Transportation Technology Center, Inc., a subsidiary of the Association of American Railroads

Strategies to Prevent Rolling Contact Fatigue on Railroad Wheels & Rails

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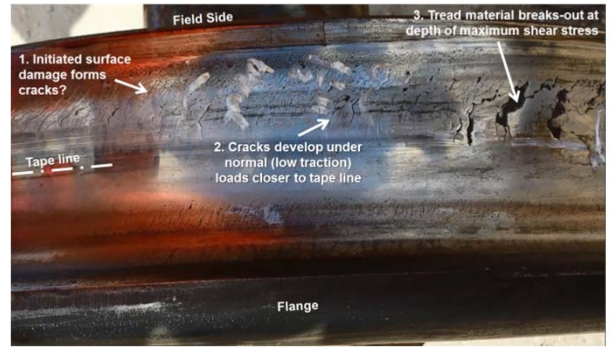
Total Life of Wheel & Rail Surfaces

- **On and (up to a maximum of 1 inch) beneath the contact band on wheel & rail.**
- **One or a combination of the following mechanisms:**
  - Wear
  - Material flow
  - Crack nucleation
  - Crack initiation
  - Crack propagation
  - Residual stress formation
  - Material break-out
  - Brittle failure

Objective

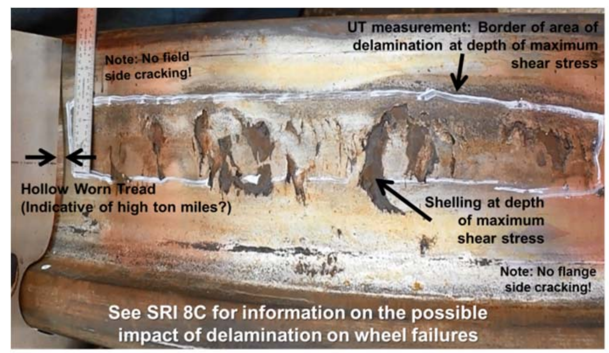
Maximize Wheel & Rail Life

- **Reduced wheel tread damage resulting from:**
  - "Scuffing" & HIW
    (consequence of high steering tractions)
  - Shelling & HIW
    (consequence of delamination)

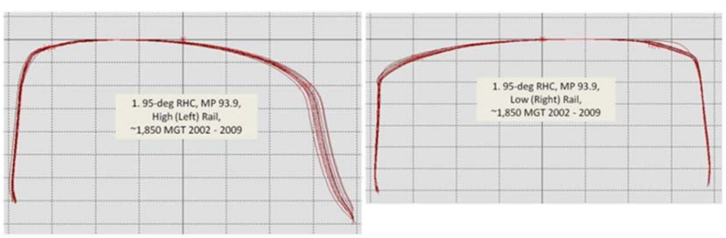


HIW due to high steering tractions

- **Reduced rail RCF**
  (wear, material flow & cracking)
  resulting from:
  - High lead axle low rail steering tractions
  - Spalling (high contact stresses)



HIW due to shelling



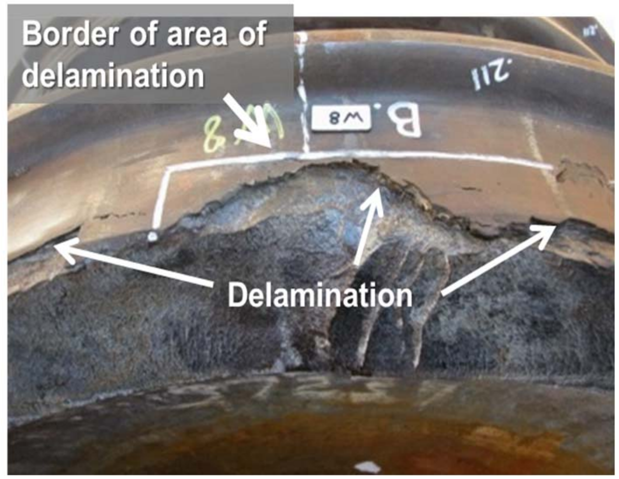
Rail Wear & Material Flow

Rail Spalling

Objective

Prevent Wheel & Rail Failure

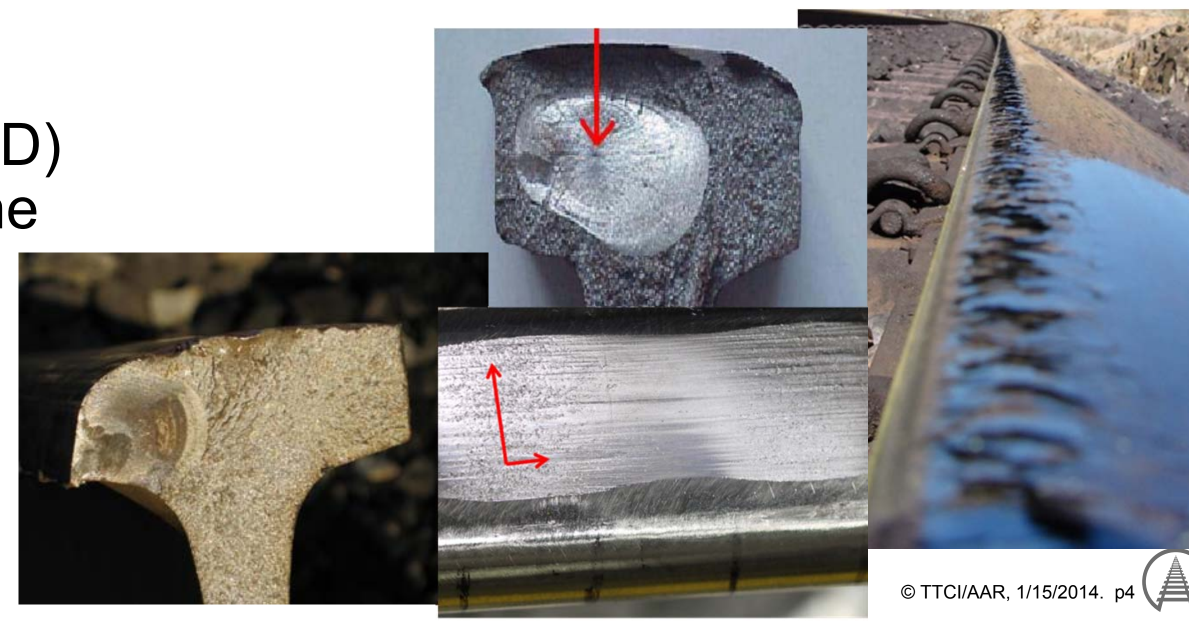
- **Wheel Failure:**
  - Vertical Split Rims (VSR) & flanges (VSF)
  - Shattered Rims (SR)



Vertical Split Rim

Shattered Rim

- **Rail Failure:**
  - Transverse defect (TD)
  - May develop from one or a combination of:
    - RCF
    - Reverse bending
    - Thermal stresses



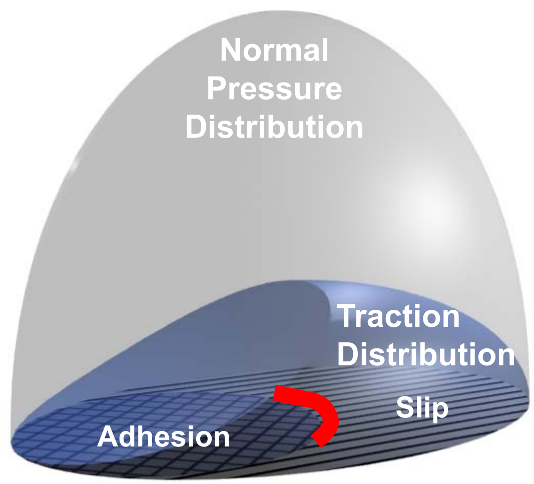
Estimated Industry Costs

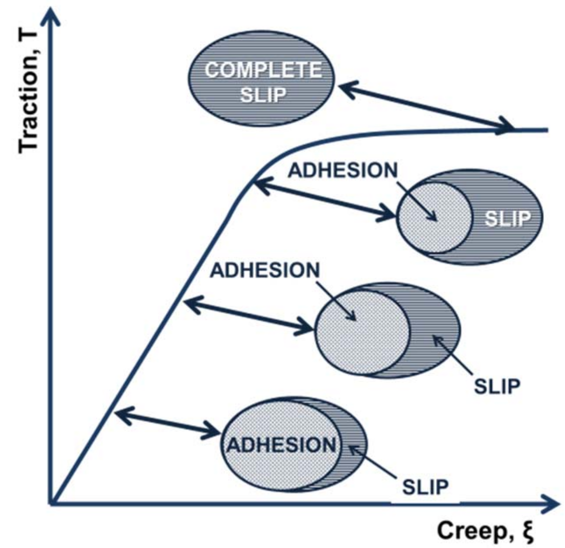
- **$800M**
  - Approximately $400M in wheel replacement cost
  - Approximately $400M in rail grinding & replacement

Tread (Surface) Scuffing Damage

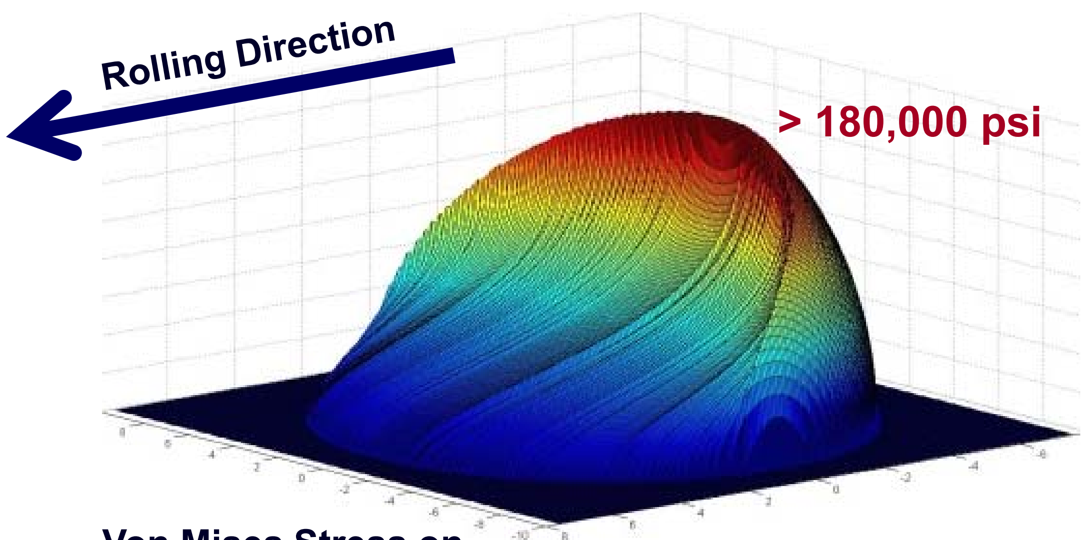
♦ Findings

- Slip can occur:
  - Under high specific loads in the contact patch
  - At tractions substantially less than for limiting friction / complete slip





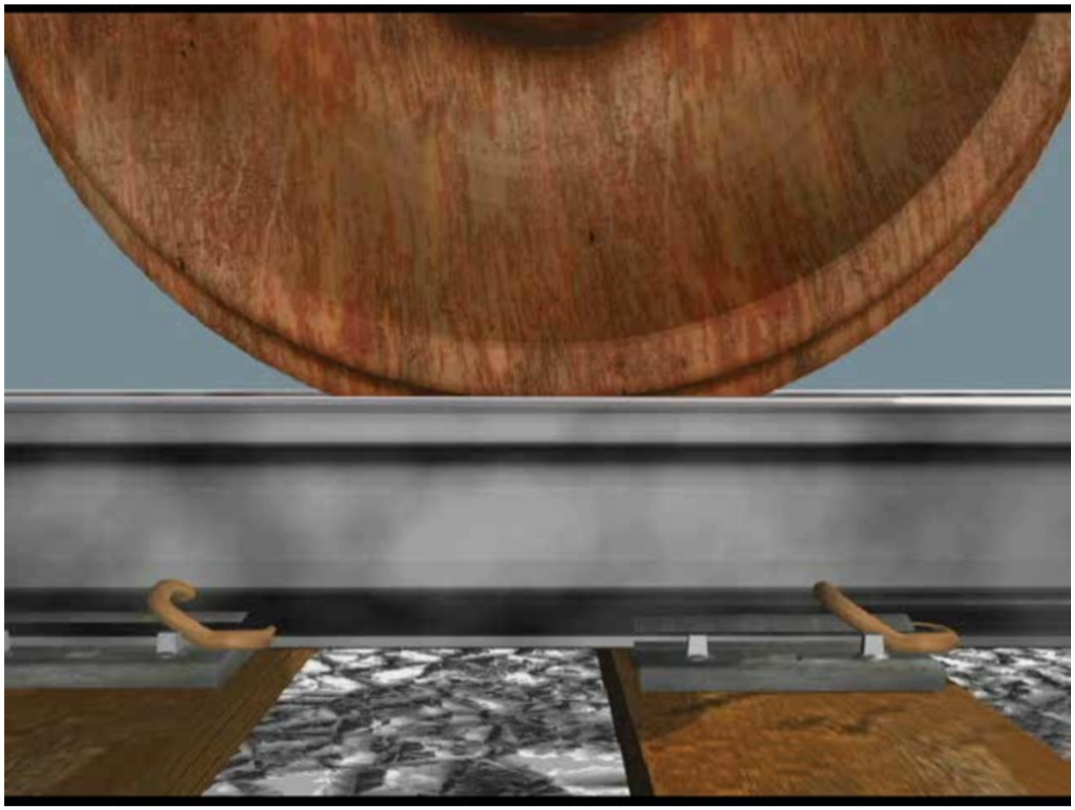
- CONTACT modeling confirms this suggestion & that resulting surface stresses can approach or exceed the ultimate tensile stress of the wheel material under 286,000-pound operation

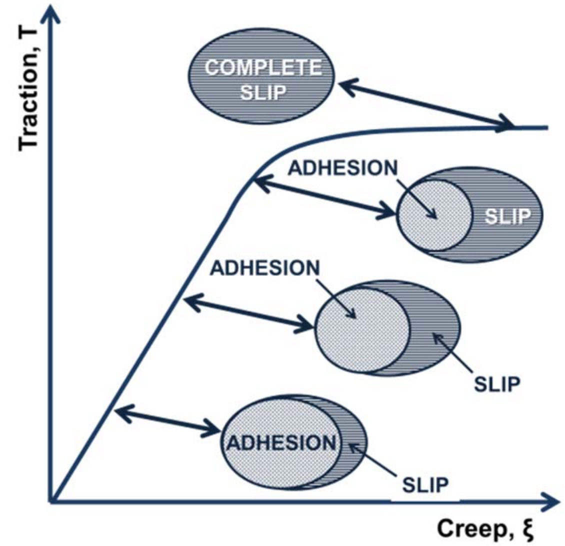


Von Mises Stress on surface of contact patch

Tread (Surface) Scuffing Damage

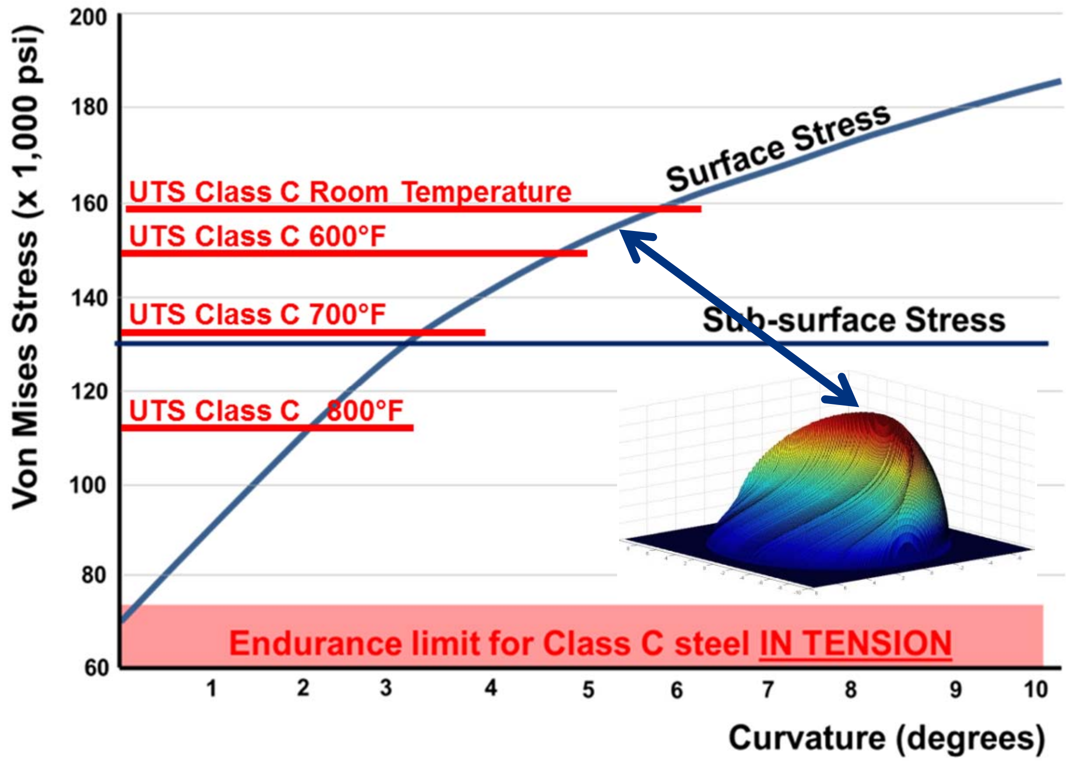
- **Review Creep Mechanism**
  - Generation of regions of adhesion & slip



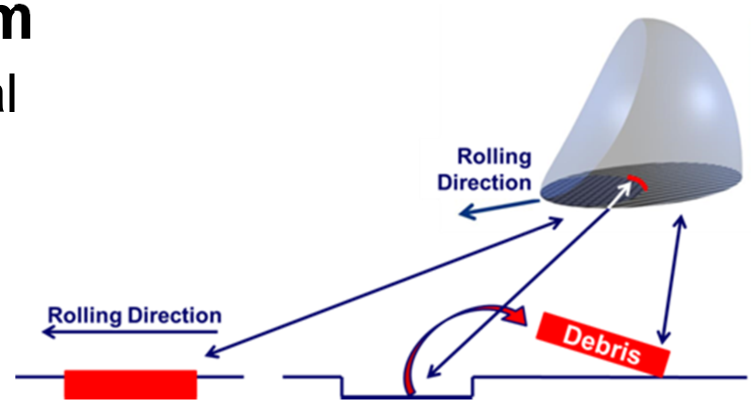


Tread (Surface) Scuffing Damage

- **Prediction**
  (Based on linear model)
  - Damage initiation in a 3-piece truck occurs:
    - In 7-degree curve:
      - Underbalance conditions
      - At 70°F
    - In shallower curves given:
      - Underbalance speeds
      - Higher wheel temperatures



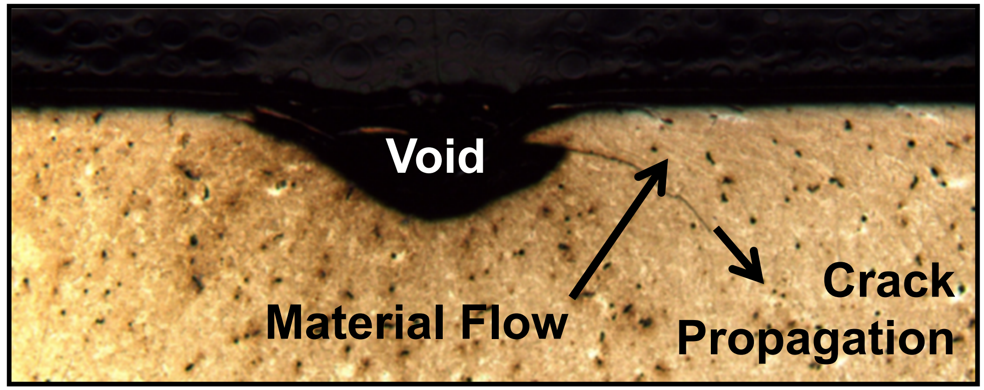
- **Suggested Initiating Mechanism**
  - Von Mises stresses "tear-out" material from the surface of the contact patch
  - Possibly exacerbated by:
    - Surface microcorrugation
    - High temperatures caused by slip and tearing-out process



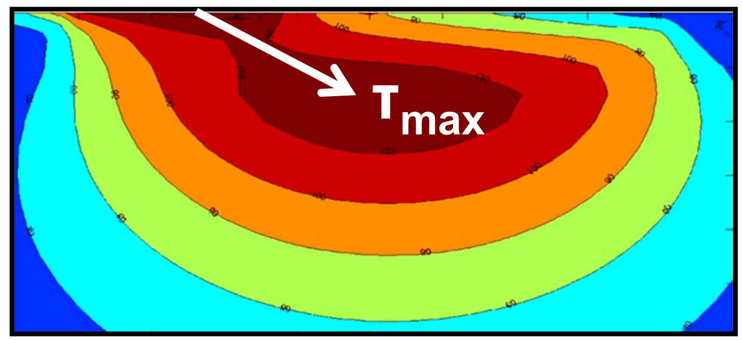
Tread (Surface) Scuffing Damage

♦ Suggested Propagating Mechanism

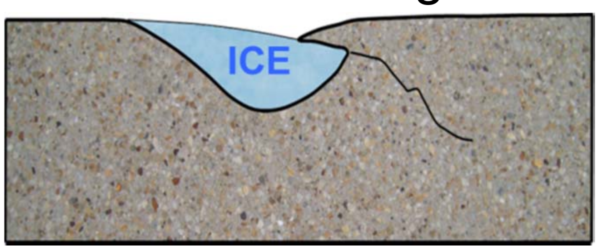
- A void is created on the surface of the contact patch
- The void allows the initiation of material flow near the surface of the wheel
- Material flow initiates cracks



- Cracks propagate down to the area of maximum shear stress (τ_{max})
- Pieces break out of the surface of the wheel at the depth of τ_{max}



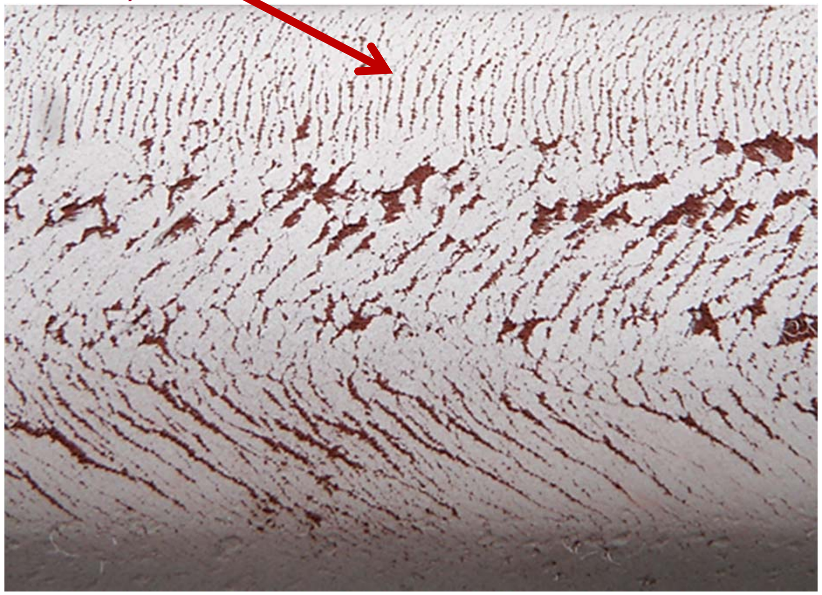
- Process is exacerbated by the ingress of ice causing winter HIW



Rail Scuffing Damage

♦ **Scuffing damage model likely to be applicable to rail:**

Scuffing Marks?
(not cracks?)



Dye Penetrant Photograph of Rail in Revenue Service

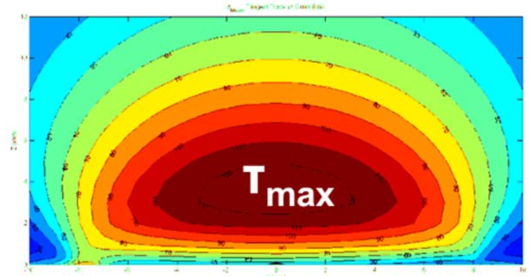
Crack formation & material break-out:

- **Why not at the depth of the maximum shear stress as occurs in wheels?**
- **Is this shallower break-out because of the higher strength of wheel steels?**
- **Is this shallower break-out what we & TTX are observing with Class D wheel steels?**

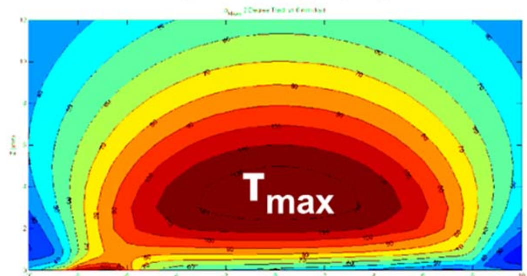
Likely shelling at the depth of the maximum shear stress

Tread Shelling

- ♦ **Initiated by subsurface fatigue**
  - Maximum shear stress (τ_{max}) approximately 3/16 inch beneath the tread surface
  - Magnitude & depth substantially independent of surface tractions
  - Result: Delamination

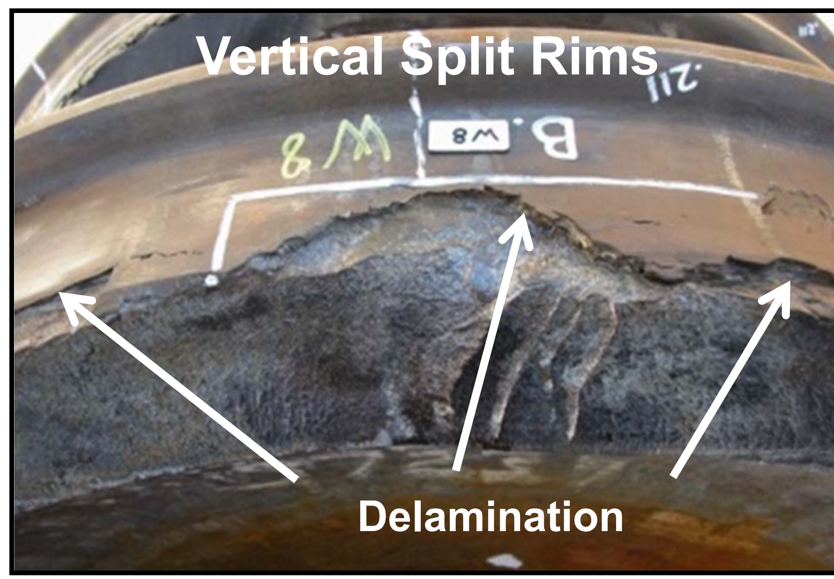


Low Tractions



High Tractions

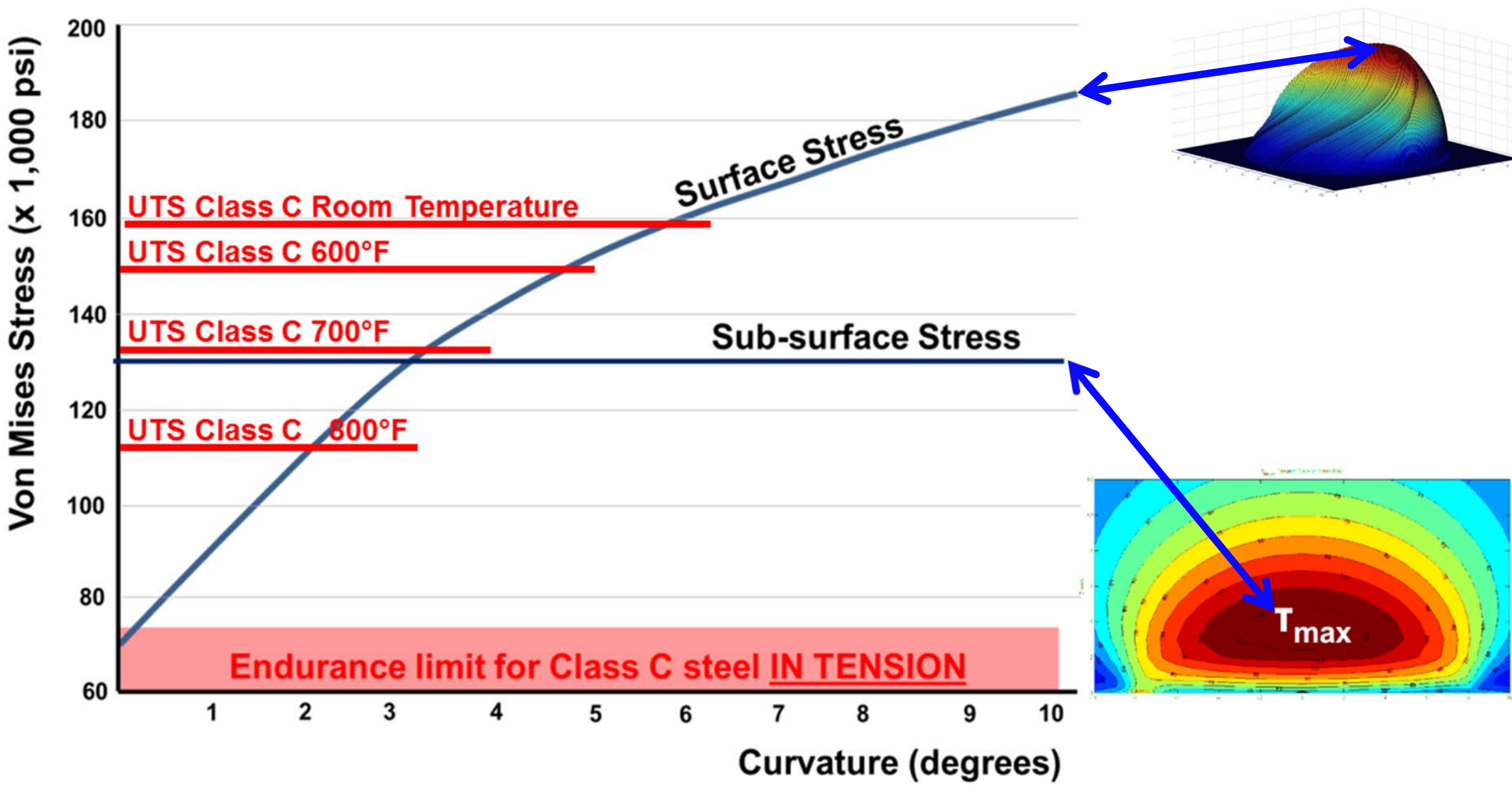
  - Break out of tread to form:



Tread Shelling

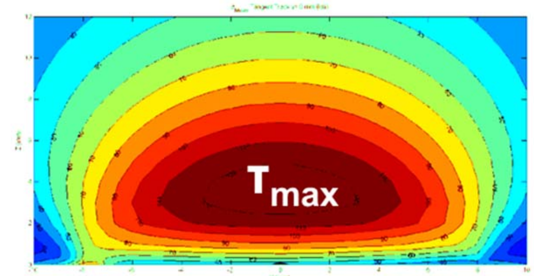
♦ **Subsurface fatigue analysis**

- Simple analysis using τ_{max} would suggest early failure
- Analysis is exacerbated by multi-axial stress condition:

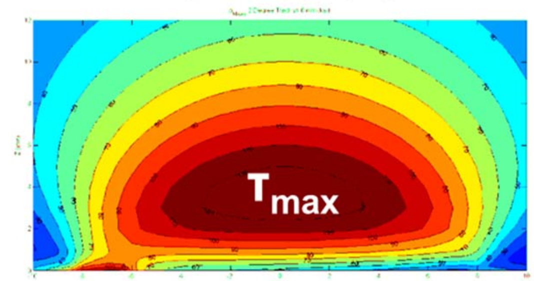


Tread Shelling

- **Robust subsurface fatigue analysis model / method could assist in design & choice of new generation wheel & rail steels:**
  - Maximum flaw size & location in wheels & rails
    - As produced
    - After machining / grinding
  - Fatigue life of wheels / rails
  - Wheel steel strength vs. fracture toughness to avoid
    - Delamination / vertical split rims
    - Shattered rims
  - Role of residual stresses
  - Role of stress / strain linearity & yield stress in fatigue life
  - Influence of grain size on fatigue life



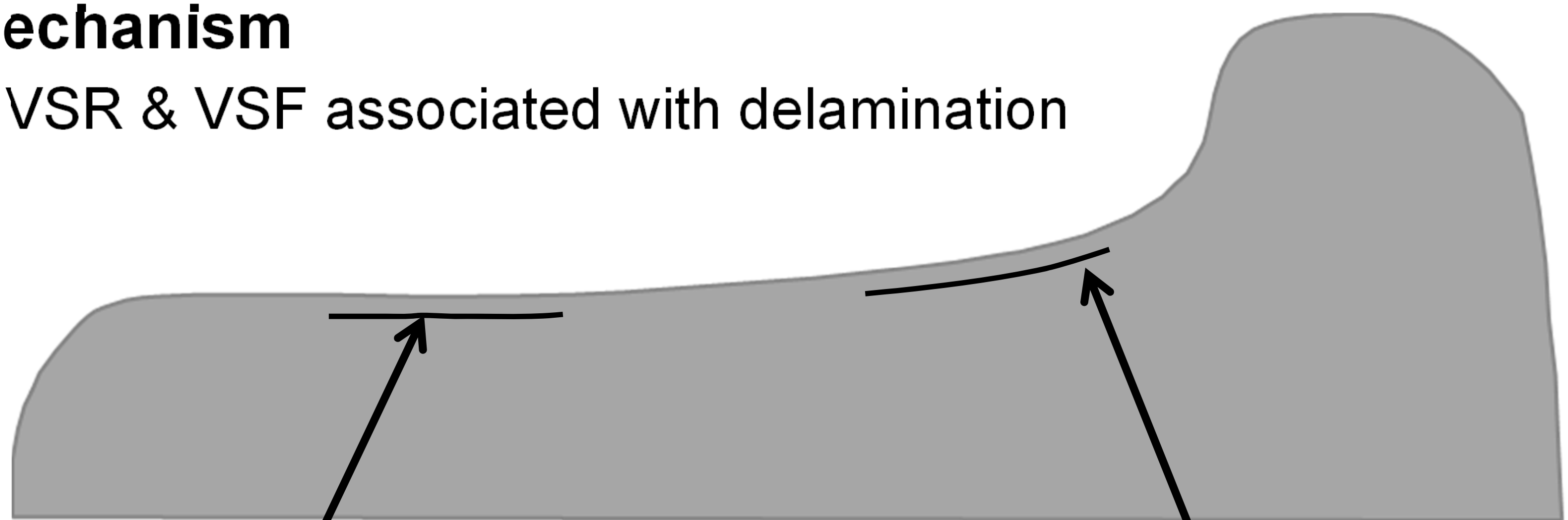
Low Tractions



High Tractions

Wheel Failure Mechanisms: VSR

- **Vertical Split Rim: Review proposed formation mechanism**
  - VSR & VSF associated with delamination

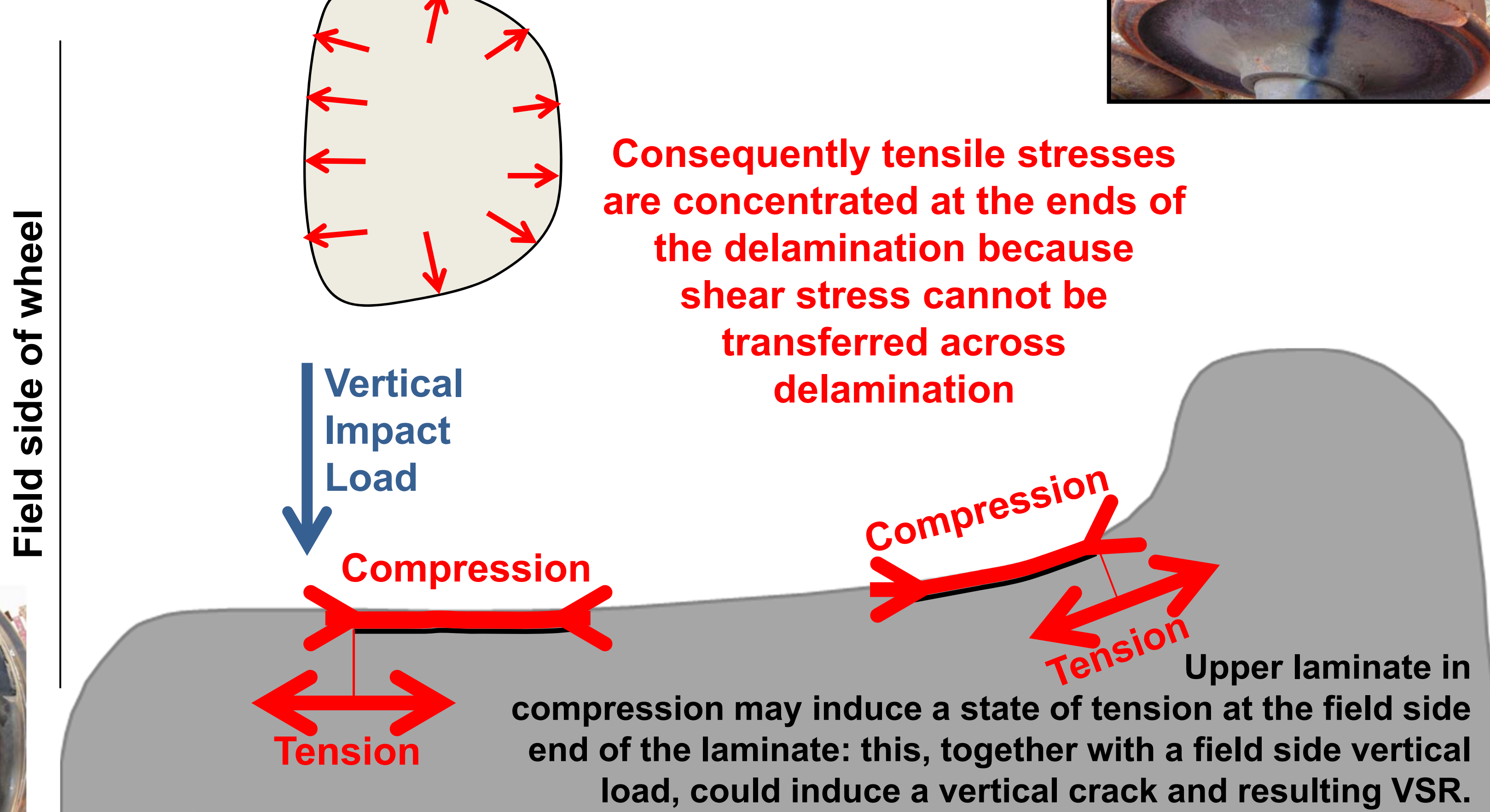


Delamination implies:

- **Shear stresses are no longer transferred across the delamination interface**
- **The contact model is no longer Hertzian**

Wheel Failure Mechanisms: VSR

- **VSR / VSF:**
  - Delamination causes the delaminated material to cold-roll introducing residual stresses



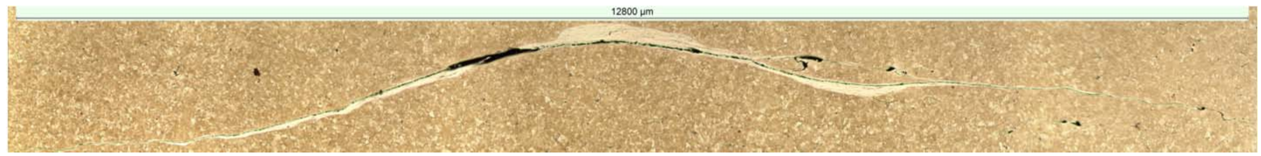
Wheel Failure Mechanisms: VSR

- **Original Objective:**
  - Measure residual stresses in both the delamination & the body of the wheel for input to finite element analysis
  - X-ray diffraction analysis of residual stresses did not find a difference

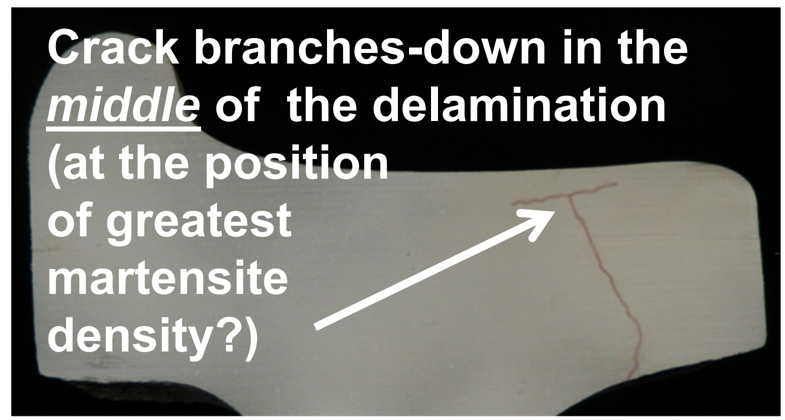
  - Subsequently advised that this method is too shallow (order of microns thick)
- **Metallurgical analysis finds martensite along delamination interface**

Wheel Failure Mechanisms: VSR

- **Presence of martensite along delamination interface:**
  - Suggests rubbing & flash cooling – commensurate with a strain differential between the delamination & the body of the wheel – in support of the proposed mechanism?



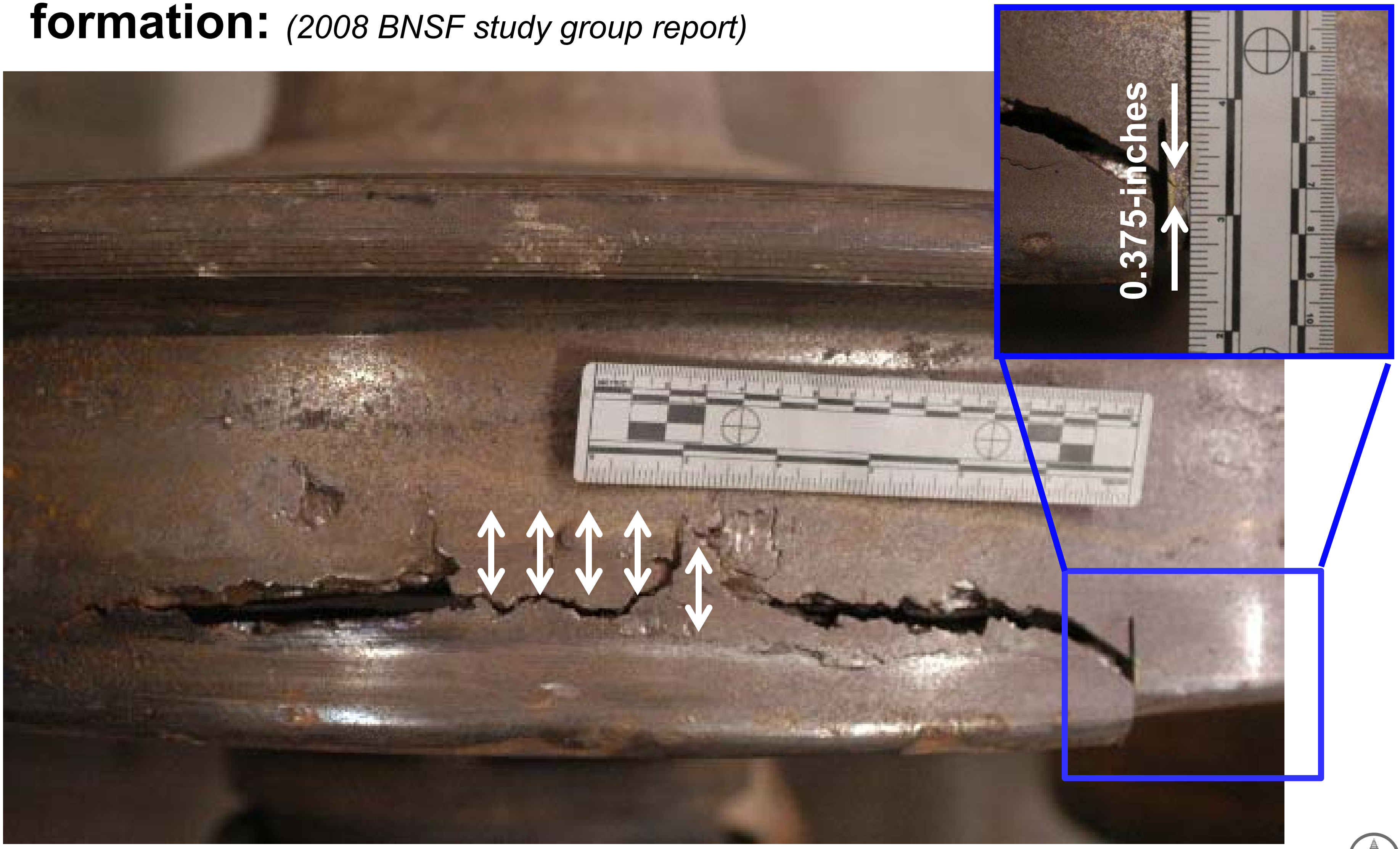
  - Might, however, suggest that the presence of martensite itself is a contributing root cause of the downward branching of the crack not necessarily at the end of the delamination



- **In other words VSR formation may require:**
  - Tensile residual tensile stresses as suggested by the model
  - Martensite formed by differential rubbing & flash cooling
- **What about the role of thermal braking stresses?**

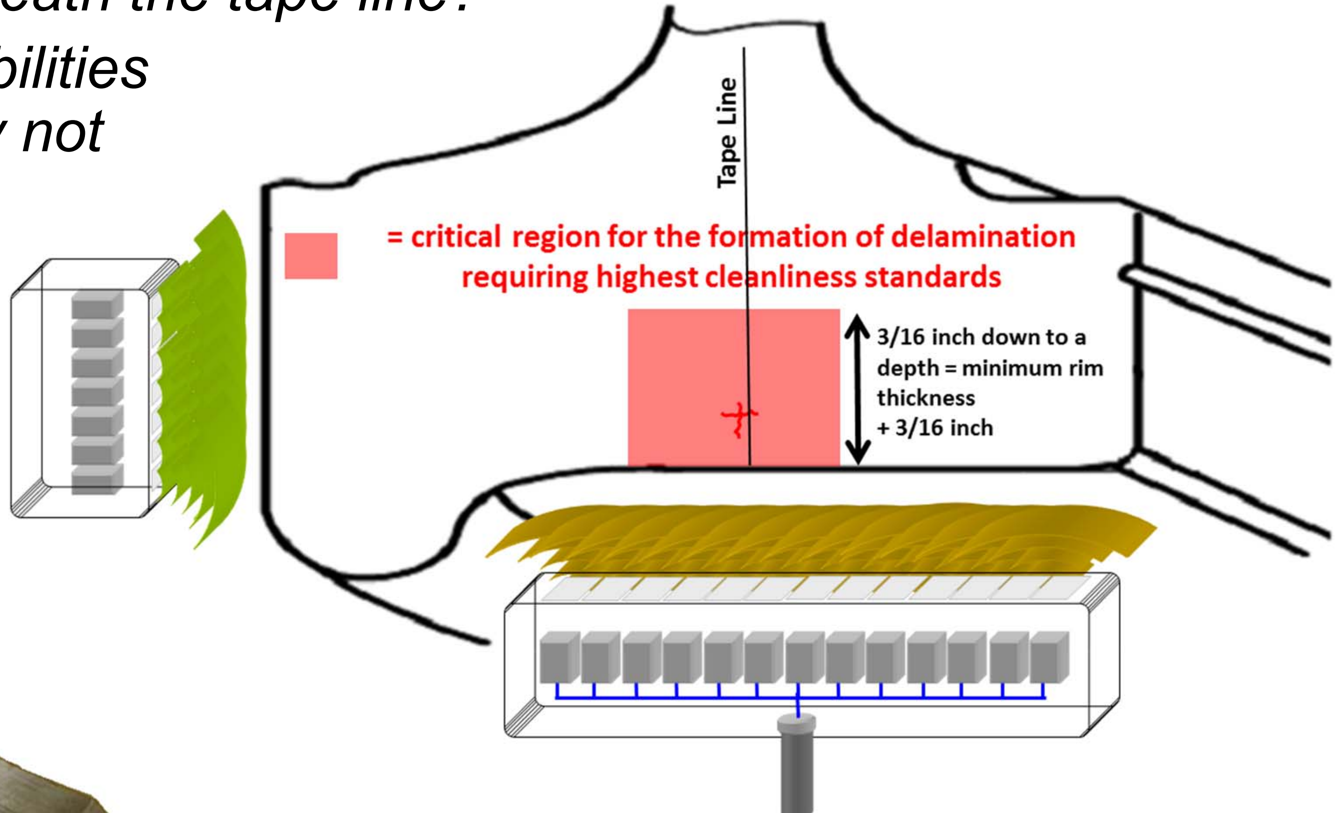
Wheel Failure Mechanisms: VSR

- **Evidence in support for the mechanism from partial VSR formation:** *(2008 BNSF study group report)*



Wheel Failure Mechanisms: VSR

- **Questions: *If delamination found to be root cause of VSR:***
  - *Should a HPW not be specified to be cleaner in the region beneath the tape line?*
  - *Should the capabilities of UT technology not be explored for this specific condition?*
  - *Limit ≤ 0.5mm?*

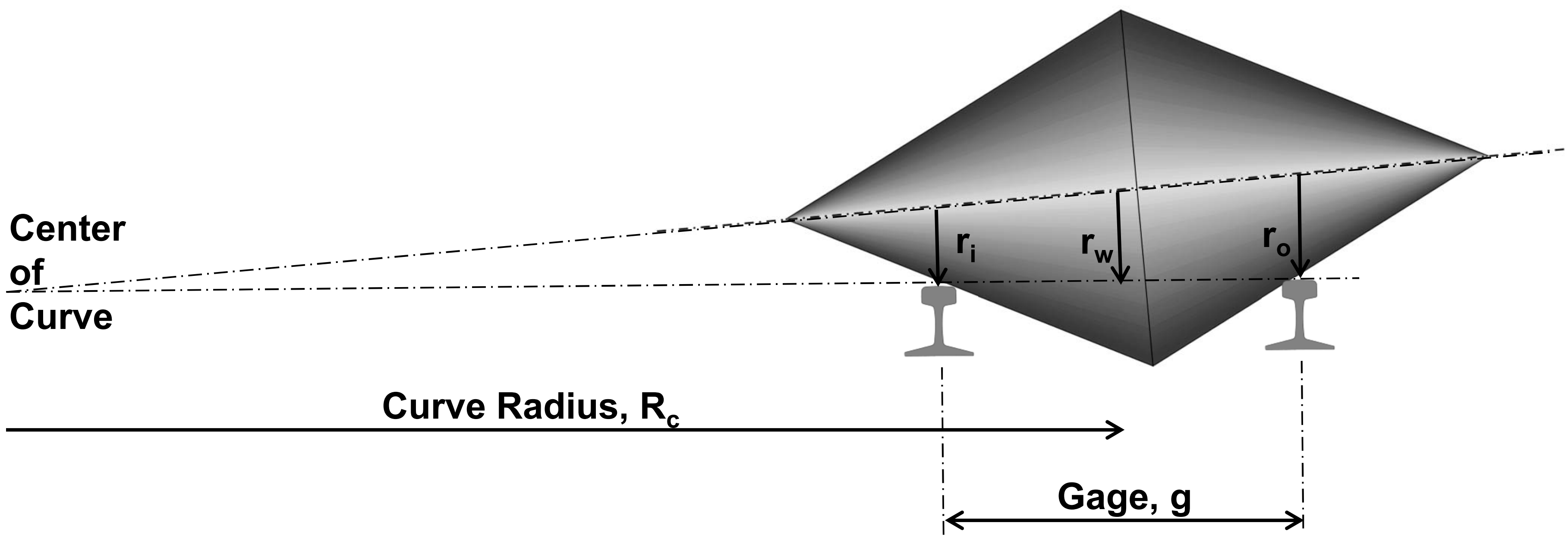


AAR block evaluation

- UT suppliers being approached to offer existing instrumentation for evaluation

Kinematic concept of a railway wheelset

- *Wheels of a di-cone run on different diameters (rolling radii) to accommodate the difference in distance traveled between the outer & inner wheel in a curve*
- $(r_o - r_i) / g = r_w / R_c$

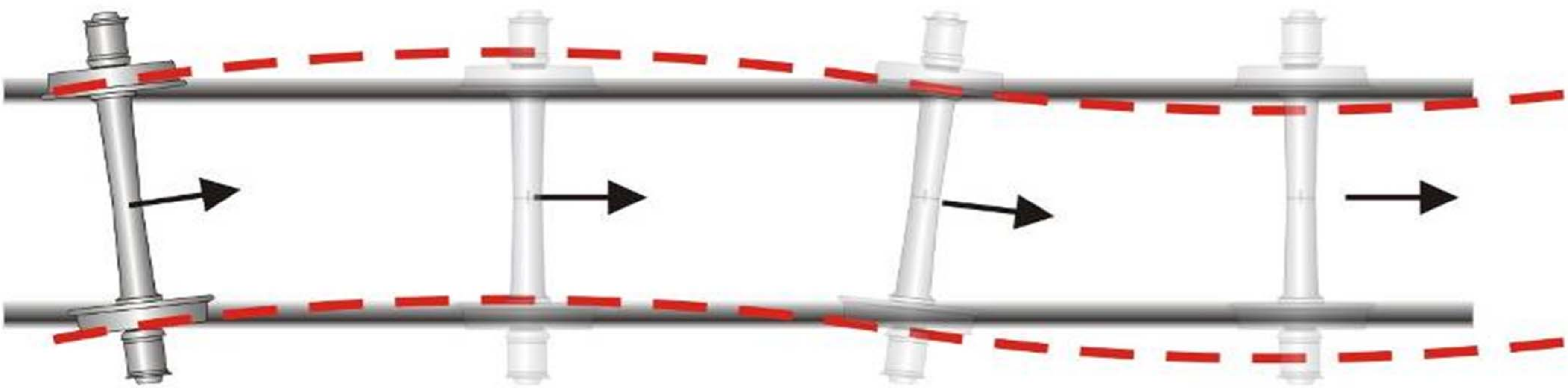


Comment:

- *This is termed a "pure rolling" position*

Kinematic concept of a railway wheelset

- *Wheels of a di-cone run centralize the wheelset on tangent track:*
  - *When laterally displaced from the center of the track*
  - *Accommodating diameter differences between the wheels (due to tolerances on machining; wear) – this within the gage clearance provided*



Comment:

- *If this motion takes place in a sustained manner with regular flange contact, it is termed "hunting"*

Support RCFS Construction & Commissioning

- ♦ **RCFS commissioned on schedule at TTC on March 11, 2015.**
- ♦ **Site preparation & support 80% complete**
- ♦ **Initial wheel tread scuffing tests in process to:**
  - Verify RCFS can produce RCF
  - Install & test:
    - Vacuum debris removal.
    - Instrumented rail & wheelset & data integration with MTS system
    - Surface monitoring cameras.
  - Develop robust test protocols to ensure traceability of specimens & repeatability of tests.
  - Develop & update safety protocols reflecting platform & access control status

Thank you for your attention!

Questions?