Enhancing Long-Term Performance of Unsealed Roads in Australia: The Use of Crushed Rock Treated with Anionic Bituminous Emulsion

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Australian Pavement Recycling and Stabilisation Conference

Designing for Reuse and Resilience

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Research Objectives

1 To develop a novel and economical solution for dust level monitoring on unsealed roads

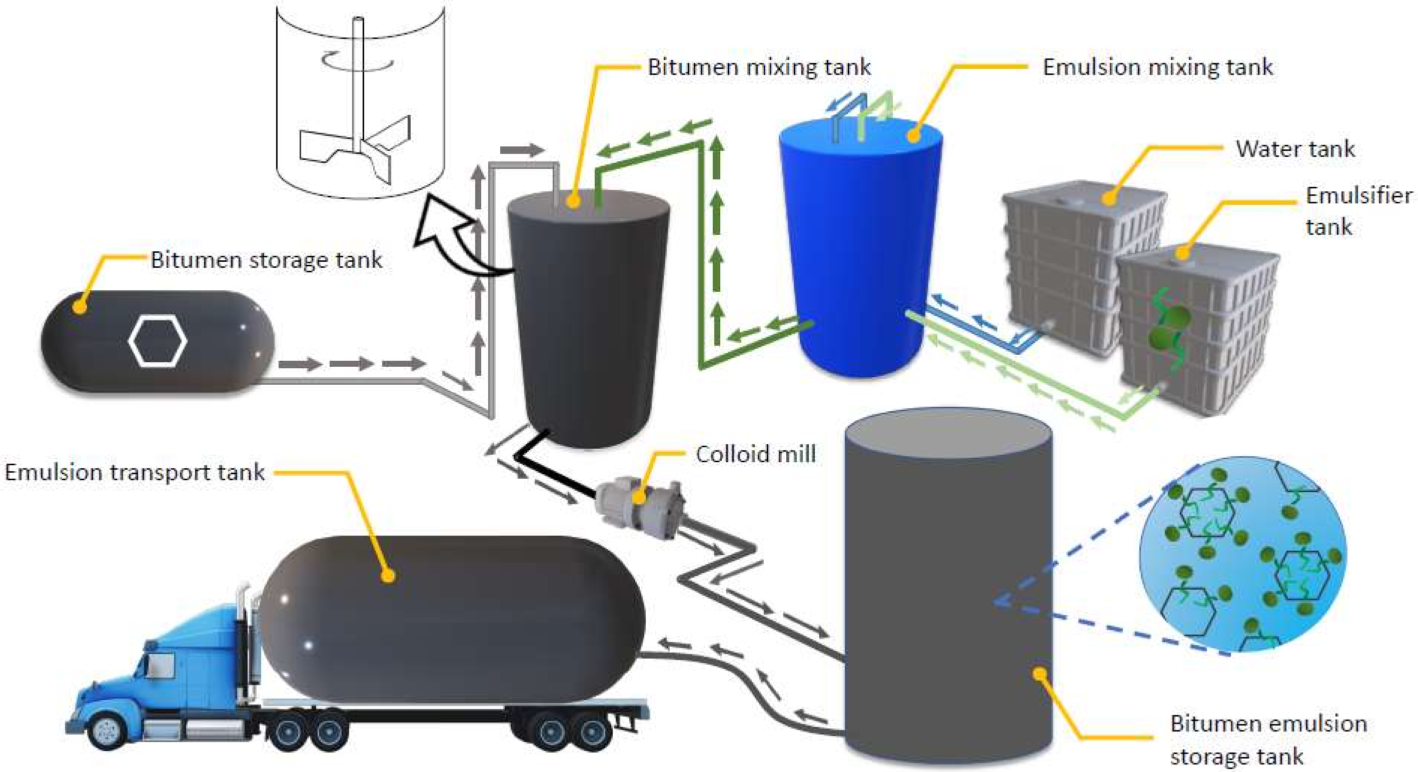
- Existing dust monitoring methods
- Machine learning - semantic segmentation
- Benchmark dataset
- Field experiments
- Different machine learning models

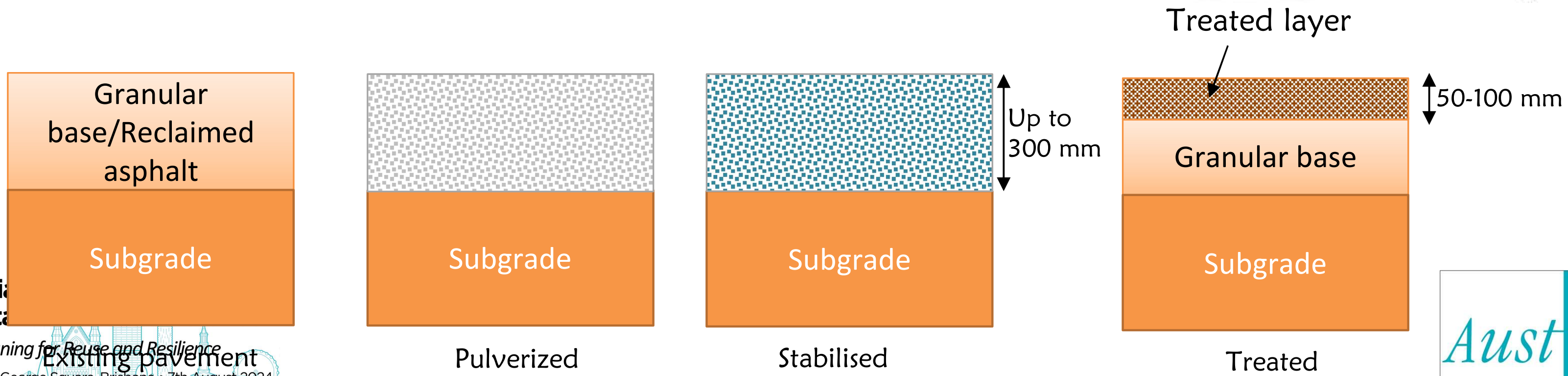
2 To investigate the effectiveness of bituminous emulsion treatment on crushed rock for enhanced performance

- Particle size distribution
- Atterberg limits
- Soil particle density
- Dry density – moisture content relationship
  - Modified Proctor
  - Gyratory compactor
- Tensile strength
- Resilient modulus
- Performance against rutting
- Ignition oven test

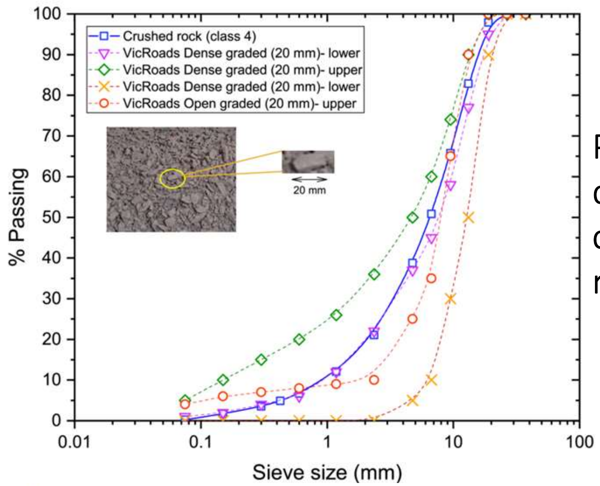
Background

~65%

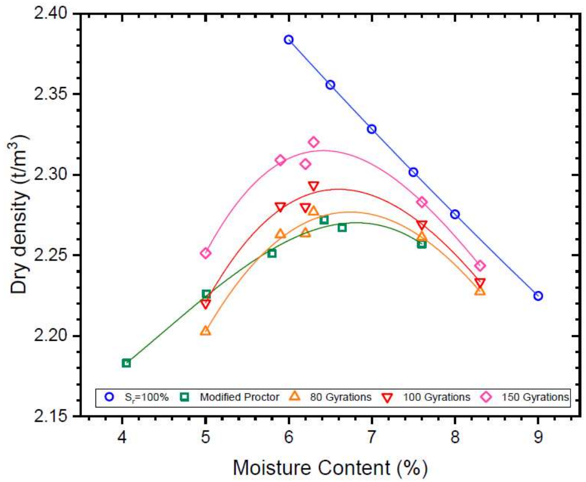




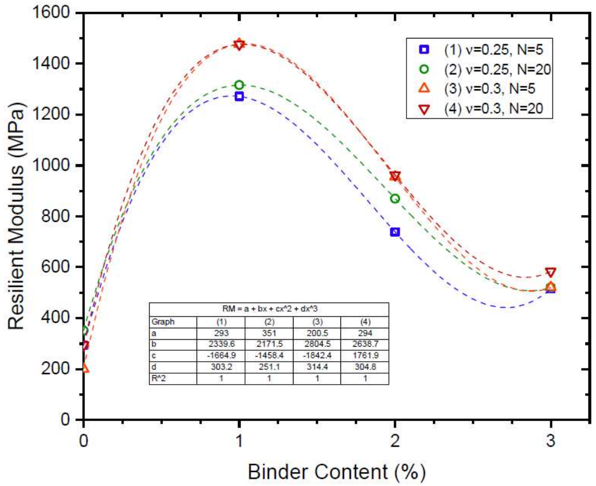
Material Characterisation



Particle size distribution of crushed rock

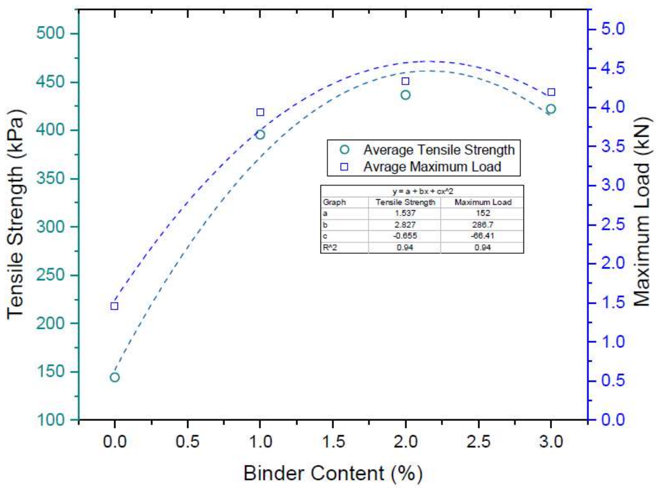


Compaction curves (modified Proctor and Gyratory compactor)



RM = a + bx + cx^2 + dx^3				
Graph	(1)	(2)	(3)	(4)
a	293	351	200.5	294
b	2339.6	2171.5	2804.5	2638.7
c	-1664.9	-1458.4	-1842.4	1761.9
d	303.2	251.1	314.4	304.8
R^2	1	1	1	1

Indirect tensile resilient modulus: *crushed rock and bitumen-emulsion treated crushed tock*



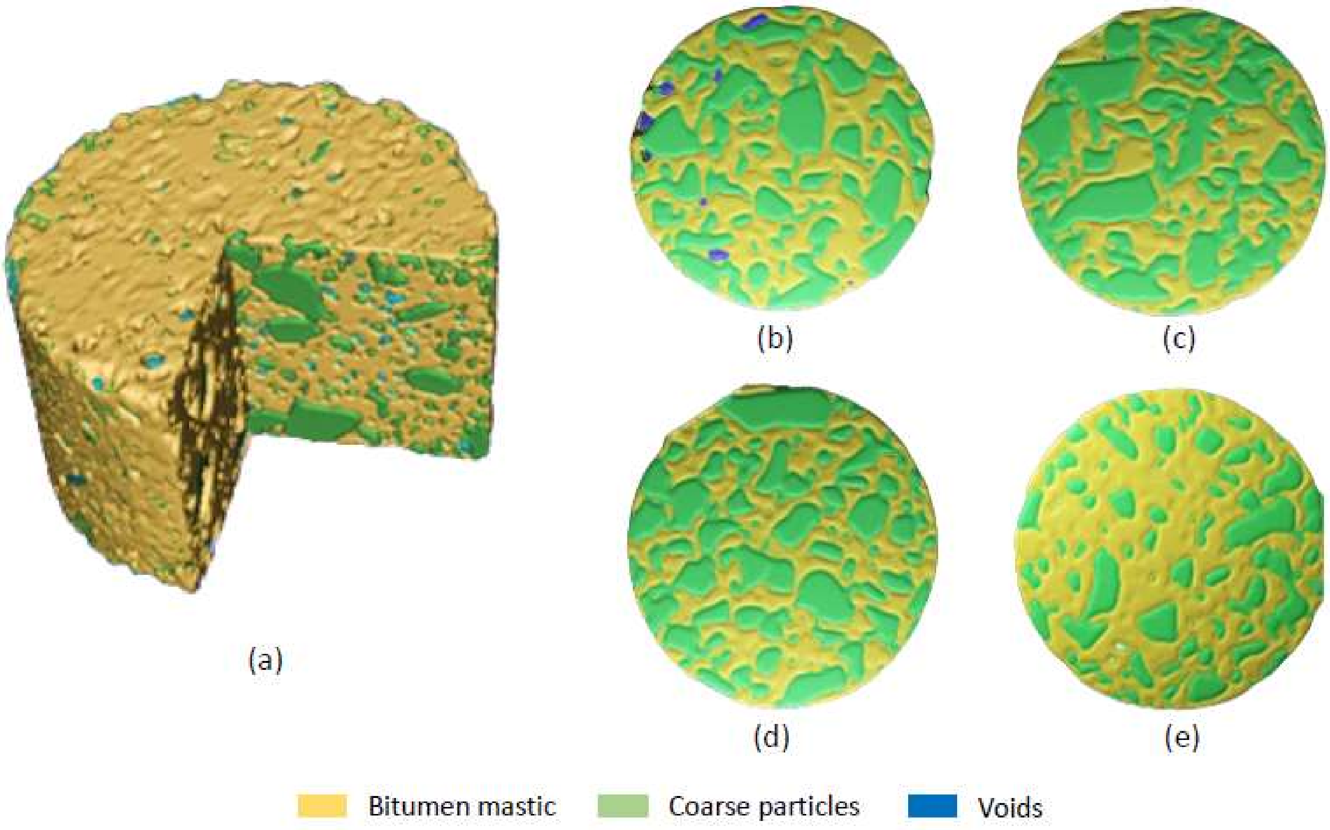
y = a + bx + cx^2		
Graph	Tensile Strength	Maximum Load
a	1.537	152
b	2.827	286.7
c	-0.655	-66.41
R^2	0.94	0.94

Indirect tensile strength: *crushed rock and bitumen-emulsion treated crushed tock*

Materials – Crushed Rock Treated With Emulsion

CT Scans

Microstructure of crushed rock treated with anionic slow set bituminous emulsion.
(a)3D view of 100 mm diameter quarter cut cylindrical sample,
(b) Cross-sectional view of untreated crushed rock,
(c) Cross-sectional view of crushed rock treated with 1% bituminous emulsion,
(d) Cross-sectional view of crushed rock treated with 2% bituminous emulsion,
(e) Cross-sectional view of crushed rock treated with 3% bituminous emulsion.



Wheel tracker testing

Table 1: OMC and MDD of different mixtures.

Mixture	Binder content (%)	OMC	MDD (t/m^3)
1	0	6.7	2.23
2	0	6.7	2.23
3	1	6.3	2.26
4	2	6.0	2.24
5	3	6.5	2.22

Table 2: Test conditions.

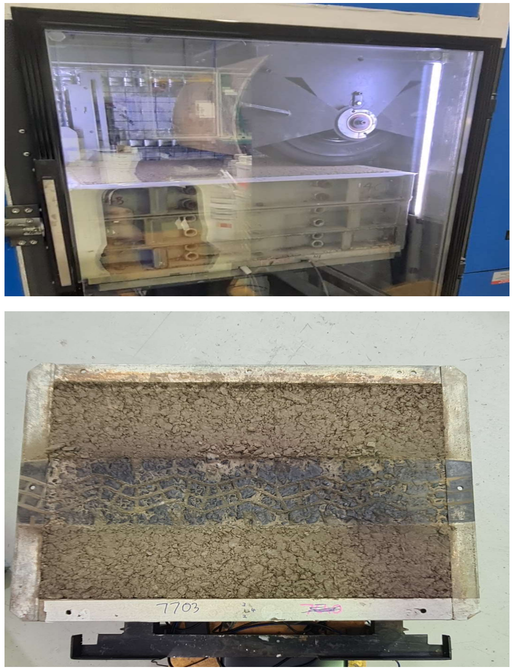
Test temperature	20 ± 5 °C
Tyre pressure	600 ± 5 kPa
Rolling load	20 ± 0.1 kN
Travel of the tyre	700 ± 5 mm
Centre line of the tyre tracking	10 mm
The angle of skew of the tyre	0.0 ± 0.5°
Vertical load	20 ± 0.1 kN
Frequency of wheel travel	0.4 ± 0.1 Hz

Wheel tracker testing ctd…

Splitting

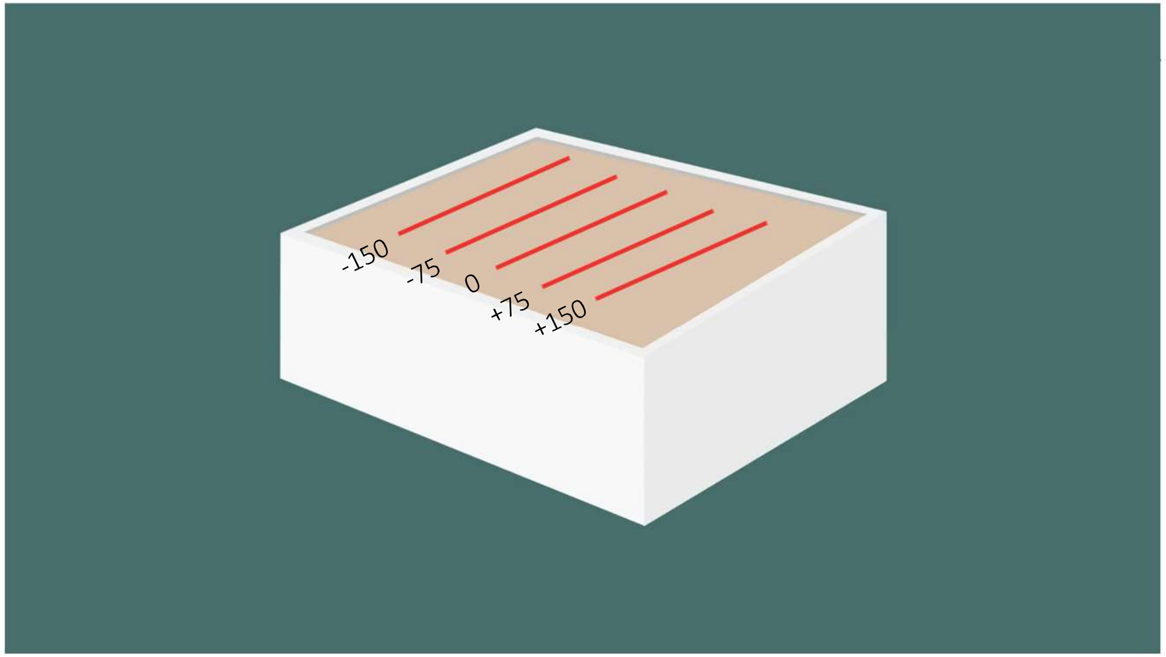
Mixing

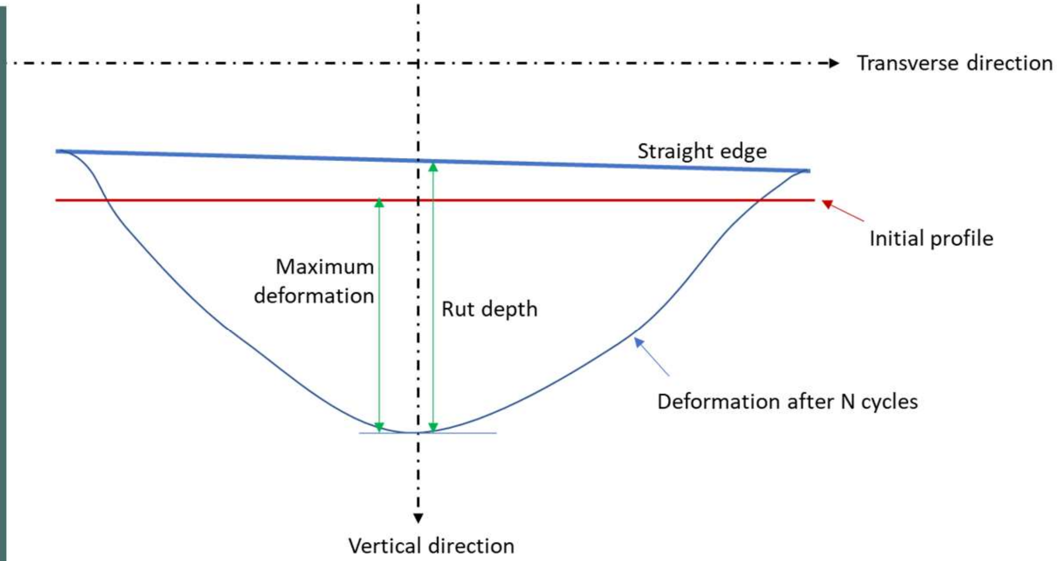
Compaction
&
Curing



Wheel tracking

Wheel tracker





Mean Profile Deformation

$$PD^{i}_{mean}(N) = \sum_{j=1}^{n_i} \frac{\left(m_{ij}(N) - m_{ij}(0)\right)}{n_i}$$

Maximum Profile Deformation

$$PD^{i}_{max}(N) = max_{j=1\ to\ n_i}\left(m_{ij}(N) - m_{ij}(0)\right)$$

$PD^{i}_{mean}(N) = i^{th}$ *profile mean deformation at cycle N (mm)*

$PD^{i}_{max}(N) = i^{th}$ *profile maximum deformation at cycle N (mm)*

$m_{ij}(N) =$ *the actual position recorded at the location j and the cycle N (mm)*

$n_i =$ *number of transverse locations defined for the* i^{th} *profile measurements located in the wheelpath defined by the tyre nominal width*

Parameter	Value
n_i	405 [–202,+202]
N	0, 10, 25, 50, 75, 100, 200, 400, 800, 1,000, 2,000, 4,000, 8,000, 10,000, 20,000, 30,000, 40,000, 80,000, 100,000

Overall Mean Deformation

$$D_{mean}(N) = \sum_{i=1}^{n_p} \frac{PD_{mean}^{i}(N)}{n_p}$$

Maximum Profile Rut Depth

$$PRD_{max}^{i}(N) = max_{j=1\ to\ n_i}\left(r_{ij}(N)\right)$$

$PRD_{max}^{i}(N) = i^{th}$ *profile maximum rut depth at cycle N (mm)*

$n_i =$ *number of transverse locations defined for the* i^{th} *profile measurements*

$r_{ij}(N) =$ *the distance calculated at the location j and the cycle N between the straight edge and the specimen surface (mm*

Overall Maximum Deformation

$$D_{max}(N) = \sum_{i=1}^{n_p} \frac{PD_{max}^{i}(N)}{n_p}$$

$D_{mean}(N)$ = *overall mean deformation at cycle N (mm)*

$D_{max}(N)$ = *overall maximum deformation at cycle N (mm)*

n_p = *number of profiles*

$PD_{mean}^{i}(N) = i^{th}$ *profile mean deformation at cycle N (mm)*

$PD_{max}^{i}(N) = i^{th}$ *profile maximum deformation at cycle N (mm)*

n_p = 5 (-150, -75, 0, +75, +150)

Overall Maximum Rut Depth

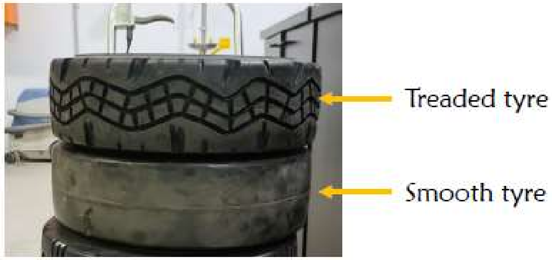
$$RD_{max}(N) = \sum_{i=1}^{n_p} \frac{PRD_{max}^{i}(N)}{n_p}$$

$RD_{max}(N)$ = *overall maximum rut depth at cycle N (mm)*

n_p = *number of profiles*

$PRD_{ma}^{i}\ (N) = i^{th}$ *profile maximum rut depth at cycle N (mm)*

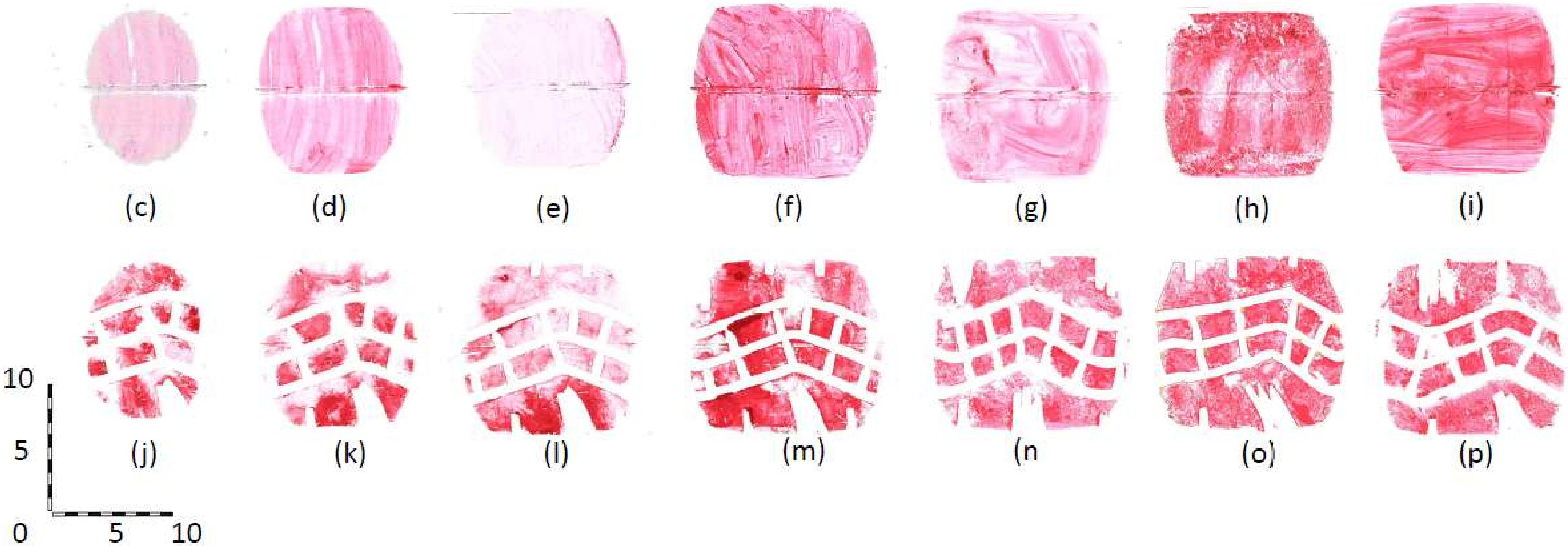
Tyres



(a)

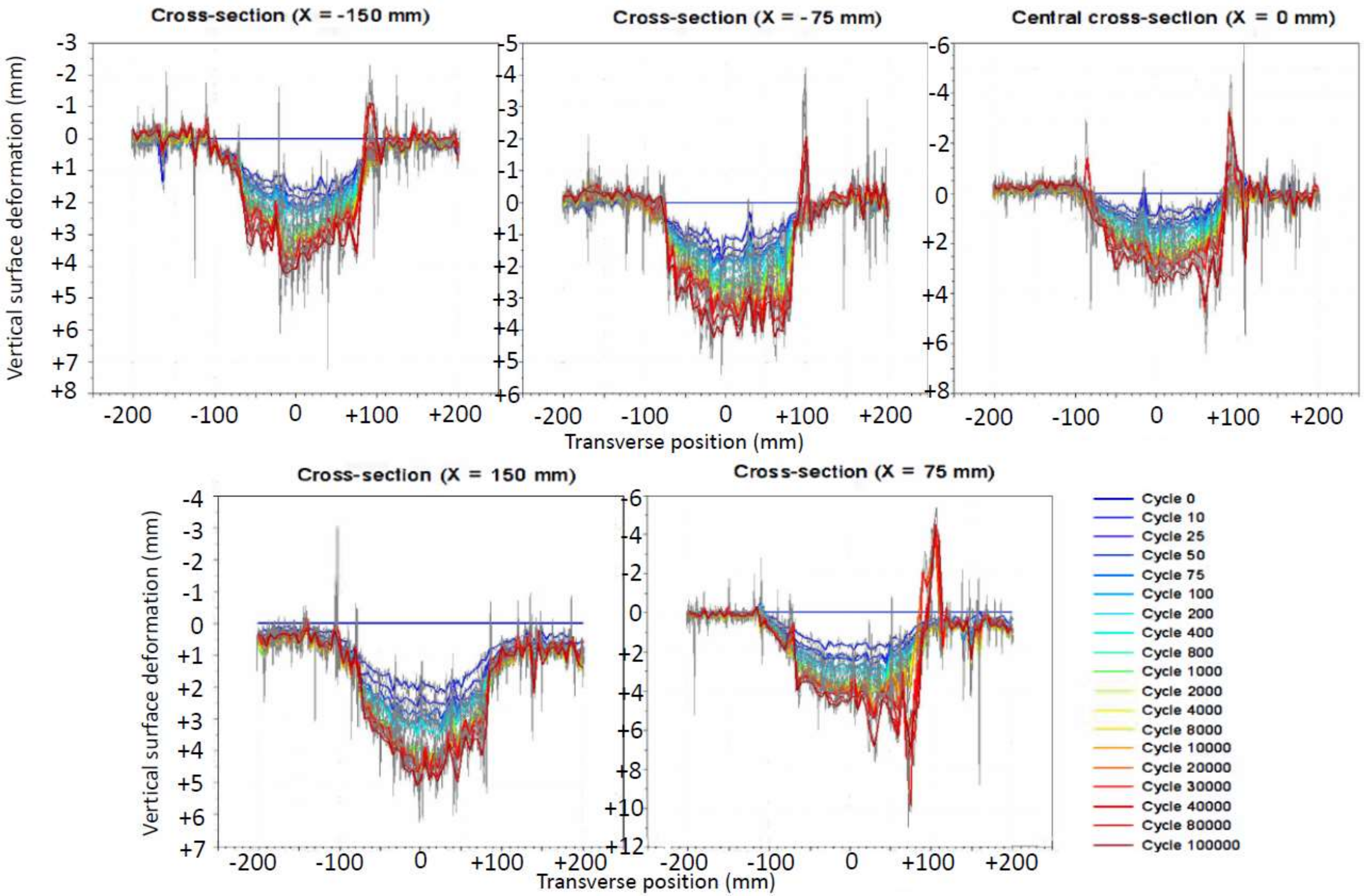
(b)

Load (kN)	Angle (°)	Tyre-Ground Contact Area (mm²)	
		Smooth Tyre	Treaded Tyre
5	0	7561.3	6064.5
10	0	12793.5	8834.2
15	0	15852.0	1619.0
20	0	18773.6	14271.2
20	90	17812.9	12238.7
20	180	20077.4	13658.0
20	270	18632.2	12716.1



Surface Deformation by Laser Profilometry

Slab 1 – Smooth tyre – Untreated



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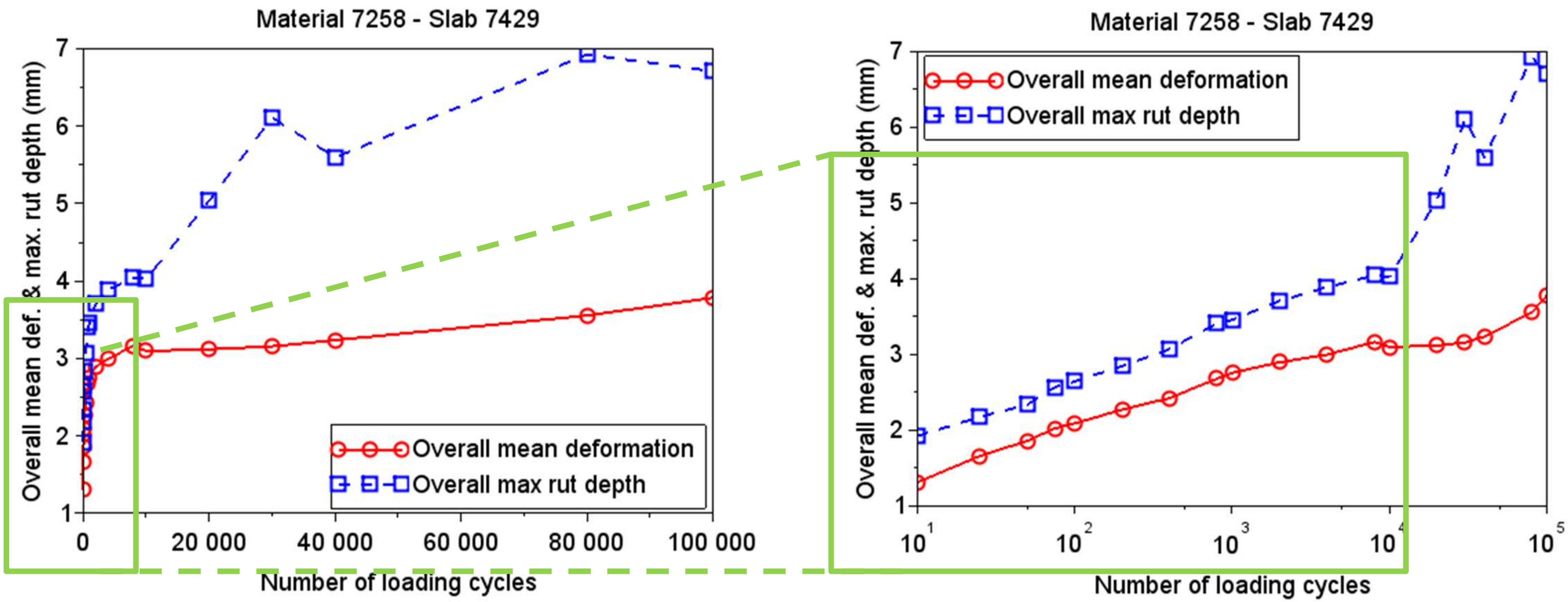
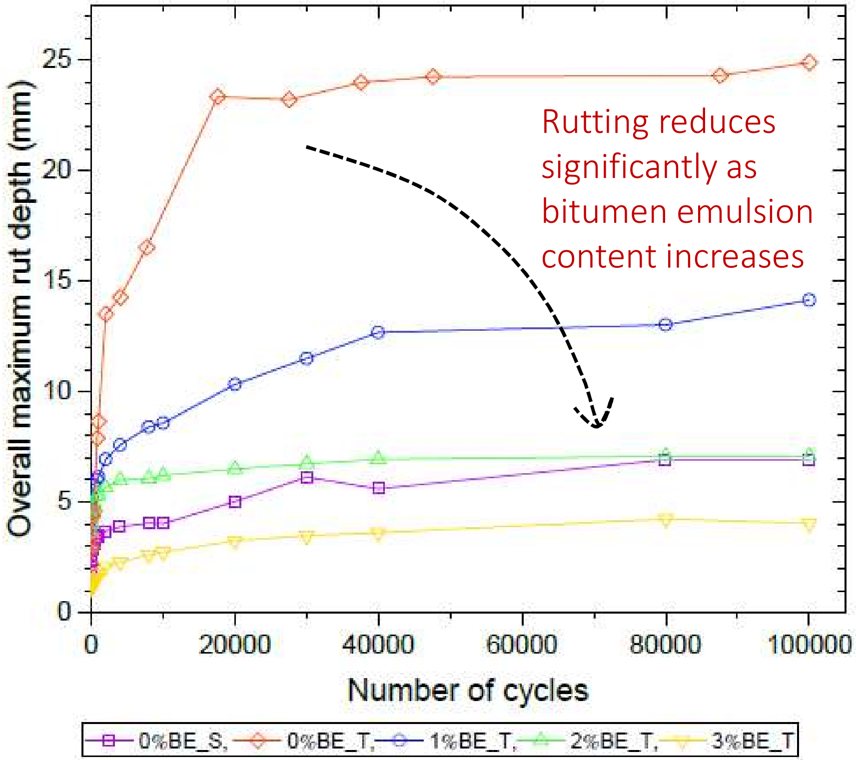
Surface Deformation by Laser Profilometry ctd…

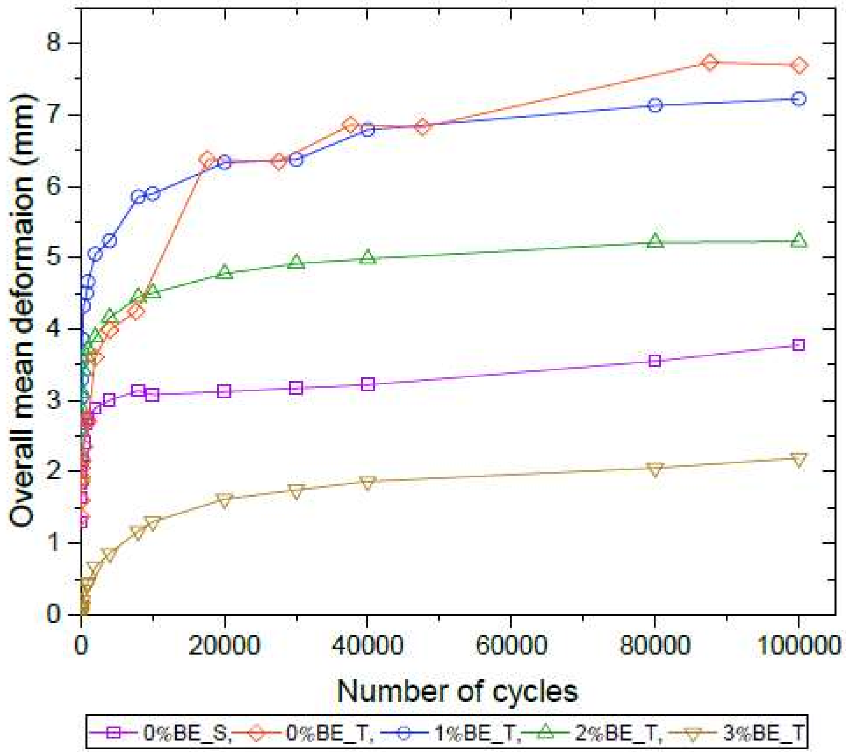
Slab 1 – Smooth tyre – Untreated



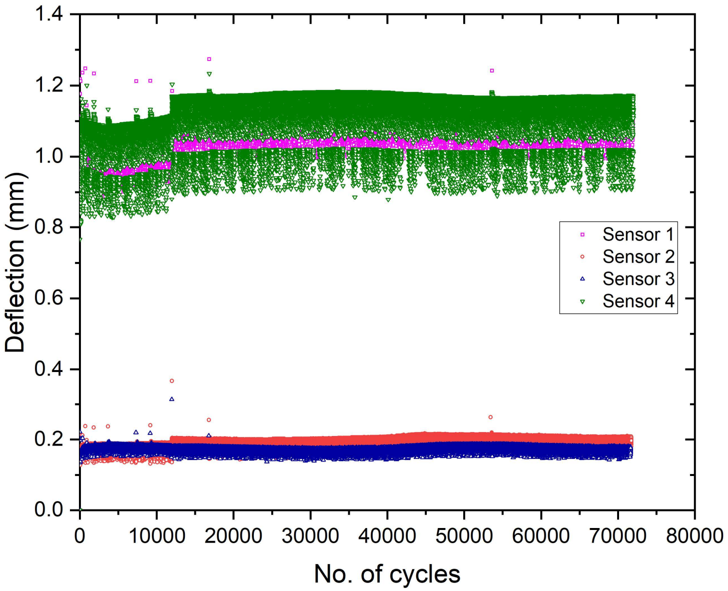
Surface Deformation by Laser Profilometry ctd…

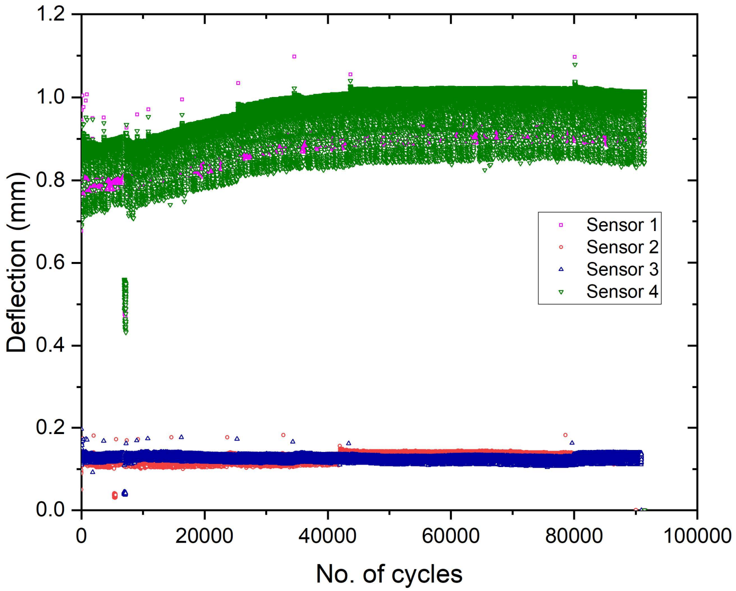
0%BE_S
- Binder content
- Bitumen emulsion
- S for Smooth tyre
- T for treaded tyre

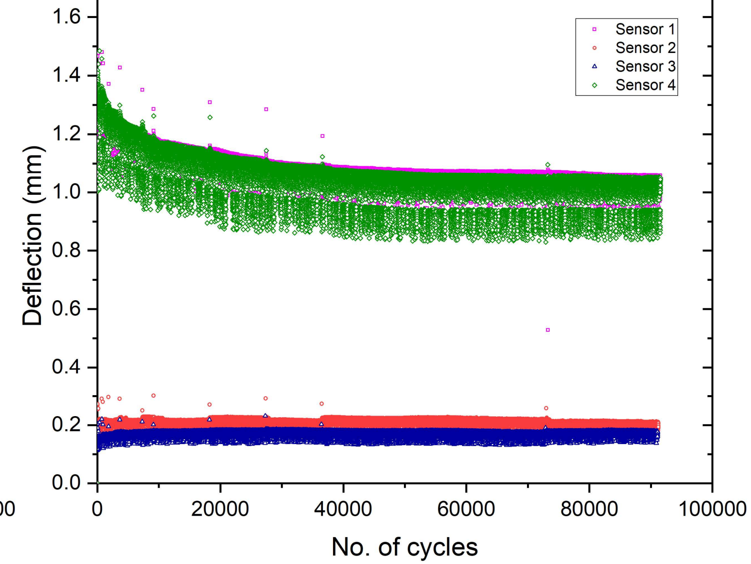




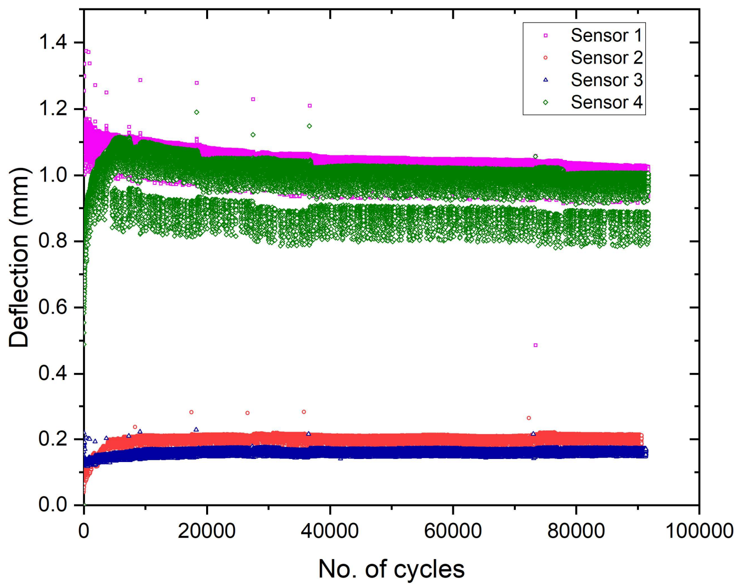
Permanent Deformation by Deflection Sensors

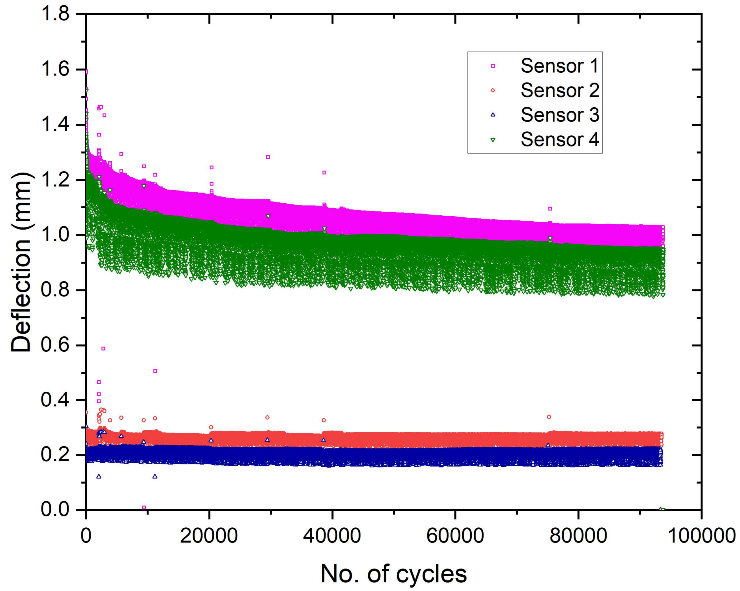






Permanent Deformation ctd...





Conclusions

The use of a treaded tyre in contrast to a smooth tyre is highlighted by observing how the rutting is considerably higher when a treaded tyre was used.

The results from WT test suggest that bituminous emulsion treatment considerably improves the rutting performance of the pavement.

Crushed rock treated with the 3% bituminous emulsion showed the lowest overall maximum rut depth and overall mean deformation whereas untreated crushed rock showed the highest overall maximum rut depth and overall mean deformation.

The results of this study show that the bituminous emulsion treatment is effective in terms of the long-term performance of unsealed road pavements.

Publications

- Asanka De Silva, Arooran Sounthararajah, Troyee Tanu Dutta, David Firth, Jaimi Harrison, Hamed Haghighi, Jayantha Kodikara, Crushed rock treated with anionic bituminous emulsion for construction of unsealed roads in Australia with enhanced long-term performance,Construction and Building Materials,Volume 427, 024,136137,ISSN 0950-0618,https://doi.org/10.1016/j.conbuildmat.2024.136137.

- De Silva, A.; Ranasinghe, R.; Sounthararajah, A.; Haghighi, H.; Kodikara, J. Beyond Conventional Monitoring: A Semantic Segmentation Approach to Quantifying Traffic-Induced Dust on Unsealed Roads. Sensors 2024, 24, 510. https://doi.org/10.3390/s24020510

- De Silva, A., Ranasinghe, R., Sounthararajah, A. et al. Semantic Segmentation Model Performance on Vehicle-induced Dust Cloud Identification on Unsealed Roads, 28 November 2022, PREPRINT (Version 1) available at Research Square [https://doi.org/10.21203/rs.3.rs-2239765/v1]

- De Silva, A., Ranasinghe, R., Sounthararajah, A. et al. A benchmark dataset for binary segmentation and quantification of dust emissions from unsealed roads. Sci Data 10, 14 (2023). https://doi.org/10.1038/s41597-022-01918-x

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