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Tread Buildup on Railroad Wheels

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13. ABSTRACT (Maximum 200 words)

Based on the results of wheel slide tests and an inspection of wheels, the root cause of tread buildup (TBU) was identified as wheel slide caused by excessive brake force. During the tests, TBU accumulated to the greatest heights under dry conditions, at longer slide distances, and under heavier axle loads. Train speeds between 20 and 30 mph appeared to increase TBU height. Chemical analysis of TBU samples indicated that the source of the material is likely a combination of wheel and rail steel. This finding reinforces the conclusion that wheel slides cause TBU. A microstructural evaluation of several TBU samples found no martensite, a microstructure that results when hot steel is rapidly cooled. A relatively slow conductive heat transfer rate from the irregular contact between the hot TBU and the cooler wheel likely does not provide sufficiently rapid cooling for martensite formation.

The railroad industry is currently poised to reduce TBU through improved brake system performance as a result of handbrake training for train crews, handbrake design improvements, an improved airbrake test, and the increased use of data from wayside detectors to identify cars with brake problems. Although TBU removals are decreasing, TBU-related accidents do not show a clear trend as a percentage of all wheel-related accidents.

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METRIC/ENGLISH CONVERSION FACTORS

ENGLISH TO METRIC

LENGTH (APPROXIMATE)

1 inch (in)	=	2.5 centimeters (cm)
1 foot (ft)	=	30 centimeters (cm)
1 yard (yd)	=	0.9 meter (m)
1 mile (mi)	=	1.6 kilometers (km)

AREA (APPROXIMATE)

1 square inch (sq in, in^2)	=	6.5 square centimeters (cm^2)
1 square foot (sq ft, ft^2)	=	0.09 square meter (m^2)
1 square yard (sq yd, yd^2)	=	0.8 square meter (m^2)
1 square mile (sq mi, mi^2)	=	2.6 square kilometers (km^2)
1 acre = 0.4 hectare (he)	=	4,000 square meters (m^2)

MASS - WEIGHT (APPROXIMATE)

1 ounce (oz)	=	28 grams (gm)
1 pound (lb)	=	0.45 kilogram (kg)
1 short ton = 2,000 pounds (lb)	=	0.9 tonne (t)

VOLUME (APPROXIMATE)

1 teaspoon (tsp)	=	5 milliliters (ml)
1 tablespoon (tbsp)	=	15 milliliters (ml)
1 fluid ounce (fl oz)	=	30 milliliters (ml)
1 cup (c)	=	0.24 liter (l)
1 pint (pt)	=	0.47 liter (l)
1 quart (qt)	=	0.96 liter (l)
1 gallon (gal)	=	3.8 liters (l)
1 cubic foot (cu ft, ft^3)	=	0.03 cubic meter (m^3)
1 cubic yard (cu yd, yd^3)	=	0.76 cubic meter (m^3)

TEMPERATURE (EXACT)

[(x-32)(5/9)] °F = y °C

METRIC TO ENGLISH

LENGTH (APPROXIMATE)

1 millimeter (mm)	=	0.04 inch (in)
1 centimeter (cm)	=	0.4 inch (in)
1 meter (m)	=	3.3 feet (ft)
1 meter (m)	=	1.1 yards (yd)
1 kilometer (km)	=	0.6 mile (mi)

AREA (APPROXIMATE)

1 square centimeter (cm^2)	=	0.16 square inch (sq in, in^2)
1 square meter (m^2)	=	1.2 square yards (sq yd, yd^2)
1 square kilometer (km^2)	=	0.4 square mile (sq mi, mi^2)
10,000 square meters (m^2)	=	1 hectare (ha) = 2.5 acres

MASS - WEIGHT (APPROXIMATE)

1 gram (gm)	=	0.036 ounce (oz)
1 kilogram (kg)	=	2.2 pounds (lb)
1 tonne (t)	=	1,000 kilograms (kg)
	=	1.1 short tons

VOLUME (APPROXIMATE)

1 milliliter (ml)	=	0.03 fluid ounce (fl oz)
1 liter (l)	=	2.1 pints (pt)
1 liter (l)	=	1.06 quarts (qt)
1 liter (l)	=	0.26 gallon (gal)
1 cubic meter (m^3)	=	36 cubic feet (cu ft, ft^3)
1 cubic meter (m^3)	=	1.3 cubic yards (cu yd, yd^3)

TEMPERATURE (EXACT)

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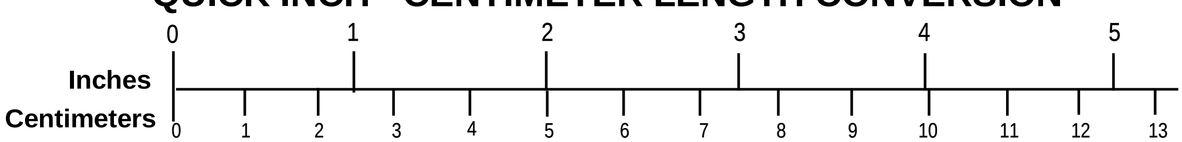
QUICK INCH - CENTIMETER LENGTH CONVERSION



QUICK FAHRENHEIT - CELSIUS TEMPERATURE CONVERSIO

°F	-40°	-22°	-4°	14°	32°	50°	68°	86°	104°	122°	140°	158°	176°	194°	212°
°C	-40°	-30°	-20°	-10°	0°	10°	20°	30°	40°	50°	60°	70°	80°	90°	100°

For more exact and or other conversion factors, see NIST Miscellaneous Publication 286, Units of Weights and Measures. Price $2.50 SD Catalog No. C13 10286

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Executive Summary

Tread buildup (TBU) is the accumulation of metallic material on the tread surface of a railroad wheel. Based on the results of wheel slide tests and an inspection of wheels with TBU, the root cause of TBU was determined to be wheel slide caused by excessive brake force. The railroad industry is currently working on different initiatives to improve conventional air brake system performance, many of which could reduce the incidence of TBU. Increased use of data from wayside detectors, handbrake training for train crews, handbrake design improvements, and an improved airbrake tests may potentially benefit these brake system performance efforts.

Ninety wheel slide tests were successful in creating TBU as high as 1 inch (radial height) from the wheel tread surface. During the tests, TBU accumulated to the greatest heights under dry conditions, at longer slide distances, and under heavier axle loads. Train speeds between 20 and 30 mph appear to increase TBU height. Although the current test program was not able to provide evidence of the transfer of metallic material from brake shoes to wheels, this cannot be ruled out as a source for some minor cases of TBU, as indicated in existing literature on the phenomenon.

Chemical analysis of TBU samples indicated that the source of the material is likely a combination of wheel and rail steel. This finding reinforces the conclusion that wheel slides cause TBU. A microstructural evaluation of several TBU samples found no martensite, a microstructure that results when hot steel is rapidly cooled. A relatively slow conductive heat transfer rate from the irregular contact between the hot TBU and the cooler wheel likely does not provide sufficiently rapid cooling for martensite formation.

An inspection of 21 wheelsets that developed TBU while in service showed indications of wheel sliding on all but one wheelset. Three of the wheels had TBU radial heights that measured greater than 1 inch, representing the highest safety risk of the group. The presence of a large flat spot adjacent to the TBU and heat discoloration concentrated near the flat spot indicate that the root cause of the TBU on these wheels was a wheel slide event.

Although wheel due to TBUremovals are steadily decreasing, accidents attributed to TBU remain the second leading cause of wheel-related accidents. TBU occurs more frequently during cold weather and in wheels in axle positions 1 and 2. Although water has been shown to facilitate the accumulation of metal pickup in brake shoes, most TBU-related accidents occur in dry weather conditions. Two separate tests of the brake valves from cars with TBU revealed high brake cylinder pressure.

1. Introduction

The Federal Railroad Administration (FRA) Office of Research and Development (ORD) has teamed with the Association of American Railroads (AAR) to fund research by Transportation Technology Center, Inc. (TTCI) regarding the root cause of wheel-related train accidents. This report describes the research conducted to better understand the conditions necessary to form TBU—accumulation of metallic material on the tread surface—on railroad wheels.

1.1 Background

Buildup of material on wheel treads is not uncommon, but it is usually benign from a safety standpoint. However, in extreme cases it can result in train accidents and derailments. The built-up material effectively produces a change in wheel radius, either at a specific circumferential location (resulting in an impact force once per wheel revolution), or around the entire circumference of the wheel (resulting in a reduction in relative flange height). Figure 1 shows photographs of two wheels with TBU around the entire wheel circumference. The left photograph shows a typical TBU appearance in both the rusted and nonrusted conditions. The right photograph shows an unusually severe case of TBU. The TBU in the right photo has clearly reduced the relative flange height, making a flange climb derailment more likely.

Figure 1. Typical TBU appearance on a rusted wheel tread with a portion wire-brushed clean (Left) and severe TBU (Right)

1.2 Objective

The purpose of the work described in this document is to identify measures for improved wheel performance by first gaining a solid understanding of the root causes of TBU on wheels.

1.3 Overall Approach

The general approach used to investigate TBU includes the following:

- Review of literature and available data to focus the remainder of the work
- Inspection of wheels with TBU that were removed from service
- Testing of TBU samples to help determine the source of the material and mechanism of formation
- Creation of TBU in a controlled environment to demonstrate a proper understanding of the root cause and to provide data about the conditions most likely to produce TBU
- Identification of measures for the reduction of train accidents caused by TBU

1.4 Scope

TTCI conducted a literature review and analyzed existing data from the FRA safety database and the AAR car repair billing database [1, 2]. A railroad wheel shop collected 21 service worn wheelsets with TBU for inspection by TTCI personnel. Dimensions of the TBU were measured along with the wheel profile, tread roughness, tread surface hardness, and wheel magnetism. Chemical and metallurgical analyses were conducted on samples of TBU to help determine the source of the buildup material and the formation mechanism. TTCI conducted 90 wheel slide tests at the Transportation Technology Center (TTC) to evaluate the effects of axle load, wheel-rail friction conditions, speed, and slide distance on the formation of TBU. Additional tests were conducted in an attempt to create TBU in a partial wheel sliding condition and from brake shoes with embedded metallic material.

1.5 Organization of the Report

This report is divided into sections describing the literature review, inspection, test, current and potential future mitigation opportunities, and conclusions.

2. Review of Literature and Existing Data

Upon searching the literature, TTCI found that the problem of TBU has not been well researched in the past. This section documents the size of the TBU problem with available data and summarizes existing work on the topic.

2.1 FRA Accident Data

FRA's safety database shows that TBU (cause code E67C "Damaged flange or tread (buildup)") is a high ranking cause of FRA reportable train accidents. Between January 2004 and December 2011, a total of 85 accidents were attributed to TBU for an average of 10.625 TBU accidents per year. Of all equipment-related accidents, TBU is the sixth most common cause. Of wheel-related accidents, TBU is the second most common cause (E61C "Broken rim" is the most frequent wheel-related accident cause and is the subject of related research conducted under this same contract). Figure 2 shows the accidents attributed to TBU as a percentage of accidents attributed to all equipment-related causes. No steady trend is evident. [1]

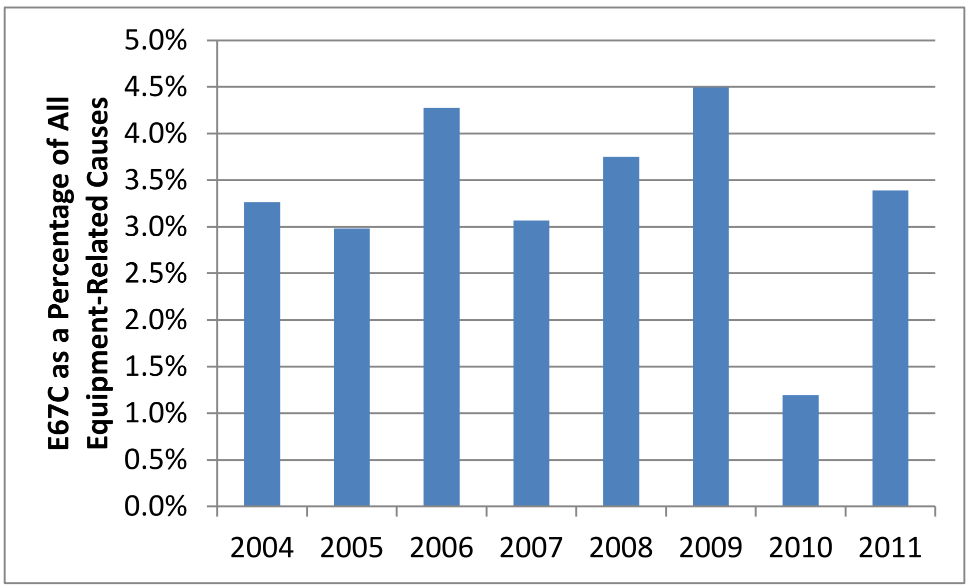


Figure 2. TBU Accidents from FRA Safety Database

A search of the text commentary in the accident detail reports in FRA's safety database shows that an additional 13 accidents between January 2004 and December 2011 reported to the FRA involved TBU, although TBU was not noted as the primary cause of the accidents. From January 2004 to December 2011, the total count of FRA reportable accidents involving TBU is 98, with an average of 12.25 accidents involving TBU per year. The accident reports include a category for weather classification at the time of the accident. The choices are as follows: clear, cloudy, rain, fog, sleet, or snow. The weather was categorized as clear or cloudy during 86 of these accidents (88 percent); only 12 accidents (12 percent) occurred during precipitation (rain, fog, sleet, or snow).

2.2 AAR Rules and Statistics

A wheel with TBU at a radial height of one-eighth inch or greater is condemnable according to the *Field Manual of AAR Interchange Rules*, Rule 41. The AAR has assigned Why Made Code 76 for TBU. This rule is in place to prevent impact loads and the reduction in relative flange height that can result in broken rails and train derailments. [3]

AAR's car repair billing database shows that TBU causes only a small percentage of wheel removals each year. TBU removals have been declining from January 2004 to December 2011, both in terms of the number of wheels removed and the percentage of wheels removed. Figure 3 shows TBU removals as a percentage of all wheel removals in the AAR car repair billing database. A total of 44,050 wheels were removed during this time because of TBU, resulting in an average of 5,506 TBU wheels removed per year [2]. This data, combined with FRA safety statistics, shows that the vast majority of TBU wheels are identified and removed in advance of a safety issue. Only about 0.22 percent of TBU wheels result in a train accident (98/44,050 * 100 % = 0.22 %).

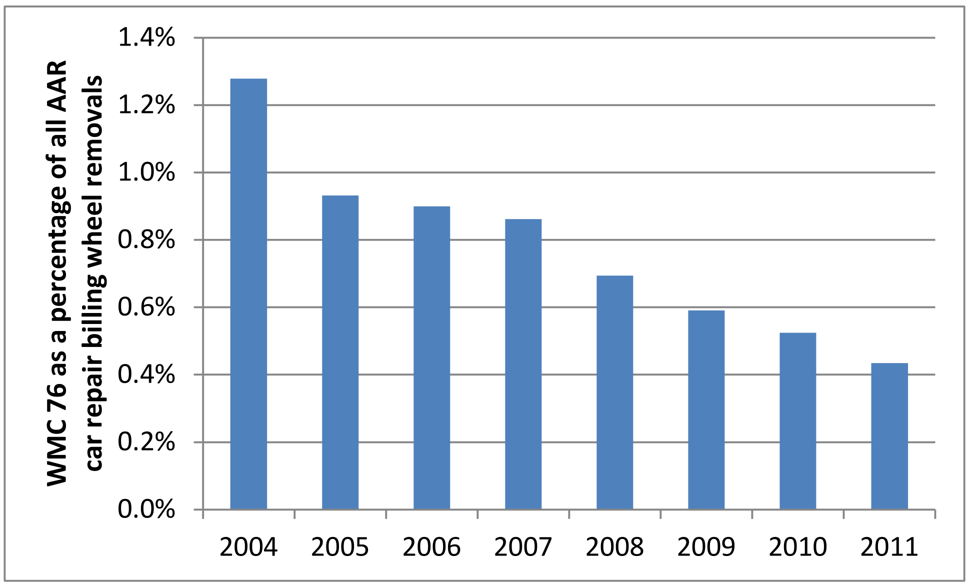


Figure 3. Wheel Removals for TBU from AAR Car Repair Billing Database

2.3 Previous Research

Existing literature on the topic suggests that TBU is tied to brake system problems [4, 5]; however, there is no consensus about the mechanism that causes the material to build up on the wheel. Metal from brake shoes has long been suggested as a source of the TBU material [6]. In fact, during laboratory testing on a dynamometer, the metal in brake shoes was found in at least one case to be a source of small amounts of TBU [7]. Historically, brake shoes were made of cast iron, but this is no longer the case because high friction composition brake shoes began to replace cast iron shoes in the 1960s [8]. Significant sources of metal in modern brake shoes include metal "pickup" in standard composition brake shoes and tread conditioning brake shoes manufactured with either an iron insert or a high metal powder content. Figure 4 shows an example of a brake shoe with metal pickup composed of metallic wear particles that have become embedded in the composition material.

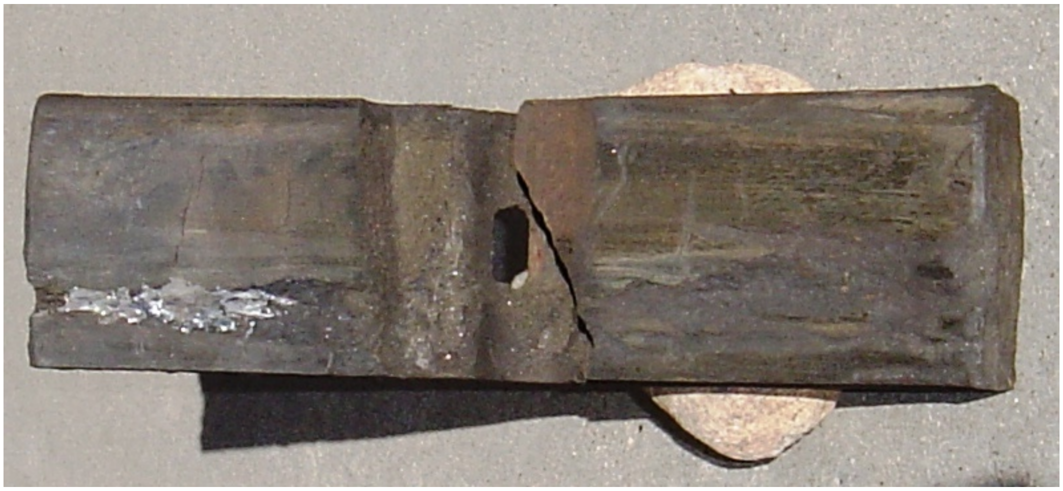


Figure 4. Composition Brake Shoe with Metal Pickup

The presence of water has been shown to be a contributing factor to brake shoe metal pickup and, perhaps, to TBU [9]. However, laboratory dynamometer tests designed to produce TBU on a full-scale railroad wheel using a variety of brake shoes under wet and dry conditions were unsuccessful. These tests were initiated after a small amount of TBU was inadvertently developed during a dynamometer test using a brake shoe with high metal content. Extensive followup testing was conducted with a wide range of brake shoe forces and different brake shoes—including normal composition shoes, shoes with metal pickup, and brake shoes with high metal content. None of this testing produced any TBU on the wheel or metal pickup in the brake shoes [7].

A previous inspection of service worn wheels with TBU found that the wheels had developed stronger magnetic fields and had rougher tread surfaces compared with other wheels removed from service. In that report, photographs of the only two wheels with heavy TBU showed large slide marks [7].

An analysis of TBU wheel removal data from the AAR car repair billing database was conducted with a focus on seasonality and axle position [10]. TBU removals increase during colder times of the year and tend to occur more frequently in axle positions 1 and 2 (truck B) compared with axle positions 3 and 4 (truck A). One possible explanation for the seasonal effect is that frozen moisture in the train brake pipe causes valve performance problems which reduce wheel-rail adhesion levels and lead to more wheel slide events. As for the discrepancy in the location of TBU wheels, the following two theories are offered:

- "The handbrakes on cars with truck-mounted brakes only apply braking force to wheels in Truck B. Additionally, the handbrake ratio for the wheels in Truck B of a car with truck-mounted brakes is twice as high as the handbrake ratio of all wheels in a similar car with body-mounted brakes."

- "The brake cylinder on cars with foundation rigging is located nearest to Truck B. The addition of mechanical components in the brake rigging between the brake cylinder and the wheels in Truck A may produce a lower effective brake ratio at Truck A, especially as rigging components wear and age."

Repair track airbrake testing in the 1990s of 35 cars with TBU wheels found high brake cylinder pressure in 80 percent of the cars [4]. Two more recent tests of brake valves removed from cars that had developed TBU were also conducted [10]. The valves were tested at room temperature and at colder temperatures. The tests were conducted to check for air leakage into the brake cylinder, which would produce higher than intended brake effort and potentially result in wheel sliding. In the first test, valves from eight cars were tested and air was found to leak into the brake cylinder from the service or emergency valve portions of all eight cars. The second test involved a different set of valves that had been removed from cars with TBU wheels. In the second test, only 2 out of 19 valve portions tested were found to leak air into the brake cylinder. This study concluded that there may be a link between certain types of brake valve malfunctions and TBU, especially in cold ambient temperatures when valves tend to exhibit more performance problems.

2.4 Section Summary

TBU wheel removals are steadily decreasing, but accidents attributed to TBU remain the second leading cause of wheel-related accidents. Literature on the formation of TBU suggests that metal from brake shoes and wheel sliding are two probable causes. Although water has been shown to facilitate the accumulation of metal pickup in brake shoes, most TBU-related accidents occur in dry weather conditions. No TBU was generated during a previous laboratory test program in which brake shoes were pressed against the wheel tread surface under a variety of conditions. TBU occurs more frequently during cold weather and in wheels in axle positions 1 and 2. In addition, two separate tests of the brake valves from cars with TBU found high brake cylinder pressure.

3. Inspection

TTCI inspected 21 service worn wheelsets with TBU to increase the knowledge base regarding TBU wheels. This section describes the inspection procedure and findings.

3.1 Inspection Procedure

TTCI contacted a railroad wheel shop and requested that they hold wheelsets with TBU for inspection. After 4 months, the shop had accumulated 21 wheelsets with TBU, and TTCI sent an inspection team to conduct the inspection at the wheel shop. If the markings—AAR Why Made Code, car number, wheel position, and removal date—on the wheels were legible, the inspectors noted them. Bearing locking plate dates and wheel hub stampings were also recorded, as was the presence of any shells, spalls, slid flats, rim rollover, rolling contact fatigue crack bands (heat checks), and thermal cracks. A wheel gauge with a moveable finger was used to measure the flange width, flange height, and rim thickness of each wheel. The radial height, axial width, and circumferential length of the TBU were measured. An Equotip portable surface hardness tester was used on the wheel tread surface and on the TBU. A handheld analog Annis magnetometer was used to measure the magnetism of the wheels both at the TBU and at locations in the rim and flange with no TBU. A handheld surface roughness tester was used to determine tread surface roughness in locations with no TBU. A Greenwood Engineering Wheel Miniprof was used on some wheels to record the shape of the wheel profile. Photographs were taken of the wheels, and comments were recorded regarding any special conditions found on particular wheels.

3.2 Inspection Findings

Based on a comparison of the bearing locking plate dates and the removal dates, the service life of the wheelsets was determined to range from 2 months to 21 years with a median value of 3 years. The car types from which the wheelsets were removed included one box car, three covered hoppers, two gondolas, five hoppers, one flat car and one multiunit double stack container car. The wheelsets were all AAR Class C (heat treated), and 19 out of the 21 wheelsets used 36-inch diameter single-wear wheels. The other two wheelsets used two-wear 33-inch wheels. Four wheel manufacturers were represented among the wheels. Nine of the wheelsets used wrought wheels and the other 12 wheelsets used cast wheels.

Each wheelset inspected had TBU present on both wheels. All but one wheelset showed obvious indications of sliding on the tread surface, although the visible slides were not always immediately adjacent to the largest mass of TBU material. In some cases, the TBU material appeared to partially obscure slide marks, indicating that the wheelset had rotated during the sliding event(s).

Varying amounts of TBU were found. Three wheelsets had TBU heights greater than 1 inch; the highest measured 3 inches radially off the tread surface. Figure 5 shows this wheel. The wheels with the highest TBU measurements were also the wheels with some of the shorter TBU lengths. Figure 6 shows the circumferential length and radial height of the TBU on each wheel. From a safety standpoint, the radial height of the TBU material is of primary concern. The three wheels with a TBU radial height of more than 1 inch and a circumferential TBU length less than 20 inches showed obvious signs of a wheel slide immediately adjacent to the TBU. Heat discoloration on the rim, flange, and plate of these three wheels was concentrated near the flat spot and TBU. The root cause of the TBU on these three wheels was clearly a wheel slide event.

Figure 5. Wheel with 3-Inch TBU

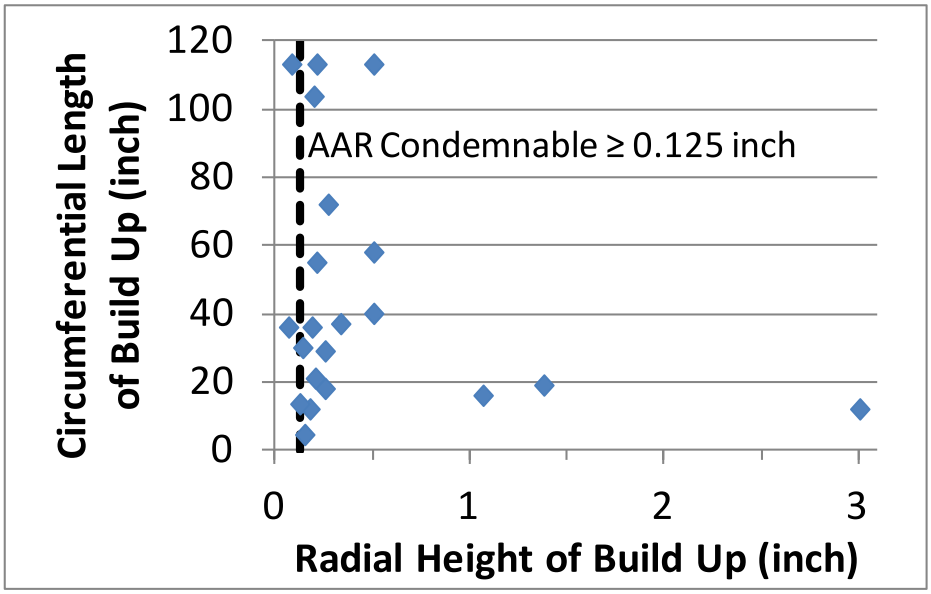


Figure 6. TBU Dimensional Data

Wheel wear readings, hardness readings, and surface roughness readings were made on a portion of the tread with no TBU after cleaning off the rust and contaminants with a wire brush. Table 1 lists statistical results of the inspection data.

Table 1. Statistical Results of the Inspection Data

Measurement	Minimum	Maximum	Average	Median	Standard Deviation
Flange width (Finger gauge reading on narrow flange scale)	0	5	0.5	0	1.3
Flange height (inches)	1.06	1.38	1.18	1.13	0.09
Rim thickness (inches)	1.00	1.81	1.48	1.50	0.23
TBU circumferential length (inch)	4.5	Entire circum-ference	45	36	37
TBU radial height (inch)	0.06	3.0	0.46	0.21	0.67
Wheel tread surface hardness (Brinell)	354	499	424	415	41
TBU surface hardness (Brinell)	168	585	364	371	102
Magnetism of wheels (Gauss)	0	4	1.0	1	0.9
Magnetism of TBU (Gauss)	0	2	0.8	1	0.7
Tread surface roughness (μ inch)	19	140	49	41	31

Surface hardness readings on the wheel treads were generally in the low to mid 400s on the Brinell hardness scale. These values are typical for service worn wheels and indicate an increase in hardness from the manufacturing specification for wheels—most likely resulting from cold working of the tread surface against the rail. TBU hardness readings were more difficult to obtain because the TBU material was not always formed in the cohesive manner necessary for hardness readings. The hardness readings recorded from the TBU were generally lower than the readings from the tread. Most of the TBU readings were in the 300s on the Brinell hardness scale, indicating a nonmartensitic microstructure.

The magnetism and tread surface roughness were substantially less than in a previous report [7]. Measurement technique can explain some, but not all, of the magnetism discrepancy. Recent measurements were made solely on the tread and flange, whereas previous measurements encompassed the entire wheel. Differences in surface preparation are the likely source of the discrepancy in the surface roughness readings.

Wheel profile readings were captured on select wheels. Figure 7 shows three overlaid wheel profiles from the same wheel taken at a flat spot, at the TBU, and at a circumferential location with no damage. This figure illustrates how TBU wheels can generate large impact loads because of changes in the wheel radius and how the TBU can reduce the effective wheel flange height and angle.

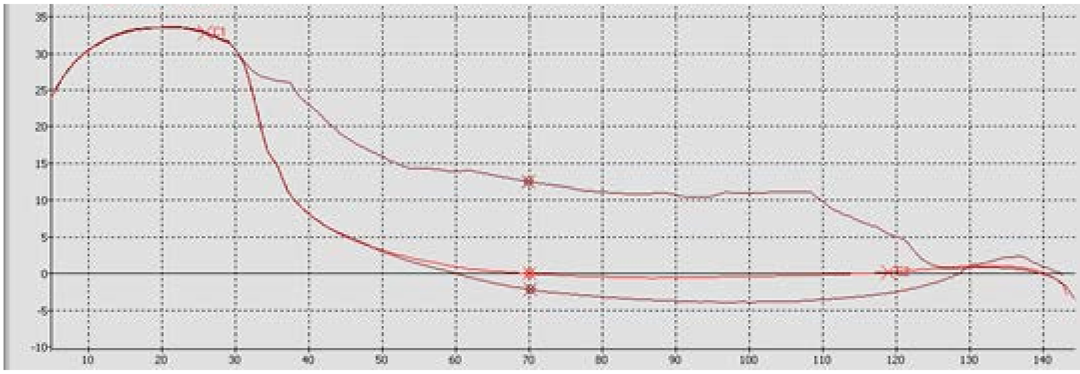


Figure 7. Three Wheel Profiles from the Same Wheel

For the wheels that had a legible car number written on the plate, an attempt was made to query historical impact load history. A system of wayside wheel impact load detectors (WILD) measure impact loads of passing wheels and report the data to an industry-wide database known as *Inte*RRIS®. Only one wheelset showed elevated impact loads prior to removal, which means that most of the wheelsets at the inspection were identified through a means other than WILD data.

3.3 Section Summary

An inspection of 21 wheelsets that developed TBU while in service showed the following:

- Indications of wheel sliding were found on all but one wheelset.
- Three of the wheels had TBU radial heights that measured greater than 1 inch.
  - These wheels represent the highest safety risk of the group.
  - The root cause of the TBU on these wheels was clearly a wheel slide event—indicated by the presence of a large flat spot adjacent to the TBU and heat discoloration concentrated near the flat spot and the TBU.
- Wheel wear, magnetism, and tread surface roughness readings of the wheels did not indicate any particular link to the TBU.
- TBU hardness readings were generally lower than the wheel tread surface, indicating a nonmartensitic microstructure.

4. Test

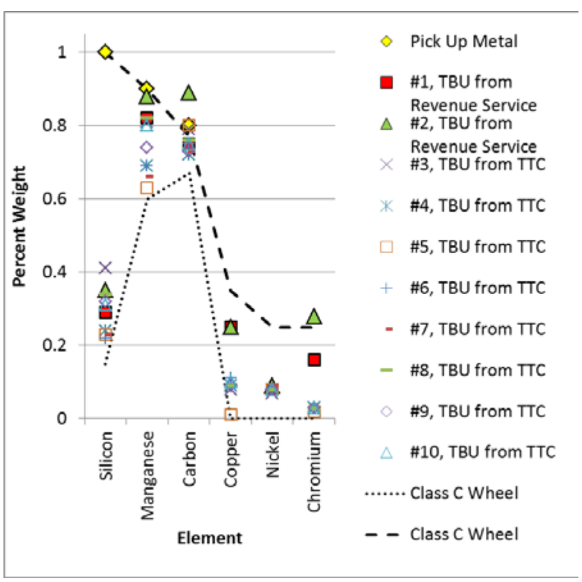
To further the understanding of the conditions necessary to create TBU, TTCI conducted laboratory analyses and wheel slide tests that involved variations of railcar speed, gross axle load, and moisture at the wheel-rail interface.

4.1 Laboratory Testing

Chemical and microstructural analyses of TBU material were conducted to provide insight into the source of the material and the formation mechanism.

4.1.1 Chemical Analysis

A chemical analysis of TBU samples indicated that the source of the material is likely a combination of wheel and rail steel. The TBU material from two wheels removed from revenue service and from eight wheels that were dragged on the tracks by TTCI was evaluated for chemical content. The percentage of carbon in the TBU material was in the range of Class C wheel steel (0.67 to 0.77) for six of the TTCI-created samples and one of the revenue service samples. Two of the TTCI-created samples had carbon content between the maximum for wheels (0.77) and the maximum for standard rail steel (0.84). One of the TBU samples from revenue service had a carbon content of 0.89, which is higher than the maximum for wheels or standard rail steel, but within the range for premium rail steel (approximately 1 percent). The percentages of other elements in the TBU samples were generally within the specified limits for wheel steel. Figure 8 shows the chemical content by percent weight of 10 TBU samples in comparison with the specified minimum and maximum chemistry limits for AAR class C wheels. Also included in Figure 8 are the previously reported percentages of silicon, manganese, and carbon from brake shoe metal pickup [11].



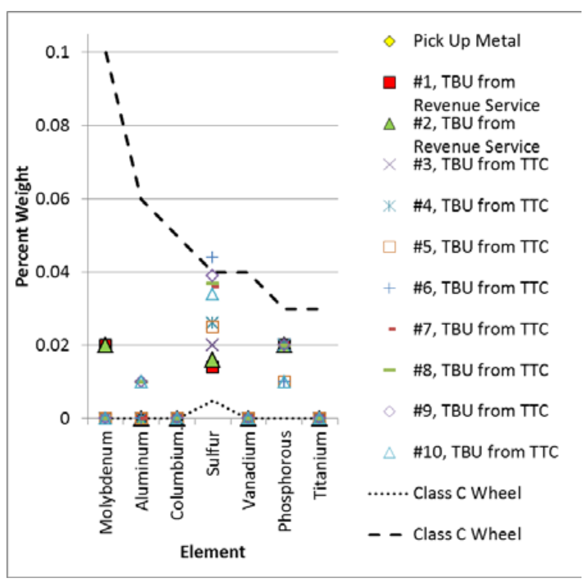


Figure 8. Chemical Content of Metal Pickup [11] and TBU Compared with Wheel Steel

4.1.2 Microstructural Analysis

Evaluation of the microstructure of several TBU samples showed a notable absence of any martensite, indicating that any heating of the steel from sliding either did not reach the austenitic transformation temperature (approximately 727 °C), or more likely did not cool at a sufficient rate to form martensite. TBU material typically makes contact with and adheres to the wheel tread surface in select locations rather than throughout the entire bulk of the material. This imperfect contact most likely slows conductive heat transfer from the hot TBU to the cooler mass of the wheel and does not allow the formation of martensite.

4.2 Wheel Slide Testing

TTCI conducted parametric wheel slide tests to explore the effects of axle load, moisture at the wheel-rail interface, speed, and slide distance on the formation of TBU. The majority of the tests were conducted with the brakes completely locked, allowing no rotation of the wheels. Additional tests were conducted in an attempt to generate TBU with wheels that were alternately sliding and rolling and with rolling wheels exposed to brake shoes containing metal pickup.

4.2.1 Test Procedures

For the wheel slide tests, a specific distance on the track was selected for the slide. Each test began by applying the brakes to a stationary car, accelerating to the test speed, maintaining the test speed, and decelerating to a stop. An aluminum gondola car equipped with truck-mounted brakes was selected for the test. The pneumatic line to the brake cylinder at the A-end truck was capped, allowing brake applications only to the B-end truck. The handbrake in this car also applies to the B-end truck only. The handbrake and airbrake were applied to the B-end truck only, and the wheelsets in this truck were slid the entire test distance. When a test run was completed, the brakes were released and the wheels rotated to allow measurements and photographs of the slide areas and the TBU. After documenting the damage, the car was moved enough to position an undamaged portion of each wheel in contact with the rail in preparation for the next test. Using this method, eight slide tests could be conducted using the same two wheelsets in the B-end truck. All of the test wheelsets had significant accumulated mileage prior to the wheel slide testing, and, therefore, had work-hardened tread surfaces.

A series of 54 short slide tests were conducted at a slide distance of 4,000 feet on tangent track. The car was tested in the empty condition (11,800-pound axle load) and again with enough lading to increase the axle load to 14,930 pounds and to 18,050 pounds. Train speeds for the short slide tests were 5 mph to 30 mph in 5 mph increments. A water-spray system was installed on the car to provide a steady stream of water on the rail immediately in front of the leading wheelset of the test car. This allowed all of the tests to be conducted under wheel-rail conditions of dry, wet, and lubricated (water with soap solution). Video cameras were positioned behind one wheel of each wheelset in the B-end truck to record the sliding action of the wheels on the rail.

An additional 36 tests at longer distances were also conducted using only the empty car with no lading. All of the tests were conducted on a 9-mile track loop. For the longer distance tests, the wheels were slid for 1, 2, or 3 laps at test speeds of 10 mph to 40 mph in 10 mph increments. The longer distance tests were also conducted with dry, wet, and lubricated conditions.

In past unrelated work, TTCI created TBU all around the circumference of wheels by purposely dragging an empty car with the handbrake tightly applied. The wheelsets alternatively slid and rotated (ratcheted) until a small amount of buildup material covered the majority of the tread circumference. In the current work, TTCI attempted to recreate this delicate force balance between the friction of the brake shoe and the friction of the rail. The handbrake was tightly applied, but the airbrakes were released. The ratcheting test was conducted over the distance of one track lap (9 miles).

TTCI ran three tests with brake shoes that had metal pickup in them. A light handbrake application was used to keep the brake shoes in contact with the wheels as they rotated. One test run was conducted at 20 mph, and two additional test runs were conducted at 40 mph. Each test was conducted over a distance of 9 miles, after which the test vehicle was stopped and the wheels were inspected for TBU.

4.2.2 Short Slide Tests

Figure 9 shows the average TBU height for the four sliding wheels from each of the short (4,000 feet) slide tests. Although there was much variation in the data, the measured TBU was highest when the rail was dry and the car was loaded to its heaviest test condition (18,050-pound axle load). Test speeds between 20 mph and the short slide maximum speed of 30 mph generally produced the most TBU. This is a logical trend, because the heat at the contact patch is related to the wheel-rail normal force and the friction conditions. Review of the video during the slide tests showed that, in some cases, TBU would form and fall off the wheel during the test. TBU measurements were recorded at the conclusion of the slide, so the final TBU height was not always indicative of the total amount of TBU formed during the slide.

Figures 10 and 11 show the average and maximum TBU heights grouped by axle load and wheel-rail condition, respectively. The trends of the results are more obvious with the results grouped in this manner; they indicate that heavier axle load and dry rail produce more TBU. An exception to this trend can be seen in Figure 11 in which the test with the lightest axle load and wet rail produced a higher maximum TBU measurement than expected compared with the trends of the other tests.

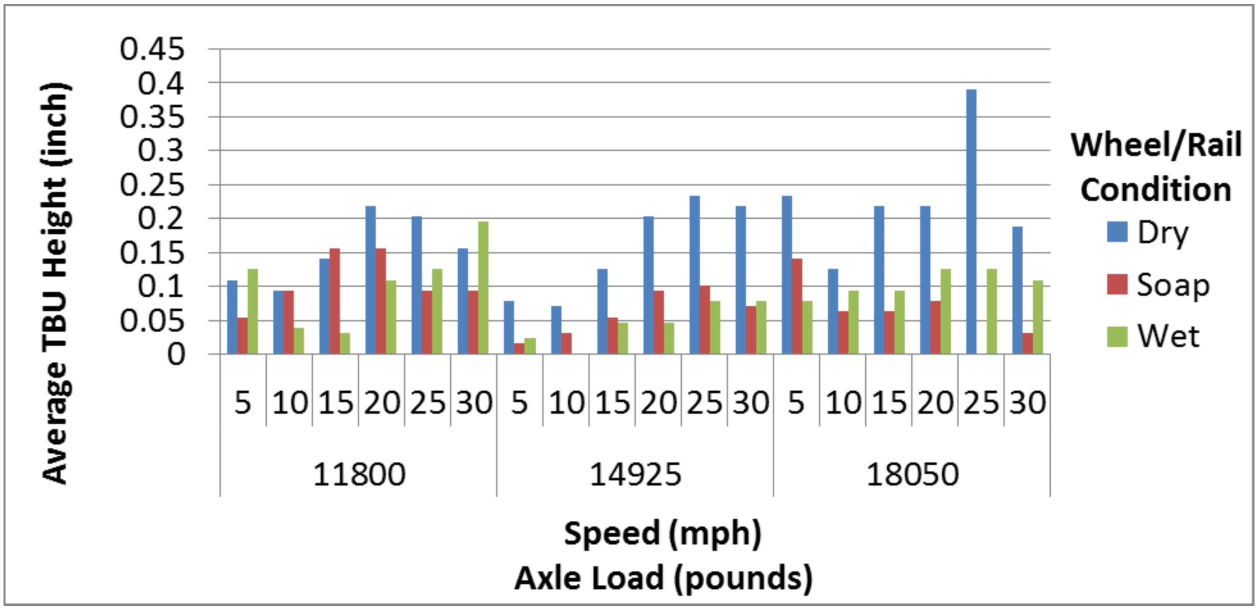


Figure 9. Average TBU for the Short Slide Tests

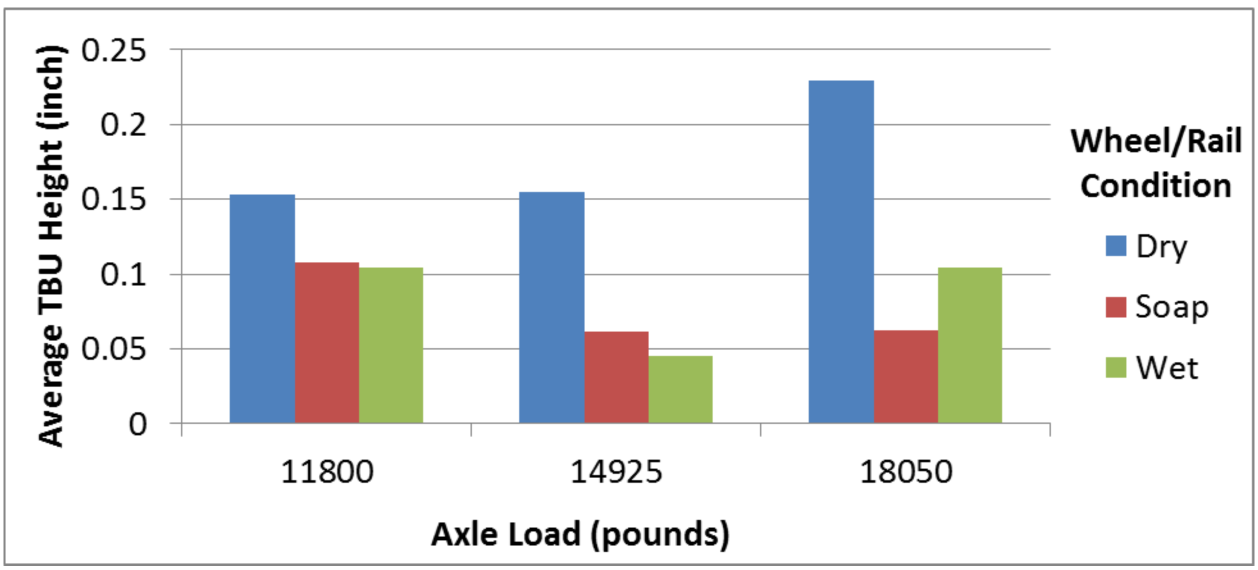


Figure 10. Average TBU for the Short Slide Tests Grouped by Axle Load

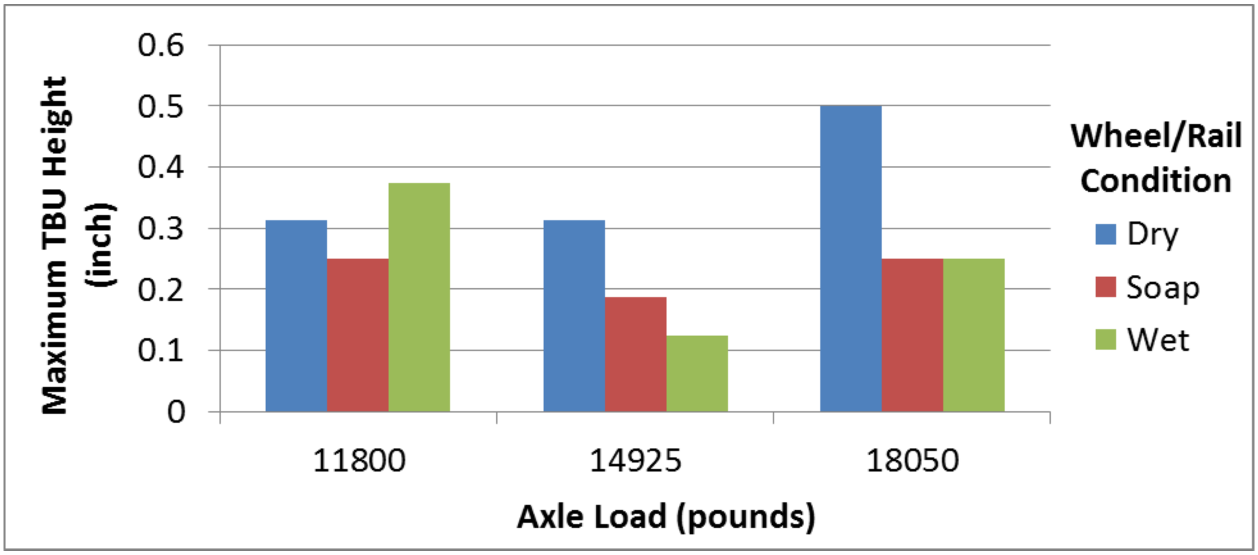


Figure 11. Maximum TBU for the Short Slide Tests Grouped by Axle Load

During the short slide tests, increasing the axle load of the car presented some difficulties as far as maintaining the wheelsets in a fully locked position with no rotation. With the car completely empty (11,800-pound axle load), the wheelsets would only stay reliably locked in place with no rotation when 90 psi brake cylinder pressure was applied followed by a tight handbrake application. This level of braking would be possible, but highly unusual, in a revenue service situation if the brake valve was bleeding air directly from the train line into the brake cylinder.

It was necessary to supply air pressure directly from the locomotive main reservoir to the brake cylinder at 140 psi. A tight handbrake application was also required to get the wheels to stay reliably locked in place with no rotation at the intermediate axle load (14,925 pounds). Such high pressures would not occur in revenue service, but the test provided useful information—without requiring a change in the test vehicle—about the effect of increased axle loads.

At the heaviest axle load tested (18,050 pounds), cast iron brake shoes were applied to the car to provide a higher static coefficient of friction between the wheel and the brake shoe. The brake cylinder was pressurized to 140 psi and the handbrake was tightly applied. Some runs under these conditions needed to be repeated because the wheels rotated during the slide test; eventually, the test matrix was completed with minimal wheel rotation.

4.2.3 Long Slide Tests

Based on the results of the short slide tests, the slide distance and maximum test speed were increased for an additional 36 long slide test runs. The lightest axle load was selected for the long slide tests because the wheel-rail vertical force fluctuations associated with negotiating special track work present on the test loop would almost certainly have caused some wheel rotation had the test been conducted with the heavier axle loads.

Figure 12 shows the average TBU height for the four sliding wheels from each of the long slide tests. As was the case with the short slide tests, the long slide data showed much variation. In general, TBU accumulated to the greatest heights under dry conditions and at longer slide distances. Train speeds between 20 and 30 mph appeared to optimize TBU height. Figure 13 shows a photo of the highest TBU created during the tests, measuring 1 inch high after a 27-mile slide at 30 mph in dry conditions.

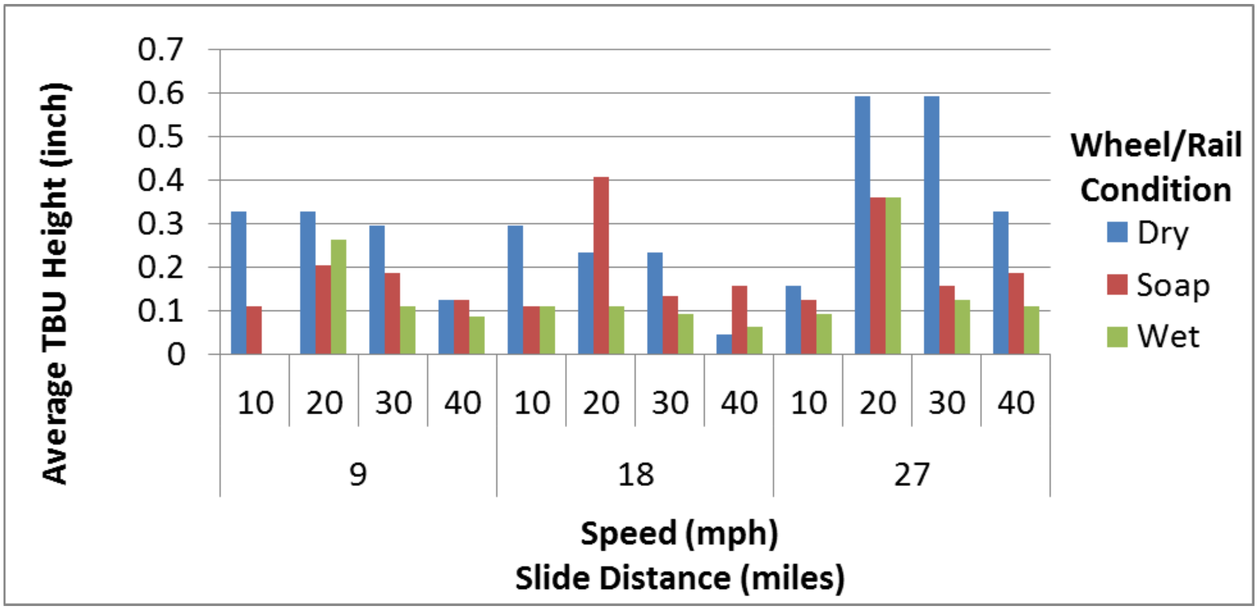


Figure 12. Average TBU for the Long Slide Tests

Figure 13. 1-Inch High TBU Created During Slide Tests

Figure 14 shows the data grouped by slide distance and wheel-rail condition. Figure 15 shows the data grouped by test speed and wheel-rail condition. Grouping the data in these ways allows the trends to be more readily identified.

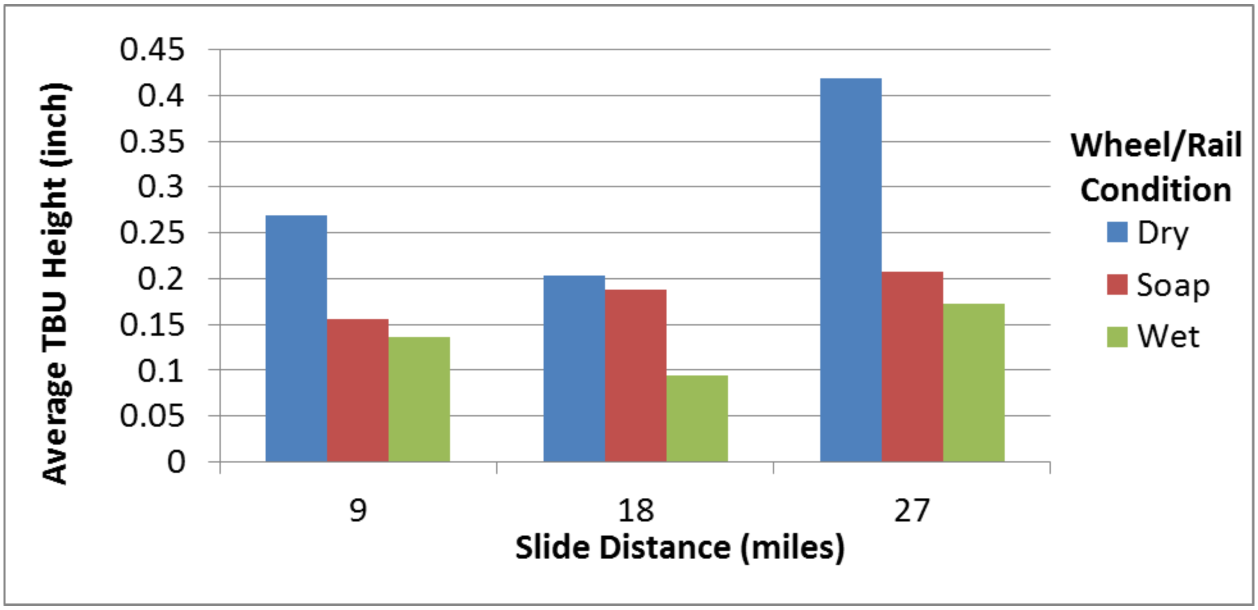


Figure 14. Average TBU for the Long Slide Tests Grouped by Slide Distance and Wheel-Rail Condition

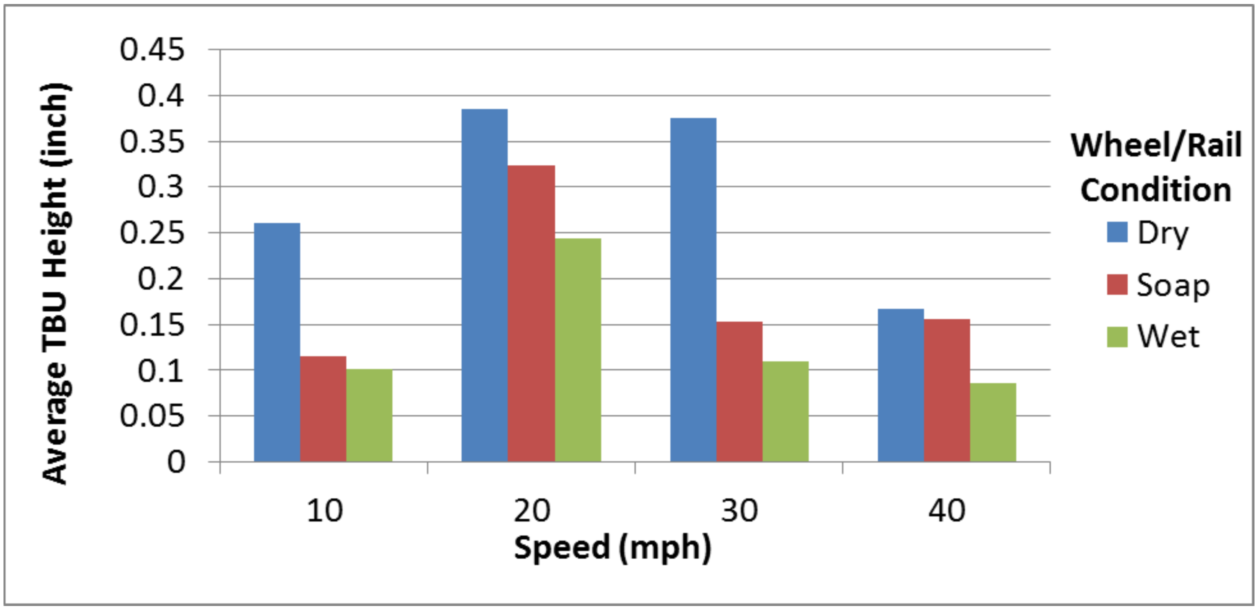


Figure 15. Average TBU for the Long Slide Tests Grouped by Speed and Wheel-Rail Condition

4.2.4 Ratcheting Test

The intention of the ratcheting test was to develop TBU around the entire circumference of the wheel by allowing the wheel to intermittently slide and rotate. During this testing, the wheels were made to slide on the rails periodically as desired. The test crew could see the TBU that developed on the wheel from their location on the instrument couch coupled to the test vehicle. However, after a significant distance of ratcheting, the wheels ceased sliding and began to roll. After this rolling began, any evidence of TBU began to disappear. By the end of the test, the only evidence remaining on the wheel was a slight bluing near the flange; all TBU was gone.

4.2.5 Brake Shoes with Metal Pickup

Brake shoes with metal pickup have been posited as a possible source of TBU. However, the results of the three test runs involving brake shoes with metal pickup showed no measurable signs of TBU on the wheel treads. The quantity of metal pickup embedded in the brake shoes decreased during the test runs, most likely as a combined result of wear and pieces of the metal pickup becoming dislodged from the brake shoe.

4.3 Section Summary

A chemical analysis of TBU samples indicated that the source of the material is likely a combination of wheel and rail steel. No martensite was found during a microstructural evaluation of several TBU samples. Wheel slide tests were successful in creating TBU with as much as a 1-inch radial height from the wheel tread surface. Heavier axle loads, dry conditions, longer slide distances, and slide speeds between 20 and 30 mph appeared to optimize TBU height. TBU was visually observed around the wheel circumference during a ratcheting test, but the wheels ceased sliding midway through the test and began to roll. This rolling action removed all of the TBU material before the end of the test. No metal pickup was observed to transfer from the brake shoes to the wheel tread during the three test runs.

5. Mitigation

TBU is a brake-related problem. This section describes some of the industry's current efforts to improve brake performance, as well as potential means of reducing TBU accidents in the future.

5.1 Current Industry Efforts to Improve Brake Performance

The North American freight railroad industry is currently focused on improving brake inspection and performance. Many of these initiatives could have a significant impact on the number and severity of TBU wheel removals and TBU-related train accidents. Descriptions of these efforts will be divided into three categories: wayside detection, handbrakes, and airbrakes.

5.1.1 Wayside Detection

When a handbrake and/or airbrake is applied unintentionally to a car, the wheels on that car get hotter than other wheels on the same train. Many railroads have taken the initiative to install wayside wheel temperature detectors to track the relative brake effort of each wheel in a moving train, allowing cars with unusually hot wheels to be identified for inspection and maintenance, and thereby reducing the window of opportunity for such cars to slide the wheels and generate TBU.

At least one freight railroad examines the WILD data history of cars on its property to find instances of a sudden increase in impact loads. This method of analysis may more quickly identify cars with wheel sliding issues and TBU, in addition to other wheel problems.

5.1.2 Handbrakes

Educating employees about the importance of fully releasing handbrakes is the goal of a short training video titled "Please Release Me…Let Me Roll" [12] created by the Wheel Defect Prevention Research Consortium (WDPRC), which is a group comprised of railroads, manufacturers, car owners, and FRA's ORD. More than 1,500 DVD copies of the video have been distributed since 2006; it can be viewed and downloaded online at www.aar.com/wdprc.

Mechanical problems with handbrakes can also lead to partial releases when the lever is pulled. The WDPRC recently published results of handbrake testing, which showed that partial releases can result from a combination of factors including handbrake age and design of the brake rigging [13]. Improving the handbrake release functionality could reduce the number of wheel slides and resulting TBU.

TTCI is testing several prototypes of remote release handbrakes. These handbrakes can be released from the ground on either side of the car by simply pushing a button or pulling a lever. In addition to eliminating the need to climb onto the car to release the handbrakes, this type of handbrake can be released with more ease and speed than a standard handbrake, and could therefore result in fewer misapplied handbrakes.

In an effort to minimize problems with partially released handbrakes, industry manufacturers have recently introduced "prolonged release" handbrakes. Vertical wheel handbrakes operate by tightening a chain around a drum. To maintain chain tension, a pawl holds a gear attached to the drum. In a normal handbrake, the pawl holding the drum releases when the lever is lifted and re-engages as soon as the lever is released. After lifting the release lever on a prolonged release handbrake, the pawl holding the wheel does not re-engage until the handbrake wheel is turned clockwise for the next application. If some of the chain does not release from the drum when the lever is pulled, the advantage of a prolonged release handbrake is that it will continue to release chain from the drum while the car is in motion, whereas a normal handbrake will not release any additional chain. This could have the effect of shortening the distance traveled with the wheels sliding due to a misapplied handbrake. The test results described in the previous section of this report indicate that increased distances of wheel slide events produce more TBU on average.

5.1.3 Airbrakes

The AAR is considering some improvements in both the structure and content of the single car airbrake test [14]. By simplifying the wording and reorganizing the procedure, the test should be easier for new employees to master in a shorter time. Small changes to some of the test details may enable improved identification of valve performance problems such as air leakage into the brake cylinder during the type of extended brake applications necessary to descend long grades.

5.2 Longer Term Solutions

Technology appears to be a good solution for railroads in many arenas, and TBU is no exception. Brake cylinder pressure sensors on board each car, combined with a communication system, could provide the locomotive engineer with real time feedback about any brake cylinders in the train with excessive air pressure. Likewise, handbrake sensors could be added to each car to notify the locomotive engineer about applied handbrakes. Manufacturers could modify their prototype remote release handbrake systems to accept an electronic communication signal from the engineer. This would allow the engineer to remotely release all of the handbrakes on the train from the cab of the locomotive.

In the meantime, wayside detectors could help identify sliding wheels. This could be done in a number of ways, including video image analysis.

Another potential solution is the use of an automatic handbrake release wireless signal. Manufacturers could modify their prototype remote release handbrake systems to accept a wireless communication signal from a short range transmitter located just outside of a yard. With this system, a car with sliding wheels would not be able to travel far enough or fast enough to create enough a TBU-related safety concern.

5.3 Section Summary

The railroad industry is currently working on various efforts to improve brake system performance, many of which could reduce the incidence of TBU. Increased use of data from wayside detectors, handbrake training and design improvements, and an improved airbrake test may offer potential benefits for brake system performance. In the long term, sensors on each car, paired with a communication system and some technological advances in handbrake release control, would provide an excellent opportunity to dramatically reduce the number of TBU wheels and related accidents.

6. Conclusions

On the basis of an inspection of wheels and the results of wheel slide tests, it was concluded that the root cause of TBU of significant height is wheel slide caused by excessive brake force. During the tests, TBU accumulated to the greatest heights under dry conditions, at longer slide distances, and under heavier axle loads. Train speeds between 20 and 30 mph also appear to boost TBU height. Although the current test program was not able to provide evidence of the transfer of metallic material from brake shoes to wheels, this cannot be ruled out as a source for some minor cases of TBU, as indicated by the existing literature on the topic.

Chemical analysis of TBU samples indicated that the source of the material is likely a combination of wheel and rail steel. This finding reinforces the conclusion that wheel slides cause TBU. A microstructural evaluation of several TBU samples found no martensite, a microstructure that results when hot steel is rapidly cooled. A relatively slow conductive heat transfer rate from the irregular contact between the hot TBU and the cooler wheel likely does not provide sufficiently rapid cooling for martensite formation.

The railroad industry is currently poised to reduce TBU through improved brake system performance as a result of the increased use of data from wayside detectors to identify cars with brake problems, handbrake training for train crews, handbrake design improvements, and an improved airbrake test. Although TBU removals are decreasing, TBU-related accidents do not show a clear trend as a percentage of all wheel-related accidents.

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Abbreviations and Acronyms

AAR	Association of American Railroads
FRA	Federal Railroad Administration
*Inte*RRIS®	Integrated Railway Remote Information Service, a registered trademark of TTCI
TBU	tread buildup
TTC	Transportation Technology Center (the site)
TTCI	Transportation Technology Center, Inc. (the company)
WILD	wheel impact load detector
WDPRC	Wheel Defect Prevention Research Consortium