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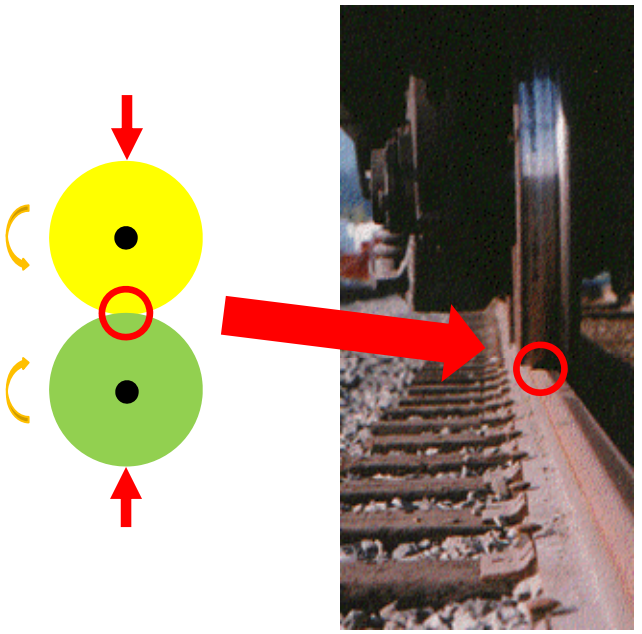
Scaling of Small-Scale to data to Full-Scale Modelling

Professor Roger Lewis
Dr Adam Beagles



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Outline

- ICRI Wear Mapping Activity
- Why do Tests?
- Choice of Test?
- Issues with small-scale tests and how to deal with them…
- Application of small-scale data – case studies
- Summary

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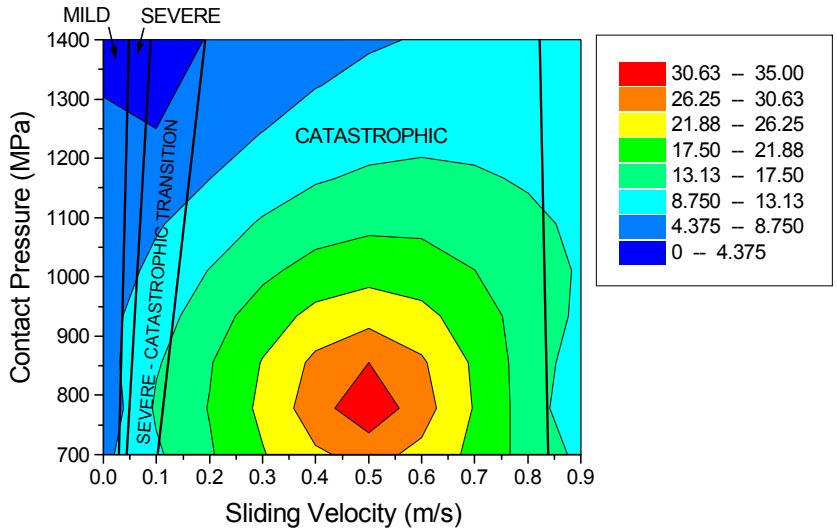
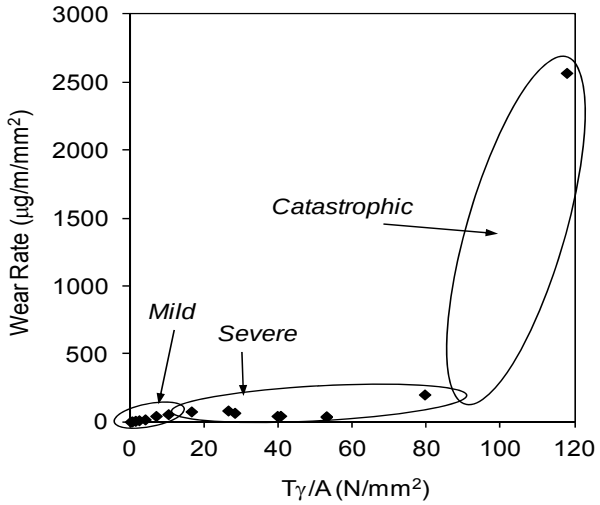
ICRI Wear Mapping Scope

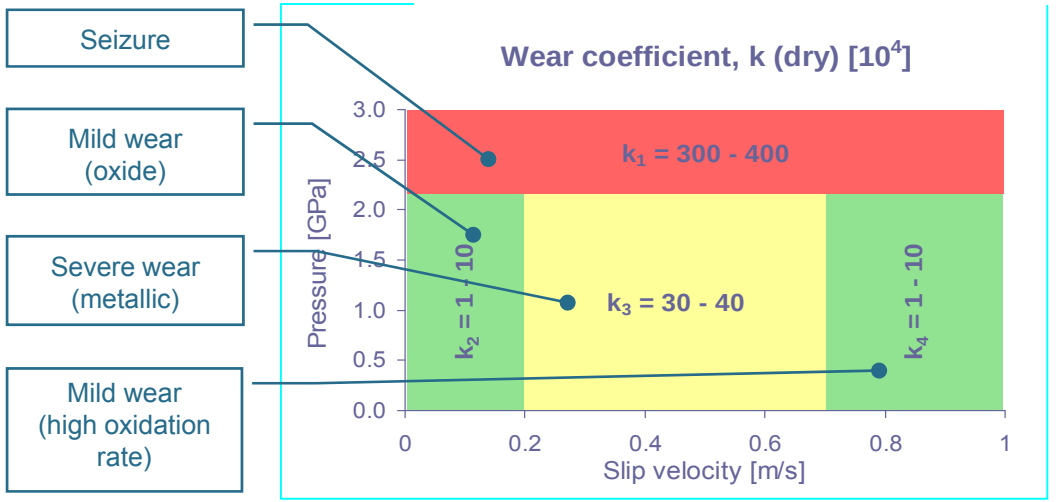
- To develop “universal” wear maps representative of full-scale operation that take account of the full range of operating environmental conditions prevalent for the wheel/rail contact.
- These would be used as stand alone tools as well as providing input data for MBD simulation based tools for predicting wheel and rail wear.

Existing Wear Maps





- $T\gamma$ wear relationships
- KTH Archard wear coefficient map extensively used



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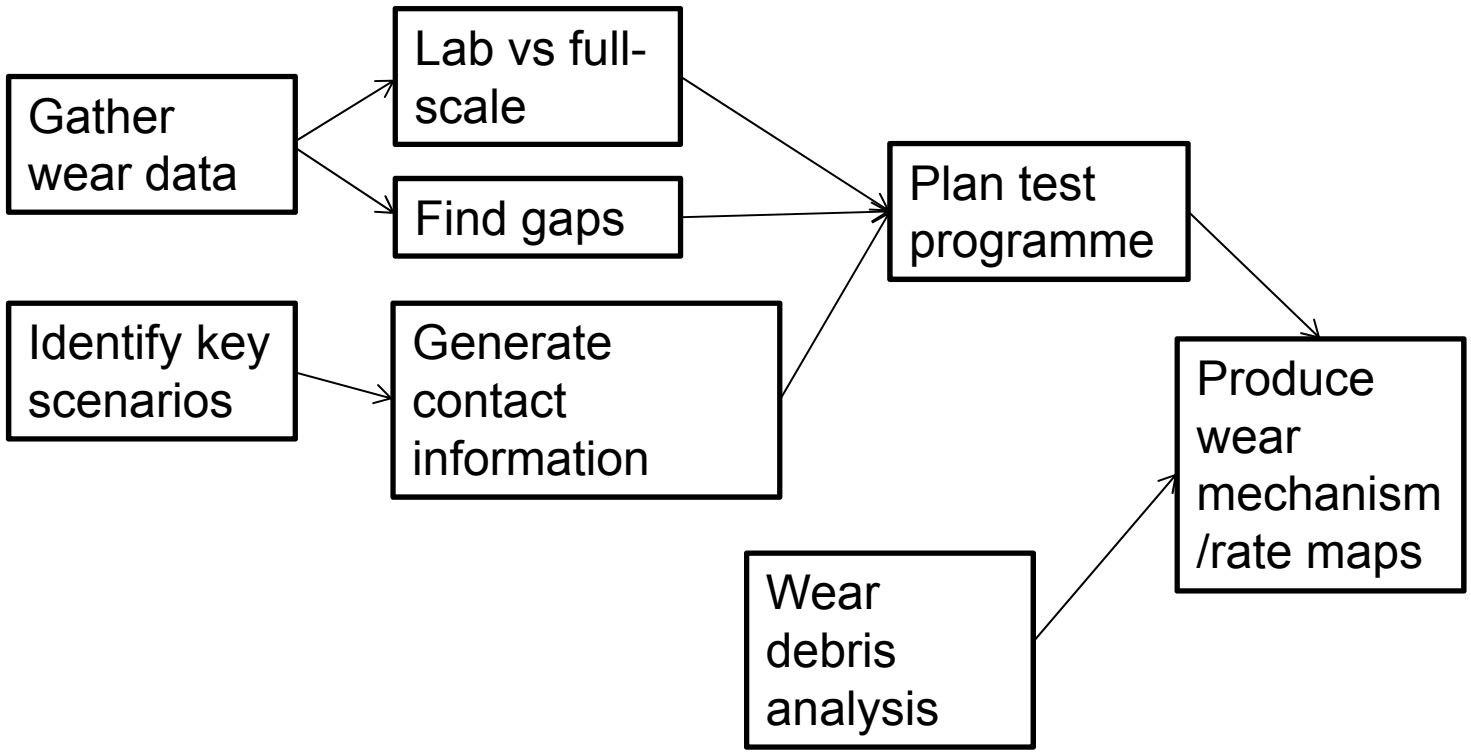
Strategy



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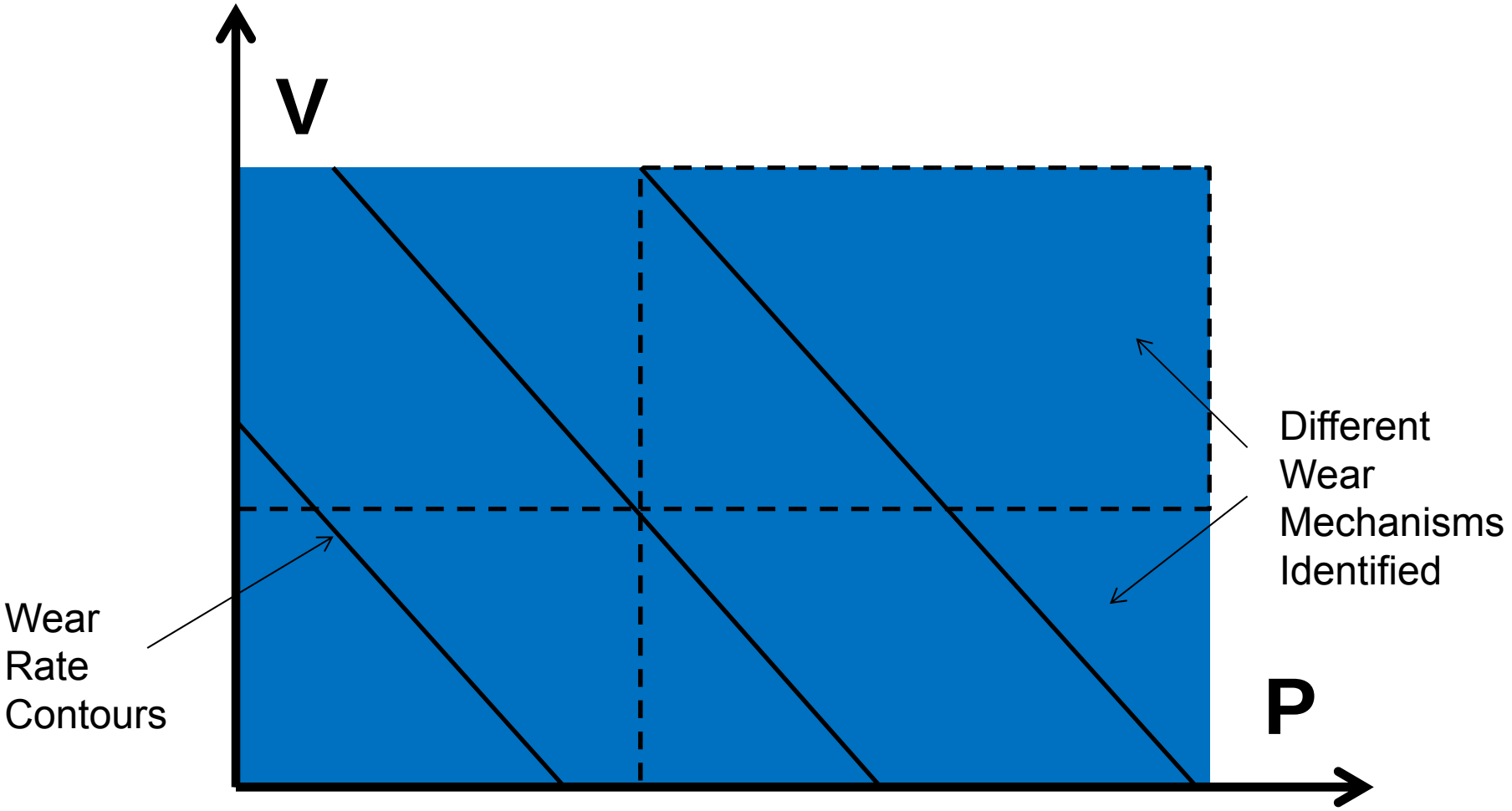
Outcome – Wear Map(s)



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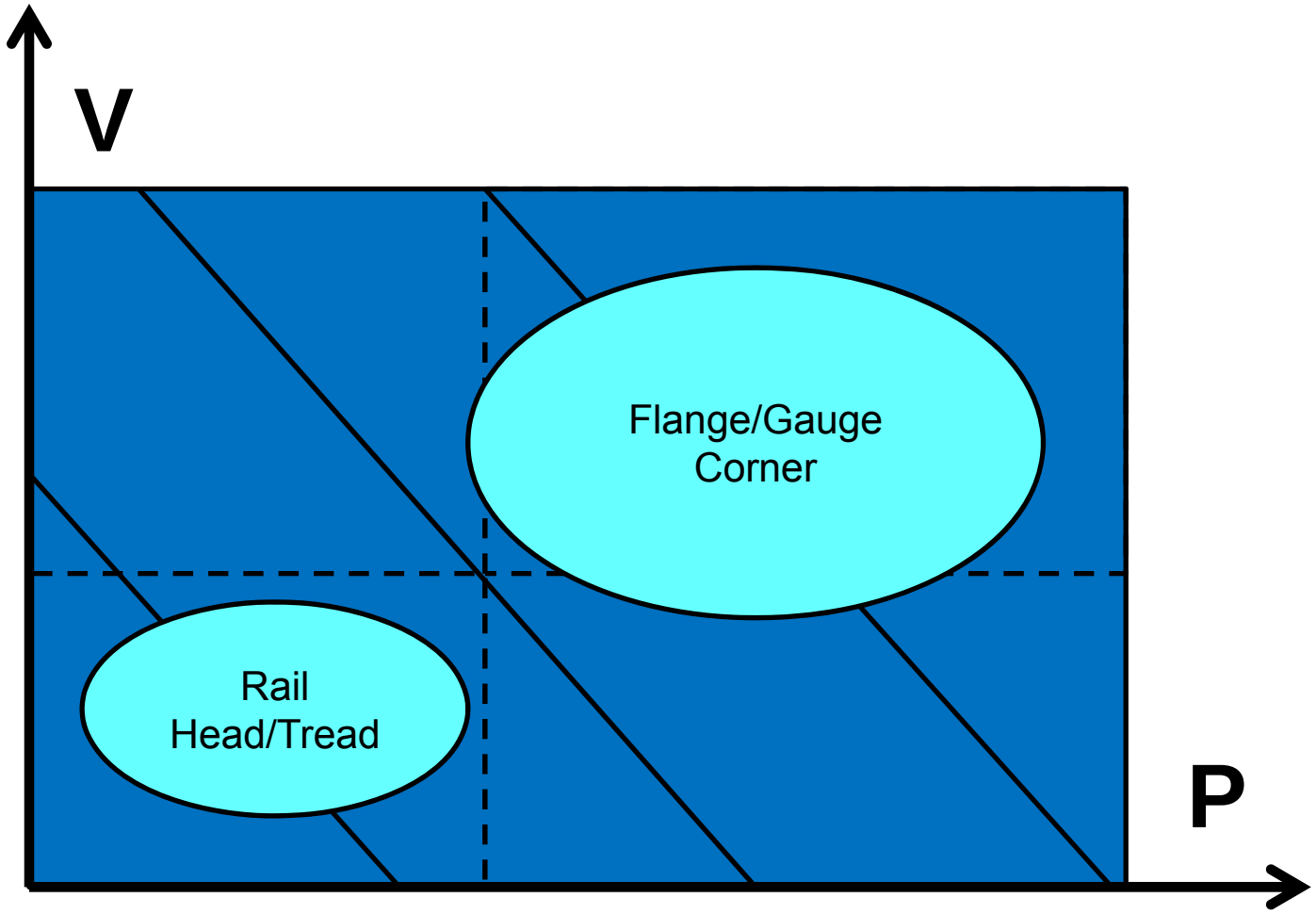
Outcome – Related to Actual Contact Conditions



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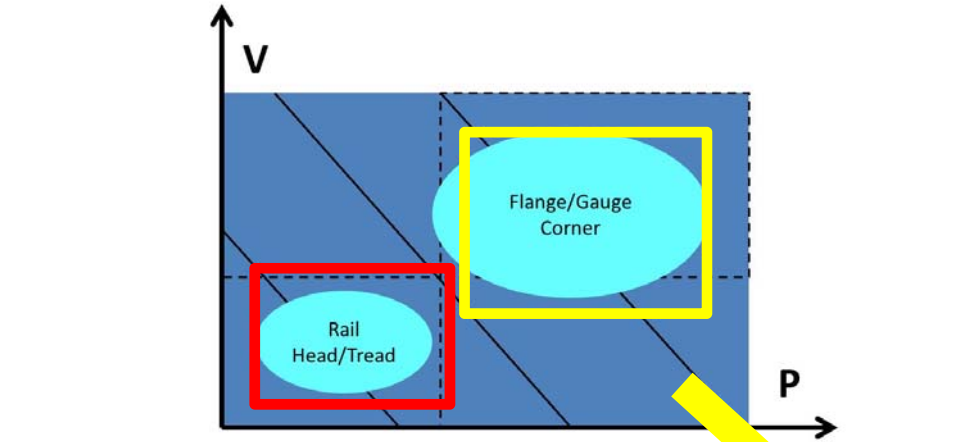
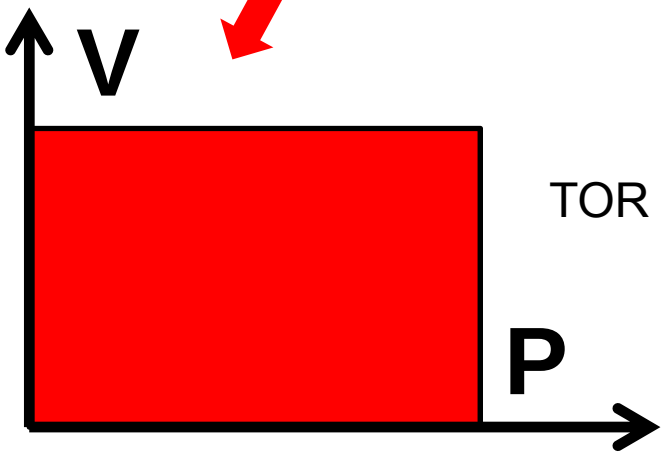
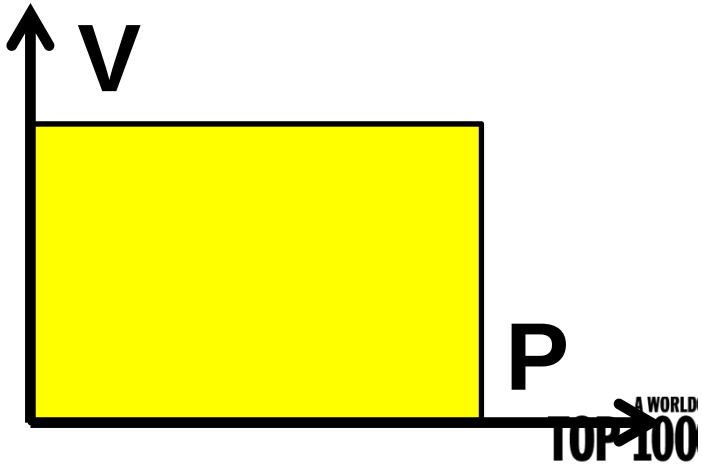
Outcome – "Sub-maps" for Third Body Scenarios





TOR FM

Curve Lubricant



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What we need…

- More contact data
- More wear data
- Input on scenarios – where are the issues?
- In obtaining more wear data a better defined methodology is needed…
- Approach to scaling…..?

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Why do we do tests?

- To understand mechanisms
- To develop models/performance maps
- To determine model inputs
- To validate models
- To assess material performance
- To assess applied product performance
- For all of these to provide relevant results we need tests to be as representative as possible of field conditions…

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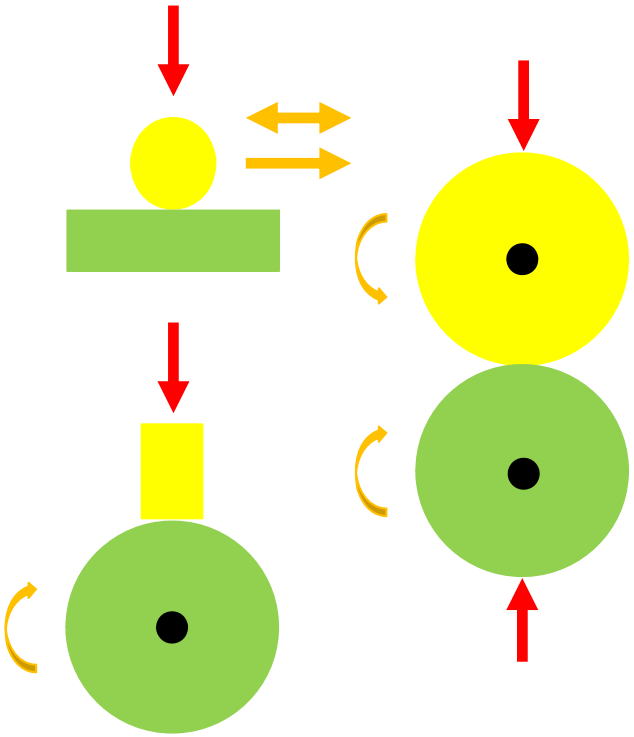
How do we choose what type of test to use?...

Tribometer



Scaled Component

Full-scale/Field

Increasing Complexity, Time Cost…

Increasing Control and Ease of Measurement

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Issues with Small Scale Tests

- Specimens – geometry (and therefore contact size and shape); surface conditions and properties
- Contact conditions
- Acceleration…
- Test length
- Temperature
- Environmental conditions
- Constant contact position
- Constant recycling

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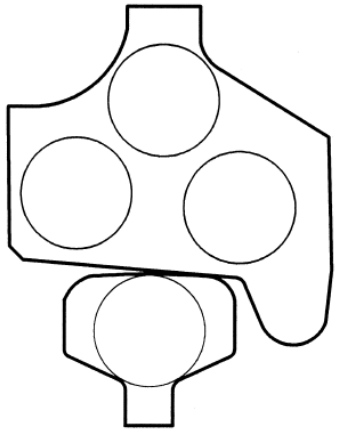
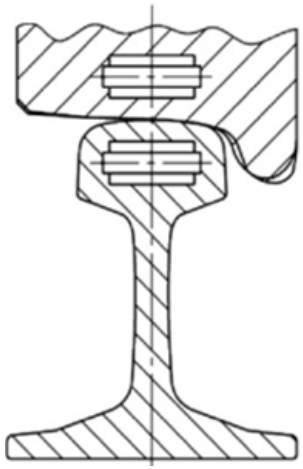
Specimens

- Good to have specimens made from actual wheel and rail
- Need to take parallel to running bands
- Preparation – clean?
- Geometry – particularly important for 3B material application





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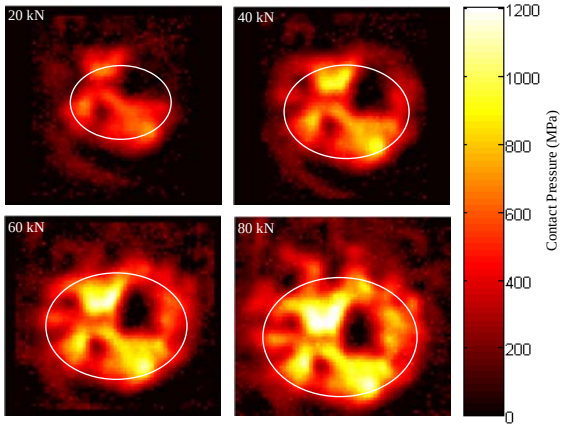
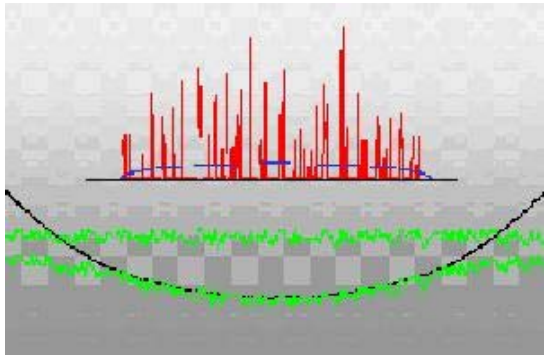
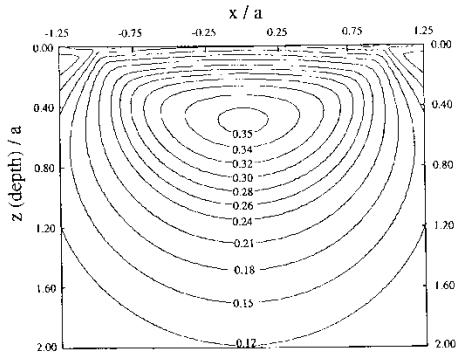
Marshall et al., *ASME Journal of Tribology*, 128 (2006), 493-504

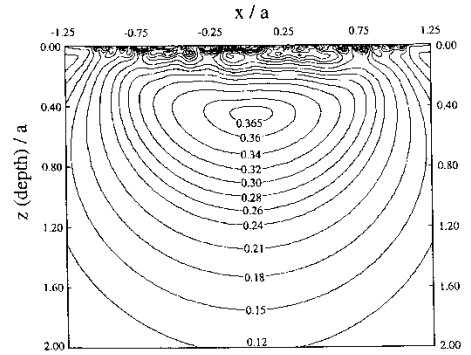




Specimens

- Surface roughness key – worn wheel/rai 1μm Ra?
- Models assume smooth – is this okay?
- Work by BRR looking at roughness effects concluded that for full-scale roughness not critical (i.e., smooth assumption okay), however, it appeared more critical for small-scale tests…
- Needs more work…





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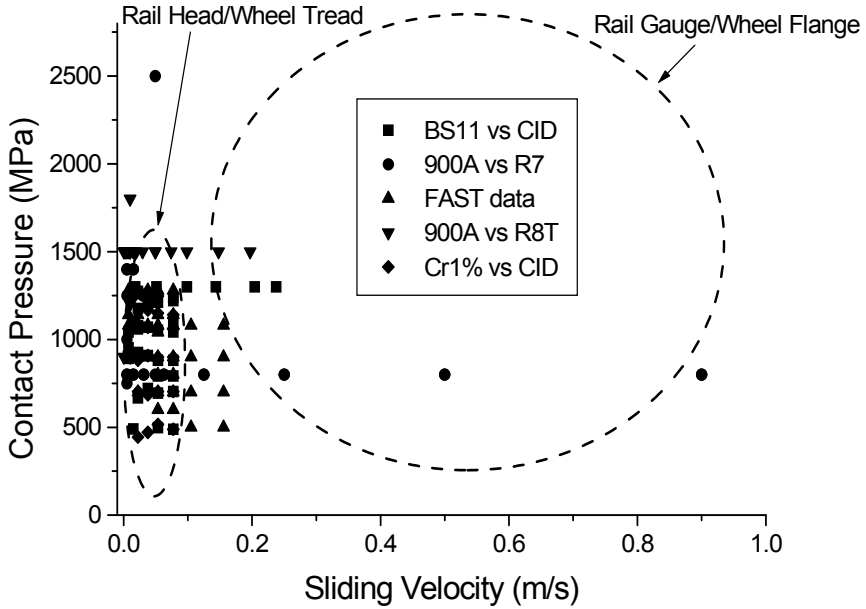
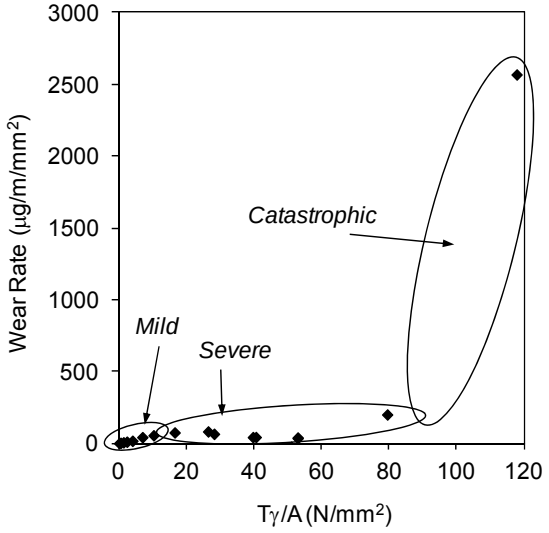
Contact Conditions

Lewis & Olofsson, U., *Wear*, 257 (2004), 721-729.

- Dynamic modelling has helped develop envelope of contact conditions (for passenger vehicles)
- Scope to expand this for different scenarios
- Conditions along track vary
- Conditions different for every contact – different wheel profiles etc.
- Global to local - conditions vary across contact





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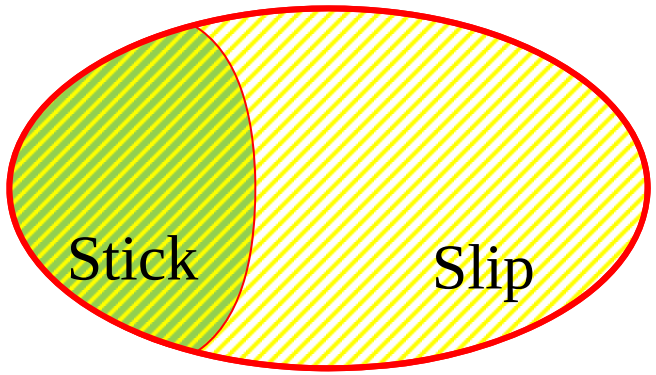
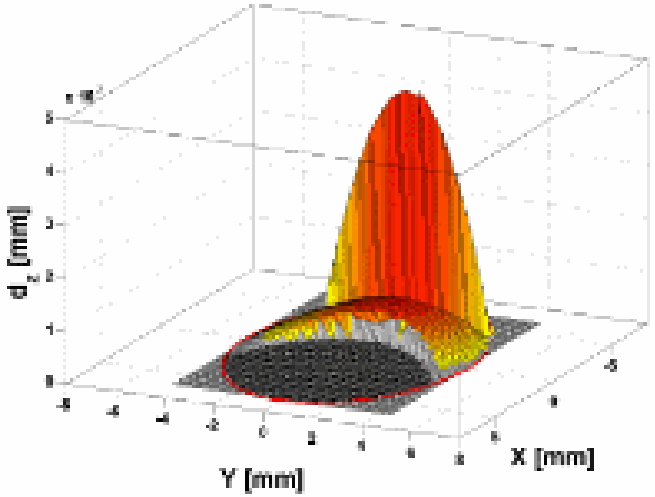
Contact Conditions



Full-scale contact patch idealised to ellipse:

- Areas of stick and slip
- Variations of normal contact stress (e.g., Hertzian)
- Variations of creep and shear stress (non-linear)



https://www.ave.kth.se/avd/rail/research/sword-1.48488

Mats Berg: Wear depths predicted over contact patch (highly non-linear)

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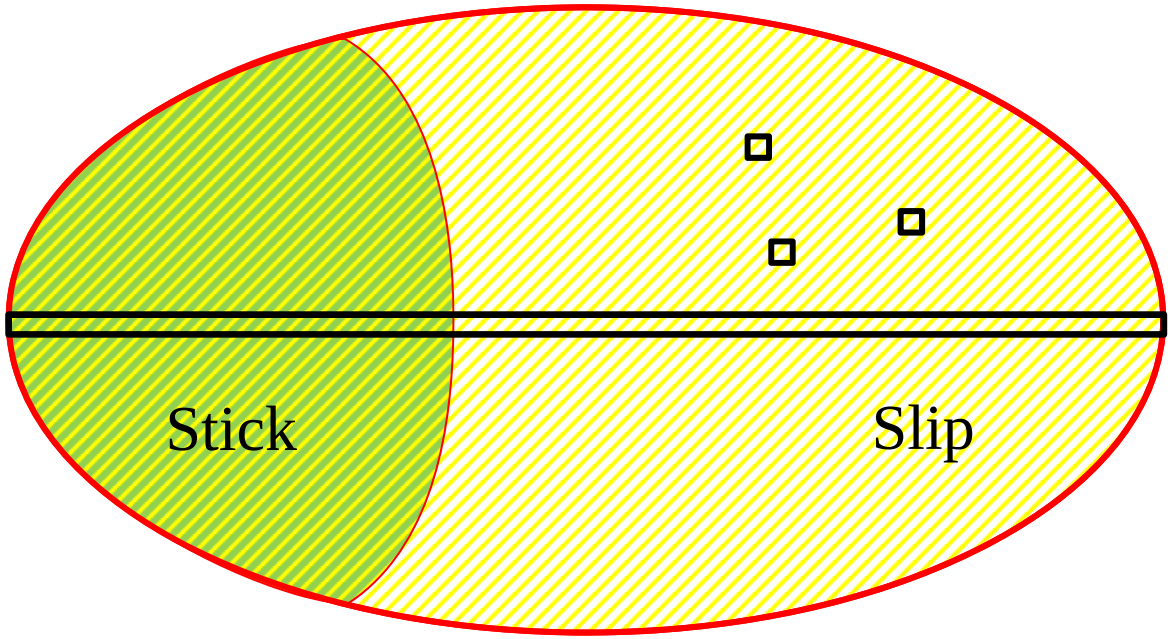
Small-scale Conditions

Wheel-rail contact



Pin-on-disc tests: conditions correspond to one point of the wheel-rail contact

Twin-disc test: contact corresponds to one line through the wheel-rail contact

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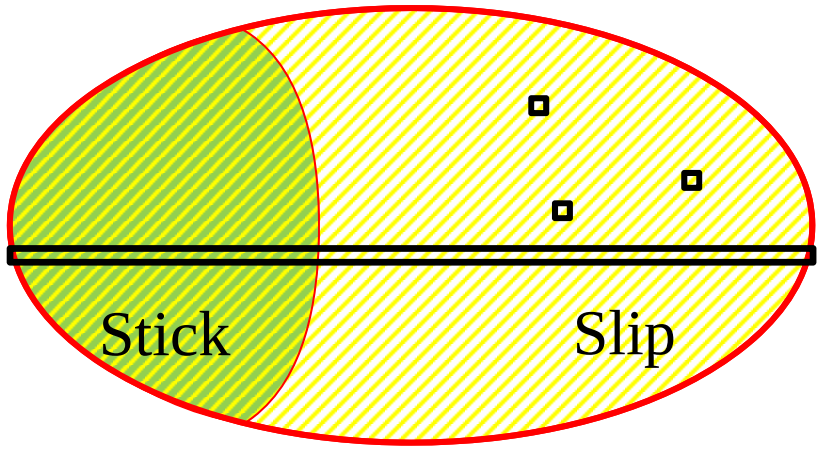

Scaling

Twin-disc tests:

- Carry out tests for different lines through the contact patch?
- Assume average conditions will produce representative results?

Pin-on-disc tests:

- Multiple tests required to represent all parts of contact patch
- One test at average conditions unlikely to be representative

Need to consider relevant (i.e., for vehicles and wheels passing over rail) contact geometries and produce averages of appropriate small-scale results to predict wear and RCF of rail.

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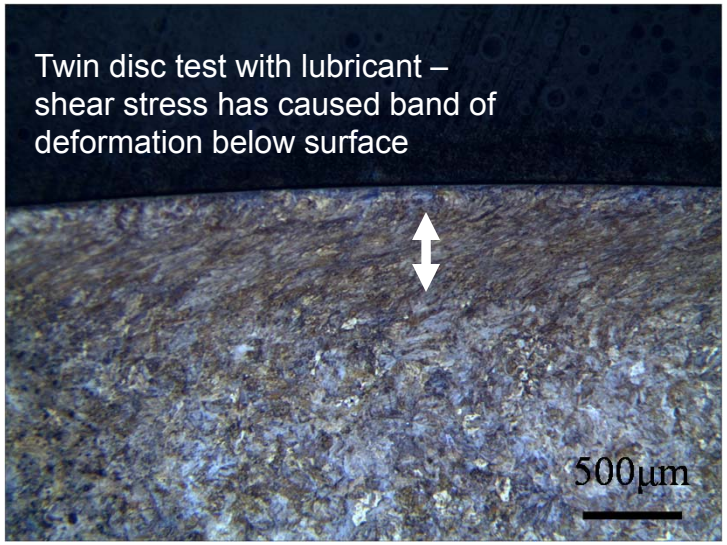
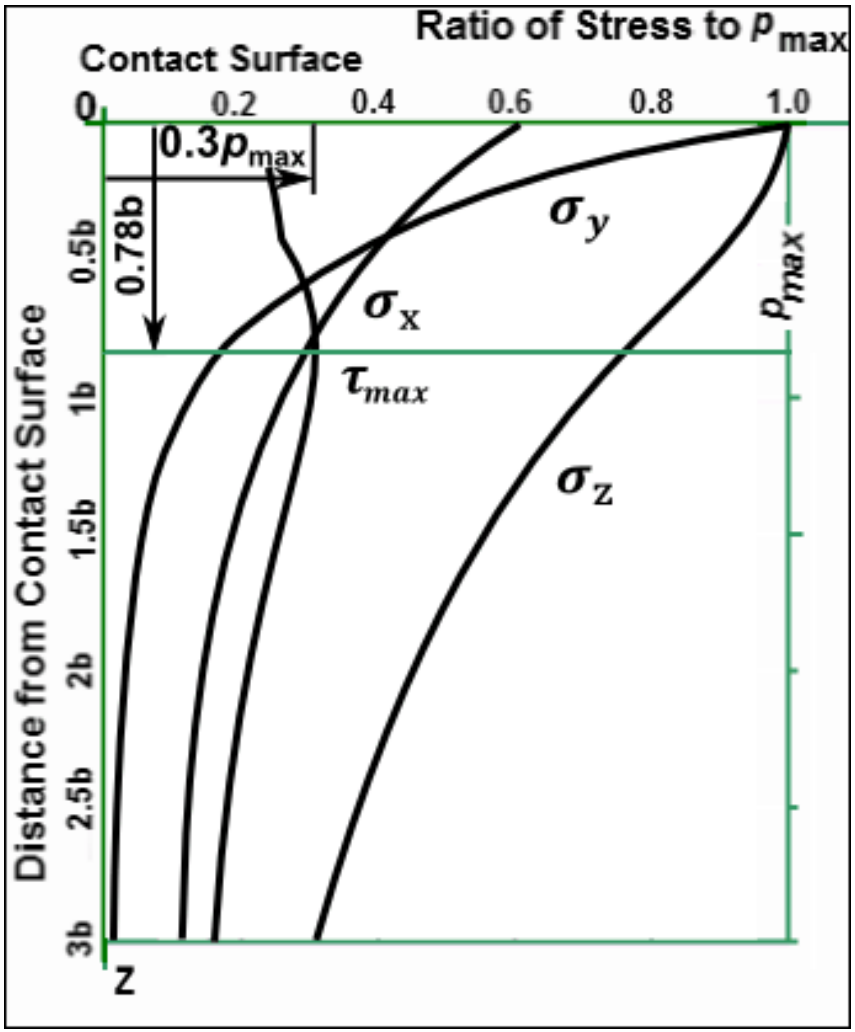
Sub-Surface

- Shear stress – important in dictating damage mechanisms
- Depth and magnitude important
- Friction and load effects





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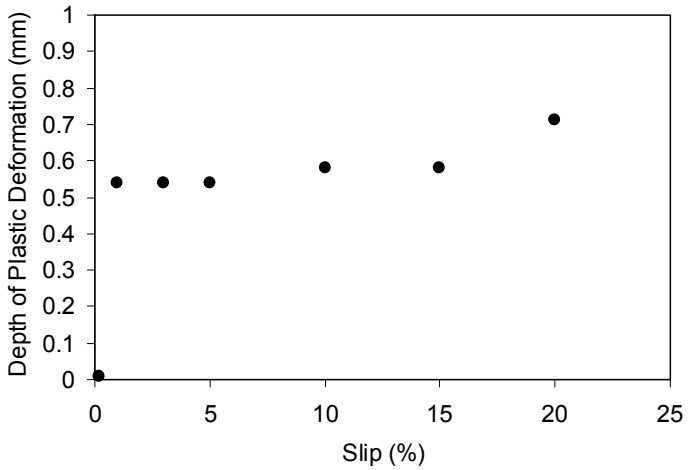
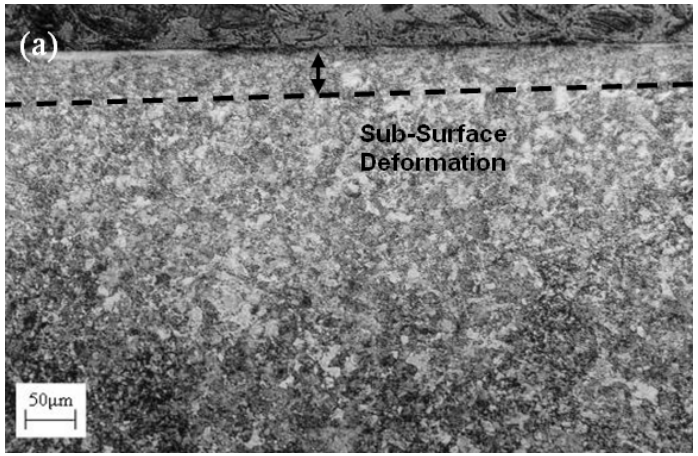
Sub-Surface

- Depth of peak shear stress – important in dictating damage mechanisms
- Big difference between small and full-scale…

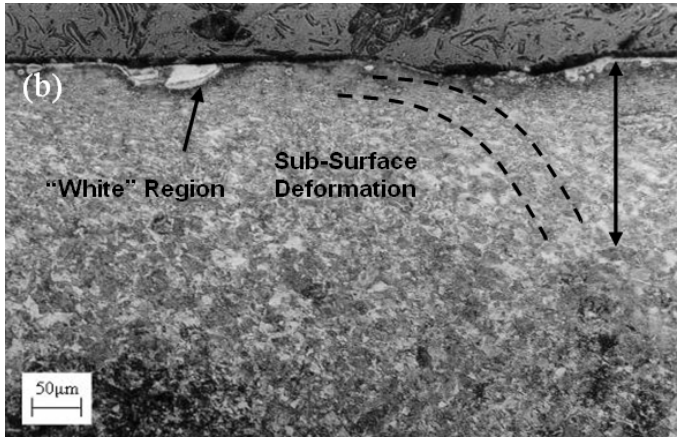


Wheel Twin Disc

Wheel Tread



Wheel Flange



Lewis et al., *Journal of Rail and Rapid Transit*, *Proc. of the IMechE Part F.*, 224 (2010), 125-137.

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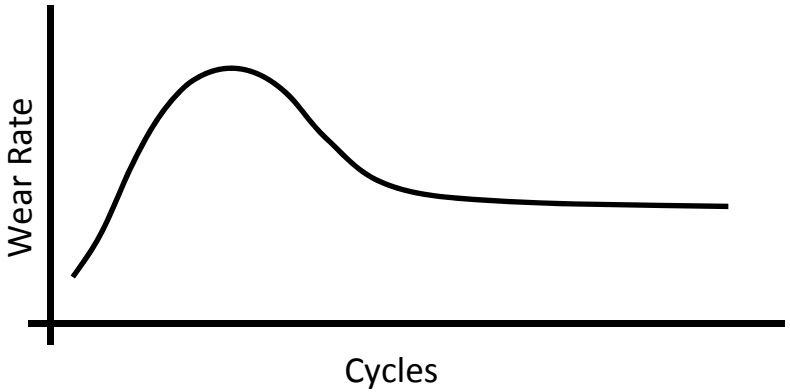
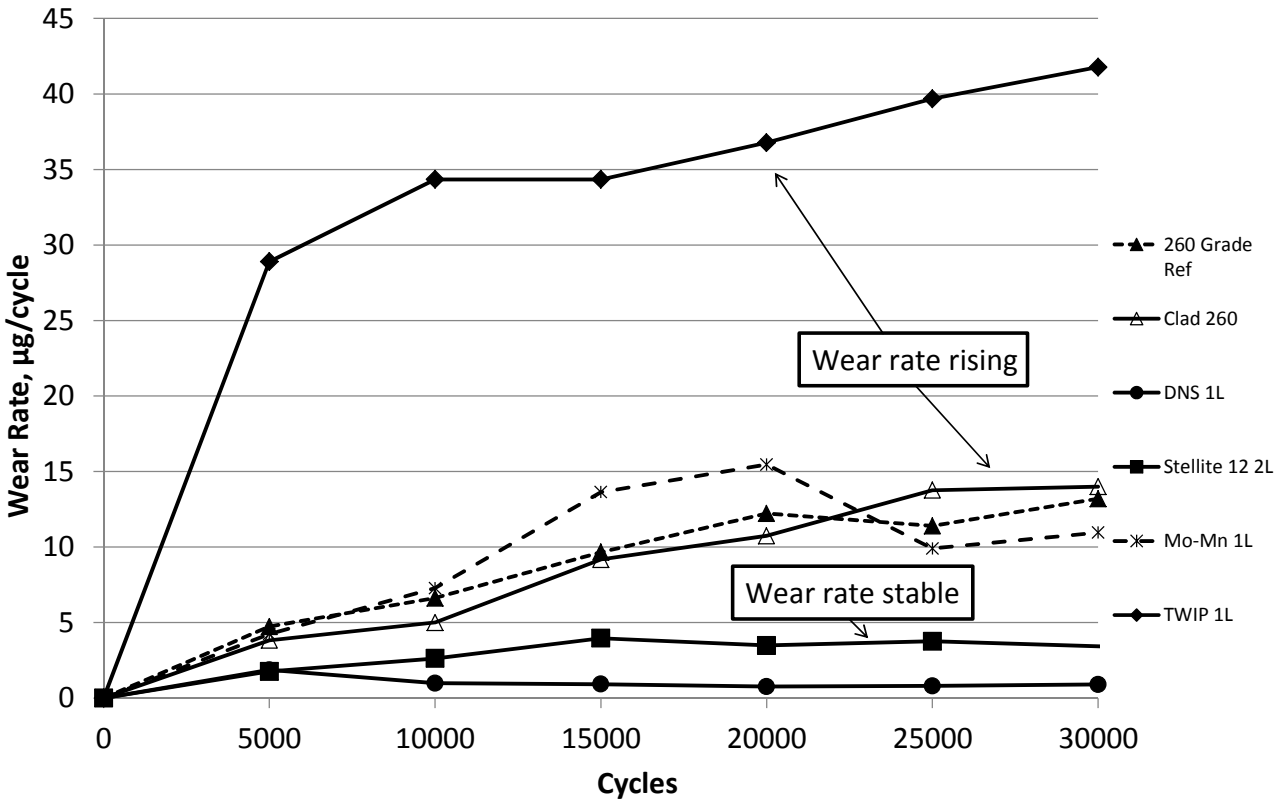
Test Length

- Test length needs to be long enough to reach steady state wear conditions – work hardening





Lewis et al., *Wear*, 366-367 (2016), 268-278

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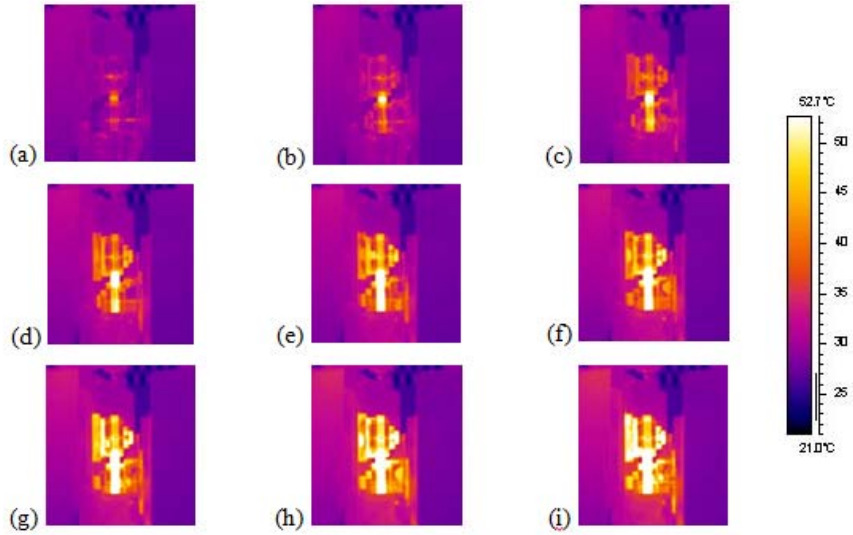
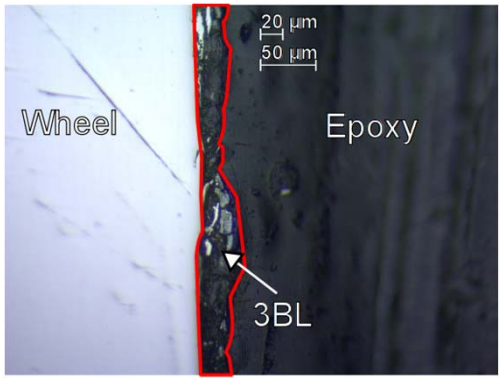
Temperature

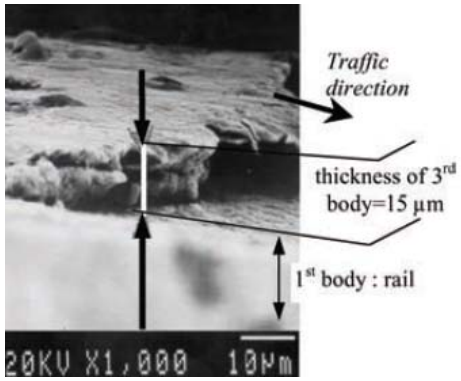
Gallardo-Hernandez et al., *Tribology International*, 39 (2006), 1653-1663.

- Temperature in small scale specimen high due to repeated cycles
- Third-body layer thicker as a result
- Options for dealing with this: *air cooling; oxide removal*

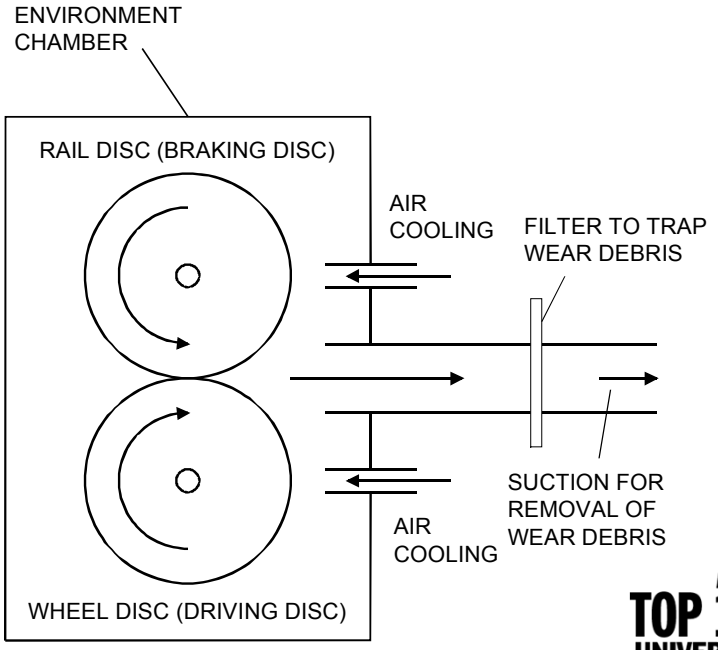




Twin disc 3BL



Actual rail 3BL



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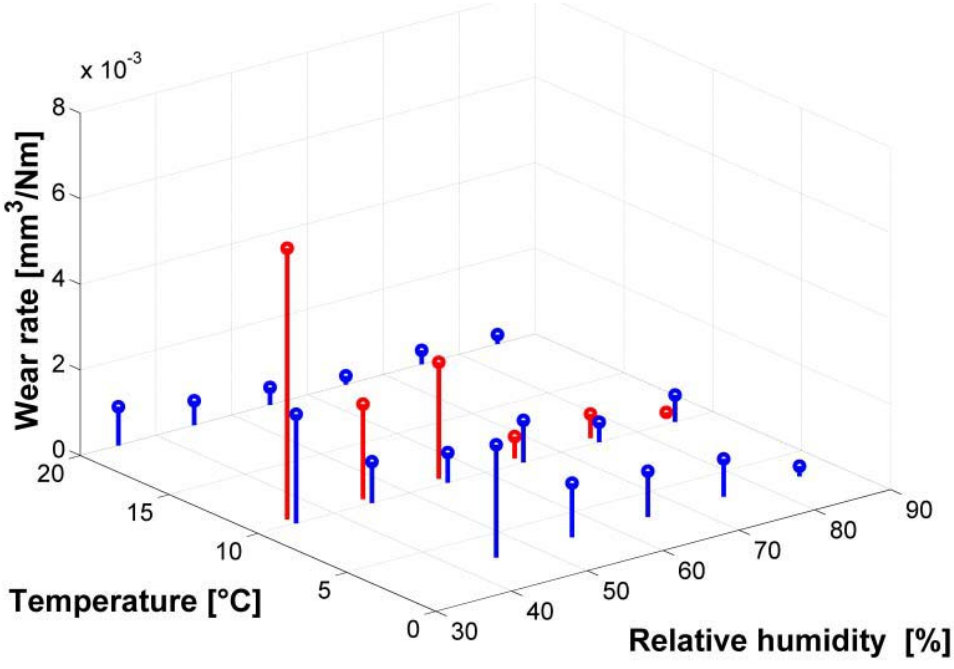
Environmental Conditions

- Tests generally run “dry”
- In the real world humidity and temperature vary, precipitation occurs…
- Some data for vary environmental temperatures, but rigs capable of such control are rare

Zhu et al., Proceedings of Railways 2014.



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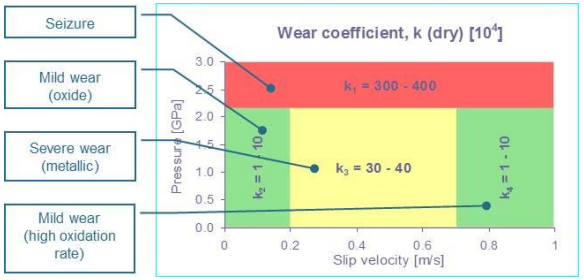
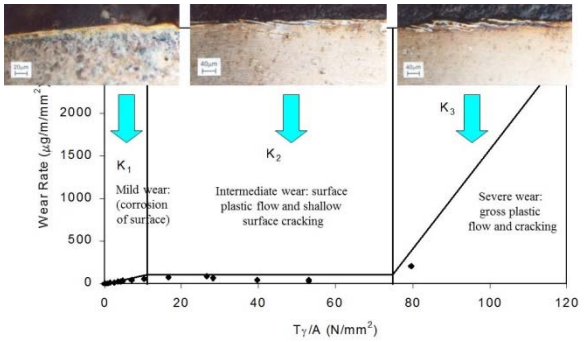
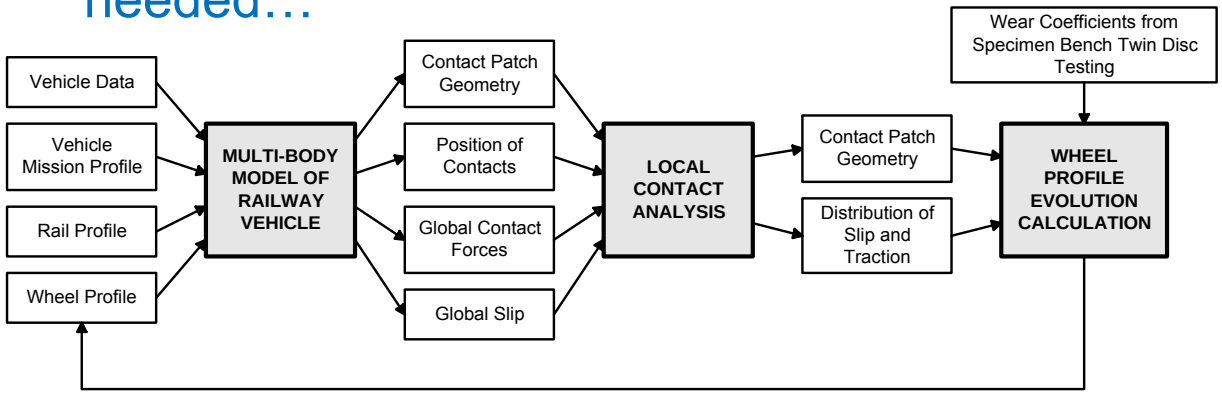
Applying Output from Small-Scale Tests: Wear Modelling

- Global wheel/rail conditions from MBD simulations
- Local contact analysis
- Two approaches: Archard and $T\gamma$ – wear coefficients for a range of conditions
- Validated – comparison with full-scale data (dry)
- Third-body layers – more wear coefficients needed…







See e.g., Braghin et al., Wear, 261 (2008), 1253-1264.

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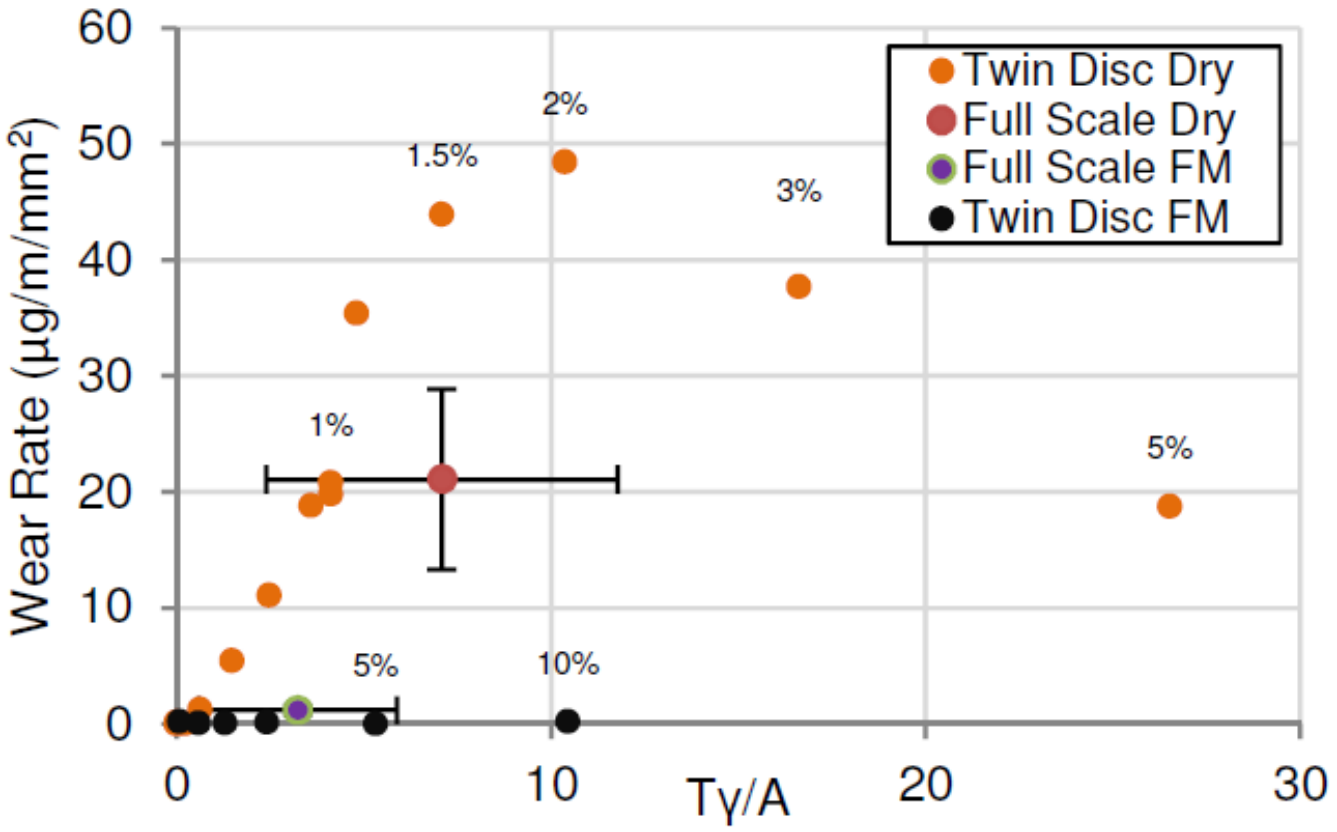
Comparing Full and Small Scale Tests



Buckley-Johnstone et al., *Proceedings of Railways 2016*

- Twin disc and full-scale tests (on VoestAlpine rig) in dry conditions and with water based Friction Modifier

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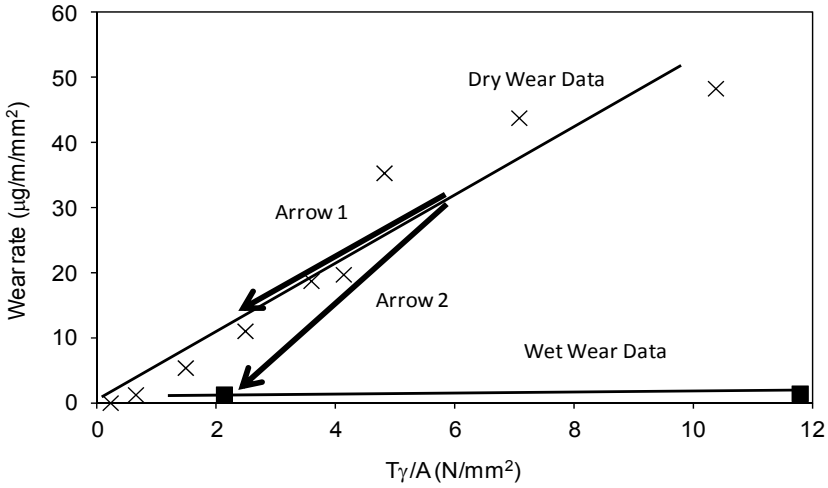
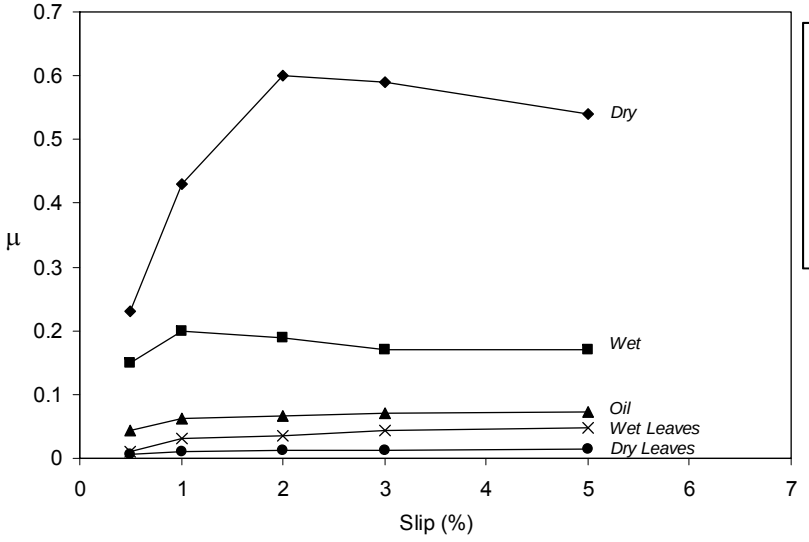
Third-Body Materials – Incorporation into Models

- Typically third body materials incorporated by changing μ
- Friction results from contact conditions!
- This can mean errors in force predictions
- Problems with wear predictions
- More creep force data needed for 3BLs



Rovira et al., *Wear*, 274-275 (2012), 109-126.



Gallardo-Hernandez et al., *Wear*, 265 (2008)1309-1316.

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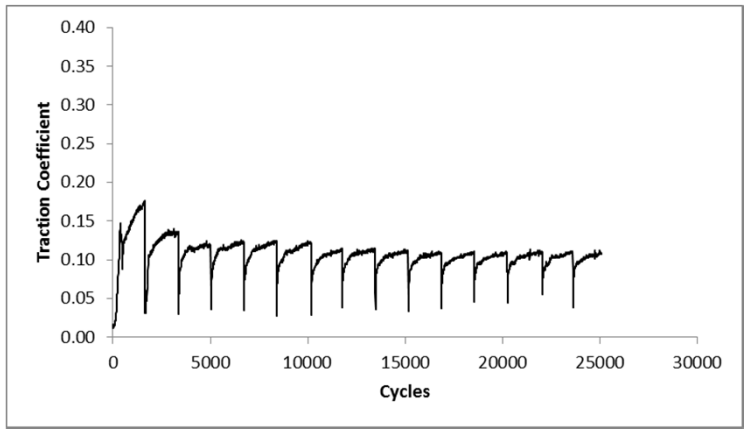
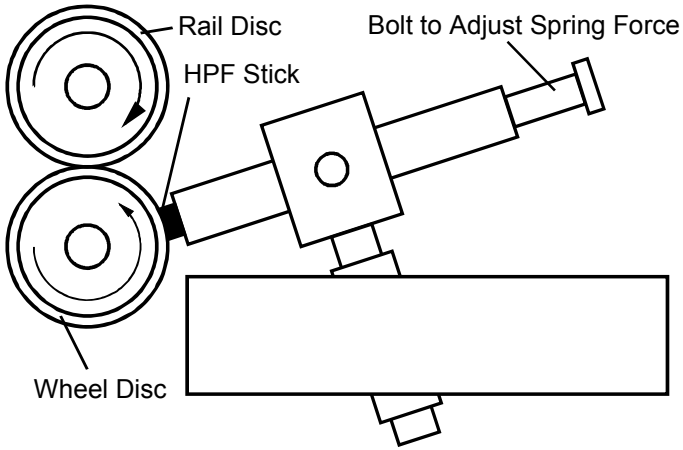
Third-Body Materials – Application

- Correct application critical for representative tests
- Can be difficult – scaled contact – scaled application?
- Constant cycling also makes it problematic





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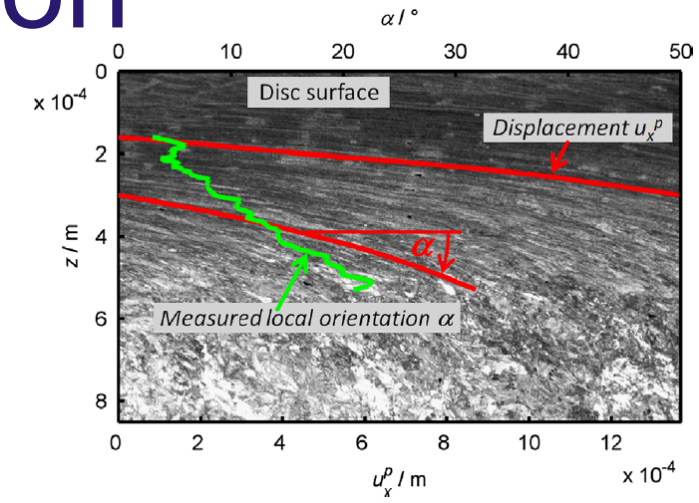
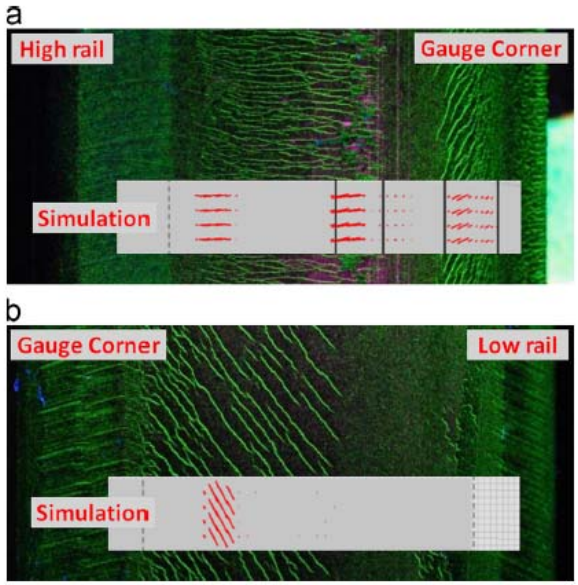
Applying Output from Small-Scale Tests: Crack Initiation

- Physically based, ratcheting model, which can be applied to general three-dimensional problems.
- Provides plastic shear strain data, which aid in predicting rolling contact fatigue crack initiation.
- Takes advantage of creep information from elastic contact calculations in determining the ratcheting strains in longitudinal and lateral directions of the rail
- The model has been applied to results of multi-body system simulations





Trummer et al., *Wear*, 314 (2014), 28–35

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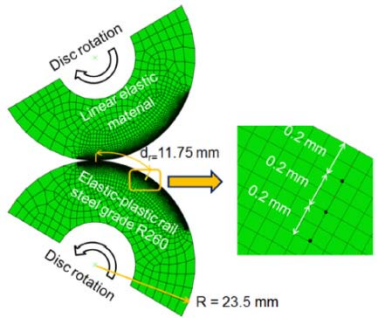
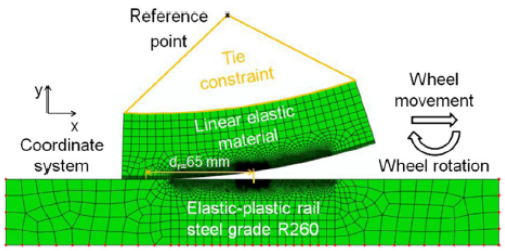
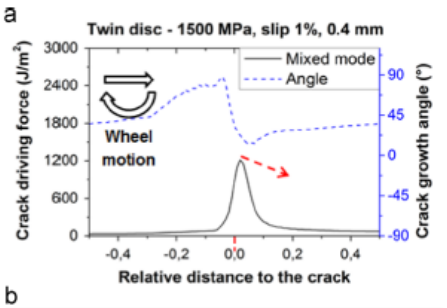
Applying Output from Small-Scale Tests: Crack Predictions

Kráčalík et al., *Wear* (2016), 346-347,140–147

- The contact patch size is approximately 30 times bigger in the wheel/rail experiment than in a usual twin-disc test.
- Subsequently the calculated plastically deformed depth is approximately 30 times deeper in the wheel/rail model than in the twin-disc model.
- Cracks lengths must be scaled by this factor to produce identical results.
- The scaling requires very short crack lengths in the discs.
- Such short cracks will be influenced by the surface roughness or are easily worn away.
- New test approach needed – using actual component geometry







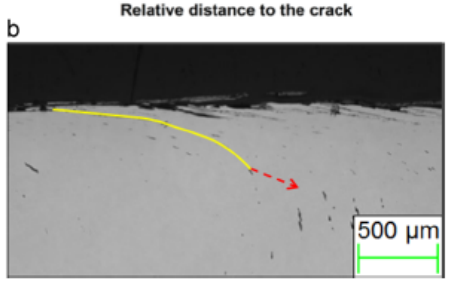


Fig. 12. The computed crack growth angle for the twin-disc FE model for a crack length of 0.4 mm (a) and the highlighted deformation lines after 25.000 loading cycles in the twin-disc test with indicated calculated crack growth direction by an arrow (b). The computed crack growth angle in the depth of 0.4 mm is very similar to the possible crack growth angle that follows the deformation lines in the shear dominated zone obtained in the twin-disc test at the same depth.

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Summary and Future Directions

- Improved test methods can increase relevance of small-scale tests
- Many approaches to testing and modelling – more consistency needed…
- Consideration of context of use important
- Maps of data covering wide range of conditions to cover entire contact patch and account for all causes of variation are needed
- Wear relatively advanced – need for more data on 3BLs
- Crack initiation more complicated, but useful results can be achieved – more data needed for different contact conditions and rail materials (and weld materials!; and clad layers…)
- Crack growth even more tricky – not possible to scale from twin disc tests, a test using actual component geometry is required – such tests exist – need to have more widespread use