Investigating the effect of mixing conductive and non-conductive particulate friction modifiers at wheel-rail interface on rail isolation

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UKRRIN 2025 Student Conference, The University of Sheffield, United Kingdom

7th – 8th Jan 2025

Motivation and Significance

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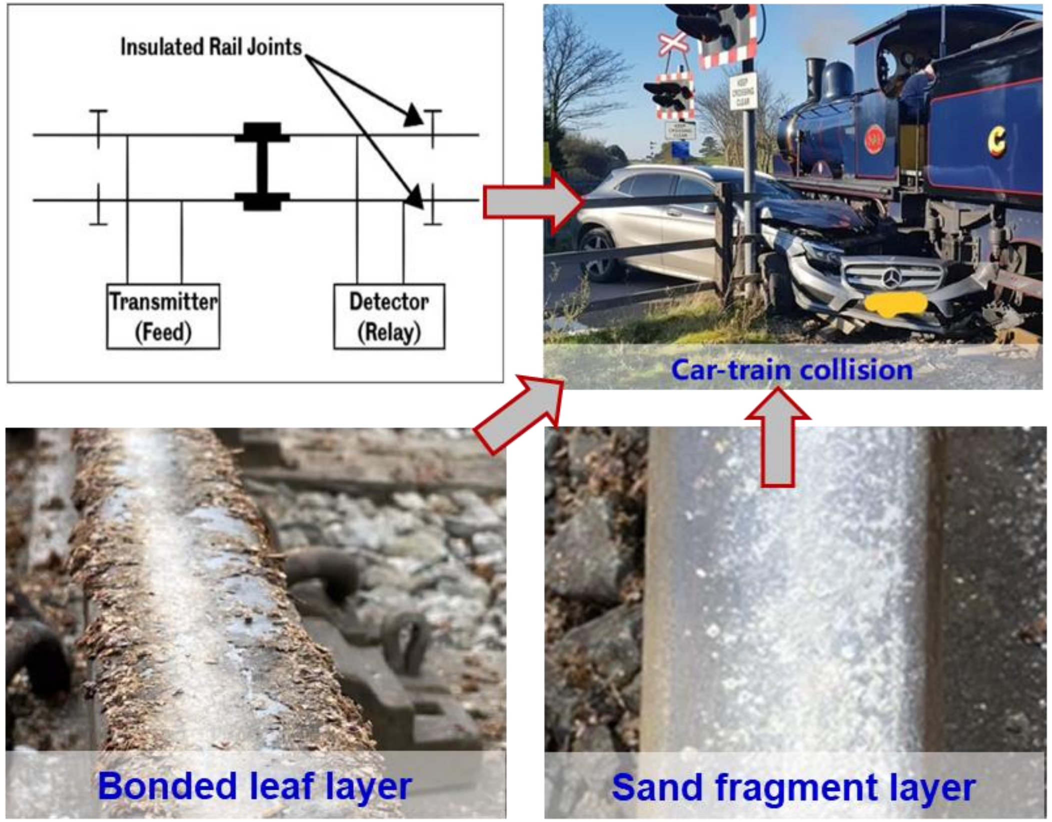
Rail isolation has always been challenges for the railway industry

Rail isolation

Track circuit



RSSB report (7.5g/m sand usage rates):

- 97% contaminated layer
- 3% rail sanding

More sand ⇨ Higher risk of rail isolation

[1]Rail Accident Investigation Branch, Autumn adhesion investigation Part 3: Review of adhesion-related incidents Autumn 2005, RAIB Report (2007).

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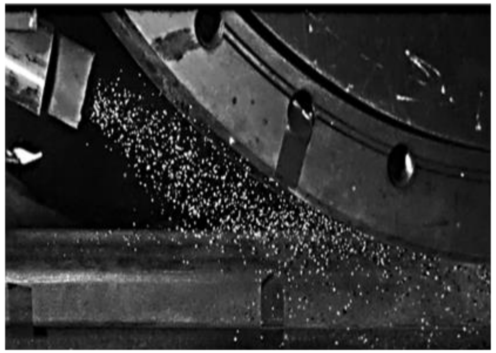
Motivation and Significance

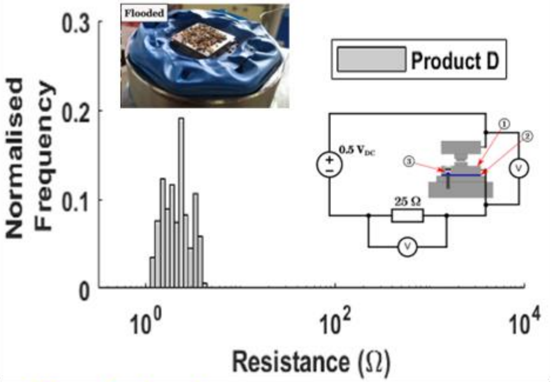
Sanding has been used in early days of rail industry

Literature review

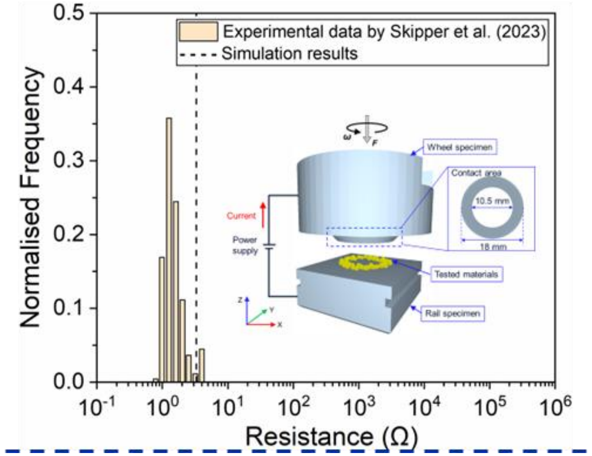
Sanding



HPT test



Numerical simulation



Track test

Conductive particulate friction modifiers effectively increase the conductivity at wheel-rail interface

Cost analysis

⇩

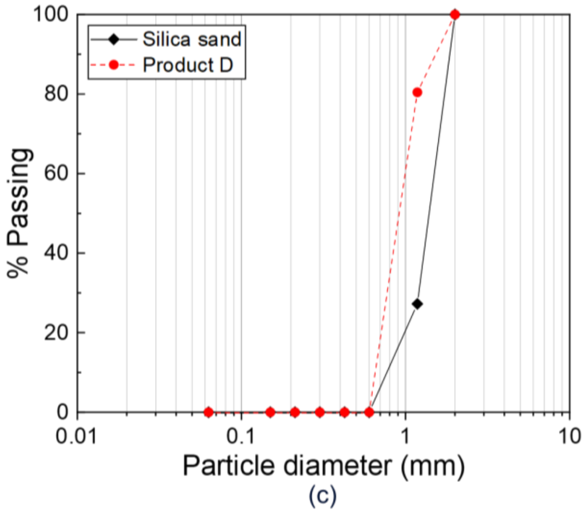
Mixture

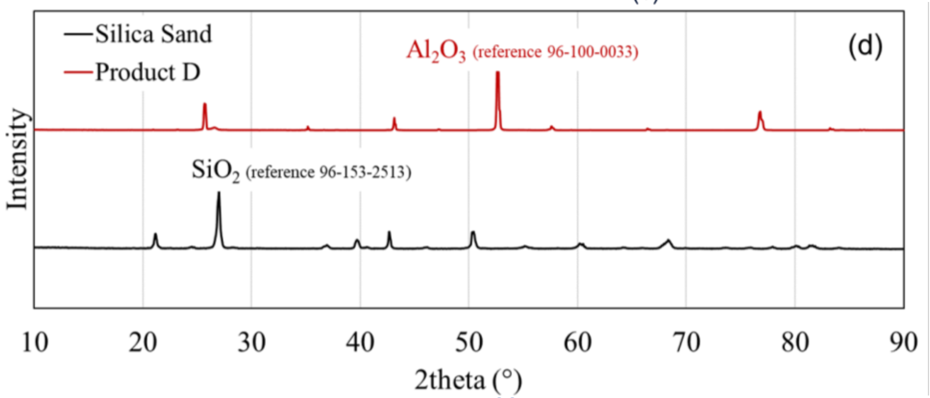
[1] Skipper, W., Nadimi, S., Lewis, R. et al., 2023. Investigating the effect of different adhesion materials on electrical resistance using a high pressure torsion rig. Wear, 532, p.205116
[2] Zhang, C., Maramizonouz, S., Milledge, D. and Nadimi, S., 2024. An electro-mechanical contact model for particulate systems. Powder Technology, 440, p.119759.

Experimental Investigation

1-D compression test for mixture of conductive and non-conductive sands

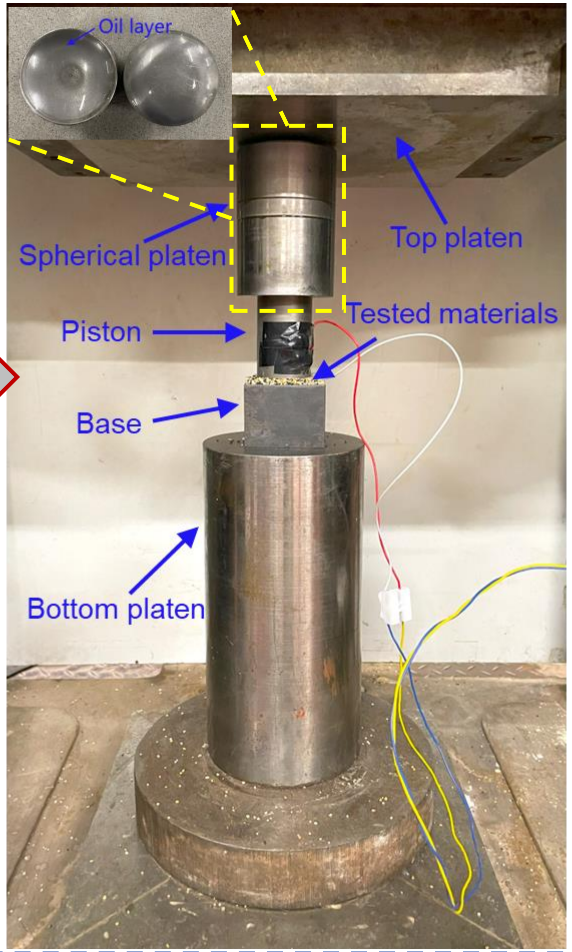
Material properties

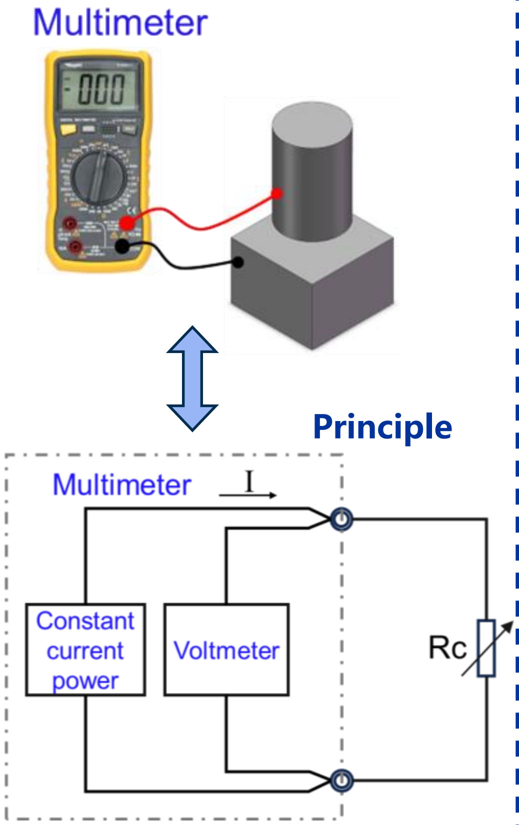




Powder X-ray Diffraction (XRD)

Experimental set-up





Experimental Investigation

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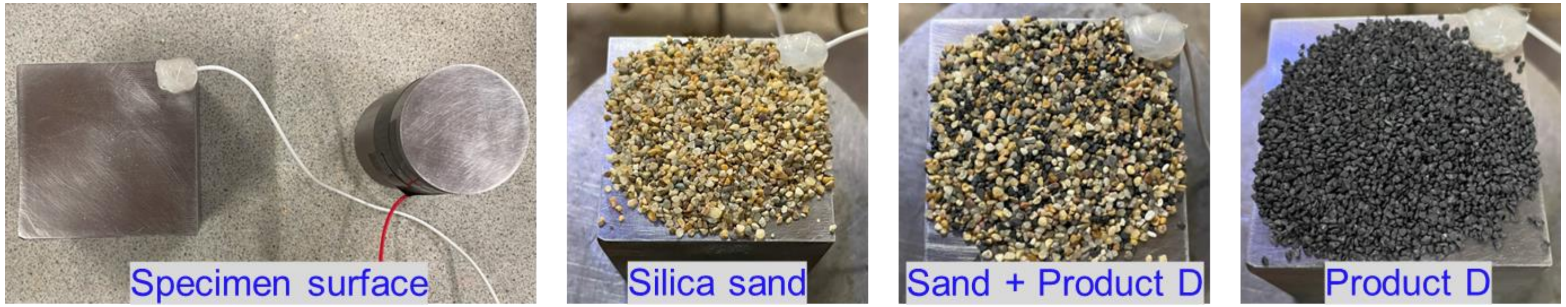
1-D compression test for mixture of conductive and non-conductive sands

❑ Experimental scenarios

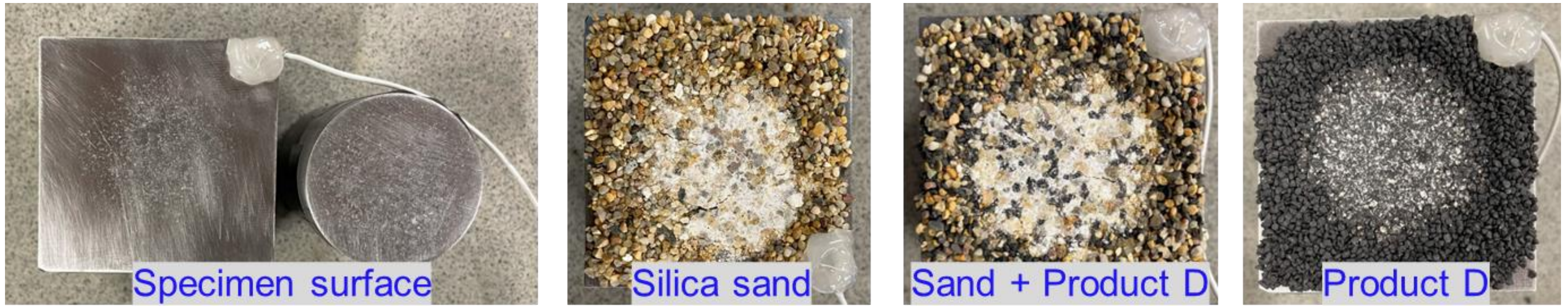
Test No.	Silica sand (g)	Product D (g)
1	10	0
2	9.5	0.5
3	9	1
4	8	2
5	7	3
6	5	5
7	0	10

- ❑ **Mechanical load increases to 577 kN**
- ❑ **Contact pressure keeps 600 MPa**
- ❑ **Record the resistance values during loading**
- ❑ **Collect fragment layers after testing**

Before test

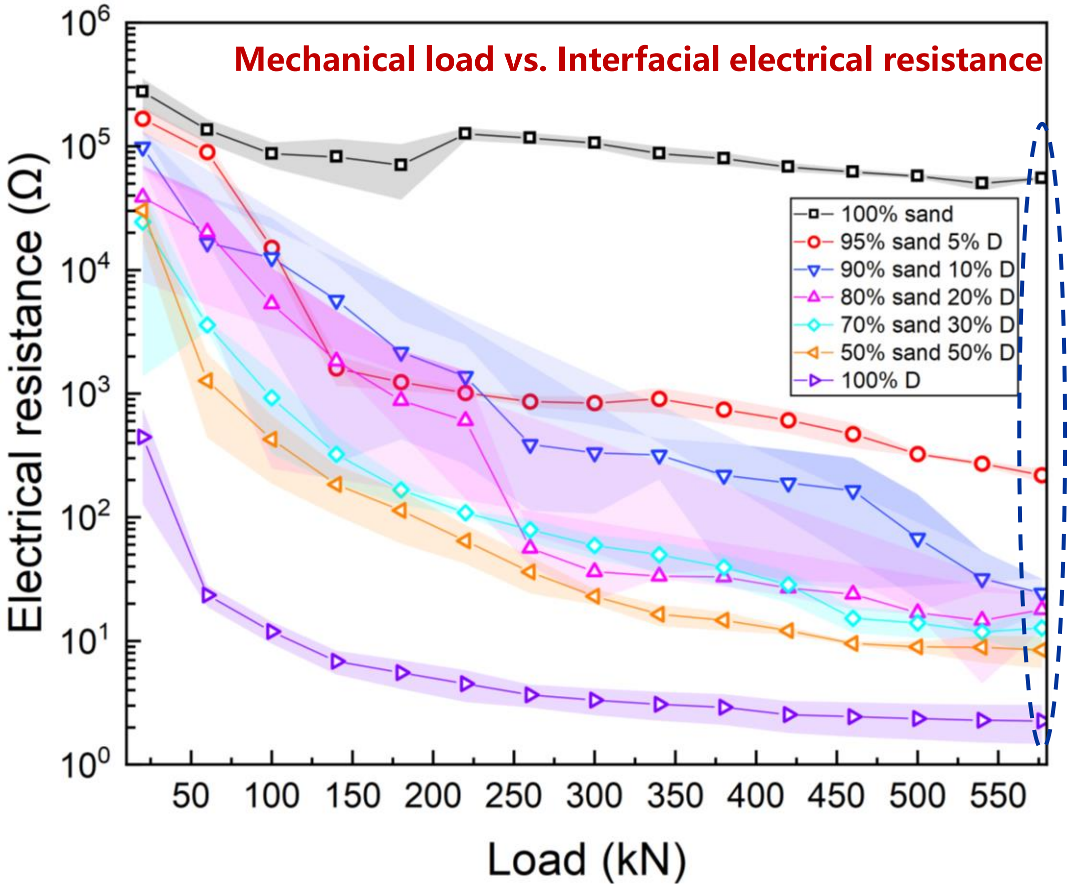


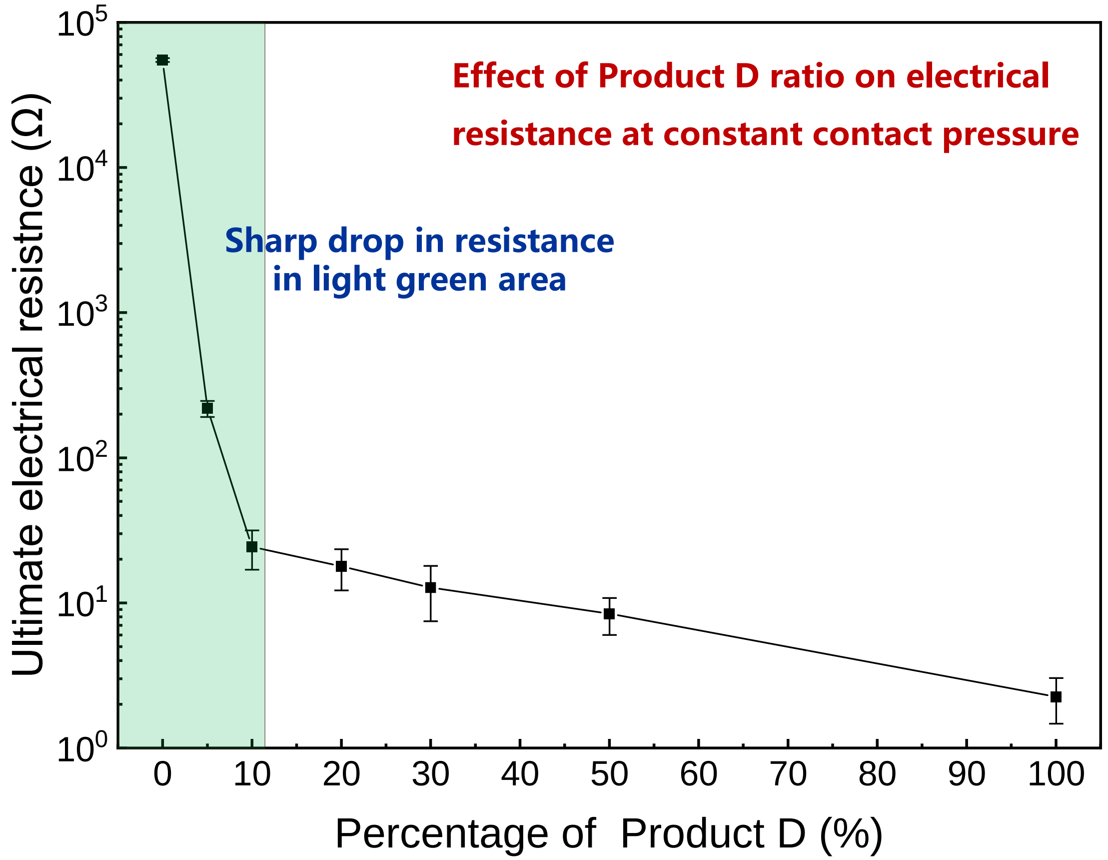
After test



Experimental Investigation

1-D compression test for mixture of conductive and non-conductive sands





- ❑ Silica sand particles impede the flow of current
- ❑ When the mixing ratio of alumina particles reaches 5%, the electrical resistance drops dramatically from 55 kΩ to 220 Ω

Experimental Investigation

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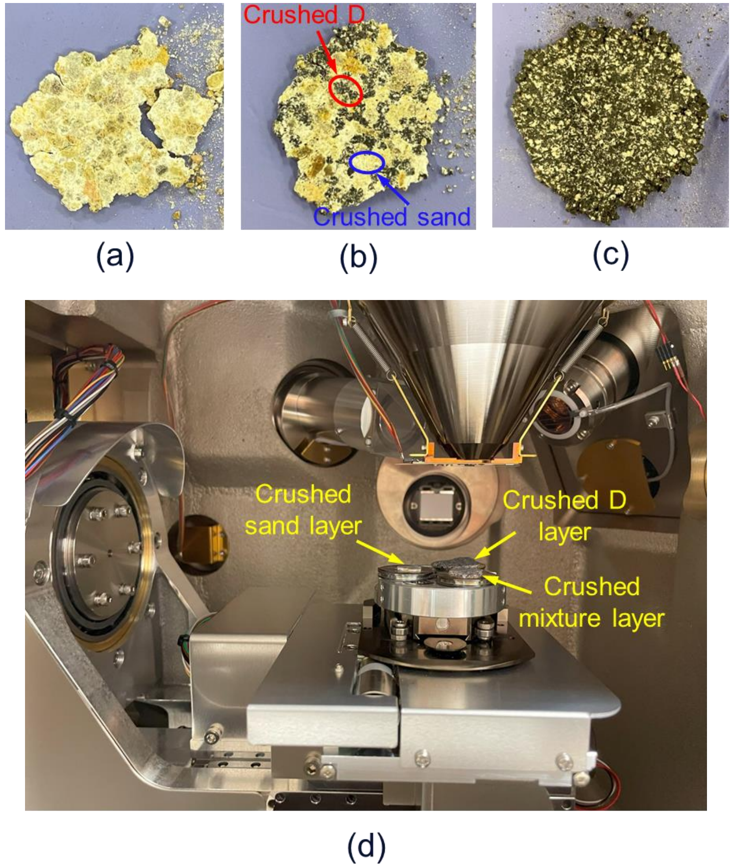
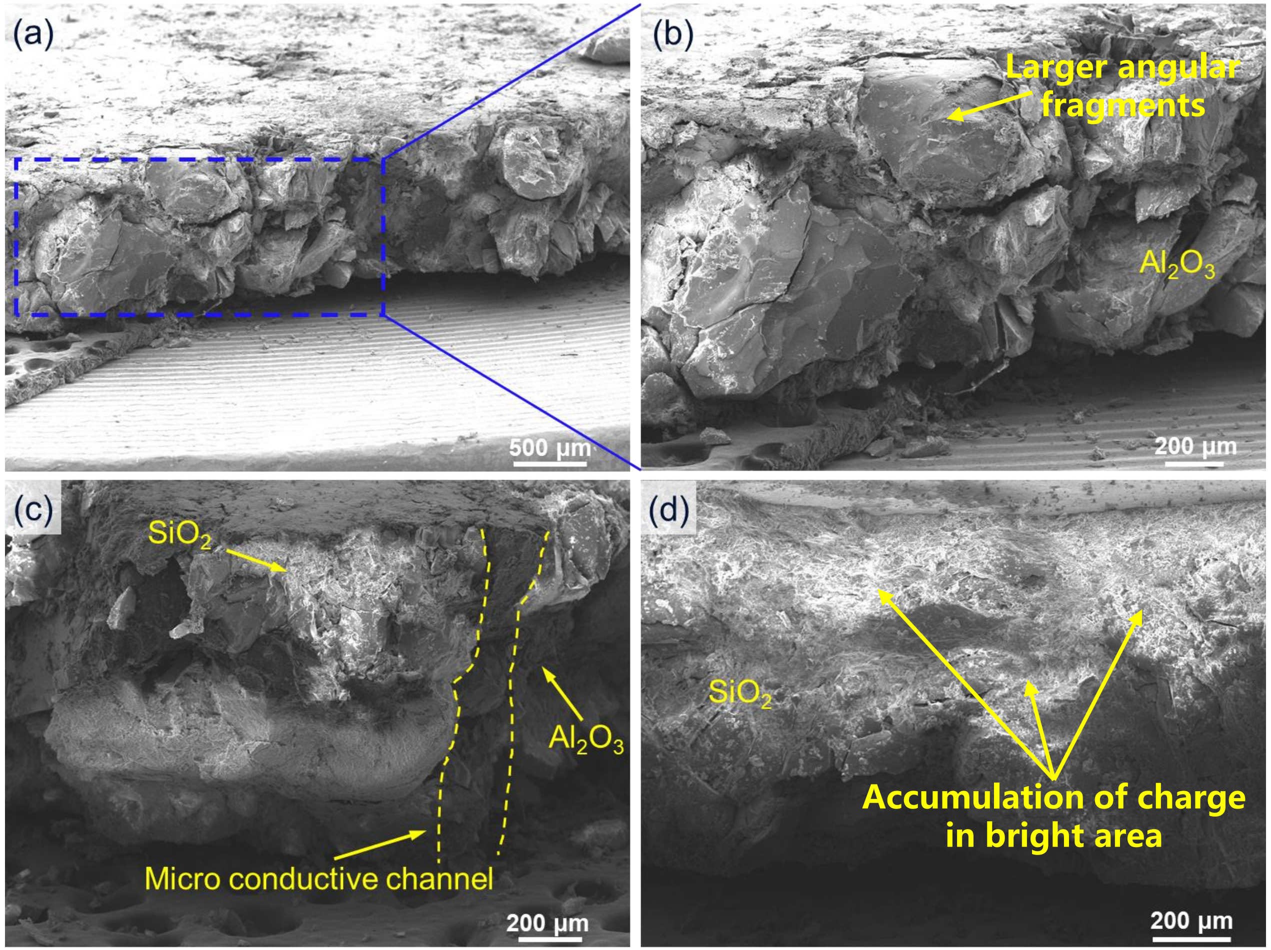
1-D compression test for mixture of conductive and non-conductive sands

❑ Microstructure of the fragment layer

Sample collect and SEM



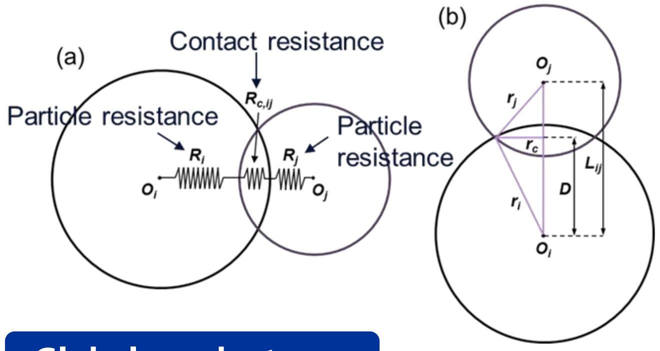
Fragment layers



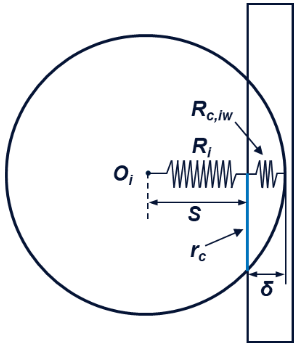
Numerical Investigation

Electro-mechanical contact model

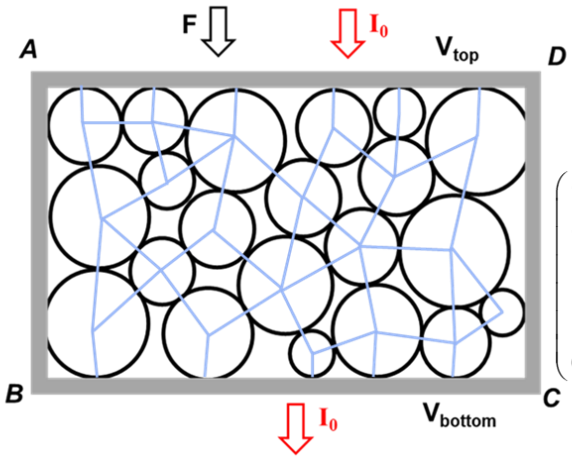
Particle-to-particle



Particle-to-wall



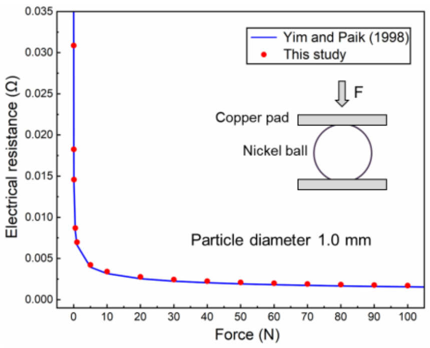
Global conductance

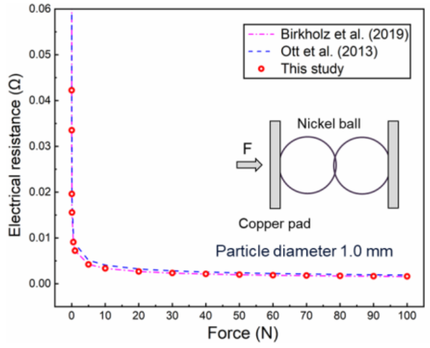


Mathematical model

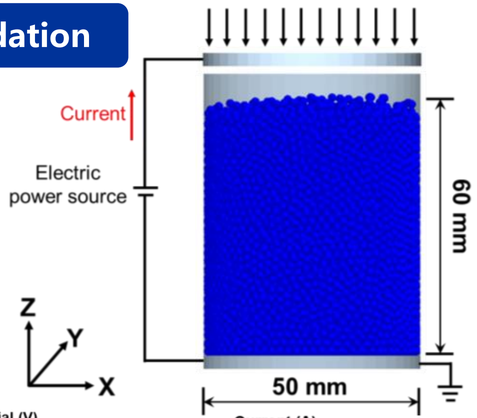
$$\begin{pmatrix} G_{00} & G_{10} & G_{i0} & \cdots & G_{n0}\\ G_{01} & G_{11} & G_{i1} & \cdots & G_{n1}\\ G_{0i} & G_{1i} & G_{ii} & \cdots & G_{ni}\\ \vdots & \vdots & \vdots & \ddots & \vdots\\ G_{0n} & G_{1n} & G_{in} & \cdots & G_{nn}\end{pmatrix}\begin{pmatrix}V_{top}\\ V_{bottom}\\ V_i\\ \vdots\\ V_n\end{pmatrix}=\begin{pmatrix}-I_0\\ I_0\\ 0\\ \vdots\\ 0\end{pmatrix}$$

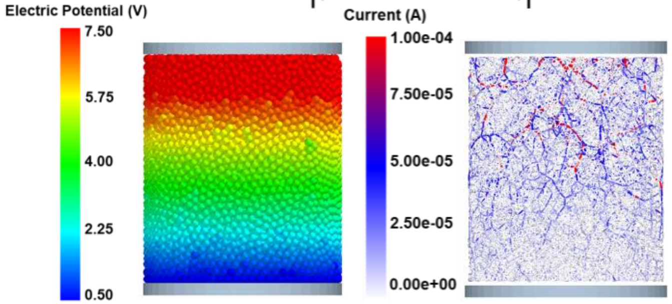
Verification

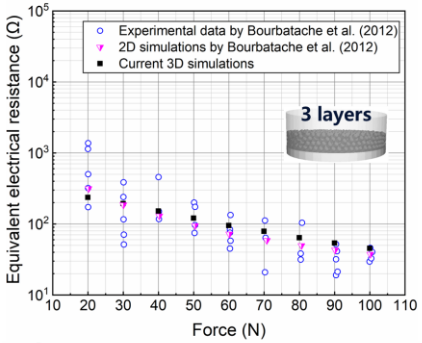


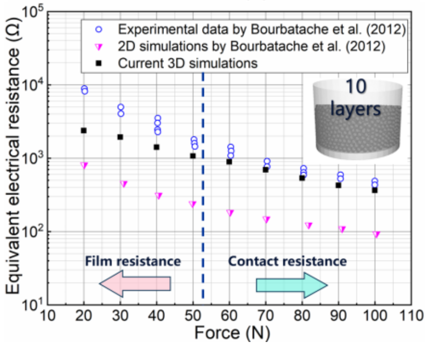


Validation







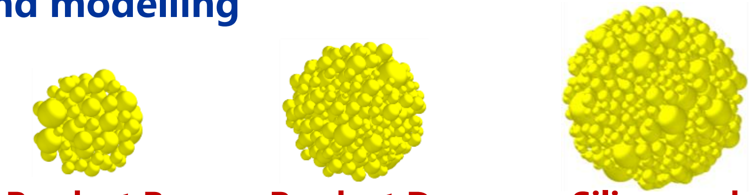


1. Zhang, C., Maramizonouz, S., Milledge, D. and Nadimi, S., 2024. An electro-mechanical contact model for particulate systems. Powder Technology, 440, p.119759.

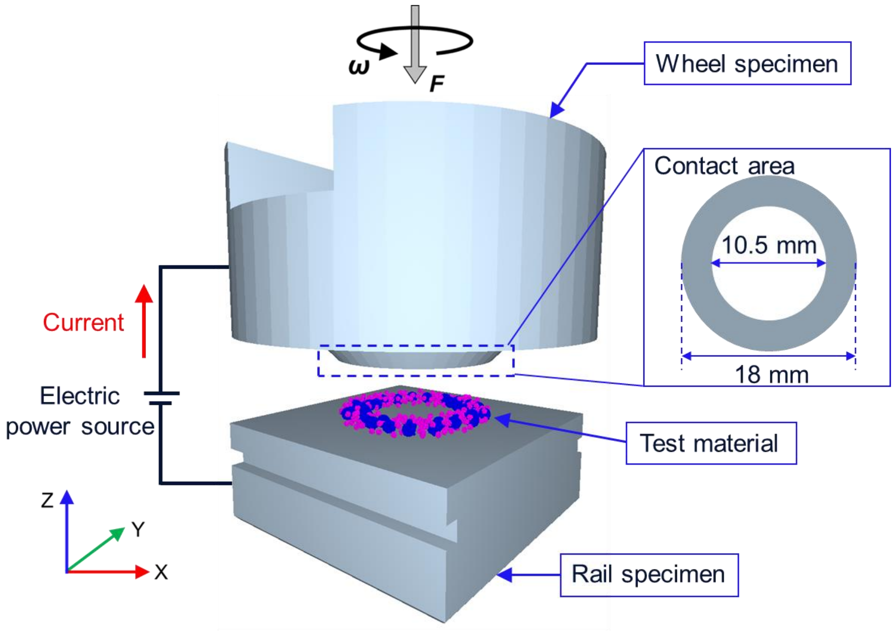
Numerical Investigation

HPT modelling for mixture of conductive and non-conductive sands

Sand modelling



Product B (d = 0.5 mm) | **Product D** (d = 0.9 mm) | **Silica sand** (d = 1.45mm)



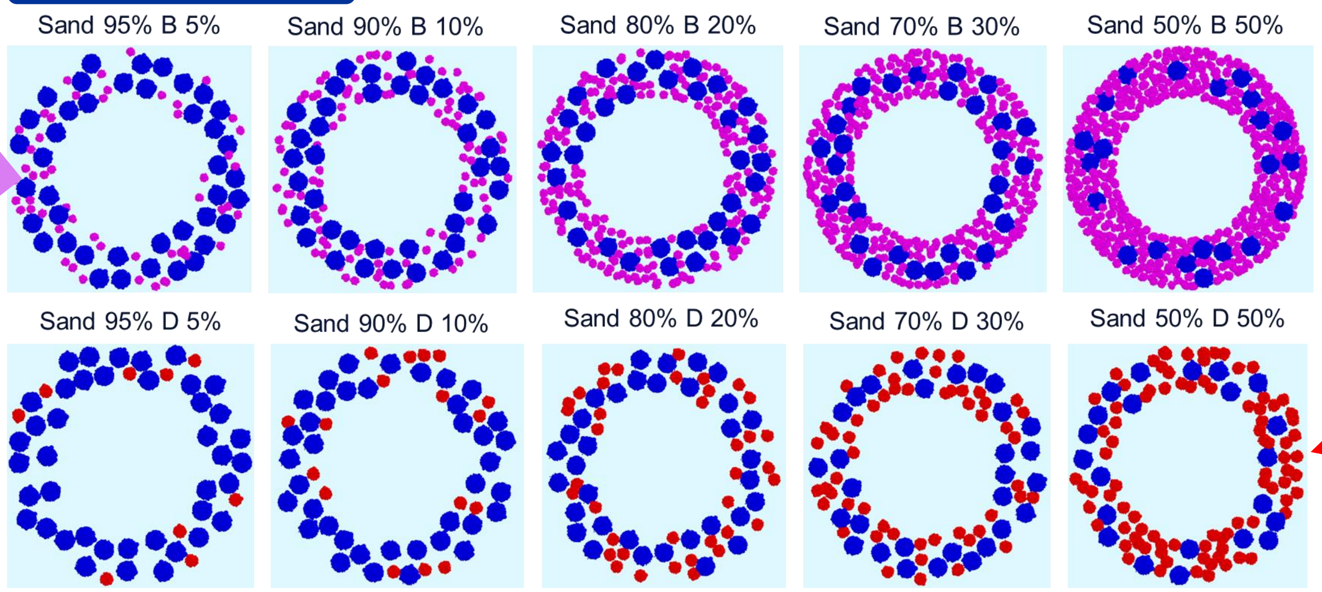
HPT modelling for mixture of Product B and Silica sand

Volume and mass ratio

Case No.	Sand	B	By Volume	By Mass
Case 1	41	52	Sand 95% B 5%	Sand 93% B 7%
Case 2	39	105	Sand 90% B 10%	Sand 86.3% B 13.7%
Case 3	34	210	Sand 80% B 20%	Sand 73.3% B 26.7%
Case 4	30	315	Sand 70% B 30%	Sand 61.8% B 38.2%
Case 5	22	524	Sand 50% B 50%	Sand 41.6% B 58.4%

Case No.	Sand	D	By Volume	By Mass
Case 1	41	9	Sand 95% D 5%	Sand 93.1% D 6.9%
Case 2	39	17	Sand 90% D 10%	Sand 87.1% D 12.9%
Case 3	34	38	Sand 80% D 20%	Sand 72.6% D 27.4%
Case 4	30	55	Sand 70% D 30%	Sand 61.7% D 38.3%
Case 5	22	88	Sand 50% D 50%	Sand 42.5% D 57.5%

Mixing scenarios



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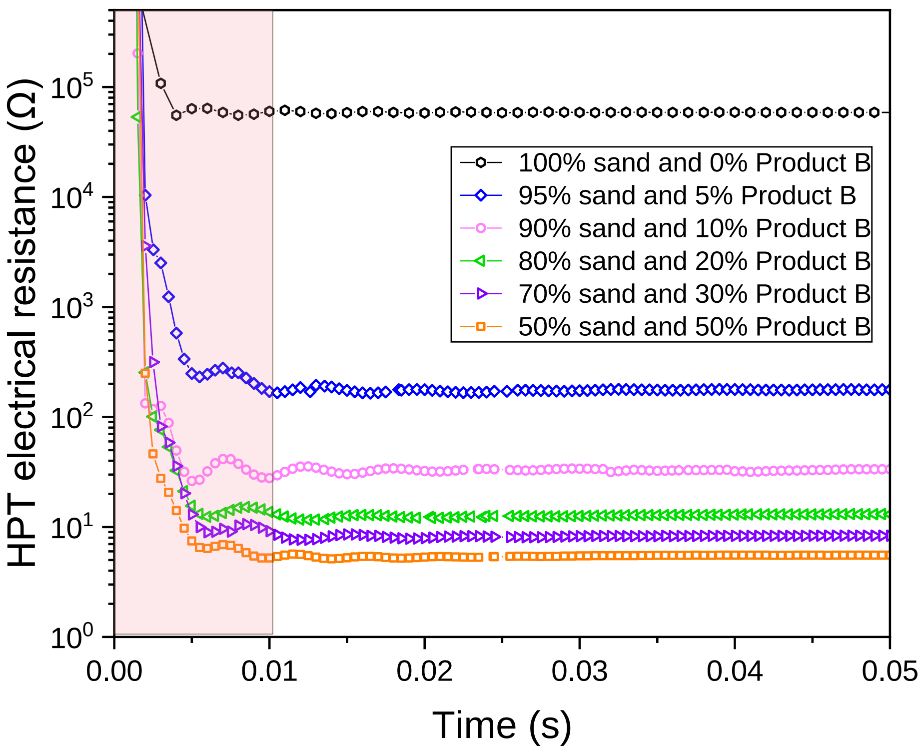
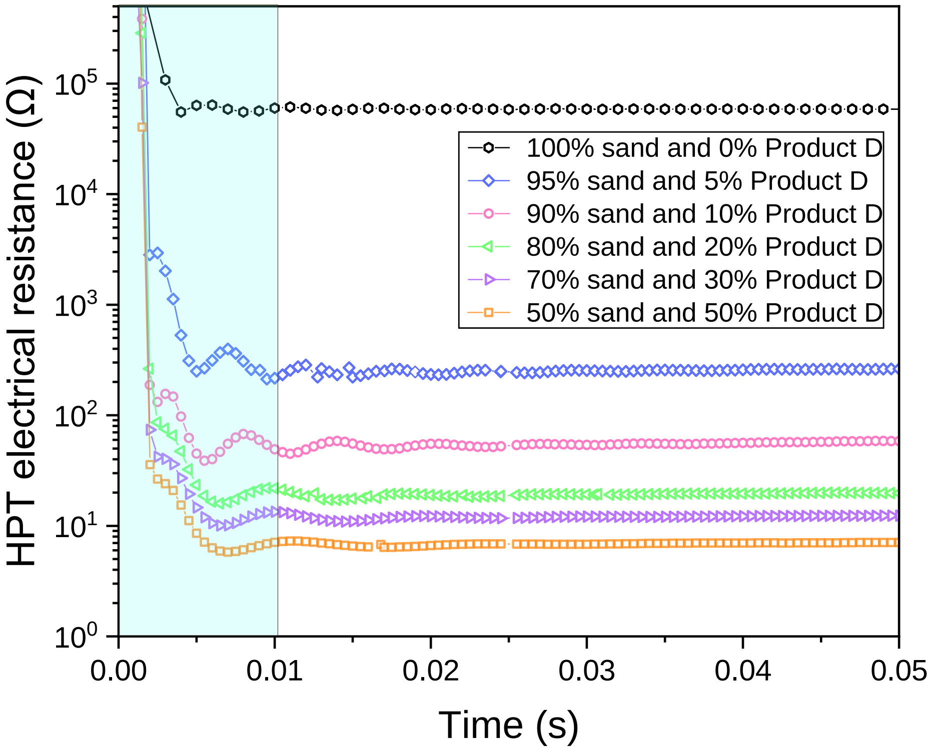
Numerical Investigation

HPT modelling for mixture of conductive and non-conductive sands

❑ HPT electrical resistance at constant contact pressure





Marked areas:
- ➢ **Particles are crushed and contact surfaces between fragments increase**
- ➢ **Fragments are mechanically rearranged to form conductive micro-channels**

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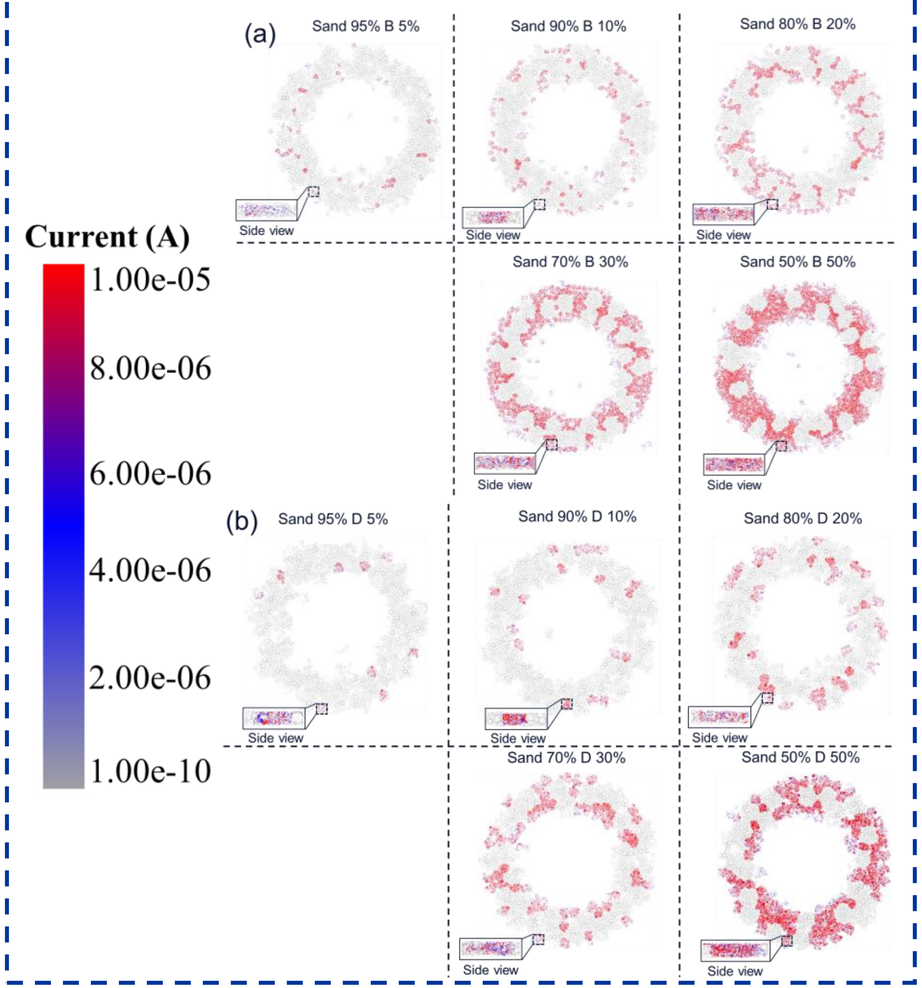
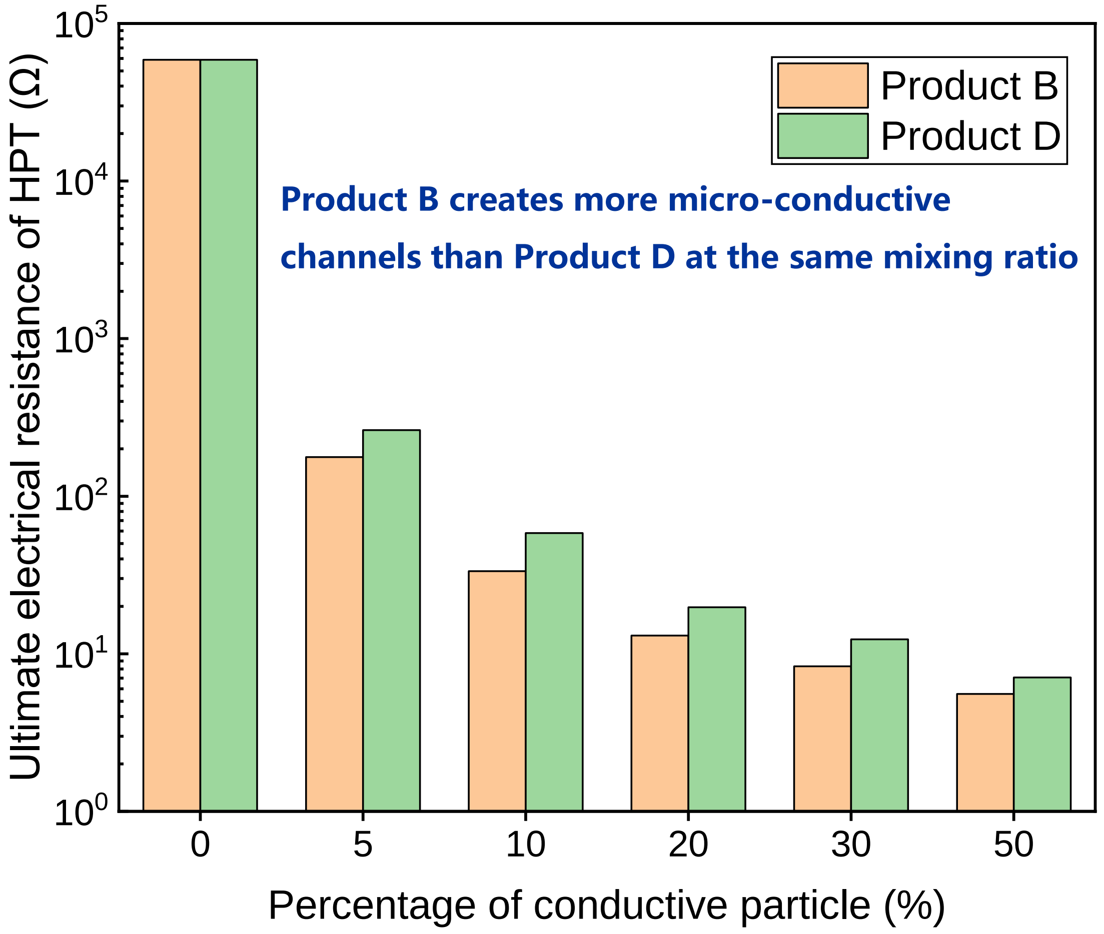
Numerical Investigation

HPT modelling for mixture of conductive and non-conductive sands

Current distribution in the fragment layer



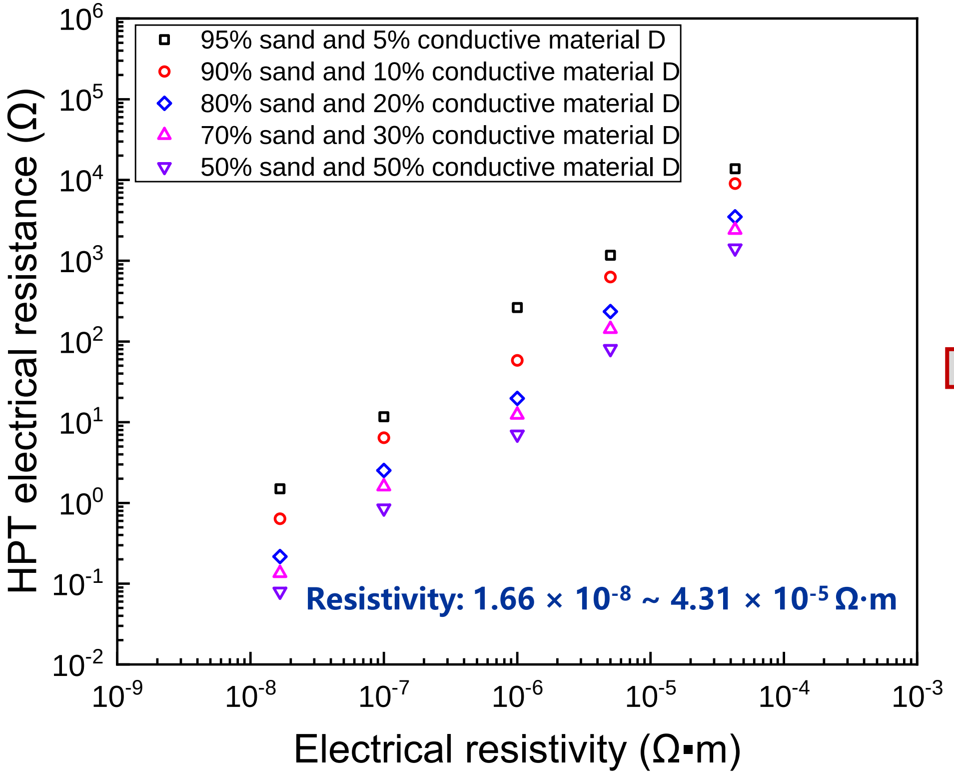


Product B creates more micro-conductive channels than Product D at the same mixing ratio

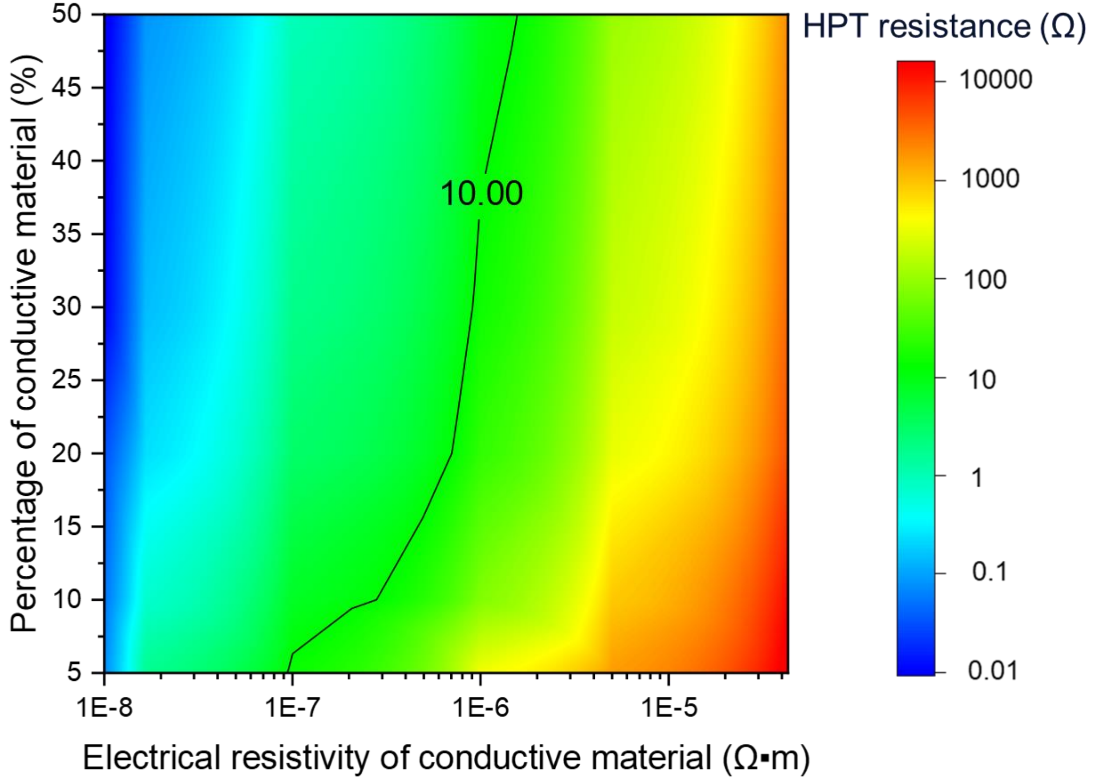
Numerical Investigation

HPT modelling for mixture of conductive and non-conductive sands

Electrical resistivity



Heatmap



- A heatmap is produced to estimate the percentage of conductive sand required
- Heatmap links the resistivity of various sands with their required percentage

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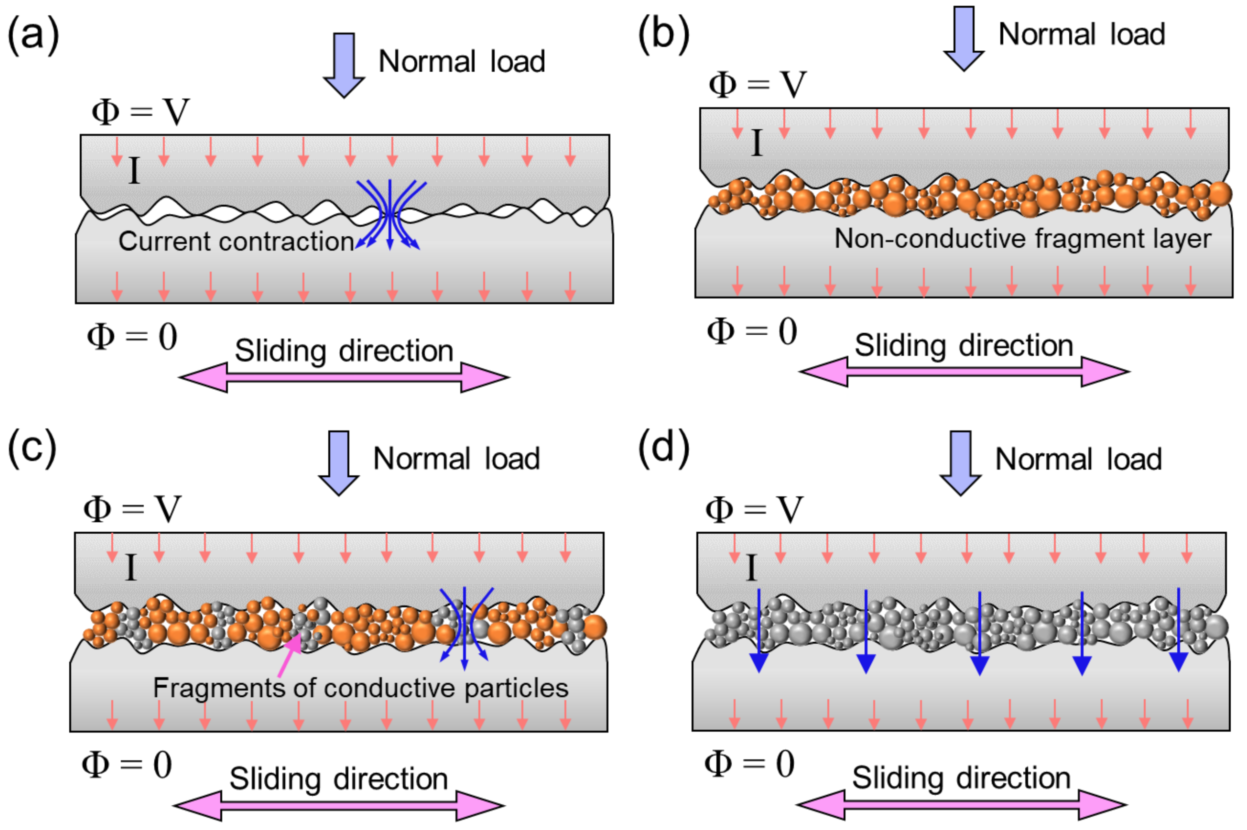
Current Transfer Mechanism

Effect of mixture of conductive and non-conductive sands on current at the interface

Four scenarios



1. Metal-to-metal contact without sand
2. 100% non-conductive particles
3. Mixing conductive with non-conductive particles
4. 100% conductive particles

Concluding Remarks

- The electrical resistance at the interface decreases rapidly with an increasing load and Product D content, dropping sharply when conductive particles exceeds 5%.
- Fragments of conductive particles form conductive micro-channels, reducing localised charge build-up and improving conductivity in the fragment layer.
- Finer conductive particles, interpenetrate better with the fragment layer, enhancing conductivity and reducing resistance in the HPT system.
- Lower resistivity conductive materials require less proportion in the mixture to achieve significant resistance reduction in the HPT system.

Thank you for you listening!