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# Properties and Microstructure of High Performance Wheels

Francisco C. Robles Hernández (formerly of TTCI), Semih Kalay, and Scott Cummings

## Summary

This *Technology Digest* summarizes the results of mechanical testing and cleanliness analysis of high performance wheels from different manufacturers. The wheels are part of a new generation of high performance wheels that offer life extension through higher wear, shelling, and ideally, vertical split rim resistance. The wheels represent state-of-the-art products from six world leading manufacturers as well as an experimental wheel steel (known as SRI wheel steel) developed by the Transportation Technology Center, Inc., under the Association of American Railroads' (AAR) Strategic Research Initiatives Program.

A major goal of this research effort is to identify a high performance steel that will considerably extend wheel life, significantly reduce life cycle costs, and lead to the development of a new high performance wheel steel specification (Class D wheel steel) for heavy haul operations in North America.

Major findings of the mechanical and cleanliness testing for all high performance wheels in the test program are summarized as follows:

- All high performance wheels have a pearlitic microstructure except for the wheel identified as Wheel 6, which has a bainitic microstructure.
  - The SRI wheel steel has a significantly finer pearlitic structure when compared to the AAR Class C wheel steel.
- Three out of eight high performance wheel steels meet the proposed minimum yield strength for the next generation of high performance wheel steel.
  - The other wheel steels have yield strengths comparable to AAR Class C wheel steel.
  - The yield strength results of the tests conducted at -40°F and at room temperature show only minor differences.
  - The elongation measurement results for all wheel steels, except Wheel 1, were above 15 percent.
- Five out of eight high performance wheel steels meet the proposed surface hardness range for the next generation of high performance wheel steel.
  - The other wheel steels have surface hardness values comparable to or less than AAR Class C wheel steel.
  - Wheel 2 and Wheel 3 were purposely designed with lower hardness values.
- Five out of eight high performance wheel steels meet the proposed minimum cleanliness values for high performance wheel steel.
- All eight high performance wheel steels meet the proposed minimum fracture toughness value for high performance wheel steel.
- The SRI wheel steel meets all of the proposed requirements for high performance wheel steel.



**BACKGROUND**

For the last few decades, wheel and axle loads in heavy haul lines have increased considerably. In contrast, wheel development has not improved accordingly. Recently, Transportation Technology Center, Inc. (TTCI) proposed a new Strategic Research Initiative (SRI), titled “Strategies to Prevent Wheel Failures,” to develop and test high performance wheels, from domestic and international manufacturers.

In order to improve wheel performance and extend wheel life, TTCI has identified mechanical properties and cleanliness as the major factors that require improvement. There are two main routes to improve mechanical properties: chemical and thermomechanical. Rail manufacturers have, until now, explored the chemical route with relatively good success. TTCI and wheel manufacturers have followed similar approaches in the development of high performance wheels. TTCI has developed a new high performance steel identified as SRI wheel steel and the conversion of the ingots into wheels was conducted by MWL Brasil. The SRI wheel steel will be tested along with the other wheel steels from other manufacturers at the Facility for Accelerated Service Testing (FAST) and in North American heavy haul service. The intention of this test is to identify alternative wheel(s) that offer wheel life extension under typical North American heavy haul traffic conditions. It is anticipated that high performance wheels will possess superior shelling, wear, and ideally, vertical split rim resistance. This will in turn reduce premature wheel removal due to wheel surface damage and potentially reduce derailments due to catastrophic wheel failure.

TTCI proposes the following properties for the high performance wheels:

- Yield strength measured at room temperature  $\geq 130$  ksi
- Fracture toughness measured at room temperature  $>$  AAR Class C wheel steel
- Surface hardness = 380 to 420 hardness Brinell (HB)
- BNSF microcleanliness requirements
  - Average area percent of voids plus oxides  $\leq 0.100$  percent
  - Maximum area percent of voids plus oxides  $\leq 0.200$  percent
  - Maximum area percent of sulfides  $\leq 0.200$  percent

The following wheel manufacturers are participating in the wheel test program:

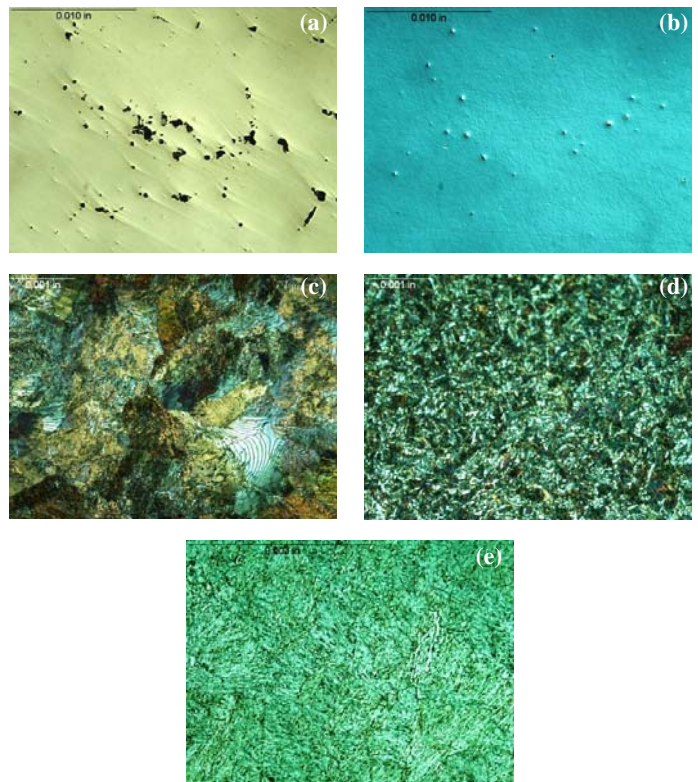
- Griffin
  - Lucchini\*
  - OneSteel\*
  - Standard Steel
  - Sumitomo
  - Valdunes
  - TTCI
- \*Wheels previously tested in international (Lucchini-Sweden and OneSteel-Australia) heavy haul lines. OneSteel wheels were tested in the BHP Billiton line with approximate axle loads of 44 tons.

Each of the above manufacturers donated the wheels that were evaluated in the test program. One wheel of each type was used for mechanical properties and cleanliness testing.

The other wheels have been used for residual stress tests, braking, and durability tests with the remaining to be tested at FAST and in revenue service on a heavy haul coal line. This *Technology Digest* (TD) presents the results of mechanical properties (tensile, hardness and fracture toughness) and cleanliness tests for the wheels from the above manufacturers and the SRI wheel steel. All tests were conducted using standard American Society for Testing Materials (ASTM) methods.

**Microstructure**

Figure 1 shows examples of the microstructures of the test wheels in as-polished (1a and 1b) and as-etched (1c-1e) conditions. Figures 1a and 1c are examples of AAR Class C wheel steel for comparative purposes. Figures 1b, 1d, and 1e are microstructures of the high performance wheels. Figures 1b and 1e show the higher cleanliness of some of the test wheels as compared to AAR Class C wheel steel. The superior microstructure refinement of the SRI wheel steel is shown in Figure 1d (compare with Figure 1c). Figure 1e presents the microstructure of a bainitic wheel steel, Wheel 6. The microstructure of all other high performance wheel steels is pearlitic.



**Figure 1. Microstructures of AAR Class C Wheel Steel (a,c), SRI Wheel Steel (b,d) and Bainitic Wheel Steel (e), in As-Polished (a,b) and As-Etched (c-e) Conditions**

**Tensile Test Results**

Tensile testing was performed in accordance with ASTM E8-00. Three specimens of each wheel type were tested at room temperature and -40°F. Quantities recorded during testing included ultimate tensile strength, yield strength, and percent elongation at failure. Figure 2 shows the results of the tensile test conducted at room temperature and at -40°F. Only three of the wheel steels met the minimum yield strength proposed by TTCI. The yield strength of the rest of the wheel steels is comparable to AAR Class C wheel steel. The yield strength results of the tests conducted at -40°F and at room temperature show only minor differences. It is important to note that the higher yield strength of Wheel 6 is attributed to its microstructure.

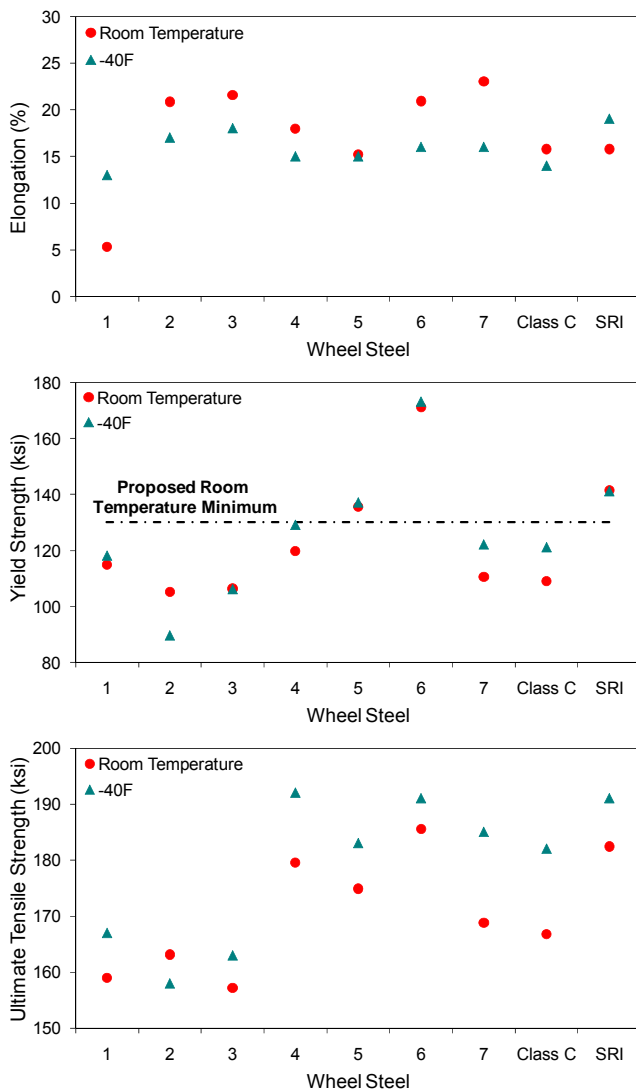


Figure 2. Summary of the Tensile Properties for High Performance and AAR Class C Wheels

**Hardness**

Table 1 shows the hardness values of the high performance wheel steels and AAR Class C wheel steel. The internal

hardness results are an average of 20 measurement locations along the cross section of the wheel rim. The surface hardness results are an average of three measurements taken along the wheel tread. Wheel 6 and the SRI wheel steel have the highest internal hardness values and the rest of the wheels have comparable internal hardness values ranging from 312 to 340 HB. The surface hardness values of Wheels 1, 4, 5, 7, and the SRI wheel steel meet the proposed surface hardness range for high performance wheels.

Table 1. Summary of Hardness (HB)

Wheel Steel	Average Internal Hardness	Average Surface Hardness
1	332	396
2	312	362
3	314	349
4	340	405
5	339	404
6	376	368
7	334	411
AAR Class C Steel	320	366
SRI Wheel	368	405

**Cleanliness**

The cleanliness analysis of the wheel steels was conducted using the method developed by the BNSF Railway. This method involves the E-45 and E-1245 ASTM standards. The BNSF cleanliness analysis requires the analysis of six metallographic samples.

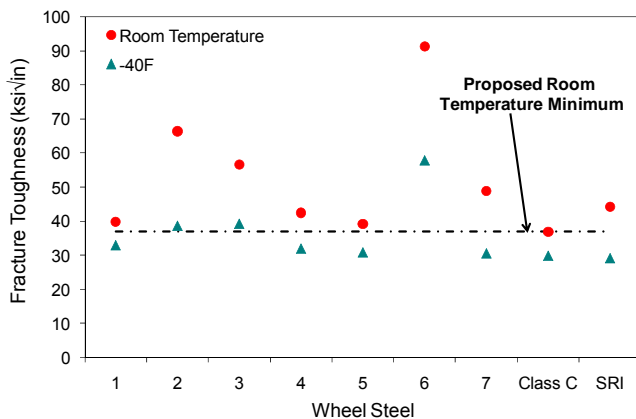
The cleanliness results in Table 2 indicate that Wheels 1, 2, 6, 7, and the SRI wheel steel meet the proposed cleanliness requirements. Values that do not meet the proposed cleanliness requirements are highlighted in yellow.

Table 2. Summary of Cleanliness Results

Wheel Steel	Sulfides (%)	Oxides + Voids (max.)	Oxides + Voids (avg.)
1	0.12	0.12	0.010
2	0.16	0.04	0.002
3	0.38	0.31	0.017
4	0.33	0.11	0.003
5	0.31	0.17	0.045
6	0.09	0.04	0.002
7	0.15	0.12	0.002
AAR Class C	0.22	0.03	0.001
SRI	0.07	0.03	0.002
Median Value of 40 AAR Class C Wheels <sup>1</sup>	Not Reported	0.26	0.048

**Fracture Toughness**

Fracture toughness testing was performed in accordance with ASTM E399 at room temperature and at -40°F. Figure 3 shows the results of fracture toughness tests for the high performance wheel steels and AAR Class C wheel steel. Figure 3 shows that at room temperature, all high performance wheels have fracture toughness values above AAR Class C wheel steel meeting TTCI’s proposed minimum fracture toughness for high performance steel. Note the significantly higher fracture toughness of Wheel 6 (bainitic).



**Figure 3. Results of Fracture Toughness Test Conducted at Room Temperature and at -40°F**

**CONCLUSIONS**

A detailed metallurgical examination was conducted on the new high performance wheels donated by manufacturers worldwide. The overall quality and characteristics of the eight high performance wheels are considered satisfactory. The microstructural examination indicated that all wheels but one are primarily composed of pearlite. One test wheel is composed of a bainitic microstructure. The SRI wheel steel has considerably finer pearlitic microstructure than the AAR Class C wheel.

Only the SRI wheel steel met all of the proposed requirements for high performance wheel steel. The yield strength of three of the eight test wheels is greater than 130 ksi. The surface hardness values for five of the eight test wheels are in the range of 380 to 420 HB. Five out of the eight test wheels meet the proposed cleanliness standards for advanced wheel steels. All of the test wheels have room temperature fracture toughness values greater than AAR Class C wheel steel.

**ONGOING TESTS**

All of the wheels were subjected to residual stress measurements. The results of these tests will be presented in a companion TD in the near future.

The test wheels have been installed under 286,000- and 315,000-pound cars for initial performance testing at TTC. Pursuant to excessive braking tests conducted under loaded cars, the test wheels have begun a series durability tests at FAST. Beginning in 2009, a test train composed of a mixture of advanced wheels and control (AAR Class C) wheels will undergo performance evaluations under 286,000-pound coal hoppers operating between Wyoming’s Powder River Basin and the power plants served by the Union Pacific (UP) Railroad.

It is expected that the testing at FAST and in revenue service will reveal further information that will help in redefining the minimum metallurgical and nonmetallurgical characteristics that will serve as the basis for the development of the Class D wheel steel standard.

**Acknowledgements**

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1. Dahlman, G., and C. Lonsdale. May 2003. “Strategies to Prevent Heavy Haul Wheel Failures,” *International Heavy Haul Association Proceedings*, Table 3, pg 2.13, Dallas, Texas.

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