Wheels and Rail – A Quarter Century of Improvements

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Wheels and Rail – A Quarter Century of Improvements

Congratulations to Gordon Bachinsky, Bob Tuzik and Brandon Koenig on the 25th Anniversary of the Wheel – Rail Interaction Conference!

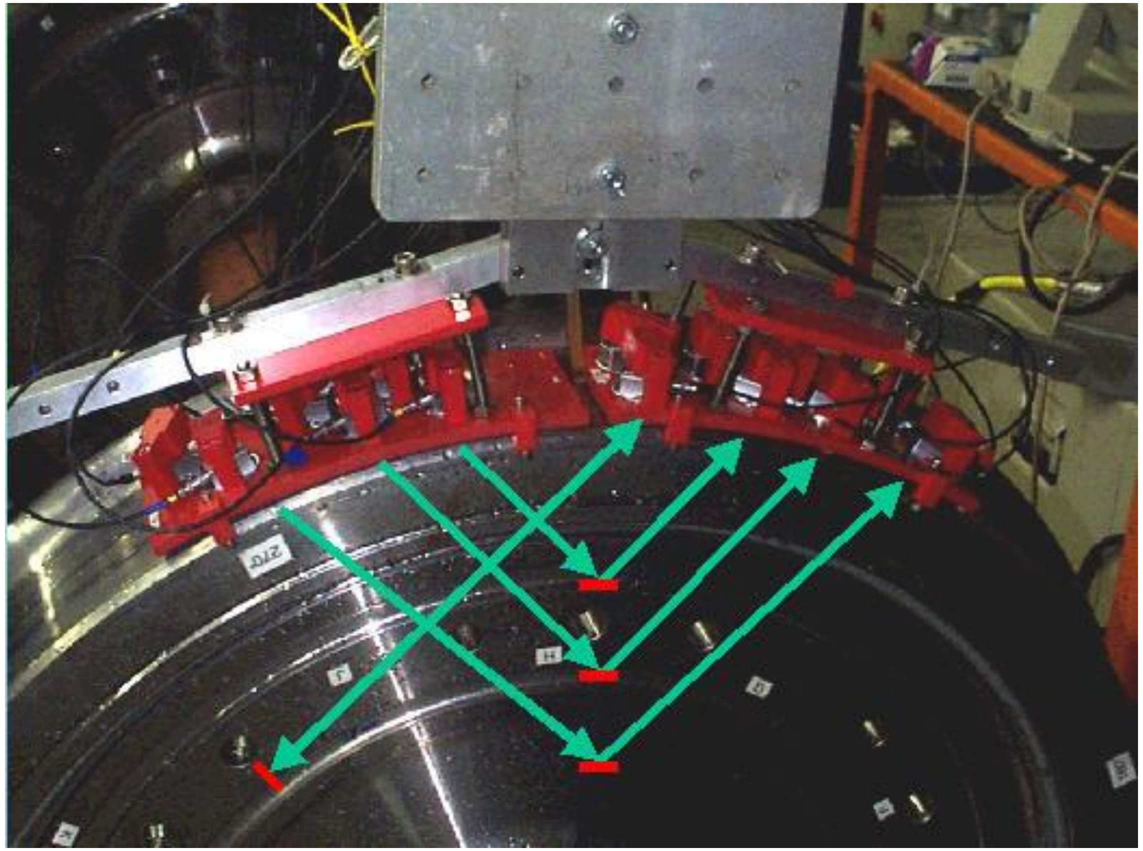
Wheels and Rail – A Quarter Century of Improvements

- Wheels
  - Ultrasonic testing
  - Magnetic particle testing
  - Shot peening
  - New wheel designs
  - AAR Quality Program
  - Curved plate
  - Microcleanliness, chemistry specifications
  - Microalloy specifications
  - Storage requirements
  - Defect codes added
  - Tread worn hollow specifications

Improvements to Wheels

- 1971 Ultrasonic testing of wheel rims added – rejection standard 1/8” flat bottom hole
- July 1999 – Ultrasonic rejection tightened to 50% of a 1/8” flat bottom hole
- June 2006 – Ultrasonic rejection tightened to 25% of a 1/8” flat bottom hole

Improvements to Wheels



Ultrasonic Testing of Wheel

Improvements to Wheels

- 1971 – Magnetic particle testing of wheel plates
- 2004 – Magnetic particle rejection length standard for plates added

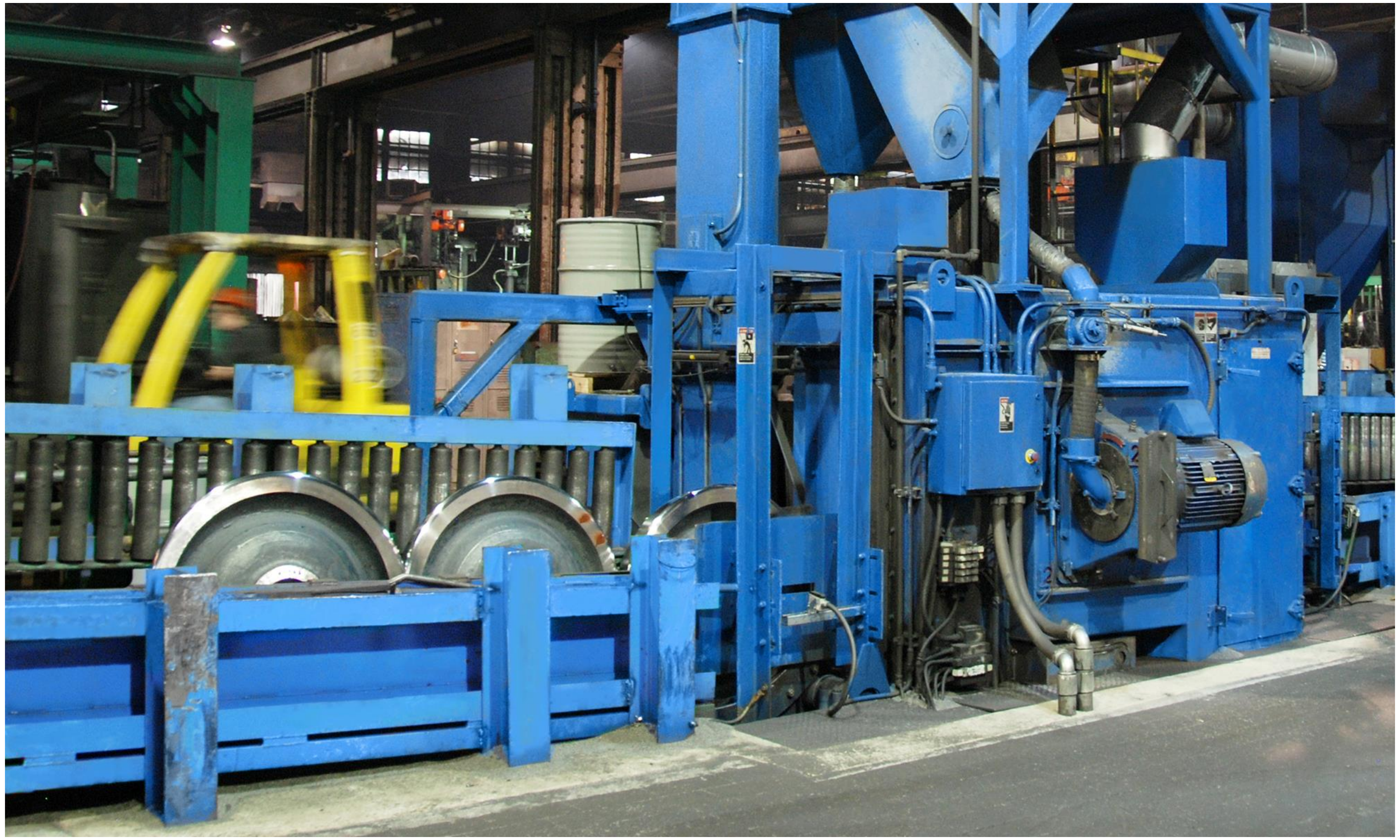
Improvements to Wheels

Magnetic Particle Testing

Improvements to Wheels

- 1971 – Shot peening required for wheel plates
- Shot peening requirements refined and improved

Improvements to Wheels

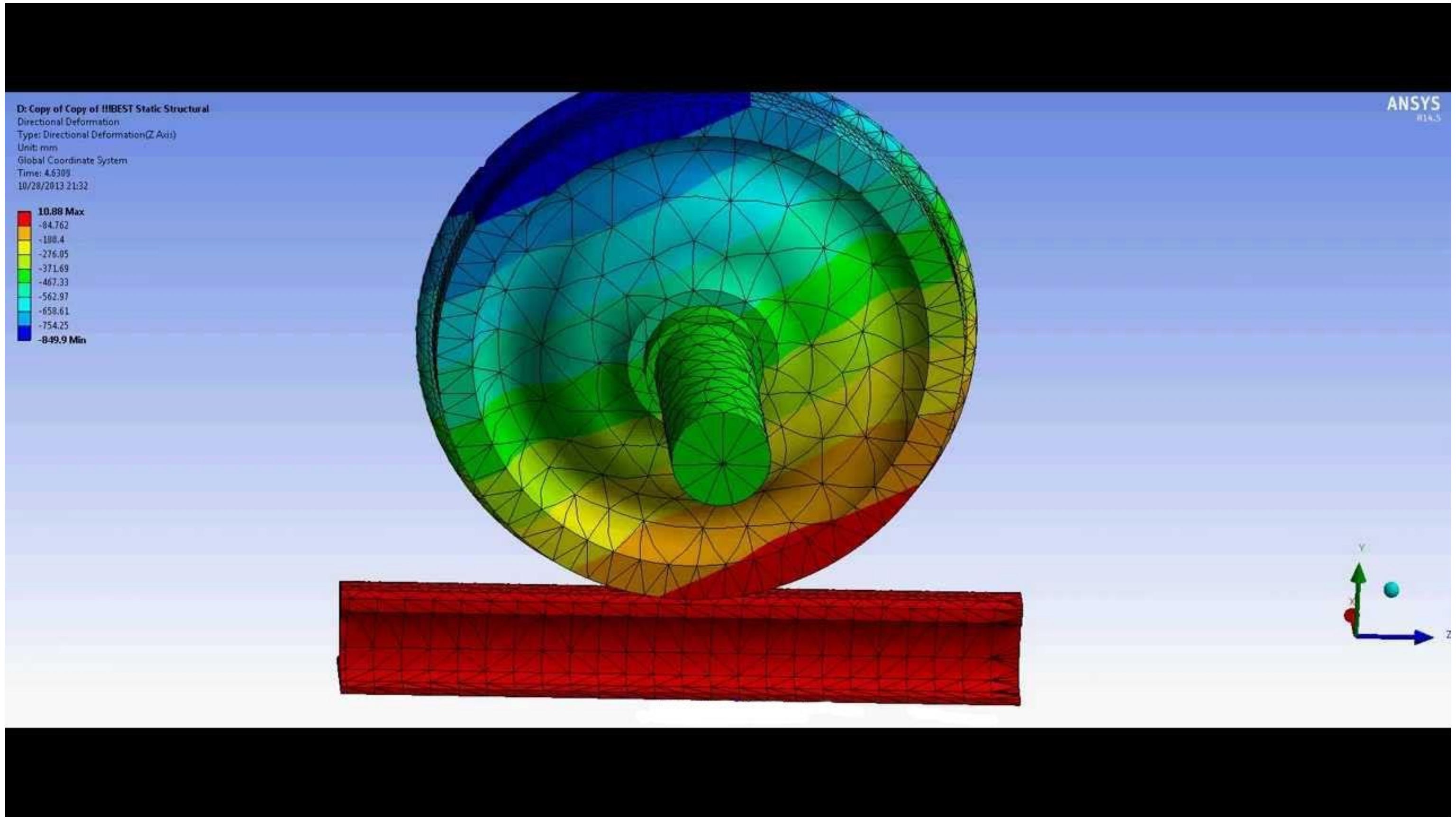


Shot Peening of Wheel

Improvements to Wheels

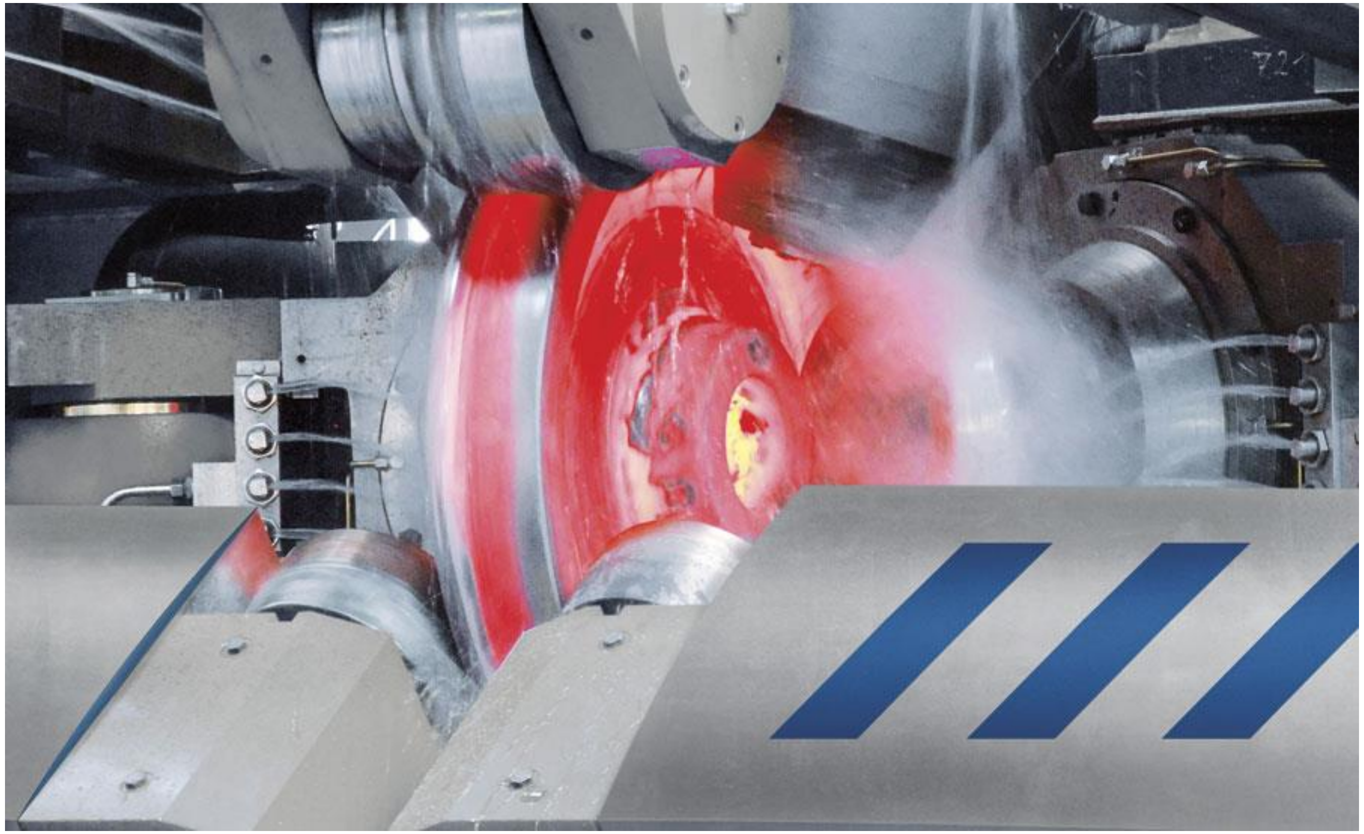
- 1981 - AAR S-660 finite element analysis computer simulation required for acceptance of new wheel designs
- 1985 – AAR M-1003 Quality Program
- September 1988 – AAR requires new wheels to be curved plate “low stress” and heat treated (rim quenched)

Improvements to Wheels



Finite Element Analysis

Improvements to Wheels



Heat Treatment of Wheels

Improvements to Wheels

- 2004 – Microcleanliness testing of rim samples added based upon ASTM-1245
- 2004 – Chemistry requirements tightened, Class D added
- Class D “microalloy wheel” approval process is added

Improvements to Wheels

- Wheel storage provisions added to prevent wheels from being excessively corroded before mounting
- Why Made Code 65 added to account for wheels being removed via detectors for high impact load
- Tread Worn Hollow requirements added

Improvements to Wheels

Storage of Wheels

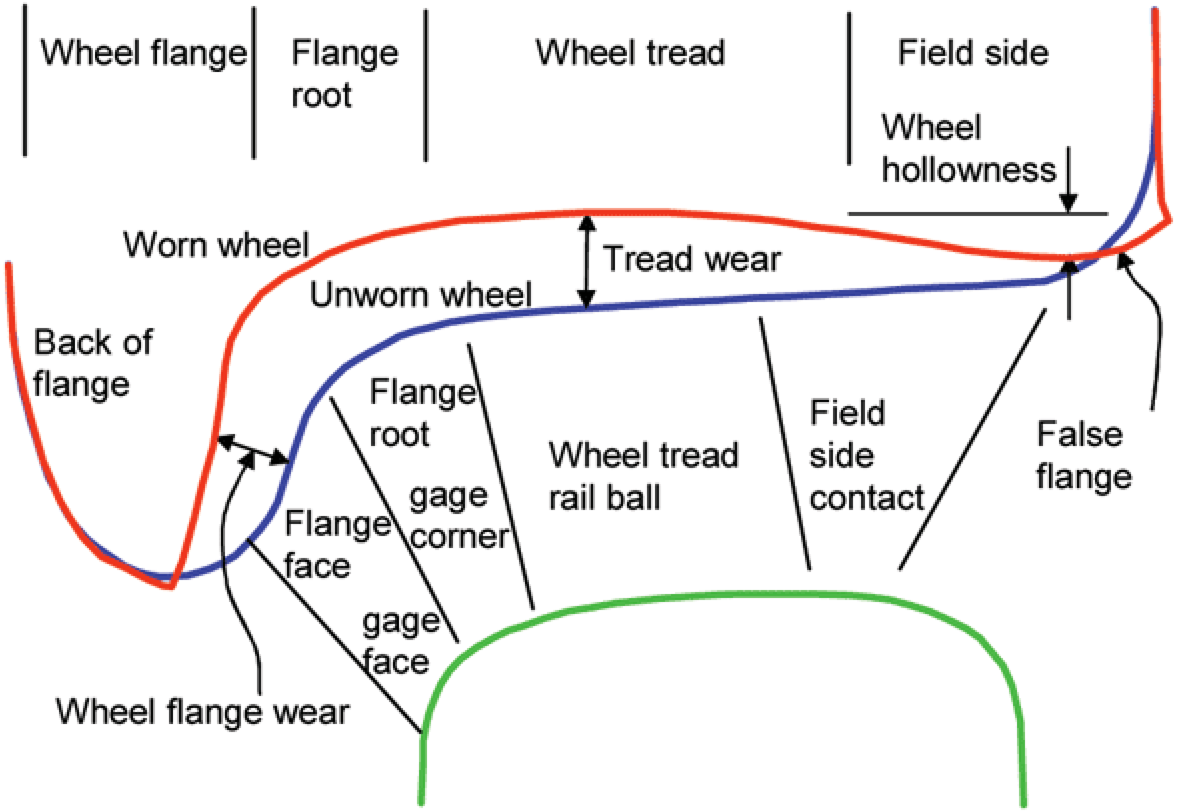
Improvements to Wheels

Storage of Wheels

Improvements to Wheels

Wheel Impact Load Detector

Improvements to Wheels



Hollow Worn Wheel

Improvements to Wheels

- Class B (locomotive and passenger cars), 15 years ago, hardness was 277-341HB. Now 302-341HB
- Class C (freight cars), 321-363HB
- Class D same as Class C, with microalloys, 341-415HB

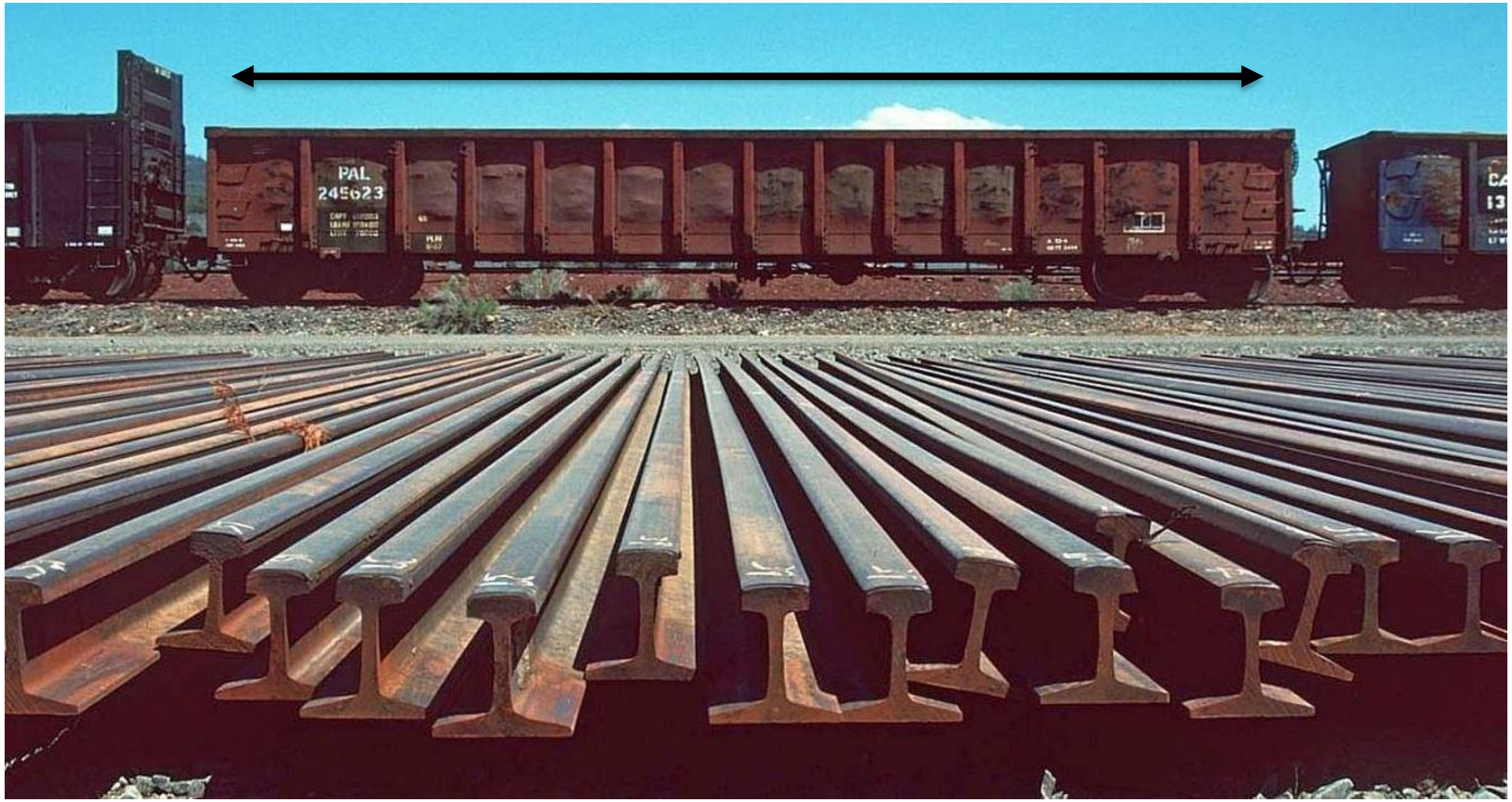
Wheels and Rail – A Quarter Century of Improvements

- Rails
  - Length
  - Rail Handling
  - Design
  - Manufacturing
  - Hydrogen Elimination
  - Workmanship
  - Testing of rail
  - Brands and Stamps
  - Marking
  - Chemical Composition
  - Mechanical Properties
  - New Technologies

Improvements to Rail

- Length
  - 39 feet (loaded into 40 foot gondola)
  - 80 feet
  - 320 feet (US domestic, Steel Dynamics)
  - 420 feet (imported, Nippon)
  - Welded into Continuous Welded Rail, longer rail decreases welds per string
  - Standard lengths of rail developed, with short rail lengths defined

Improvements to Rail



39 Foot Rail In 40 Foot Gondola

Improvements to Rail

80 Foot Rail

Improvements to Rail

Steel Dynamics 320 foot rail

Improvements to Rail

Cranes load 480-foot sections of high-strength, head-hardened continuous cast rail from a ship at the Port of Stockton to shuttle cars.

Nippon 480 foot rail on “Pacific Spike”

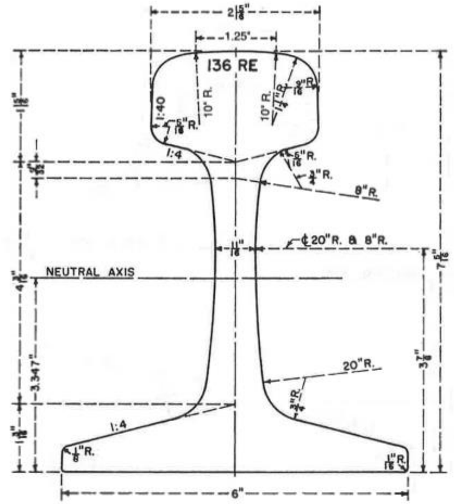
Improvements to Rail

- Rail Handling
  - Not specified until 2017
  - AREMA produced rail handling procedures for shippers
  - Inspection, loading and unloading

Improvements to Rail

- Design of Rail
  - 25 years ago, recommended rail sections: 115 RE, 119 RE, 132 RE, 133 RE, 136 RE, 140 RE
  - Current recommended rail sections: 115 RE, 136 RE, 141 RE
  - 25 years ago, head radius was 10 inches with a simple compound corner radius
  - Currently, head radius is 8 inches, with a triple compound corner radius and a 1 in 40 side slope, conformal to an average worn wheel profile
  - The head area was increased from 132 RE to 136 RE to 141 RE, to provide more head material for longer life cycle

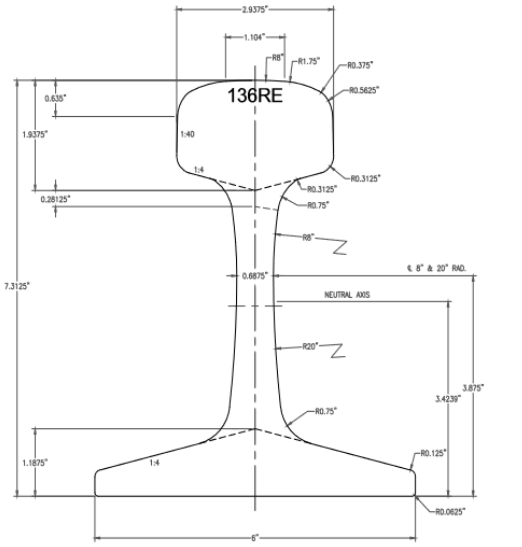
Improvements to Rail



136 RE:

1. Rail Area (sq. in.)	Head	4.92
	Web	3.39
	Base	5.01
	Whole Rail	13.32
2. Rail Weight (lbs/yd) (based on specific gravity of rail steel = 7.84)		135.80
3. Moment of Inertia about the neutral axis		94.20
4. Section modulus of the head		23.70
Section modulus of the base		28.20
5. Height of neutral axis above base		3.34
6. Lateral moment of inertia		14.44
7. Lateral section modulus of the head		9.83
Lateral section modulus of the base		4.82
8. Height of shear center above base		1.64
9. Torsional rigidity is 'KG' where G is the modulus of rigidity & K = (error for K greater than 10%)		6.24

[1]References, Vol. 63, 1962, pp. 498, 768; Vol. 92, 1991, p. 49; Vol. 96, pg. 28 (Error—1.40" should be 1.25")

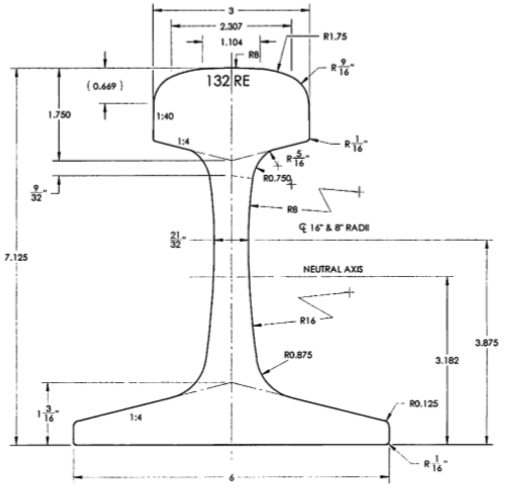


1. Rail Area (square inch)	
Head	4.8186
Web	3.6380
Base	4.8696
Whole Rail	13.3262
2. Rail Weight (lb/yd) (based on specific gravity of rail steel = 7.84)	135.8826
3. Moment of Inertia about the neutral axis	94.2148
4. Section modulus of the head	23.7310
Section modulus of the base	28.1878
5. Height of neutral axis above base	3.4239
6. Lateral moment of inertia	14.4556
7. Lateral section modulus of the head	9.8421
Lateral section modulus of the base	4.82

Figure 4-1-5. 136 RE Rail Section[1]

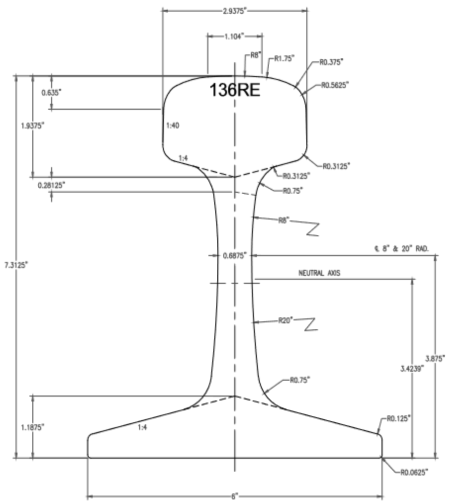
[1] References, Vol. 63, 1962, pp. 498, 768; Vol. 92, 1991, p. 49; Vol. 96, p. 28.

Improvements to Rail



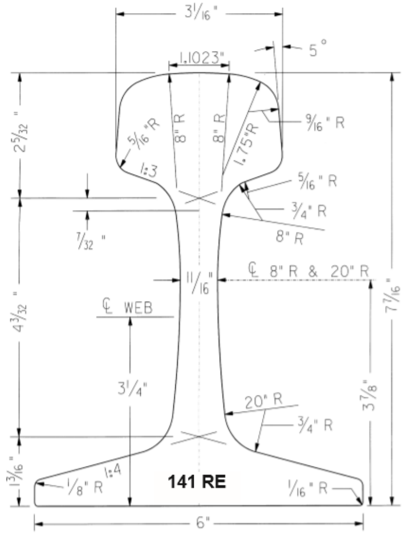
1. Rail Area (square inch) Head Web Base Whole Rail	 4.3480 3.6151 4.8701 12.8332
2. Rail Weight (lb/yd) (based on specific gravity of rail steel = 7.84)	130.7972
3. Moment of Inertia about the neutral axis	86.8
4. Section modulus of the head Section modulus of the base	22.0 27.3
5. Height of neutral axis above base	3.182
6. Lateral moment of inertia	14.2
7. Lateral section modulus of the head Lateral section modulus of the base	9.50 4.75

Figure 4-1-3. 132 RE Rail Section



1. Rail Area (square inch) Head Web Base Whole Rail	 4.8186 3.6380 4.8696 13.3262
2. Rail Weight (lb/yd) (based on specific gravity of rail steel = 7.84)	135.8826
3. Moment of Inertia about the neutral axis	94.2148
4. Section modulus of the head Section modulus of the base	23.7310 28.1878
5. Height of neutral axis above base	3.4239
6. Lateral moment of inertia	14.4556
7. Lateral section modulus of the head Lateral section modulus of the base	9.8421 4.82

Figure 4-1-5. 136 RE Rail Section[1]



il Area (square inch.) ad :b se ıole Rail	 5.3724 3.5547 4.8701 13.7972	6. Lateral moment of inertia	14.91
il Weight (lb/yd) (based on specific gravity of l steel = 7.84)	140.7002	7. Lateral section modulus of the head Lateral section modulus of the base	9.74 4.97
oment of Inertia about the neutral axis	100.44	8. Height of shear center above base	1.88
ction modulus of the head ction modulus of the base	25.24 28.97	9. Torsional rigidity is 'KG' where G is the modulus of rigidity and K = (error for K greater than 10%)	5.97

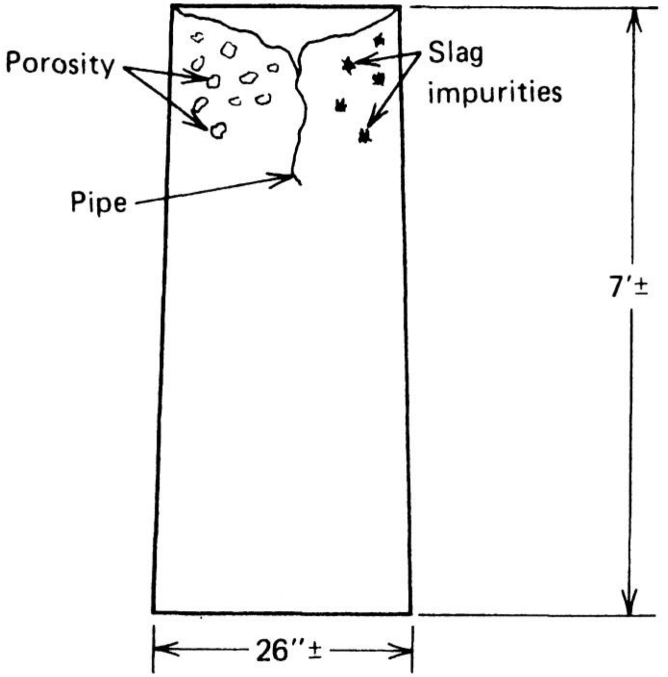
Figure 4-1-6. 141 RE Rail Section

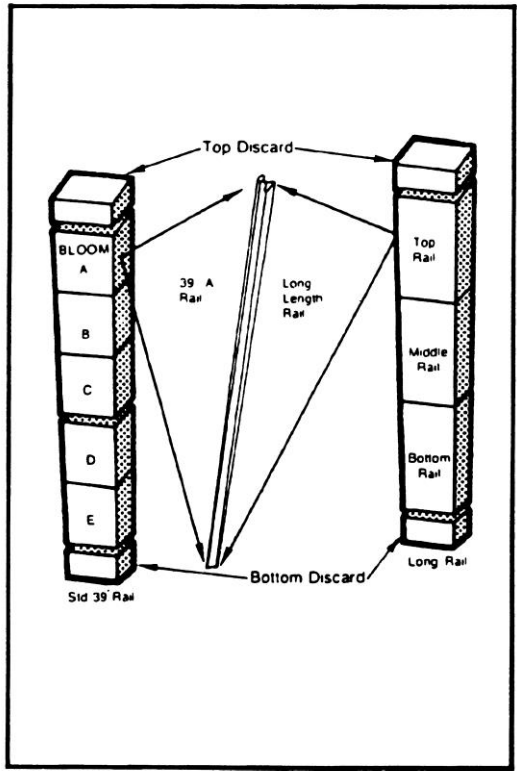
...s, Vol. 63, 1962, pp. 498, 768; Vol. 92, 1991, p. 49; Vol. 96, p. 28.

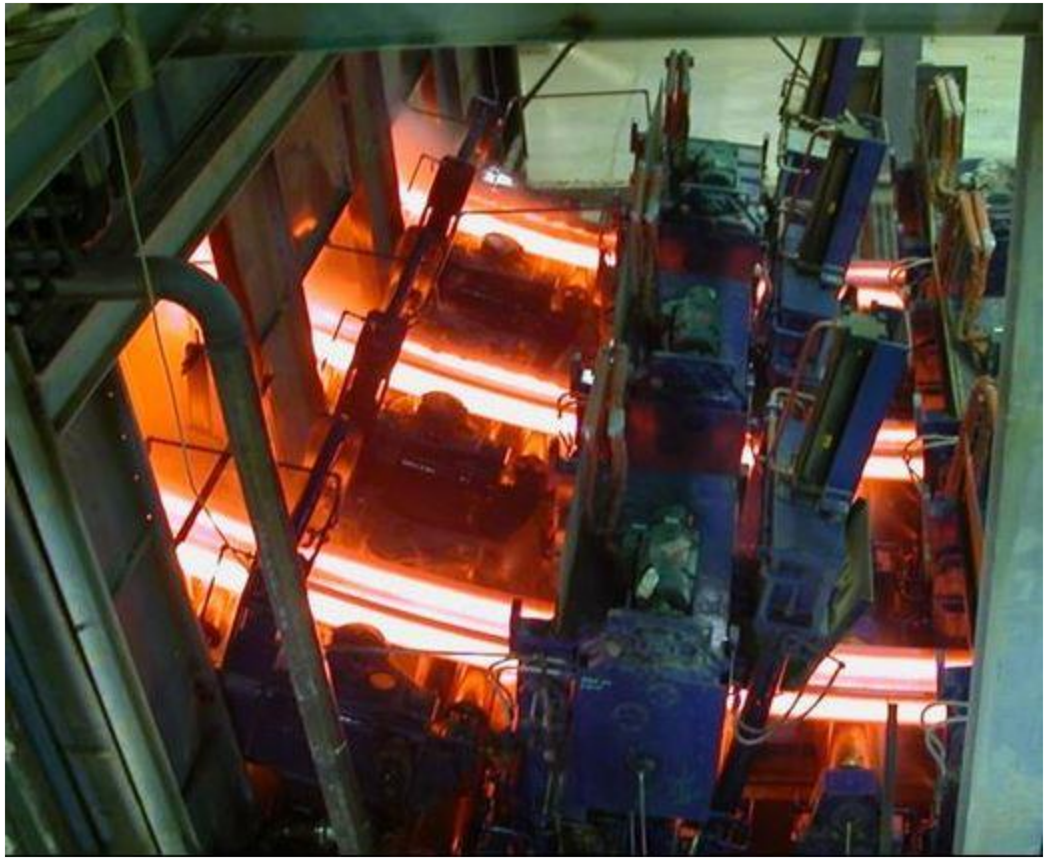
Improvements to Rail

- Manufacture of Rail
  - Clean steel technology
  - Ingot versus continuous casting
  - Control cooling of bloom/rail versus vacuum degassing
  - Argon gas stirring
  - Magnetic stirring
  - Head hardening

Improvements to Rail





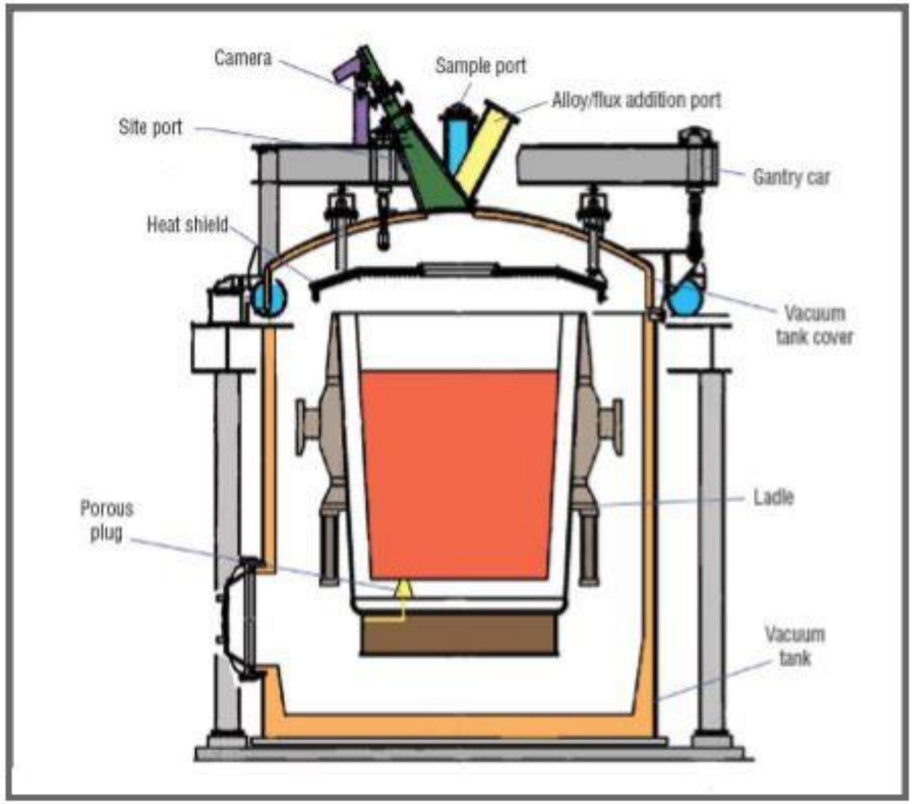


Ingot versus Continuous Casting

Improvements to Rail

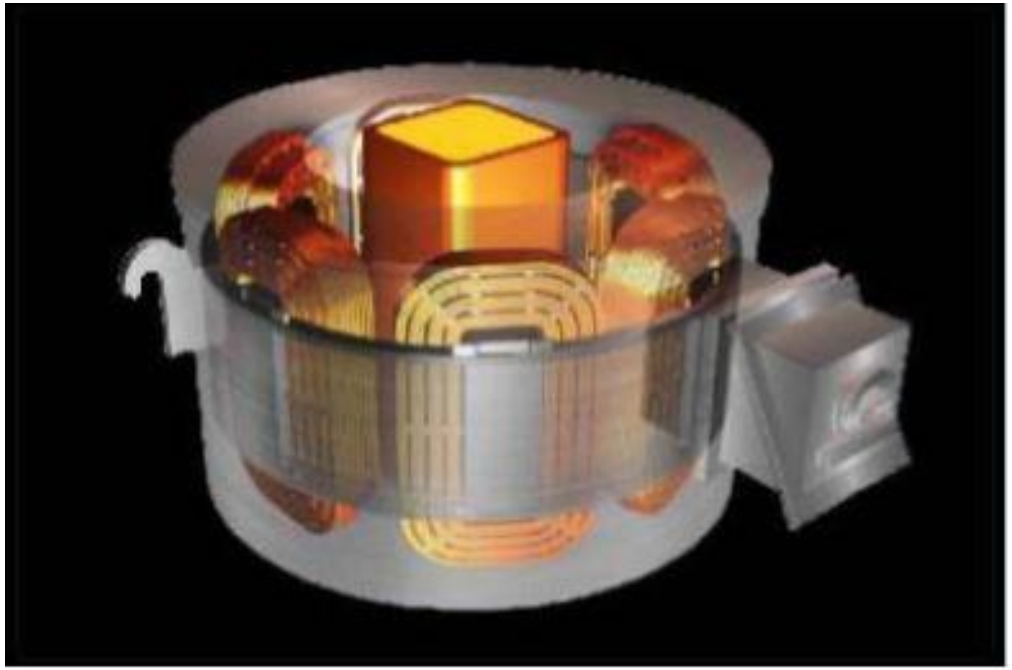
Control Cooling versus Vacuum Degassing

Improvements to Rail



Argon Stirring

Improvements to Rail



Magnetic Stirring

Improvements to Rail

- Workmanship
  - Quality control processes
  - Tighter tolerance
  - Trackwork tolerance rail
  - High speed rail

Improvements to Rail

Table 4-2-2. Section Tolerances

Description	Tolerance, Inches			
	Rail		Trackwork Rail	
	Plus	Minus	Plus	Minus
Height of rail (measured within one foot from end)	0.030	0.015	0.030	0.015
Width of rail head (measured within one foot from end)	0.025	0.025	0.015	0.015
Thickness of web	0.040	0.020	0.040	0.020
Fishing template standout	0.060	0.000	0.030	0.000
Asymmetry of head with respect to base	0.050	0.050	0.030	0.030
Width of base	0.040	0.040	0.030	0.030
Flange height	0.025	0.015	0.015	0.015

Note 1: Base concavity shall not exceed 0.010 inch. Convexity is not permitted.
Note 2: No variation will be allowed in dimensions affecting the fit of the joint bars, except that the fishing template may stand out not to exceed 0.060 inch laterally.
Note 3: All four corners of the rail base shall have the radii according to the drawing ±1/32 inch. Any disputes shall be analyzed on an Optical Comparator.
Note 4: The section of the rails to be used in AREMA trackwork shall conform to the design specified by the purchaser subject to the tolerances listed under trackwork rail above.
Note 5: Head radius to be within (±) 2 inches per Figure 4-2-40.
Note 6: On up to 5% of the order, the height of the rail plus tolerance can be between 0.030 and 0.040 inches, if the purchaser's authorized representative and the manufacturer agree. This exception does not apply to trackwork rail.

Trackwork Tolerance

Improvements to Rail

c. The uniform surface upsweep at the rail ends shall not exceed a maximum ordinate of 0.020 inch in 3 feet and the 0.020 inch maximum ordinate shall not occur at a point closer than 18 inches from the rail end as illustrated in Figure 4-2-5.

(1) (HS) The uniform surface upsweep at the rail ends shall not exceed a maximum ordinate of 0.015 inch in 3 feet and the 0.015 inch maximum ordinate shall not occur at a point closer than 18 inches from the rail end as illustrated in Figure 4-2-5 (HS)

d. Surface downsweep and droop shall not be accepted.

e. Deviations of the lateral (horizontal) line in either direction at the rail ends shall not exceed: (1) a maximum mid-ordinate of 0.020 inch in 3 feet using a straight edge and of 0.010 inch at the end quarter point as illustrated in Figure 4-2-6a.; (2) a maximum of 0.040 inch measured by the tangent offset method at the end of the rail as illustrated in Figure 4-2-6b.

(1) (HS) Deviations of the lateral (horizontal) line in either direction at the rail ends shall not exceed: (1) a maximum midordinate of 0.015 inch in 3 feet using a straight edge and of 0.008 inch at the end quarter point as illustrated in Figure 4-2-6a. (HS).; (2) a maximum of 0.030 inch measured by the tangent offset method at the end of the rail as illustrated in Figure 4-2-6b.(HS)

High Speed Rail Straightness Tolerance

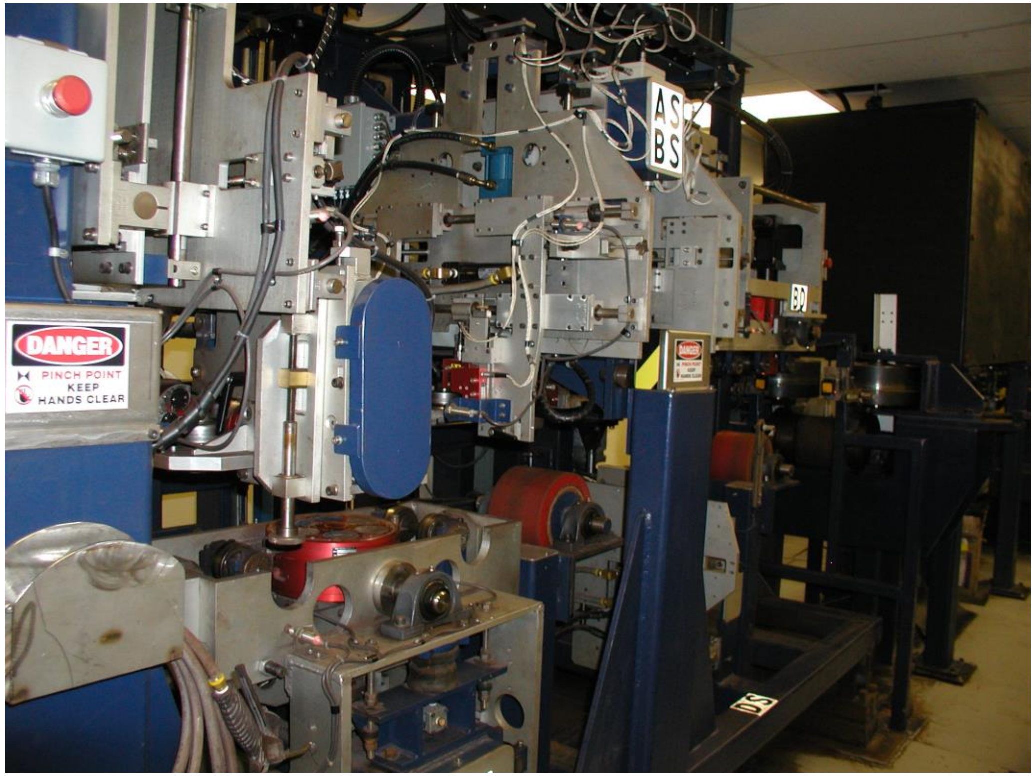
Improvements to Rail

- Testing of Rail
  - Ultrasonic
  - Eddy current
  - Laser dimension measurement

Improvements to Rail

Ultrasonic Testing of Rail

Improvements to Rail



Eddy Current Testing of Rail

Improvements to Rail

Laser Dimension Measurement of Rail

Improvements to Rail

- Brands and stamps
  - Eliminate sharp letters and numbers
  - Control cooled (CC), vacuum treated (VT), no brand

Improvements to Rail

- Marking
  - Paint

Improvements to Rail

2.1.15 MARKINGS (2017)

a. High-strength rails shall be marked by either a metal plate permanently attached to the neutral axis, hot stamped, or in the brand which gives the manufacturer, type and/or method of treatment. Heat treated rail shall be paint-marked orange. Alloy rail shall be paint-marked aluminum color. (HS) High speed rails shall be paint marked blue.

b. Non AREMA (Industrial Quality) rails shall be paint-marked yellow.

c. Short rails (less than 80 feet) shall be paint-marked green.

d. Trackwork rails shall be paint-marked white.

e. Rail length shall be painted on the end faces or in a manner acceptable to the purchaser or manufacturer.

f. Individual rails shall be paint-marked only one color, according to the order listed above.

g. Industrial Quality (IQ) rails shall be permanently identified by grinding diagonally through every "RE" or other designation within the rails' branding. Each designation brand shall be ground or milled diagonally from the top right-hand corner to the bottom left-hand corner, a minimum of 1/4" in width and to within 0.010" of the parent rail web surface.

Marking of Rail

Improvements to Rail

- Chemical composition
  - Carbon
  - Alloys
  - Other elements
    - Copper
    - Trace elements

Improvements to Rail

3. Chemical Composition

3.1 The chemical composition of the standard rail steel determined as prescribed in 3.3 shall be within the following limits:

	Chemical Analysis, Weight Percent		Product Analysis, Weight Percent Allowance Beyond Limits of Specified Chemical Analysis	
Element	Min.	Max.	Under Min.	Over Max.
Carbon	0.72	0.82	0.04	0.04
Manganese	0.80*	1.10*	0.06	0.06
Phosphorus	—	0.035	—	0.008
Sulfur	—	0.037	—	0.008
Silicon	0.10	0.60	0.02	0.05
Nickel		*		
Chromium		*		
Molybdenum		*		
Vanadium		*		

*The manganese and residual element limits may be varied by the manufacturer to meet the mechanical property requirements as follows:

Manganese Min.	Manganese Max.	Nickel Max.	Chromium Max.	Molybdenum Max.	Vanadium Max.
0.60	0.79	0.25	0.50	0.10	0.03
1.11	1.25	0.25	0.25	0.10	0.05

Chemical Composition of Rail-1995

Improvements to Rail

Table 4-2-1-3-1a. Product/Chemical Analysis Table for Carbon Rail Steel

Elements	Notes	Chemical Analysis Weight Percent Standard, Intermediate and High Strength		Product Analysis, Weight Percent Allowance Beyond Limits of Specified Chemical Analysis	
		Miminum	Maximum	Under Miminum	Over Maximum
Carbon	1	0.74	0.86	0.04	0.04
Manganese		0.75	1.25	0.06	0.06
Phosphorus	2		0.020		0.008
Sulfur	3		0.020		0.008
Silicon		0.10	0.60	0.02	0.05
Nickel			0.25		
Chromium	1		0.30		
Molybdenum	1		0.060		
Vanadium			0.010		
Aluminum			0.010		
Other	4				
Note 1: The chemical composition will be subject to the requirements listed, except as approved in writing by the purchaser. Any alteration of the chemical composition may require modification of welding procedures.					
Note 2: Up to 5% of the order may exceed 0.020 if purchaser and supplier agree, but in no case may the phosphorus exceed 0.025.					
Note 3: Up to 5% of the ordermay exceed 0.020 if purchaser and supplier agree, but in no case may the sulfur exceed 0.025.					
Note 4: Additional elements may be included in the chemistry and the chemical anaylsis when agreed upon by the purchaser and the supplier.					

Table 4-2-1-3-1b. Product/Chemical Analysis Table for Low Alloy Rail Steel

Elements	Notes	Chemical Analysis Weight Percent Note 1				Product Analysis, Weight Percent Allowance Beyond Limits of Specified Chemical Analysis	
		Standard Strength		Intermediate and High Strength			
		Minimum	Maximum	Minimum	Maximum	Under Minimum	Over Maximum
Carbon		0.72	0.82	0.72	0.82		
Manganese		0.80	1.10	0.70	1.25		
Phosphorus	2		0.020		0.020		
Sulfur	3		0.020		0.020		
Chromium		0.25	0.40	0.40	0.70		
Silicon		0.10	0.50	0.10	1.00		
Nickel	5		0.15		0.15		
Molybdenum			0.050		0.050		
Vanadium			0.010		0.010		
Aluminum			0.005		0.005		
Copper	5		0.40		0.40		
Other	4						
Note 1: The chemical composition will be subject to the requirements listed, except as approved in writing by the purchaser. Any alteration of the chemical composition may require modification of welding procedures.							
Note 2: Up to 5% of the order may exceed 0.020 if purchaser and supplier agree, but in no case may the phosphorus exceed 0.025.							
Note 3: Up to 5% of the order may exceed 0.020 if purchaser and supplier agree, but in no case may the sulfur exceed 0.025.							
Note 4: Additional elements may be included in the chemistry and chemical analysis when agreed upon by the purchaser and the supplier.							
Note 5: Copper content between 0.30 and 0.40 shall be acceptable if the ratio of nickel to copper > 1 : 3.							

Chemical Composition of Rail-2019

Improvements to Rail

- Mechanical properties
  - Hardness
    - Standard strength
    - Intermediate strength
    - High strength

Improvements to Rail

4.1 Surface Hardness

4.1.1. Rails shall be produced as specified by the purchaser within the following limits:

	Brinell Hardness, HB	
	Minimum	Maximum
Standard Rail	300	—
High-Strength Rail (alloy and heat treated)	341	388*

*May be exceeded provided a fully pearlitic microstructure is maintained.

Surface Hardness of Rail-1995

Improvements to Rail

Table 4-2-1-3-2a. Rail Hardness Table for Carbon Rail Steel

Type of Rail	Minimum Surface Brinell Hardness, HB
Standard Rail	310
Intermediate Strength Rail	350
High Strength Rail	370
Note 1: Hardness specified above shall be maintained in the head area only.	
Note 2: A fully pearlitic microstructure shall be maintained in the head.	
Note 3: If 410 HB is exceeded, the microstructure through the head shall be examined at 100X or higher for confirmation of a fully pearlitic microstructure in the head.	
Note 4: No untempered martensite shall be present within the rail.	

Table 4-2-1-3-2b. Rail Hardness Table for Low Alloy Rail Steel

Type of Rail	Minimum Surface Brinell Hardness, HB
Standard Strength Rail	310
Intermediate Strength Rail	325
High Strength Rail	370
Note 1: Hardness specified above shall be maintained in the head area only.	
Note 2: A fully pearlitic microstructure shall be maintained in the head.	
Note 3: If 410 HB is exceeded, the microstructure through the head shall be examined at 100X or higher for confirmation of a fully pearlitic microstructure in the head.	
Note 4: No untempered martensite shall be present within the rail.	

Surface Hardness of Rail-2019

New Technologies

- Harder rail
  - Wear resistance
  - Resistance to rolling contact fatigue (RCF)
  - Better fracture toughness
  - Intermediate and High strength rails
  - Use of alloys and/or head hardening

New Technologies

- Nippon HEX
  - Hardness in excess of 400HB – 410HB
  - Resistance to rolling contact fatigue (RCF)
  - Used as control rail at TTCI rail tests

New Technologies

- Evraz Apex G2 HH
  - Surface hardness in excess of 430HB
  - Wear resistance
  - Resistance to rolling contact fatigue (RCF)
  - Better fracture toughness

Wheels and Rail – A Quarter Century of Improvements

- Wheel-Rail as a System
- The Future – the Next Quarter Century

Wheel / Rail as a System

- Harder rail, harder wheel, even harder rail, even harder wheel, even more harder rail, even more harder wheels
- Wheels – axles, trucks, suspension, brake gear, car design, wheel truing, etc.
- Rail – plates, ties, pads, ballast, alignment and surface, friction modification, grinding, etc.

Wheel / Rail as a System

- Wheels eventually end up in a shop
- Maintenance scheduled, cars and locomotives swapped out
- Track is always in its location
- Maintenance brought to the track location
- Greater impact on operations

Wheel / Rail as a System

- Not all wheels, trucks, suspension, cars, locomotives are comprised of the latest configuration or best condition
- Not all rail, track is comprised of the latest configuration or best condition
- The wheel / rail interface is constantly changing

Future – The Next Quarter Century

- Transport and use longer rails
- Better maintenance processes for wheels/rail
- Wheels and rail resistant to rolling contact fatigue
- Wheels and rail compatible with each other

Acknowledgments

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- Drew Seely, Steel Dynamics
- Dan Daberkow, Joe Kristan, Mark Richards, Evraz