Interactions Between Wheel and Rail Hardness, Wear, RCF and Maintenance (Perceptions and Realities)

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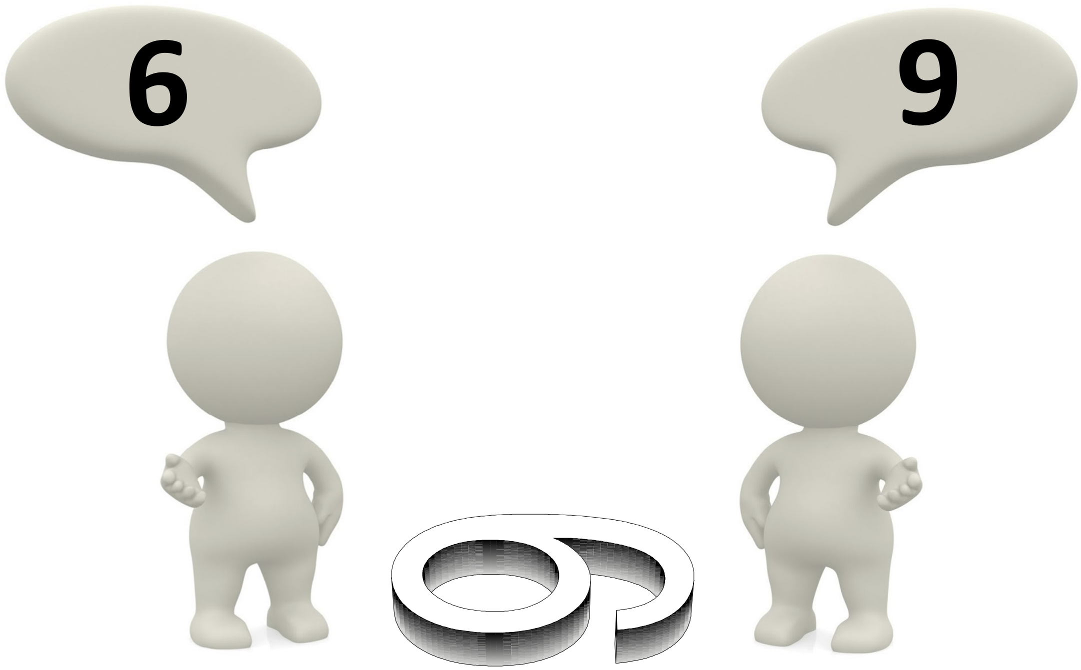
Welcome to Vancouver

Perceptions



Question

- Given wheel and rail material combination as starting point
- Hardness of one partner significantly increased

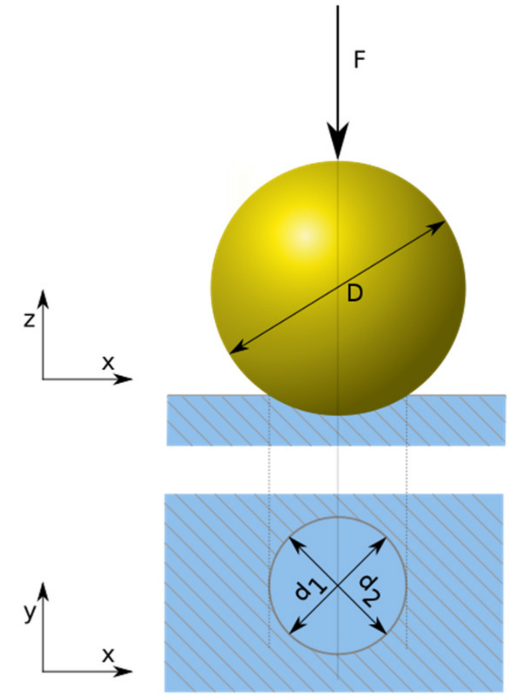
What is the performance impact (wear) on other, softer partner?

The use of "Hardness"

- Term used in daily life and technical environments
  - Materials divided in "hard" and "soft" without definition or quantification
- Associations
  - Hard and brittle vs. soft and ductile

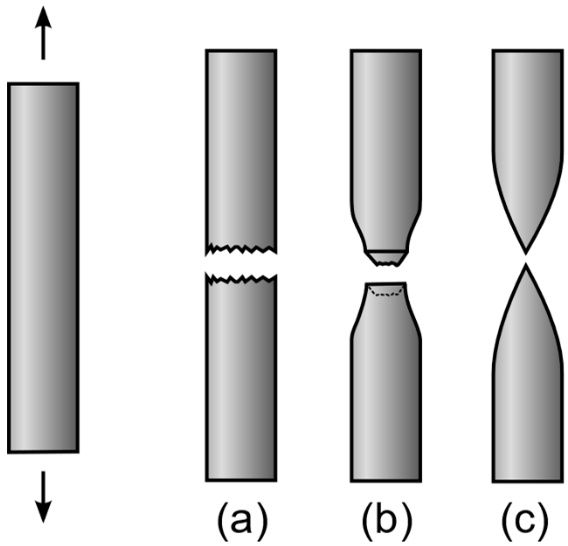
Hardness

- **Definition of Hardness:**
  - Measure of resistance to localized plastic deformation induced by mechanical indentation (diamond, tungsten carbide) or abrasion
  - Relative measure
- Hardness used to classify rail and wheel materials



Brittle vs. Ductile

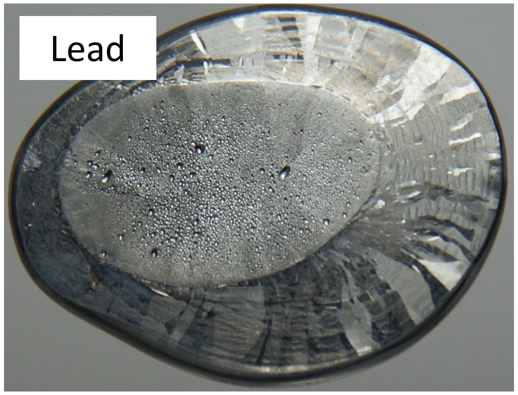
- Brittle material:
  - Fracture without appreciable plastic deformation
- Ductile material:
  - Significant plastic flow before fracture
- Seemingly hard materials do exhibit ductile behavior
  - Rail materials – ductile behavior



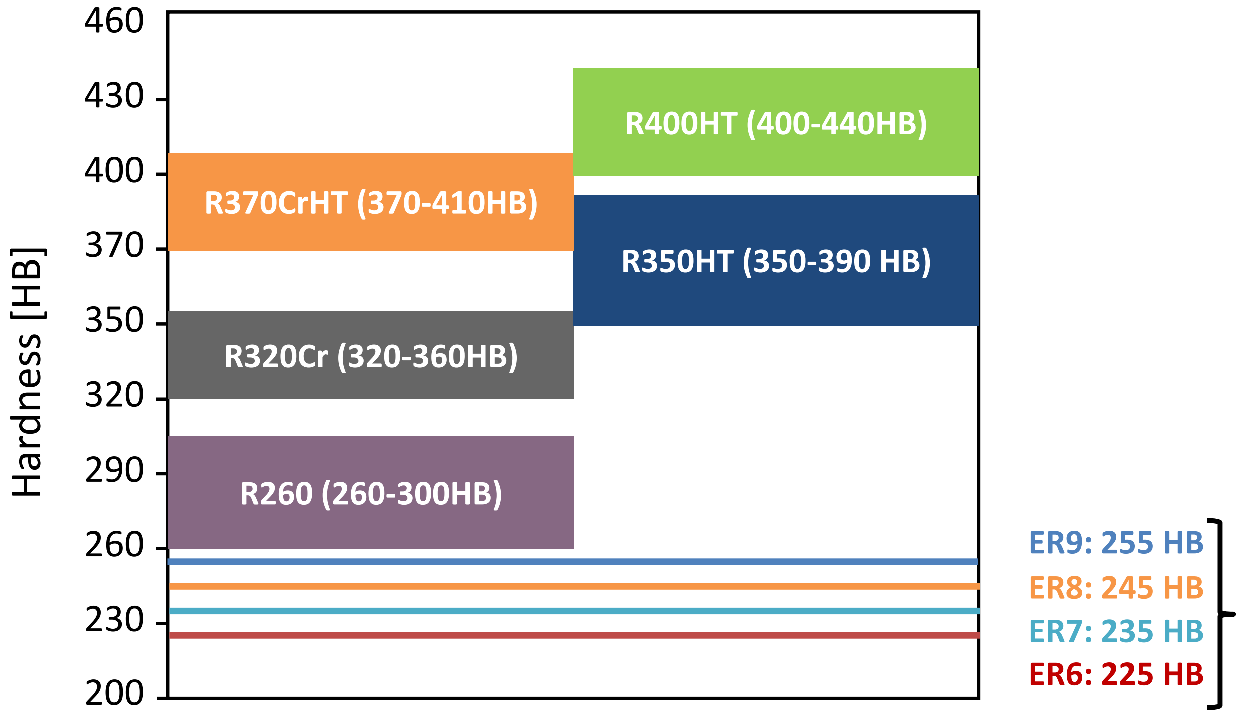
(a) Brittle fracture
(b) Ductile fracture
(c) Completely ductile fracture

Hardness of Different Materials

- Lead: 5 HB
- Rail Steel: 260-440HB (275-460HV)
- Martensite: up to 700 HB (up to 1000 HV)
- Ceramics: up to 2000 HV
- Diamond: 10000 HV



Hardness of Rail and Wheel (EU)



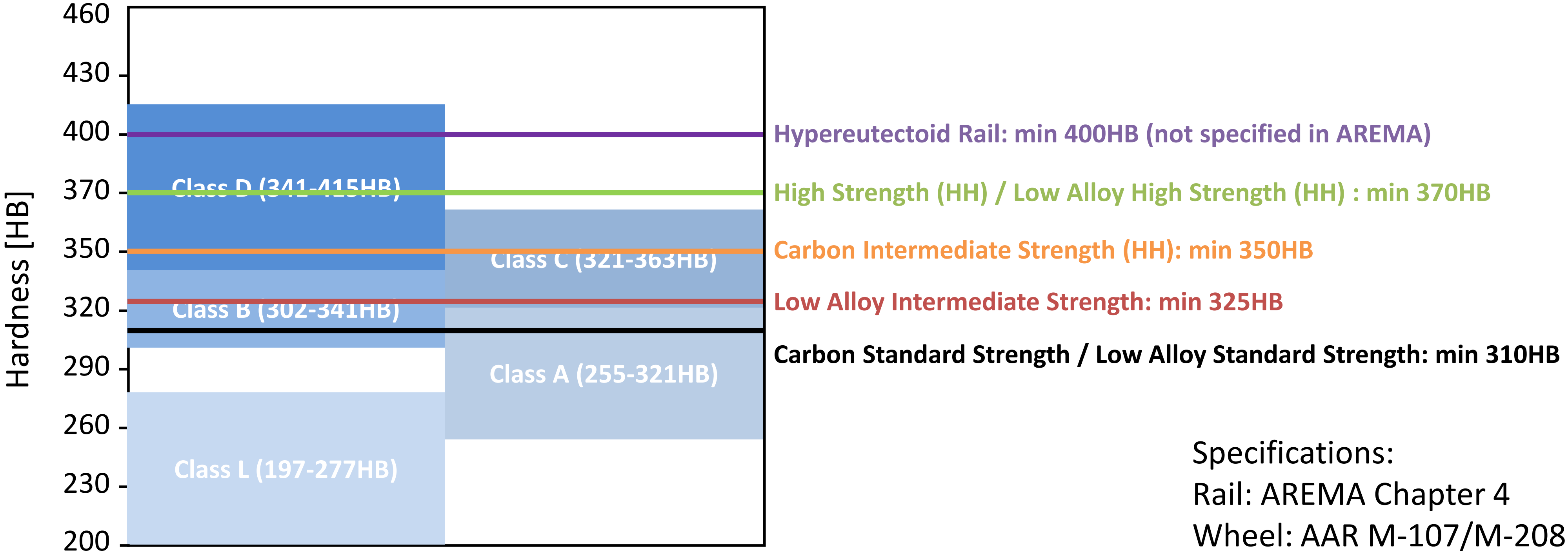
Minimum wheel rim hardness down to the maximum wear depth of 35mm (train speed < 200 km/h

Specifications:

Rail: EN 13674-1:2011

Wheel: EN 13262:2020

Hardness of Rail and Wheel (US)



Specifications:
Rail: AREMA Chapter 4
Wheel: AAR M-107/M-208

Forms of Wear

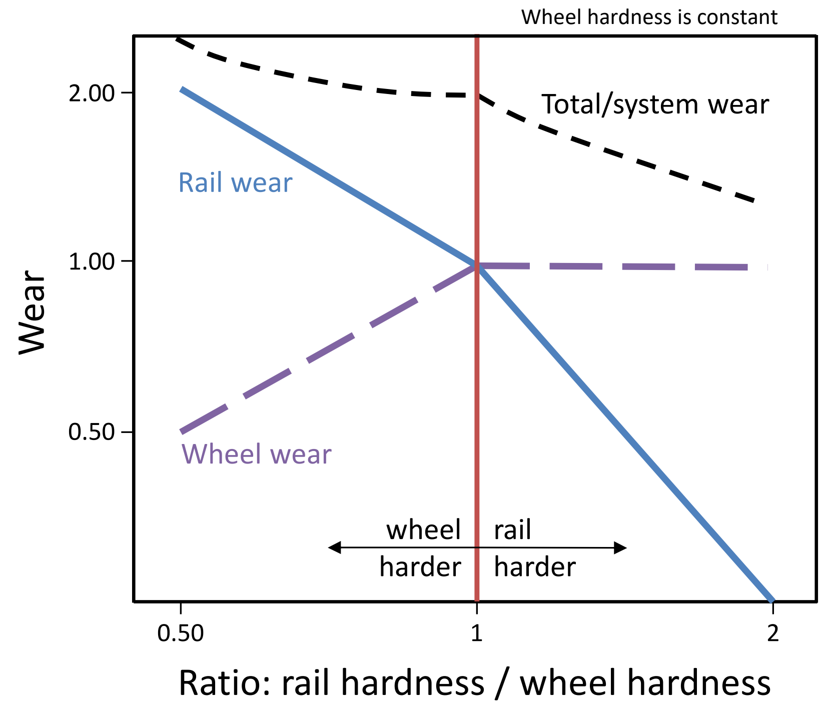
- Continuous material removal from the rail surface due to interaction of wheel and rail.
- Several modes of wear
  - Adhesive wear
  - Abrasive wear
  - Fatigue wear
  - Corrosive wear
- Several classes of wear
  - Mild, severe, catastrophic

Literature Review

- Research group in UK (Prof. Roger Lewis) reviewed and summarized prior work [1]
- Three types of experiments
  - Field trials
  - Full scale test rigs
  - Small scale test rigs

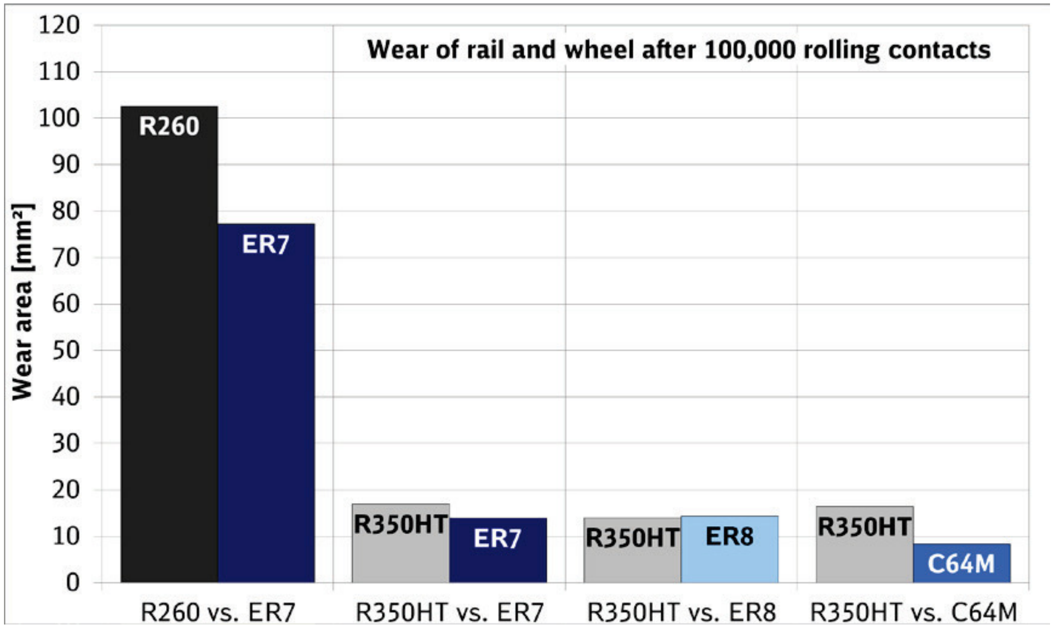
Field Trial - USA

- Field Test at FAST Loop at the Transportation Test Center in Pueblo
  - Published by Steel and Reiff in 1982 [2]
- Different rail grades against one wheel grade
- Widely referenced hardness ratio diagram
  - Assumed adhesive wear
  - Slight wheel wear increase while wheel was harder
  - Constant wheel wear for “rails harder”



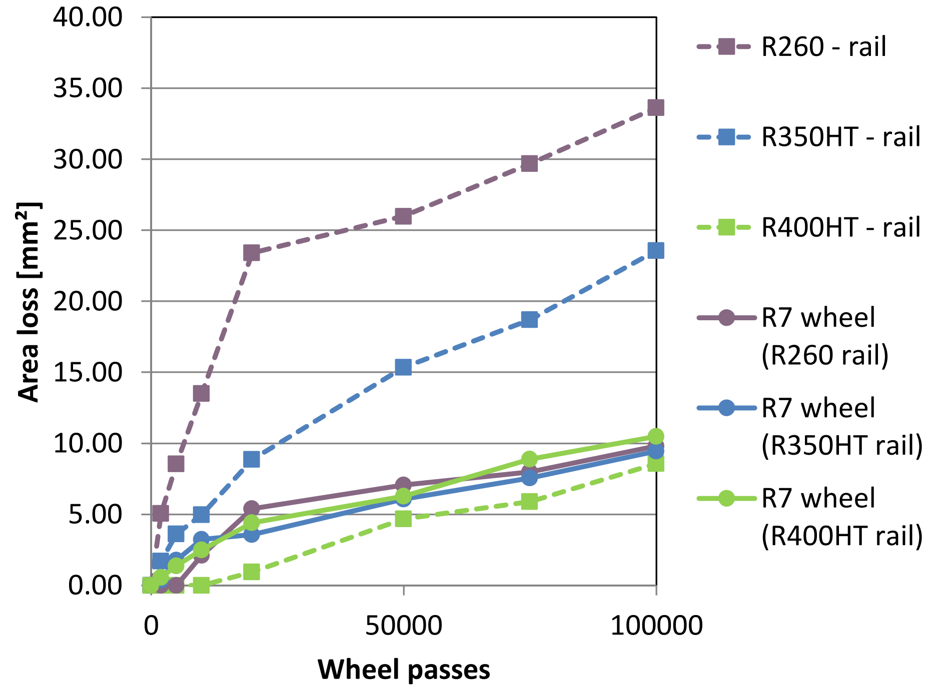
Full Scale - Germany

- Full scale linear test rig in Germany [3]
  - 100,000 test cycles
  - Wheel softer than rail
- Increase rail hardness
  - Less rail and wheel wear
- Increased wheel hardness
  - Some lower wheel wear



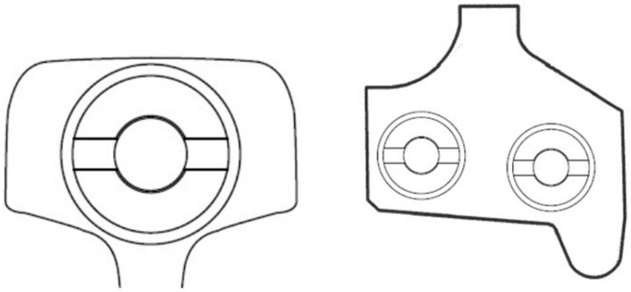
Full Scale - Austria

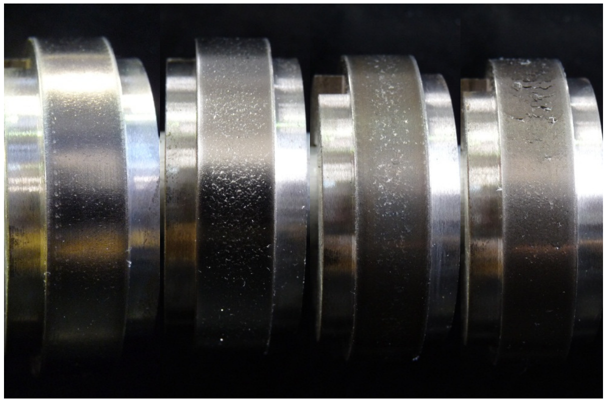
- Full scale test rig in Austria [4]
  - 100,000 test cycles
  - ER7 wheel vs. different rail grades
- Rail wear decreasing with increasing hardness
- Wheel wear not impacted



Small Scale - Europe

- Several twin-disc experiments by researchers all over the world [1,5]
- Most tests focused on rail materials
- General finding
  - Increased hardness of harder partner (rail) did not increase wheel wear
  - Increased hardness of softer partner (rail) did not increase wheel wear



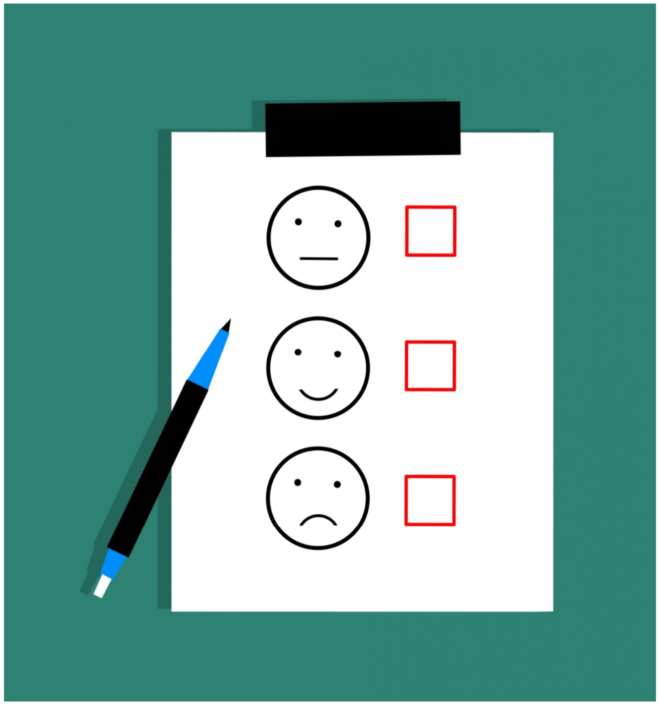


Conclusions of Literature Review

- Increasing the hardness of one partner will not increase the wear of the other partner
- Open questions
  - As produced hardness vs. surface hardness with work hardening
  - Underlying wear mechanism
  - Impact of microstructure / change of microstructure (not just hardness to impact wear)
  - Impact of temperature

Idea for a Survey

- Insights into level of agreement, overall opinions and concern amongst railway community members
- SurveyMonkey as tool
- Approval by Simon Fraser University's Office of Research Ethics (Study Number: 2020s0147)
- 11 Questions, estimated time to complete < 5min
- Survey sent to ICRI community



Central Question

Thinking about the railway system(s) with which you are most familiar, imagine the case in which wheel or rail steel hardness is increased significantly (with all other conditions unchanged).

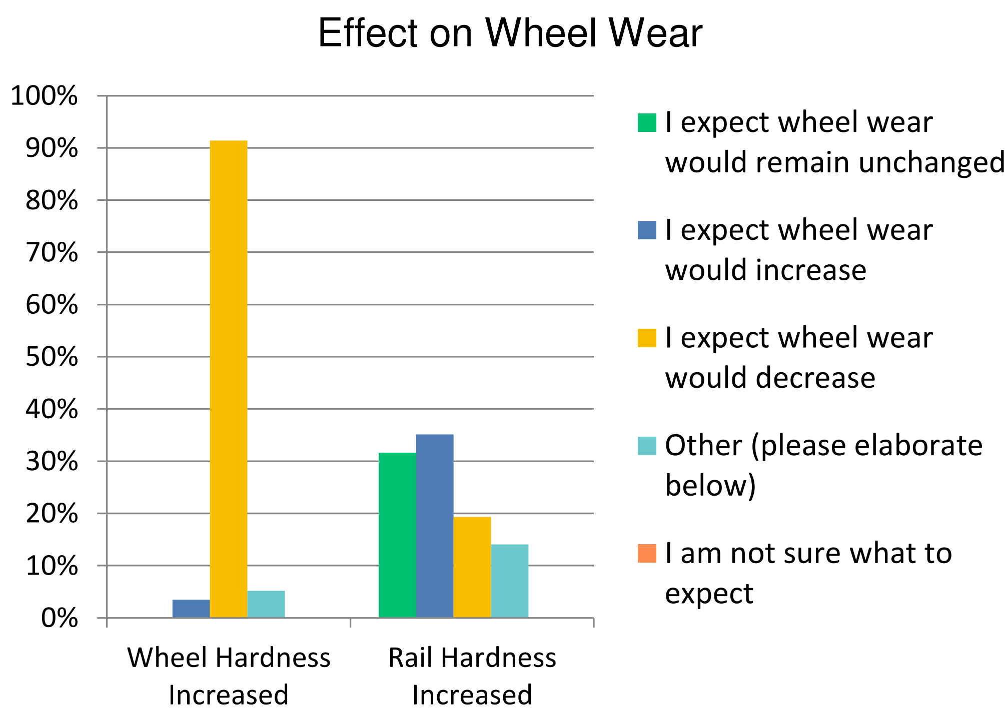
What would you expect to see with respect to subsequent wheel or rail wear?

Possible Answers

- Effect on Wheel Wear
  - I expect wheel wear would remain unchanged
  - I expect wheel wear would increase
  - I expect wheel wear would decrease
  - Other (please elaborate below)
  - I am not sure what to expect
- Effect on Rail Wear
  - I expect rail wear would remain unchanged
  - I expect rail wear would increase
  - I expect rail wear would decrease
  - Other (please elaborate below)
  - I am not sure what to expect

Results – Impact on Wheel Wear

- Clear statement:
  - Hardness increase of wheel leads to less wheel wear
- Mixed feedback:
  - Hardness increase of rail and its impact on wheel wear



Results – Impact on Rail Wear

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- Mixed feedback:
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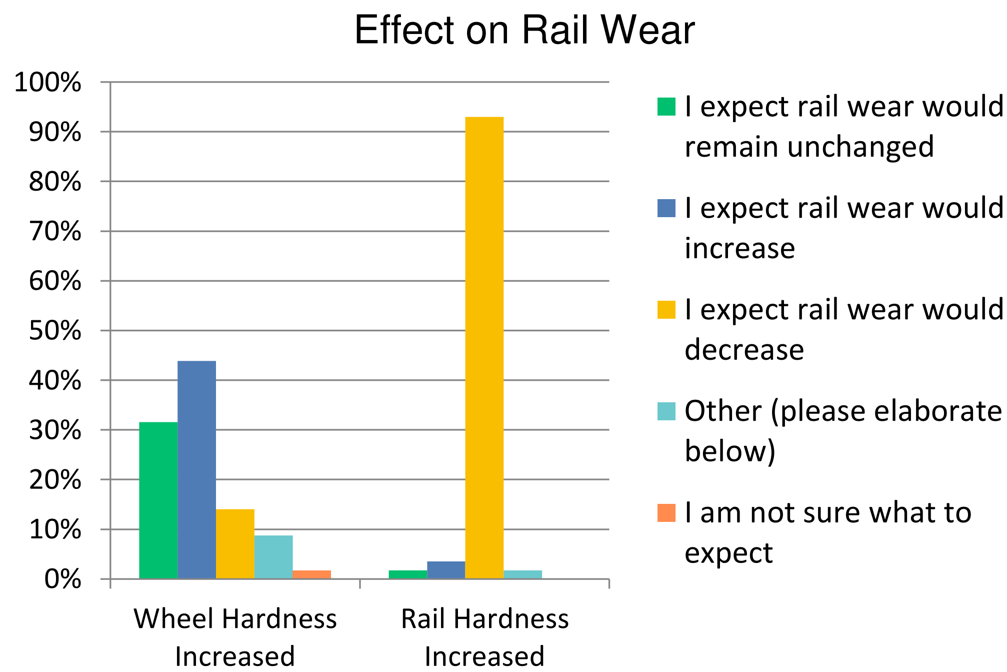
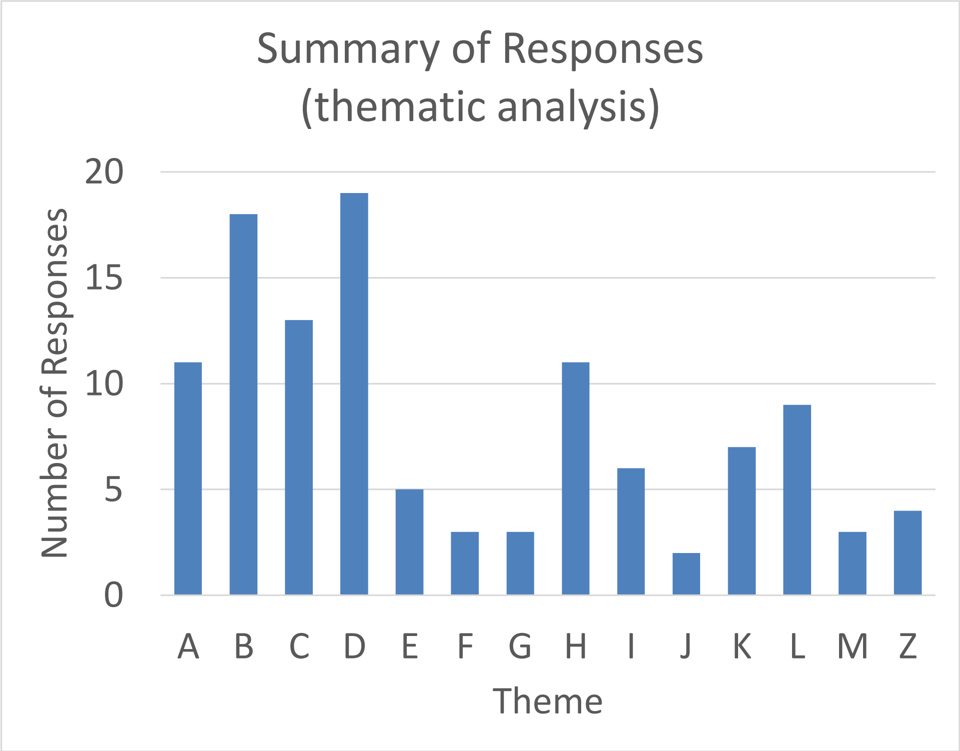


Results - Themes

- 14 themes were identified out of 58 survey responses
  - Some responses covered multiple themes
- 10 follow up discussions with respondents who had agreed to be contacted
- Three main perceptions identified



Perceptions

- Three main perceptions identified:
  - **Effects of Relative Hardness on the Contact Patch:** Intuition that the size and shape of the contact area changes with hardness.
  - **The "Sacrificial" Softer Material:** constant energy in contact patch – conservation of wear energy
  - **Trading wear for other issues ("something has to give"):** reduced wear means other damage modes become dominant (RCF)

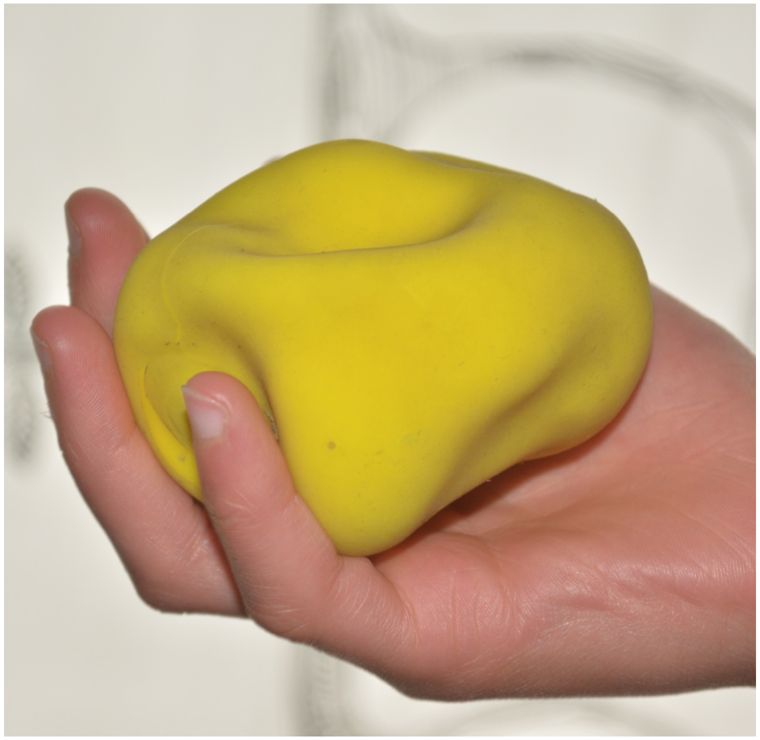
P1: Effects of relative hardness on the contact patch

- Hertz Theory: size of contact patch and pressure depend on elastic material properties
  - E-Modulus, Poisson ratio
  - Not dependent on hardness
- Also valid for non-Hertzian contact
  - Elastic half spaces – bulk elastic behavior

Heinrich Rudolf Hertz (1857 - 1894), was a German physicist

Perception 1

- Plasticity is related to hardness
- Several plasticity criteria that are proportional to k – shear yield strength
  - $K \propto HV/6 * 9.81$
- Plastic yield: peak pressure > 3 * elasticity limit
  - Usually not happening in w/r contact



Perception 1

- If plastic yield on rail: contained by elastic material
  - No global plastic flow
  - Deformation of microstructure
- Ratchetting:
  - small increments of micro-structural plastic deformation in 1000s of cycles

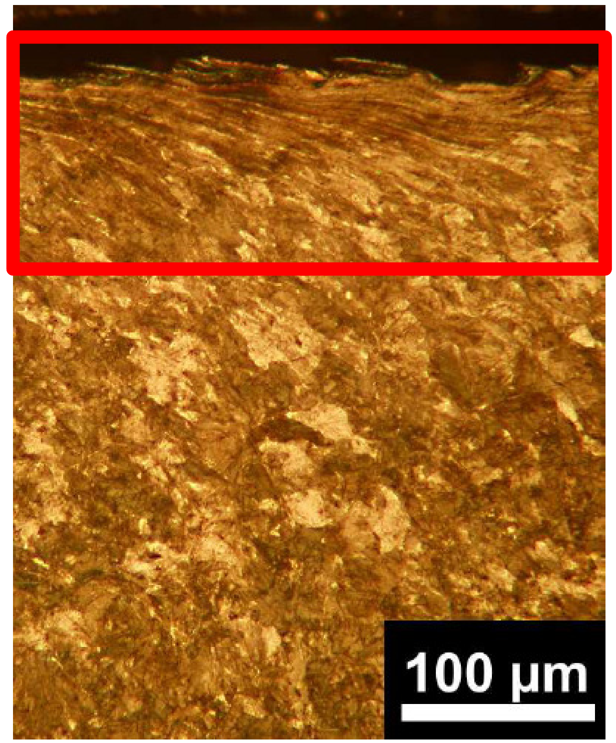


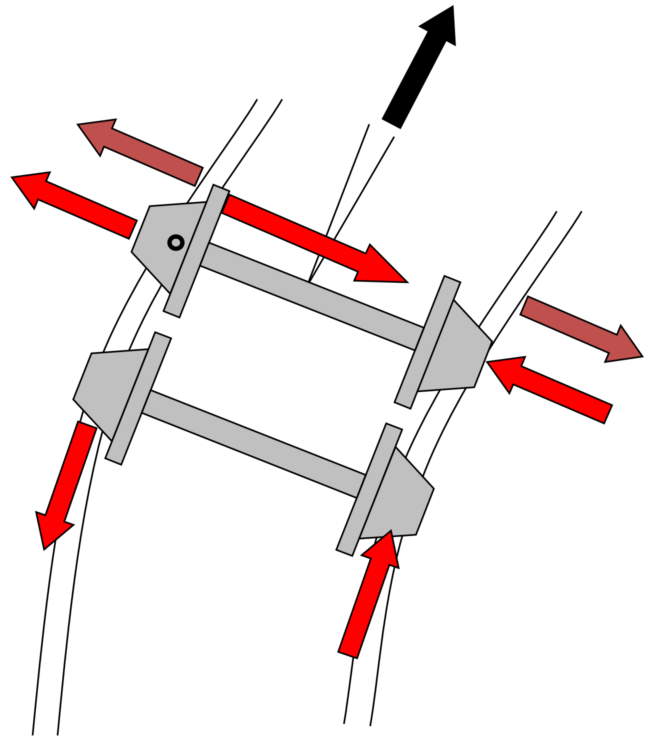
Photo: voestalpine

Perception 1: DEBUNKED

- If Hardness is increased the size of the contact patch stays the same
  - Size of contact patch depends on elastic material properties
  - Hardness related to plasticity
  - No gross plastic yield in w/r contact

Perception 2: The “Sacrificial” Softer Material

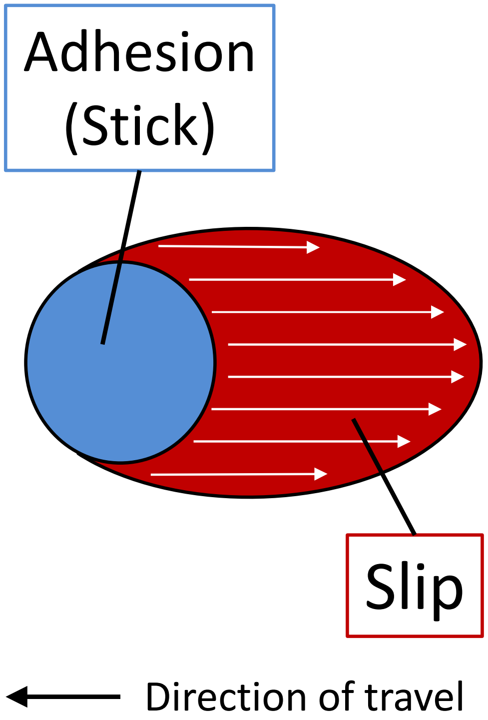
- Contact conditions:
  - El. material properties, forces curvature, steering of vehicles, traction/breaking, friction, etc…
  - Normal load and tangential load
  - None of the above is influenced by hardness



Graphics by Kevin Oldknow / LB Foster

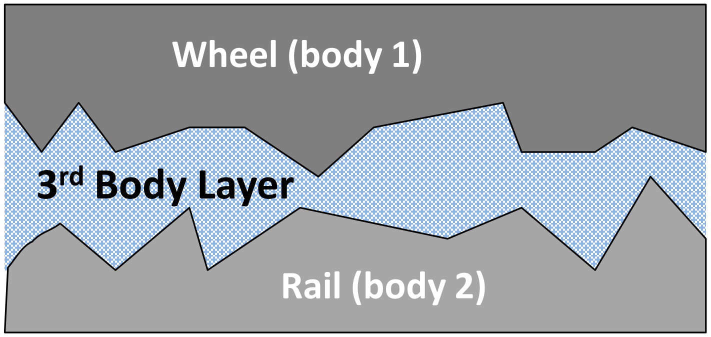
Perception 2

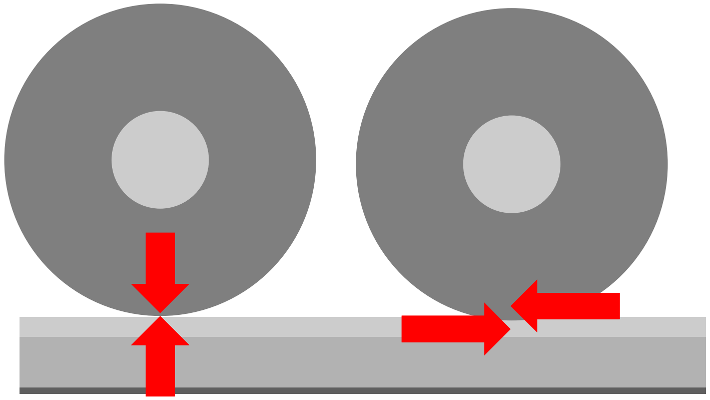
- Contact patch: Stick and Slip region
- Energy dissipation in slip region
  - Noise, heat, pl. deformation
  - Heat about 90% of energy
- 10% of energy:
  - Available for plastic deformation (theoretical)



Perception 2

- Third body layer
  - Separates wheel and rail
  - Velocity accommodation
- Only part of 10% is available for pl. deformation
- Contact mechanics:
  - Normal forces: equal and opposite
  - Shear forces: equal and opposite





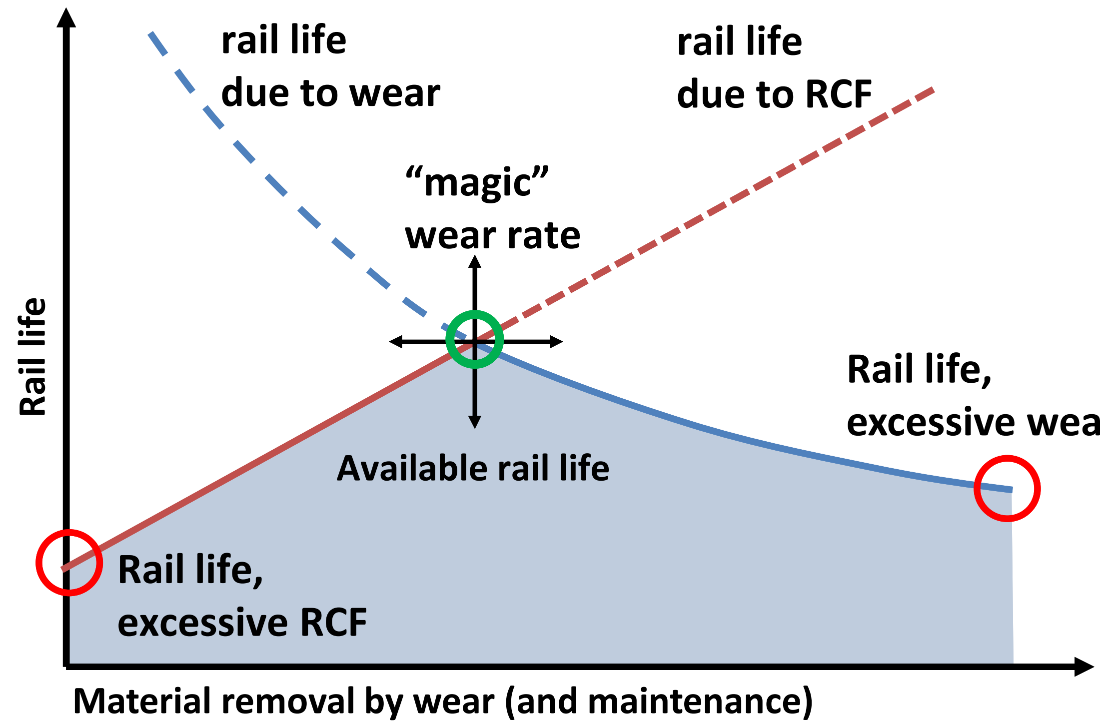
Perception 2: DEBUNKED

- Forces (energy) for each partner stays the same independent of hardness change
  - If everything else is kept constant
- Reaction of each partner (slip area):
  - Increased hardness – less wear, less plastic deformation / less ratchetting

Perception 3: Trading wear for other issues ("something has to give")

Concept of Magic Wear Rate by Joe Kalousek and Eric Magel, 1997

- Magic Wear Rate:
  - Conceptual idea
- Not considering wear types
- Does not consider any other system parameters
  - Rail grades, profiles, friction management, loads, track condition, ….



Perception 3

- Rail/wheel grade with higher hardness
  - Increased material strength (e.g. k)
  - Same or slightly increased toughness
- Increased k: higher resistance against ratchetting and fatigue
  - Besides increased wear resistance also increased damage resistance

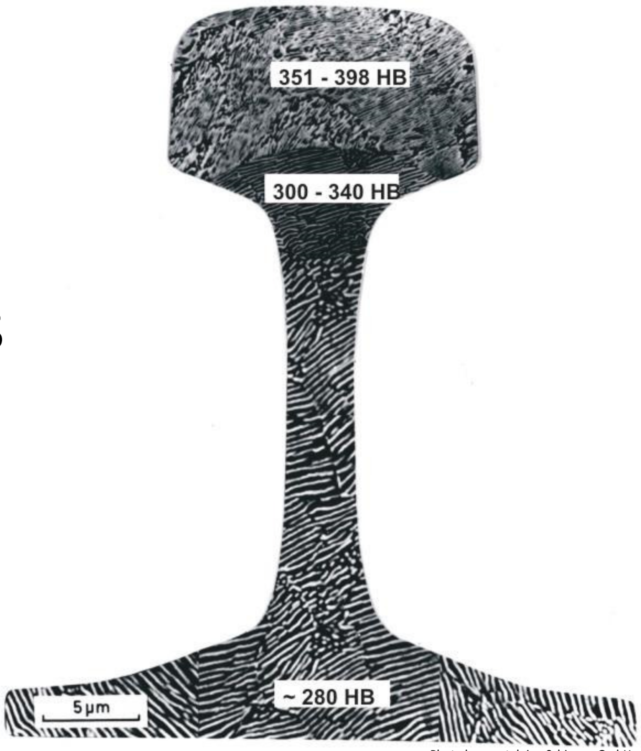
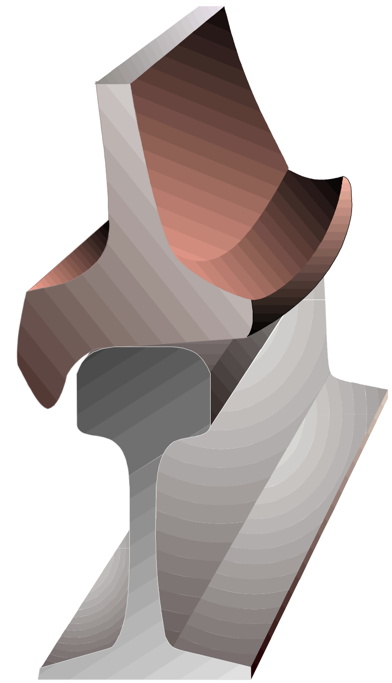


Photo by voestalpine Schienen GmbH

Perception 3 – Profile Impact

- Higher hardness – less wear
  - Profile shape longer retained
  - High stress conditions will be longer retained – increased damage possible
  - Optimised profiles will be retained longer: extended rail life
- Lower hardness rail
  - Profile shape will change/adapt quicker



Perception 3 - Maintenance

- Rail Maintenance
  - Adjust profile, correct surface damage, defined surface finish
- Adaption of maintenance practices to meet requirements of harder steel
  - Target profiles, surface finish and maintenance intervals

Perception 3 – Life Cycle

- Long lifecycle – Statement:
  - 20 years ago, this was not a problem
- Things have changed slowly but significantly
  - Axle loads, profiles, train frequencies and types, maintenance practices (or lack of), distributed power etc…
  - Most of these parameters were not measured/quantified 20 years ago

Perception 3: it depends…

Conditionally DEBUNKED

- Higher hardness rail and wheel steels have improved wear AND damage resistance
- Higher hardness steels are more sensitive to specific system parameters (profiles, maintenance, surface condition, …)
- If treated correctly harder steels will out-perform their softer versions

Summary

- Hardness of one partner significantly increased
  - What is the performance impact (wear) on other, softer partner?
- No negative impact on other, softer partner
  - If all conditions are kept constant
- Premium steels will outperform their softer counterparts if treated correctly

Literature

[1] R. Lewis, P. Christoforou, W.J. Wang, A. Beagles, M. Burstow, S.R. Lewis, Investigation of the influence of rail hardness on the wear of rail and wheel materials under dry conditions (ICRI wear mapping project), Wear. 430–431 (2019) 383–392.

[2] R.K. Steele, R.P. Reiff, Rail: its behavior and relationship to total system wear, in: 1982: pp. 115–164.

[3] R. Heyder and K. Maedler, "The influence of wheel and rail material on the wear of the respective contact partner," in Proceedings of the 10th International Conference on Contact Mechanics and Wear of Rail/Wheel Systems, Colorado Springs / USA, 2015, p. 3.

[4] R. Stock, R. Pippan, Rail grade dependent damage behaviour – Characteristics and damage formation hypothesis, Wear. 314 (2014) 44–50. https://doi.org/10.1016/j.wear.2013.11.029.

[5] A. Ekberg, B. Paulsson, INNOTRACK (projekt), and International Union of Railways, INNOTRACK: concluding technical report. Paris: International Union of Railways (UIC), 2010.

Thank You for Your Attention

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