Findings of the Wheel Defect Prevention Research Consortium

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Presentation

◆ The basics
  ● Who – are we?
  ● What – is the goal?
  ● Why – are we motivated?
  ● How – do we approach the problem?

◆ Findings
  ● Shelling vs. Spalling – Inspections of wheelsets
  ● Spalling
  ● Shelling
    ◆ Rolling Contact Fatigue
    ◆ Thermal Mechanical Shelling

◆ Recommendations

◆ Ongoing work
Who?

- WDPRC = Wheel Defect Prevention Research Consortium
- Government, Railroads, Private Car Owners, Suppliers
  - American Electric Power
  - Amsted Rail (Griffin Wheel)
  - BNSF
  - CIT
  - Canadian Pacific Railway
  - CSX Transportation
  - Federal Railroad Administration
  - GATX
  - GE Rail
  - Holland Company
  - Norfolk Southern
  - New York Air Brake
  - Progress Rail
  - Standard Car Truck Co. (Anchor Brake Shoe, Zeftek)
  - Standard Steel
  - Sumitomo
  - TTCI
  - TTX
  - Union Tank Car
  - Union Pacific Railroad
  - Wabtec (Cardwell Westinghouse, Railroad Friction Products Corp.)
What?

- Find root causes of wheel tread damage and identify remedies
- Two major categories of wheel tread damage:
  - Slid flats and spalling: wheel sliding on rail creates enough heat to produce a metallurgical transformation and eventually produce a spall
  - Fatigue and shelling: repeated cycling of stresses causes cracks to form and eventually produce a shell
Why?

- Tread damage → Impact loads → Damage to track and car
- Almost half of the 700,000 wheelsets changed out in 2006 were due to tread damage related causes (WMC 61, 65, 67, 75, and 78)
- Approximate cost in 2006: $350 million
How?

◆ WDPRC utilizes diverse data sources to determine root cause
  ● Existing literature
  ● Inspections
    ♦ Damaged and undamaged wheelsets
    ♦ Good and bad actor cars
  ● Controlled condition testing
    ♦ Air brake valves
    ♦ Brake shoe force
    ♦ Drag brake thermal testing
  ● Analysis of data from wayside detectors
    ♦ WILD (wheel impact load detector)
    ♦ Wheel temperature
  ● Computer simulation
    ♦ Wheel sliding
    ♦ Wheel fatigue
Findings: Shelling Vs Spalling

- 163 wheelsets inspected at three shops (WMC 11, 61, 64, 65)
- Etchant applied, radial runout recorded, expert observation
- Type of damage tied to car type and service
  - Coal cars = shelling
  - Noncoal cars = mix of spalling and shelling (primarily spalling)
  - Intermodal = thermal mechanical shelling according to car owner
Findings: Shelling Vs. Spalling

- Based on CRB data, overall wheel tread damage problem is split about evenly between shells and spalls.
- Noncondemnable defects found on many wheels removed for wear causes: tread damage more prevalent than repair records indicate.

<table>
<thead>
<tr>
<th>Car Type</th>
<th>Sample Size</th>
<th>Shelling Found</th>
<th>Spalling Found</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coal Hoppers and Gondolas</td>
<td>71</td>
<td>93%</td>
<td>10%</td>
</tr>
<tr>
<td>Tank Cars</td>
<td>23</td>
<td>26%</td>
<td>44%</td>
</tr>
<tr>
<td>Covered Hoppers</td>
<td>12</td>
<td>42%</td>
<td>58%</td>
</tr>
<tr>
<td>Mill Gondolas</td>
<td>7</td>
<td>71%</td>
<td>43%</td>
</tr>
</tbody>
</table>
Findings: Spalling

**Literature Review**

- Wheel slide tests show that the potential exists to create martensite on sliding wheels with almost any realistic combination of axle load, wheel slide duration, train speed, and wheel/rail adhesion level\(^1\)
- Maximum wheel slide contact patch temperatures are probably achieved within the first second of a constant velocity wheel slide\(^2\)
- Multiple authors note presence of spalling on one wheel with none on the mate
  - Different adhesion levels on each rail, such that one wheel reaches austenitizing temperature while the other does not\(^2\)
  - Very short duration slide where one wheel stays in synchronous contact with the rail\(^3\)
  - Different wear rates between wheels on same wheelset\(^4\)

More Findings: Spalling

- **NUCARS®¹ simulations**
  - Traversing rough track designed to excite suspension bounce resonance
  - Brake retarding forces applied and wheelset rotational speeds calculated, contact patch temperatures estimated
  - Traversing rough track with brakes applied is probably not a major source of spalling for loaded cars

- Empty cars (and especially those with malfunctioning E/L device) can slide wheels under heavy braking in low wheel/rail friction conditions regardless of track geometry. This may be a minor source of spalling

¹ NUCARS is a registered trademark of TTCI
More Findings: Spalling

- Movement of cars with handbrakes applied is a major source of wheel spalling
  - Numerous analyses have been conducted in the past that show cars with truck mounted brakes have more tread damage to the wheels on the “B” end
  - WDPRC found 95% / 5% split in this case for a group of 294 tank cars
- In 2007, WDPRC updated a training video about the importance of releasing handbrakes
  - “Please Release Me…Let Me Roll”
  - Target audience is operating personnel
  - Free, downloadable version at www.aar.com/wdprc
  - Free DVD versions available to training organizations by emailing this presenter with a request and your mailing address
    - Scott_Cummings@ttci.aar.com
Background: Shelling - RCF & TMS

RCF = Rolling Contact Fatigue
- Many cycles of high stress (tangential forces)
- Shakedown predicts RCF by relating
  - Ratio of tangential force to normal force (T/N)
  - Ratio of contact stress to shear yield strength (Po/K)

TMS = Thermal Mechanical Shelling
- Subset of shelling – requires hot wheels
- Resistance to fatigue is reduced at high temperatures
  - Steel properties degrade
  - Beneficial compressive residual hoop stresses are relieved

- Loaded car $P_o/K \sim 3$, therefore $RCF @ T/N \sim 0.375$
- T/N limited by wheel/rail COF
- Typical COF values 0.35 to 0.55
**Background: Shelling - RCF**

- Wheel/rail tangential forces are important to the stress near the tread surface where cracks initiate and propagate
  - Tangential forces move the stress closer to the tread surface

![Diagram showing forces and stresses](image)

**Graph**

- Maximum Octahedral Shear Stress at Wheel Surface (ksi)
- Tangential Force / Vertical Force

**Equation**

- No Tangential Force
- Tangential Force = 0.4 * Normal Force
Most RCF damage occurs on the **low rail wheel of the wheelset** in the **lead position** of the truck during **curve negotiation of a loaded car**. Finding supported by:

- Wheelset inspections
- Revenue service
- Instrumented Wheelset data
- NUCARS modeling
- WILD data analysis

Findings: Shelling (RCF)

- **Largest average runout is outboard of the tapeline**

Tapeline = 2.656 inches from Rim Edge
Shelling Progression Photos

Photos show wheel shells developing as follows:

1. Crack band appears outboard of tapeline
2. Cracks join to form shells
3. Shells grow inboard toward tapeline where contact with rail occurs on more regular basis
More Findings: Shelling (RCF)

- Potential to reduce RCF with minor changes to track & operating conditions
  - Data analyzed from instrumented wheelsets installed in a loaded coal car: 1,500 miles in revenue service
  - Total distance traveled with predicted RCF damage: < 1 mile
  - Most curves of 4 degrees or tighter caused some predicted RCF
  - 4 specific locations accounted for half of predicted RCF damage
  - Train typically operated below curve balance speed when RCF was predicted
More Findings: Shelling (RCF)

Potential to reduce RCF with improved trucks
- NUCARS modeling of many condition combinations shows truck type to be important factor (red = RCF, blue = no RCF)
Findings: Shelling (TMS)

- Maximum acceptable operating tread temperature to avoid TMS is approximately 600°F
  - Applying Larson-Miller equation to existing data allows time / temperature / % stress relief relationship
  - Sines fatigue calculation shows that wheels are far more prone to shelling in the absence of compressive residual stress
  - Short duration exposure allows higher temperatures
  - Wheels with properly functioning brake systems do not typically reach 600°F
  - Ex: 50 Hp for 30 minutes would produce 600°F

More Findings: Shelling (TMS)

- **Wheel temperature variations lead to hot wheels**
  - Data from a single wheel temperature detector installed near bottom of hill – 1,575 trains analyzed, over 600,000 wheelsets
  - Temperature variations found **between trains**
    - 15 trains accounted for more than 20% of the descending cars with hot wheels
    - Train handling can affect wheel temperature → shelling

More Findings: Shelling (TMS)

**Wheel temperature variations lead to hot wheels**

- Data from a single wheel temperature detector installed near bottom of hill – 1,575 trains analyzed, over 600,000 wheelsets
- Temperature variations found within cars and between cars
  - 76% of the descending cars with a wheel temperature greater than 500°F had only a single wheel above this level
  - While the wheels in these cars are generally at higher temperatures than the wheels of other cars in the train, there were large temperature differences between individual wheel locations
- Repeated hot wheel behavior was found on
  - 37% of the descending cars with hot wheels
  - 20% of individual hot wheel locations
The cause of hot wheel behavior within cars and between cars is difficult to identify

- Inspection shortly after passing temperature detector
  - 1 car found with handbrake applied, all wheels hot
  - No cause found for 14 other cars inspected
- Detailed inspection/teardown/brake test
  - Good and bad actor cars selected based on multiple wheel temperature readings
  - Found one bad actor car with valve leaking air into brake cylinder
- The selection of bad and good actor cars based on wheel temperatures correlated well with wheelset replacements
  - Bad actors had twice as many replacements
Abridged list of WDPRC recommendations

- Increase adherence to handbrake release policies to reduce wheel spalling
  - Utilize “Please Release Me…Let Me Roll” in training programs
- Identify problem RCF curves and investigate
  - Rail profiles
  - Superelevation
  - Rail COF
- Reduce wheel/rail tangential forces during curve negotiation
  - Use trucks with high warp resistance and low axle steering resistance
- Minimize use of train brake by maximizing use of dynamic brake, especially in regions with heavy grades to obtain the minimum average wheel temperature per train
WDPRC On-Going Work

Focus on implementing recommendations

- Proposed changes to single car test (AAR S-486) with evidence to support
- Distribute and promote “Please Release Me…Let Me Roll”
- Determine current state of industry with respect to dynamic brake training and usage
  - Possibly assist with industry standard training material
- Identify specific problem RCF curves
  - Determine why worse than other curves (profile, COF, geometry)?
  - Recommend specific course of action to correct
- Determine economics related to truck maintenance
  - Wheel savings could pay for improved truck maintenance
  - Recommend optimal ton-mileage for reconditioning
- Additional investigation into sources of wheel temperature variations within cars and between cars