test at TTC. No excessive wear or surface initiated cracking has been observed.

References

1. "Specification M-107/M-208: Wheels, Carbon Steel" AAR Manual of Standards and Recommended Practices, AAR/TTCI, Pueblo, CO, September 2016.

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