How does temperature affect wheel performance?

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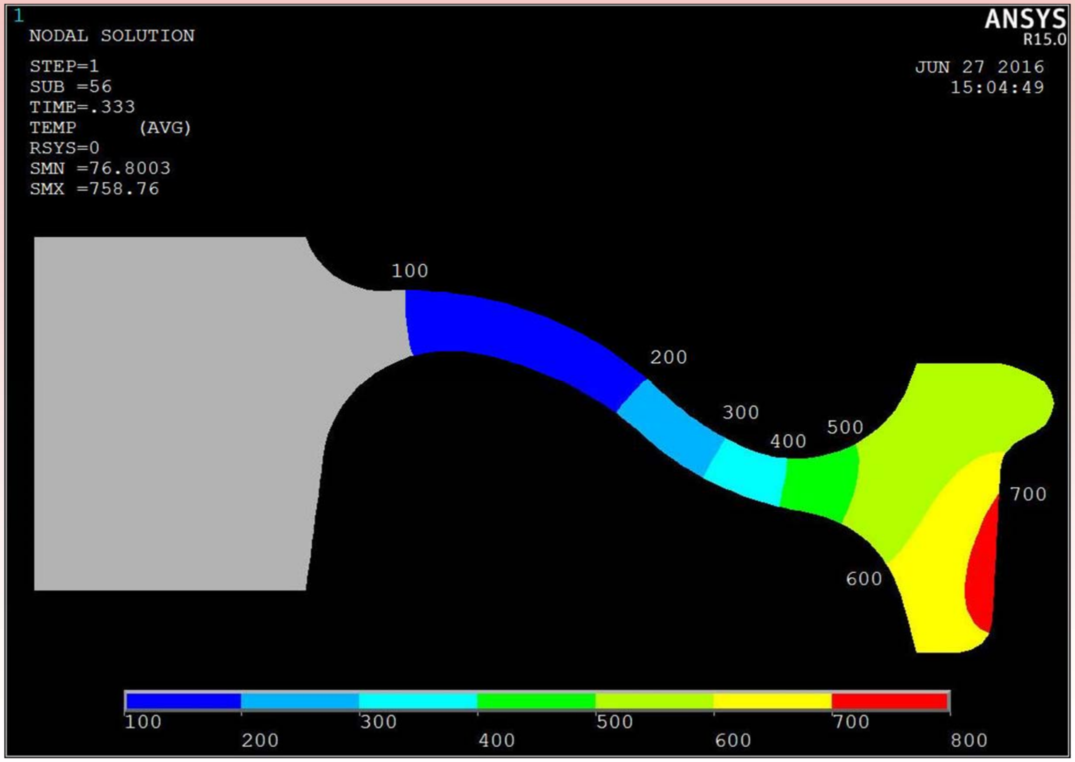
Introduction

- Mechanical Changes
- Microstructural Changes
- Property Changes
- Residual Stress Changes
- Other Effects – Environmental
- Conclusions & Questions

Mechanical Changes

- Heating causes steel to expand.
- Brake heating results in:
  - a lateral shift of the rim position.
  - rotation of the rim.
  - changes to the manufactured residual stresses

Mechanical Changes



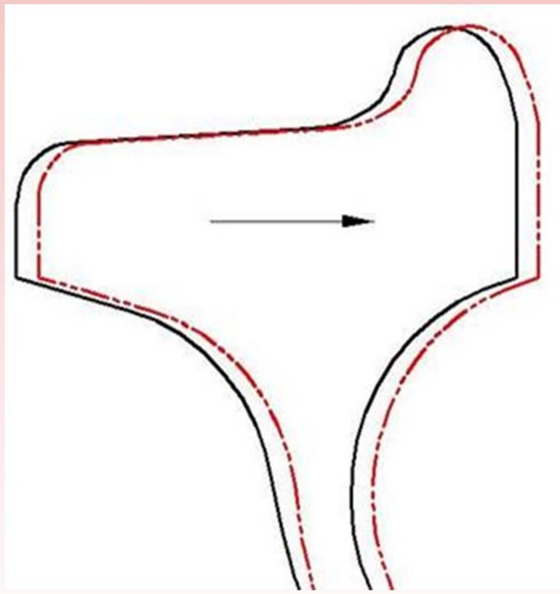
Temperatures from brake heating are highest at the field side of the rim.

These temperature differences result in distortions.

Mechanical Changes

- Higher temperatures at the field side result in rotation of the rim.

- High temperatures in the rim cause lateral displacements relative to the cooler hub.



Microstructural Changes

- Sliding a wheel generates very high temperatures which can form a pool of "Austenite" on the tread surface.
- Upon cooling the Austenite pool transforms to "Martensite". Martensite occupies about 1.7% more volume than the steel it replaces.

Microstructural Changes

- Expansion from formation of Martensite causes compressive stresses within the patch, and in counter-balancing tensile stresses nearby.

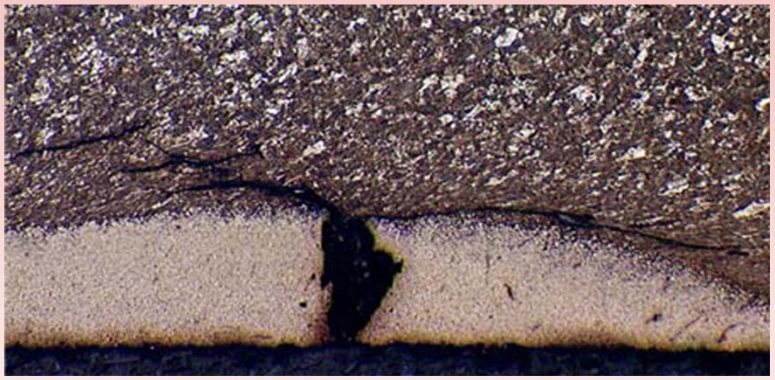
- The area surrounding the patch is over-tempered and the material's strength is decreased.

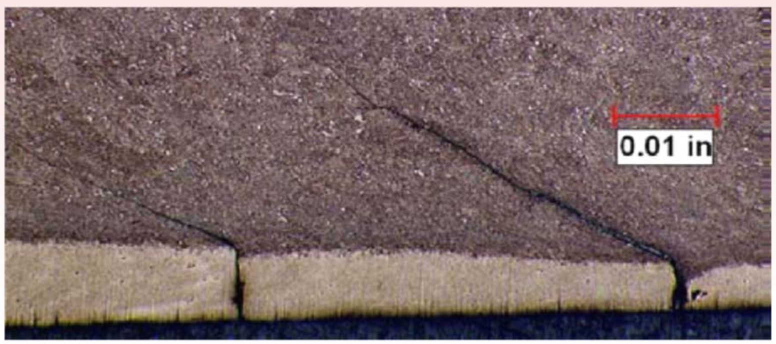
Microstructural Changes

This spall is very deep.

- When a "patch" is deeper than can be reached by the alternating stresses resulting from rolling contact, the fatigue crack can no longer propagate.
- The island of tread at center of the patch remains intact and appears like a "bulls-eye".

Microstructural Changes

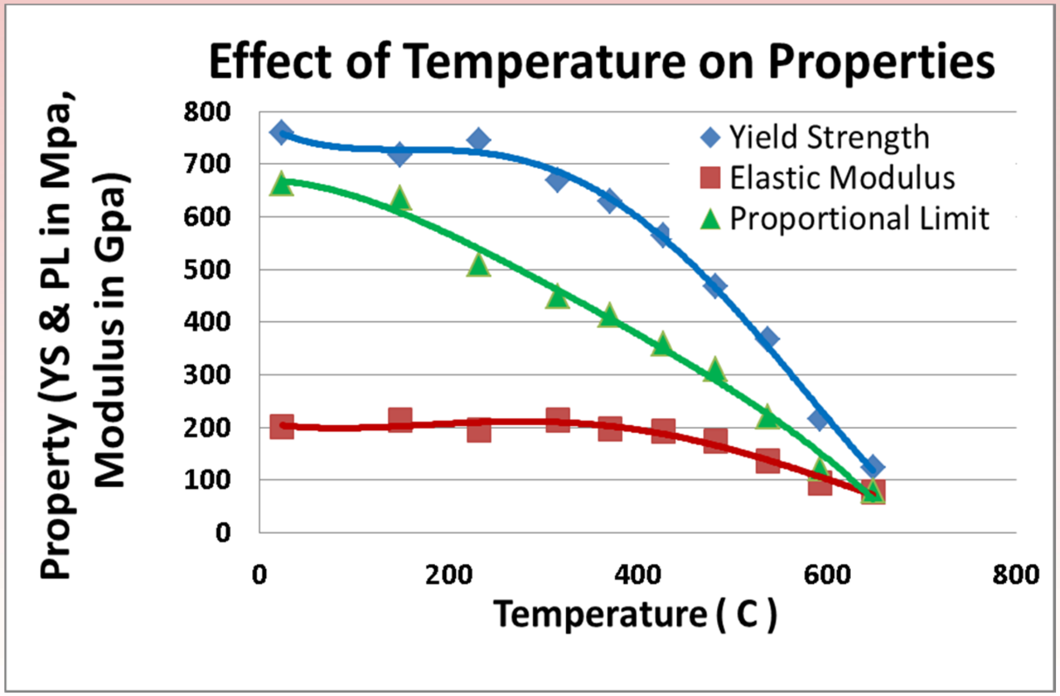




Two examples of slid wheels:

- On top is a white etching layer with a central crack formed by case-crushing and fatigue cracks.
- Below are two cracks which pre-existed the formation of the Martensite patch, from which fatigue cracks later propagated.

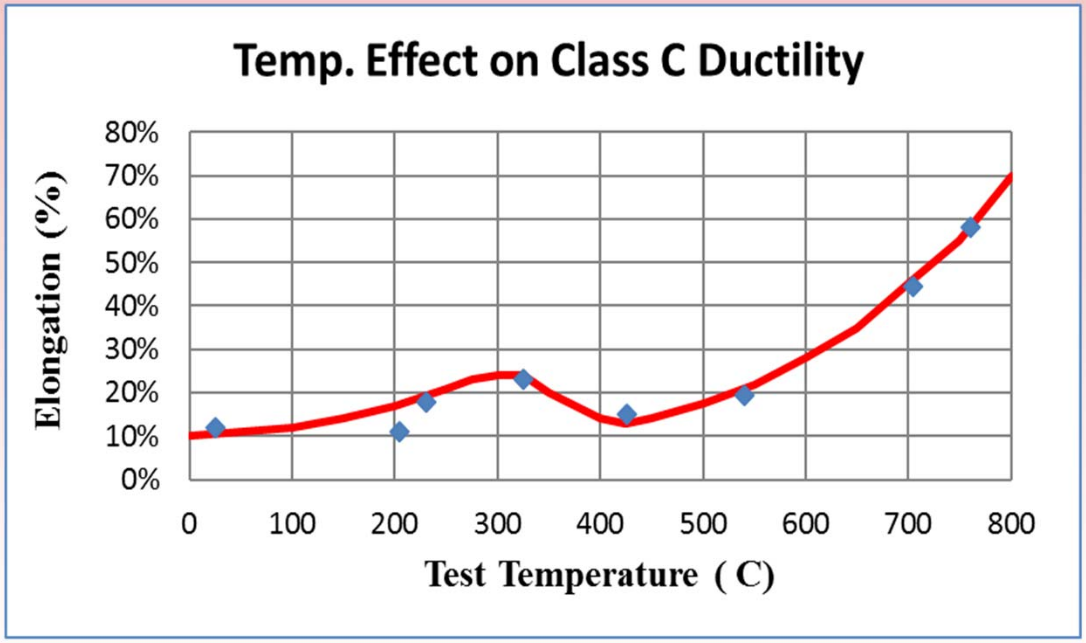
Property Changes



Tensile properties were measured for Class C wheel steel at elevated temperatures:

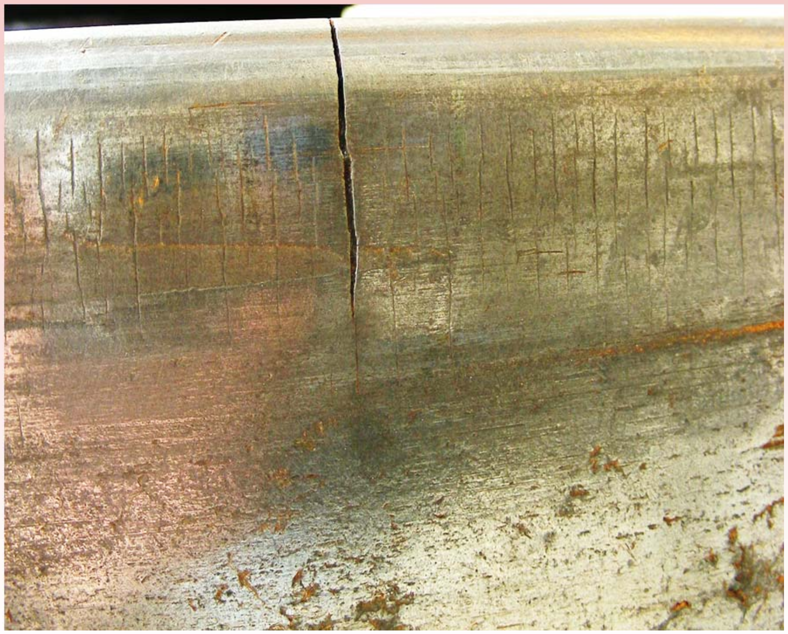
- Yield Strength was measured by 0.2% offset method.
- Proportional Limit is the maximum stress at which no plastic deformation occurs.
- Elastic Modulus is the ratio of Stress to Strain when only elastic strains are present.

Property Changes



- Elongation of a tensile specimen increases up to 300C.
- Above which ductility drops in what we call a "ductility trough" which is lowest between 400 to 450C.
- Ductility is restored at about 550C.

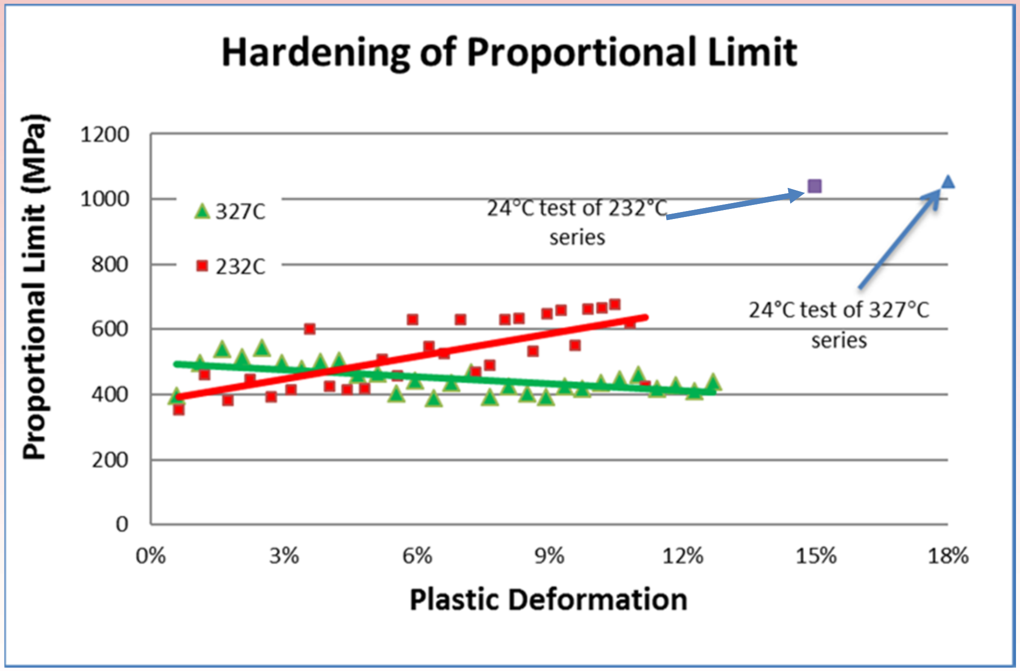
Residual Stress Changes



Residual stress changes happen in three stages:

- Less than 300C – affects tread surface and little else.
- Between 300 and 600C – affects rim and tread area, and may lead to premature shelling.
- Over 600C – will increase likelihood of premature shelling, stress reversal in rim, and thermal cracks.

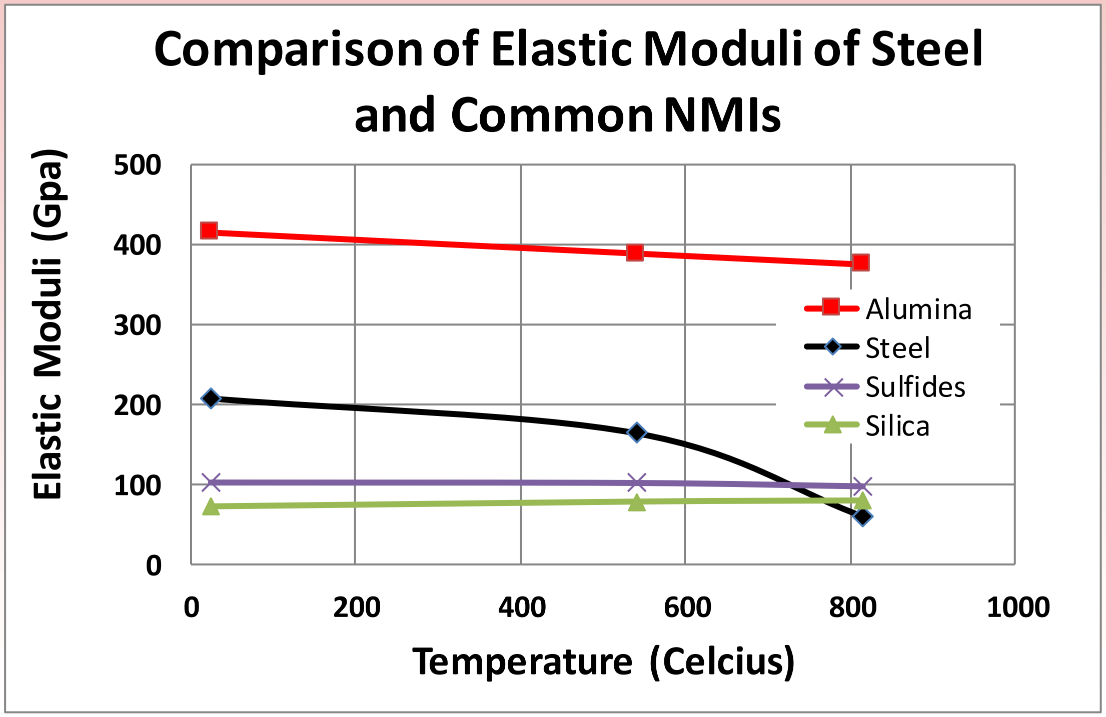
Residual Stress Changes



Cyclic loading during brake heating is also important:

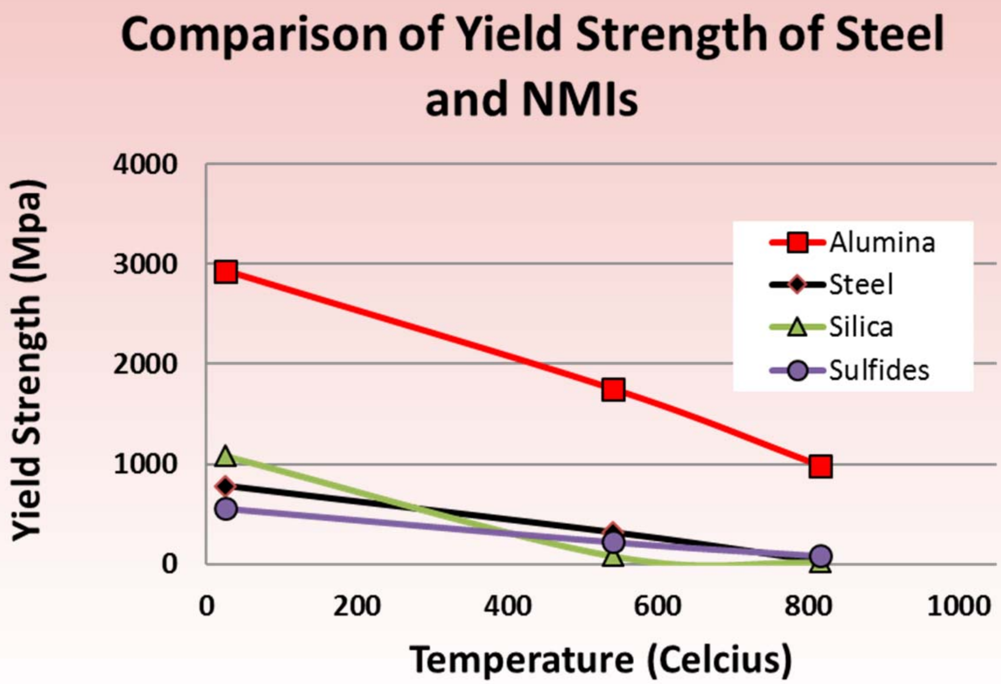
- Lower temperatures result in strain hardening of the Proportional Limit.
- Higher temperatures tend to cause strain softening.
- Restoring ambient conditions after cyclic loading results in a dramatic increase in the PL.

Non-Metallic Inclusions



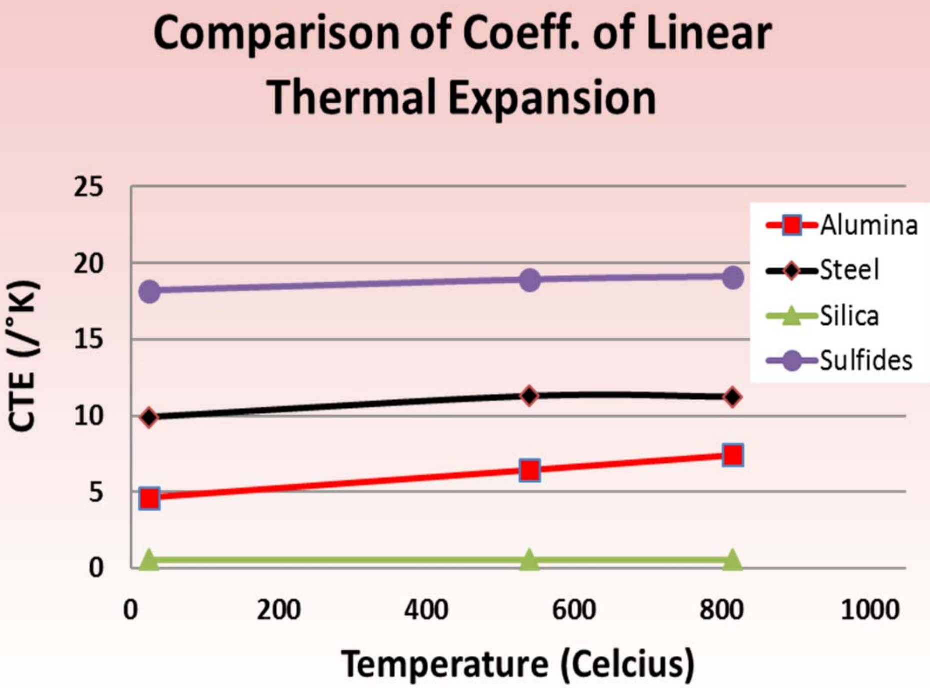
- The greater the difference in Moduli, the greater the potential damage from rolling contact forces.
- Alumina has the greatest difference in Elastic Modulus from steel, followed by Silica, then Manganese Sulfide.

Non-Metallic Inclusions



- Strength differences between the steel and non-metallic inclusion enable us to predict where a fracture is likely to initiate.
- For alumina crack initiation will be either at the interfacial boundary or in the steel surrounding the inclusion.

Non-Metallic Inclusions



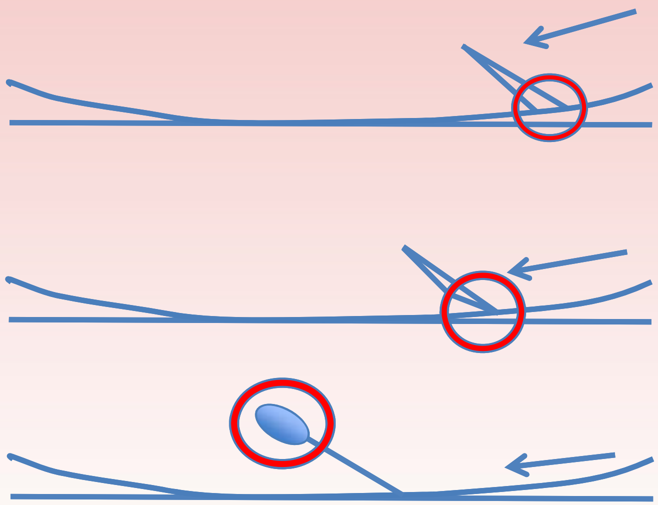
- Differences in CTE can create conditions of higher residual stress in the NMI, and in the surrounding steel.
- Predicting crack initiation requires a careful study of rolling contact stresses, the effect of temperature, manufacturing residual stresses in addition to inclusion type, shape and size.

Environmental (Wedging)Effects

Three basic wedging mechanisms:

- Hydraulic Crack Driving Mechanism.
- Water to Ice Transformation.
- Oxidation within a crack.

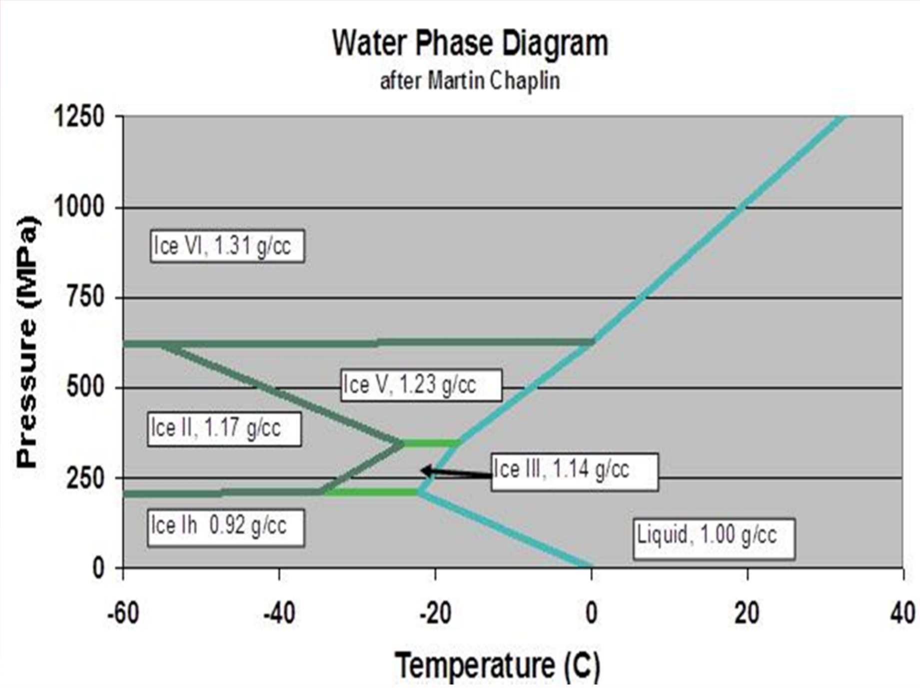
Environmental (Wedging)Effects



Hydraulic Crack Driving Mechanism:

- Requires tread cracks filled with fluid.
- Contact stresses close the crack opening, trapping fluid within the crack.
- Crack faces are pushed together by rolling contact stresses, forcing fluid to the crack tip.

Environmental (Wedging)Effects

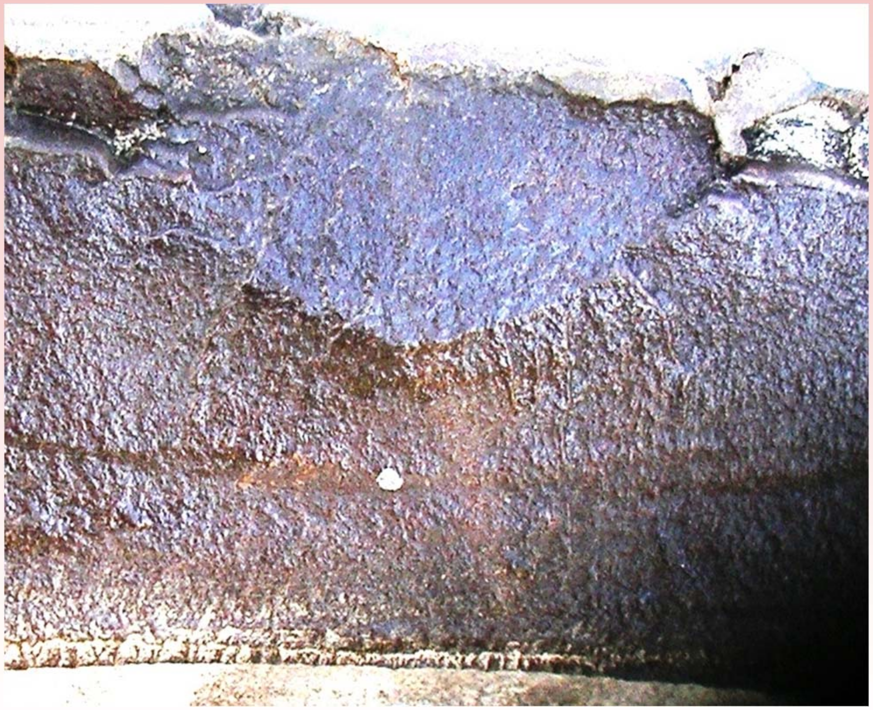


Ice-Water Transformation Mechanism:

Requires fluid filled tread cracks; freezing temperatures.

- Between 0 and -22C, Ice (Ice 1h in the diagram) can melt under pressure. The super-cooled fluid acts similarly to the hydraulic crack driving mechanism.
- When the pressure is removed, the fluid re-freezes and expands creating mode I forces at the crack tip.

Environmental Effects - Wedging



Oxidation Wedging Mechanism:

Requires tread cracks, high temperatures, time.

- Above 400C, steel rapidly oxidizes to Magnetite and Hematite. Above 570C, Wùstite also forms.
- These oxides are about 65% of the density of steel – they occupy 50% more volume than the steel they replace.
- As the oxides form within a crack, the crack faces are pushed apart.

Conclusions

- Temperature from brake heating affects wheel performance by altering the wheel/rail interface, by altering residual stresses and mechanical properties. These changes increase shelling risk.
- Sliding conditions generate enormous amounts of heat, resulting in transformations of the steel, and concurrent localized changes to properties and residual stress patterns. These changes almost always lead to spalling.

Conclusions

- Non-metallic inclusions are affected by temperature, in that physical property and mechanical property differences from steel can change local stress patterns. These changes can promote crack initiations.
- Environment can also cause accelerated shelling conditions. Water entrapment, Ice entrapment and oxide formation in a crack can cause the crack faces to be "wedged" apart.

Questions?

Description	Symbol	Density – g/cc	Volume Change
Iron	Fe	7.82	0%
Wüstite	FeO	5.95	+31%
Hematite	Fe_2O_3	5.26	+49%
Magnetite	Fe_3O_4	5.18	+51%
Goethite	FeO-OH	4.26	+84%

Non-Metallic Inclusions

- Strength/Hardness: When stressed, will the NMI deform, or will the steel surrounding the NMI deform?
- Modulus of Elasticity: Under load, will the strain be greater or less than the steel?
- Coefficient of Thermal Expansion: When heated, does the NMI occupy more volume or less volume compared to the surrounding steel, than when it was cold.
- Is the interfacial bond strong enough to prevent de-bonding?