Challenges of Wheel/Rail Interface to combat Leaf Contamination

A Collaborative Project between East Japan Railway Company and the University of Sheffield

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• East Japan Railway Company (JRE) operates bullet trains (Shinkan-sen) and local trains
• 54,880 employees, 69 lines with 7,457 km in total
• Worked as a maintenance engineer (1 year), train conductor (2 years) and train driver (2 years)
• Joined the University of Sheffield as a Ph.D. student (3 years)
Motive and Opportunity

- Many colleagues suffered wheel-slip due to low adhesion
- Oil in fallen leaves was believed to be the main cause
- But low friction problem did not happen without water

Nikko Line

Nikko

Japanese cedar

Kanuma

Continuous steep slope

https://pixabay.com, Shirley Hirst, Steve Buissinne
Motive and Opportunity

- Many UK universities have been conducting railway research
- Leaf contamination is a big problem in Euro, especially in the UK
- Professor Lewis is a leading researcher in the wheel/rail tribology at the University of Sheffield
- He published several articles about leaf contamination
Motive and Opportunity

• Opportunities to study abroad with funding
• Many students in the USA but fewer students in Euro
• Making connections in European railway industries
• Chose the University of Sheffield
Leaf contamination problem in the UK

- Black, hard and slippery leaf film
- Low friction ($\mu < 0.1$, min 0.02)
- Strong bonds between the leaf and rail
- Current measures (ex. sanding) are not perfect

Over £100 million annual loss in the UK

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Leaf film problems

- Fallen leaves
- Wheel passes

https://pixabay.com, Michael Gaida, Robert-Owen-Wahl

Research background

Low friction mechanism
How is the low friction condition caused?

Bonding mechanism
Which leaf constituent causes a strong bond?

- Pectin?
- Tannin?
- Lignin?
- Or other organics?
Research highlight: Black material synthesis

Leaf extract making
1 g : 50 ml = Leaf : Water

Leaf extract + Rail plate = Black precipitation (BP)

Black material was synthesised with leaf-extract and rail steel
Research highlight: Low friction

Black precipitation from brown leaves showed extremely low friction. What’s inside the BP?

5 mm stainless steel ball
Black precipitate (BP) with water
Rail plate

5 mm stainless steel ball

Black precipitate from brown leaves showed extremely low friction

What’s inside the BP?
Research highlight: Iron detection

**X-Ray Fluorescence**

- Characteristic X-ray
- Sample

- Most metals are detectable
- Light elements are not detectable

**ICP-MS**

- Metals in liquid are detectable

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<thead>
<tr>
<th>Element</th>
<th>Before [μg/L]</th>
<th>After [μg/L]</th>
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<tr>
<td>B</td>
<td>553</td>
<td>589</td>
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Iron dissolves into leaf extracts and forms the black precipitation.
Research highlight: Graphite-like carbon

Graphite-like carbon on black precipitation surface

Graphite is solid lubricant due to low shear strength

Low friction

Raman Spectroscopy

Incident laser

Energy $E_0$

$> E_0$: Raman shift

$= E_0$

$< E_0$: Raman shift

BP from green leaves

BP from brown leaves

$I_D/I_G=0.77$

$I_D/I_G=0.83$

Graphite-like carbon

Intensity

Raman shift [cm$^{-1}$]
Research highlight: Structure

FT-IR analysis

BP from green leaves
BP from brown leaves
Green leaves
Brown leaves

Iron-ligand is likely to be formed

ex. $\text{Fe}_2(\text{C}_2\text{O}_4)_3$

Iron-ligand is likely to be formed
Research highlight: Chemical reaction

1. Fe ion dissolution
   Leaf extract
   Rail
   Fe²⁺ or Fe³⁺

2. Reaction with organic acids
   Carbon
   Oxygen

3. Iron-ligand formation
   Iron-ligand (carboxylate)

4. Further reaction

5. Graphite-like carbon

6. Further reaction
   Various ions

Next question
Chemical reaction can be stopped at stage 2?
Other findings

• Extremely low friction was confirmed with the fine leaf powder (<160 μm) in rolling-sliding conditions using a twin disc machine
• Surface temperature was found to have a significant impact on the improvement of friction; possibly 240 °C could be enough to achieve the necessary friction coefficient for traction

Publication arising from this project

• Another article is now being peer-reviewed
Key aspects of the project

True challenge was to break down the walls between departments
Key aspects of the project

How can we break down the wall or fill the gap?

- Have your own idea based on your experience
- Expand your world with curiosity, explore other academic fields
- Share your ideas and expertise with others
- Get experts involved in your project
- Never forget your colleagues – they might suffer the problem right now
Summary

• The collaboration between East Japan Railway Company and the University of Sheffield was carried out as a Ph.D. research project

• Graphite-like carbon was found in black material synthesised with leaf extracts and rail steels

• Graphite-like carbon could be the main cause of low friction rather than oil in leaves

• A new method for the prevention of leaf contamination is now being tested, combining the research outcome with empirical knowledge