Category 2: Industry Excellence in Consulting, Research or Education

Dust Estimation on Unsealed Roads Using Artificial Intelligence and Mitigation through Bituminous Emulsion Treatment

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Monash University

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Overview

Australia has approximately 900,000 km of road network length and about 65% of this is unsealed.

The most obvious issue associated with unsealed roads is dust emission due to vehicle traffic.

This dust has negative impacts such as:

- Visibility issues leading to traffic hazards
- Poses health hazards - asthma, carcinoma, allergies, etc.
- Stunts agriculture and crop growth
- Pollutes streams, and
- Deterioration of the road surface.

Therefore, we need to quantify and mitigate this road dust.

Overview

https://blog.midwestind.com/penn-state-center-for-dirt-and-gravel-road-studies-releases-new-report-on-fugitive-dust/

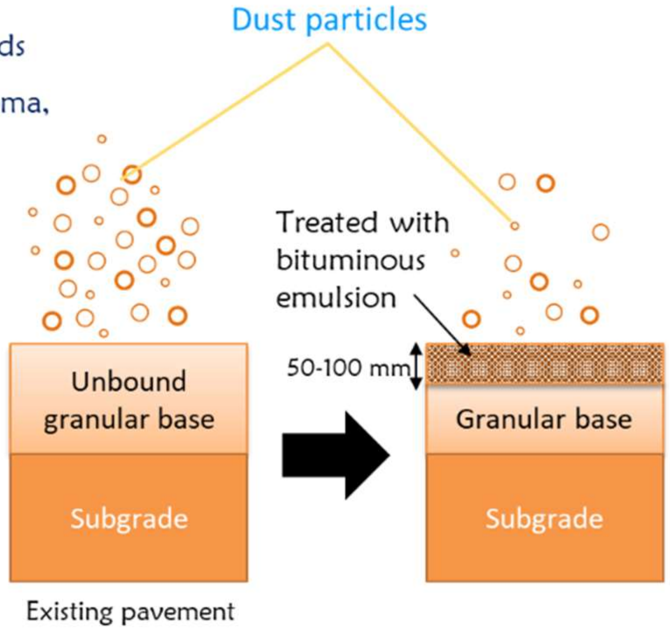
https://www.roadex.org/e-learning/lessons/environmental-considerations-for-low-volume-roads/environmental-issues-related-to-road-management/

http://www.arenadust.com/dust-control-services/road-dust-control/

https://www.whichcar.com.au/gear/how-to-4wd-on-dirt

Negative effects of unsealed road dust

- Visibility issues leading to traffic hazards
- Poses health hazards - asthma, carcinoma, allergies, etc.
- Stunts agriculture and crop growth
- Pollutes streams
- Deterioration of the road surface



Therefore, road dust should be;

- Quantified
- Mitigated

~ 65% of Australian roads are unsealed

Source: Unsealed Roads Best Practice Guide 2, ARRB (2020)

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Research Objectives

To develop a novel and economical solution for dust monitoring on unsealed roads, an Artificial Intelligence (AI) inspired approach was used. A series of field experiments throughout Victoria were carried out to obtain dust readings on various types of unsealed roads and images/videos from traffic-induced dust events on unsealed roads.

Extensive laboratory experiments were carried out in order to assess the effectiveness of bitumen emulsion treatment with respect to dust suppression and mechanical performance (modulus and rutting).

Class 4 crushed rock was used as the material that will be used for mix design experiments based on the information provided by several councils in Victoria.

Crushed rock with a higher fines content was preferred as one of the primary objectives of this study is to assess the effectiveness of the treatment in terms of dust suppression.

Bitumen emulsion was supplied by Downer and binder compliance tests were performed on that.

During this study, 1%, 2% and 3% binder contents were investigated.

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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

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AI for Dust Monitoring

Research objective #1: The biggest challenge associated with using machine learning tools such as semantic segmentation for dust monitoring is that there is no dataset containing traffic-induced dust from unsealed roads to train on machine learning models. So, in this research, one such dataset was developed. From experiments in the field to annotating the images, the whole process took months. In each field experiment, using a direct single-lens reflex (DSLR) camera, dust event was captured due to a utility vehicle travelling at different speeds. Simultaneously, dust readings were obtained using a research-grade dust monitor to develop a correlation between the actual dust readings and dust estimated in the image by machine learning. We conducted field experiments on 10 unsealed road segments with different types of road surface materials in varying climatic conditions to capture vehicle-induced road dust. A total of ~210,000 images were photographed and refined to obtain ~7,000 images. These images were manually annotated to generate masks for dust segmentation.

The dataset is publicly available for anyone to use to advance the area of dust monitoring by machine learning - https://figshare.com/articles/dataset/URDEdataset/20459784.

The citation to our article published in *Nature Scientific Data:* 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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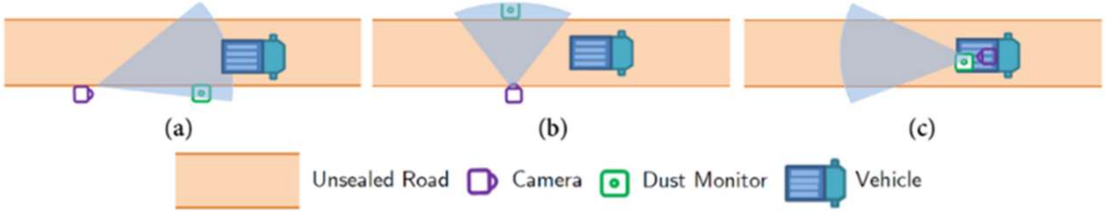
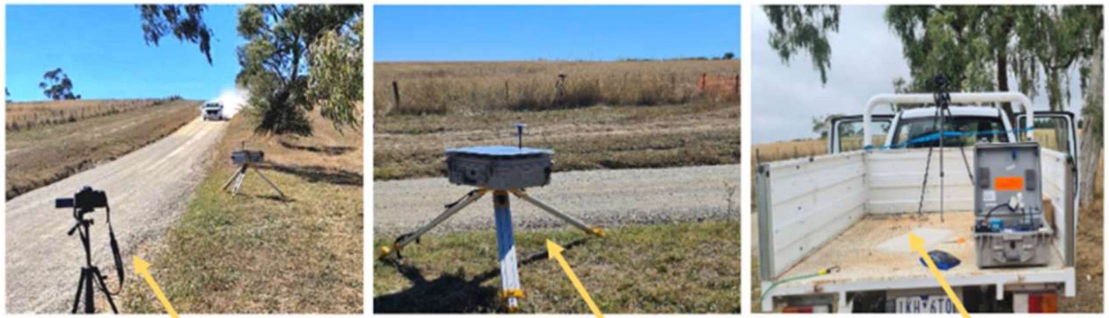
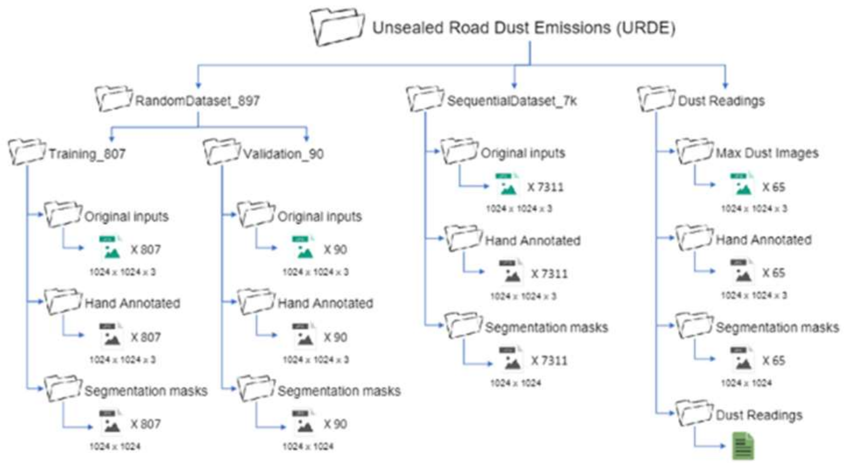
AI for Dust Monitoring

- Biggest challenge: there is no dataset of images of unsealed roads with traffic-induced dust. So, we produced one.





Camera Dust monitor Instrumented ute



Structure of the generated dataset

7,000 × 3 images + Dust measurements

- Dust cloud mages were captured from 3 different setups at different locations.
- All images were inspected, and the dataset was refined.
- Each image was manually annotated to generate masks for dust segmentation. This process took over 1,500 hours.

- *This work has been published in [Nature Scientific Data](#).*

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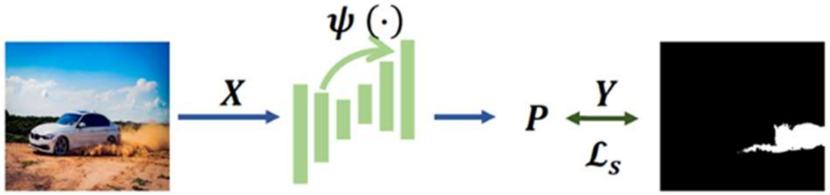
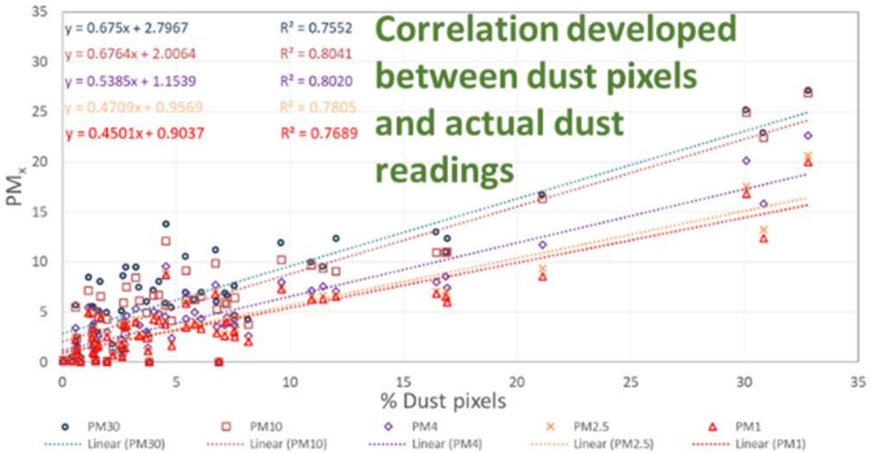
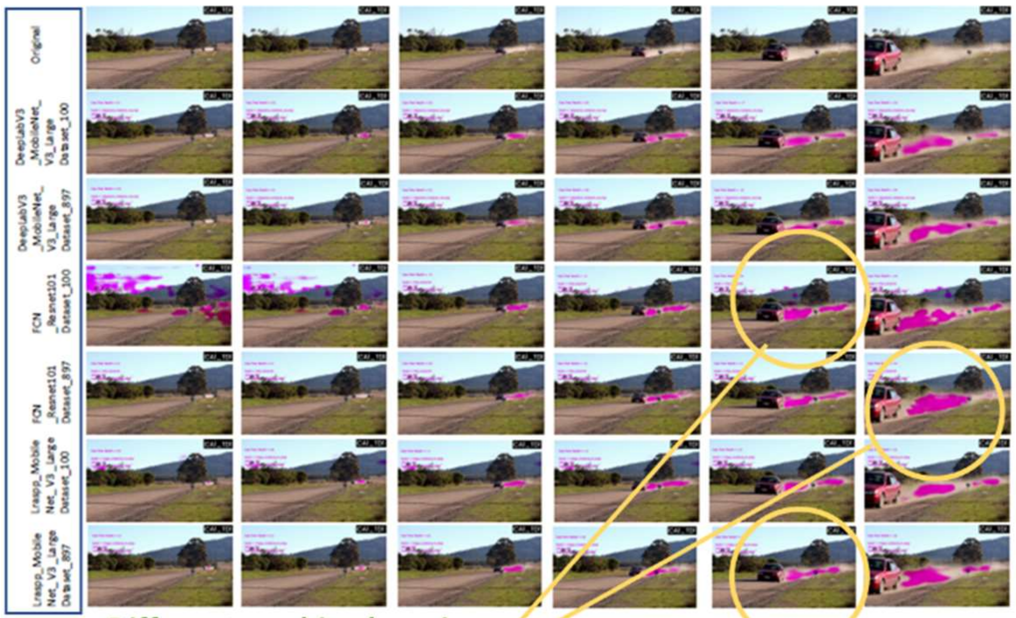
Semantic Segmentation



Machine learning models

Each dust cloud image was trained with its corresponding annotated image using multiple machine-learning models.





Different machine learning models identify dust regions differently

After an image has been annotated, using machine learning, the number of pixels containing dust was calculated. That number was correlated with the actual dust readings obtained for that particular event. After doing that for all images, they were trained for different machine learning models to see how each model perform in terms of dust segmentation. Best performed models were selected to implement in the real-word application.

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Real-world Application

In order to use the developed method, one would require a camera/smart phone, and a laptop/computer. Then, record the dust event using a camera/smart phone (e.g. a vehicle driving in an unsealed road producing dust), upload the video or images to the model and the model will provide an output video/image, with dust readings produced and the correlations in each second. The dust readings are produced as PM_1, $PM_{2.5}$, PM_4, PM_{10}, and PM_{30}. This can be further expanded to include the model that was used.

The next slide showcases six example videos (unavailable in this PDF document) recorded during this study at various unsealed roads in Victoria, demonstrating the developed model's ability to predict dust generation during vehicle-induced dust cloud formation. It is envisaged that the developed method can be integrated into an existing condition assessment vehicle, which can be equipped with a high-resolution camera to automatically estimate the vehicle-induced dust level in real-time during travel.

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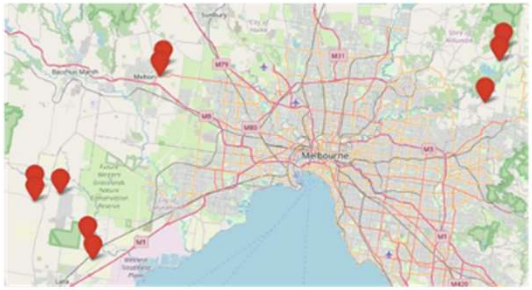
Real-world Application

How to use it? → Record & upload → When a video/image is uploaded, the machine learning model will provide an output video/image where it shows different particulate matter contents calculated using the dust pixels in each frame and the developed correlations.



Locations where the field experiments on unsealed roads were conducted.

Example performance of the developed dust prediction model

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Material Characterisation

Research objective 2: To assess the effectiveness of the bitumen emulsion treatment on crushed rock with respect to dust suppression and mechanical performance, a series of laboratory experiments were carried out.

About 4.5 tonnes of crushed rock (Class 4) that conform to VicRoads crushed roads limits for unsealed roads construction was ordered from a local quarry in Victoria. To obtain uniform samples for laboratory experiments, the crushed rock was split using a rotary splitter and filled into individual plastic containers, each weighing about 20 kg.

The dry density of crushed rock was evaluated for different moisture contents using a state-of-the-art gyratory compaction and compared with compaction curves obtained using modified Proctor. The shear stress applied during compaction was investigated using the gyratory compactor.

The strength and modulus of the treatment were determined through indirect tensile and resilient modulus tests at bitumen emulsion contents of 1%, 2%, and 3%. The results indicate that increasing the bitumen emulsion content beyond 2% does not further enhance the strength and stiffness of the treated crushed rock. This finding was further investigated by evaluating the rutting of the treated material using an extra-large wheel tracker. The results are presented in a following slide.

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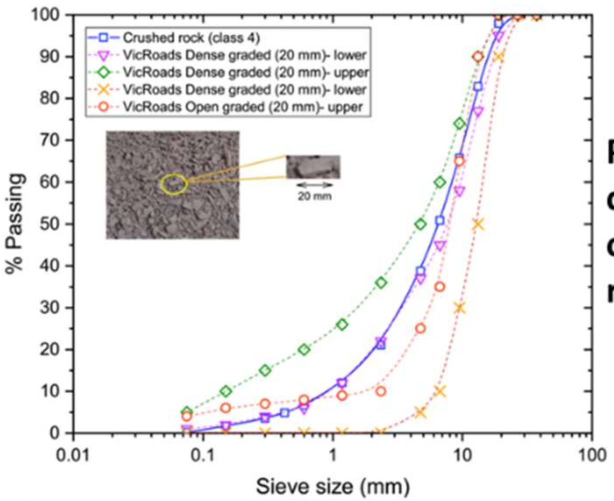
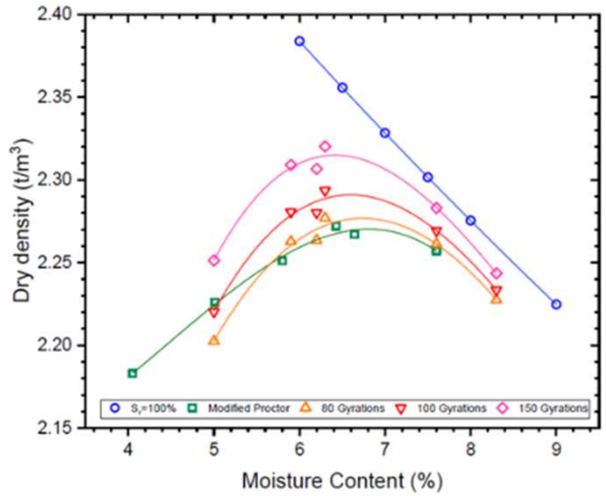
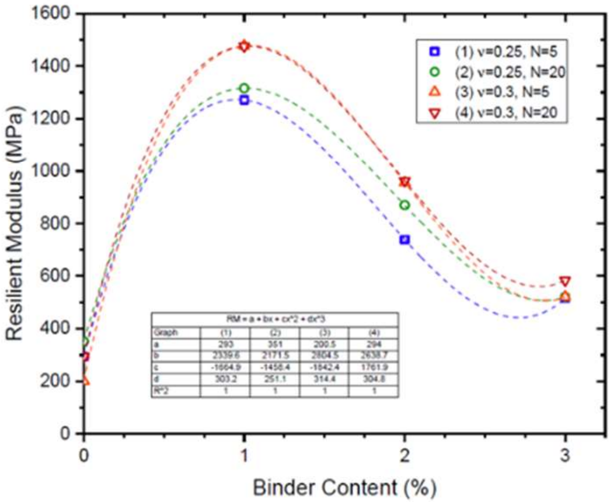
Material Characterisation



Particle size distribution of crushed rock

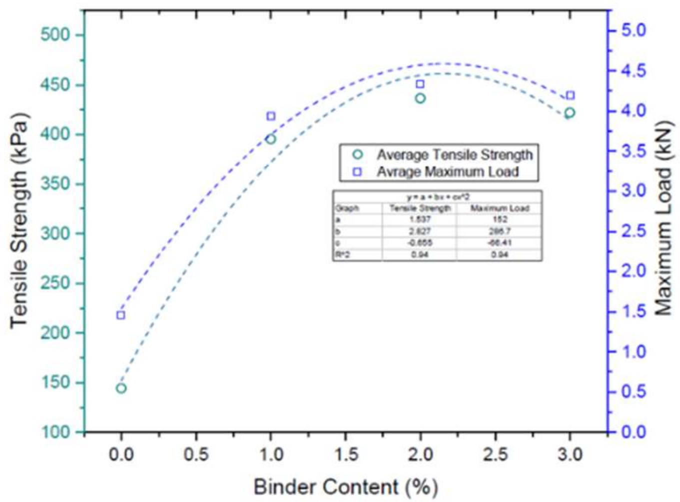


Compaction curves (modified Proctor and Gyratory compactor)



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*

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Evaluation of Rutting Using Extra-large Wheel Tracker

To investigate the rutting and permanent deformation characteristics of the treatment, the extra-large wheel tracker at ARRB was used. The crushed rock was split using the rotary splitter -> Mixed in the pugmill -> Compacted at optimum moisture content and maximum dry density -> Cured for 3 days at 40oC -> Subjected to Wheel tracking and the trafficking was continued for 100,000 load cycles.

The wheel tracker rutting assessment was individually performed for the following materials: Crushed rock alone, Crushed rock + 1% bitumen emulsion, , Crushed rock + 2% bitumen emulsion, , Crushed rock + 3% bitumen emulsion.

After 100,000 cycles, loose material on each sample in the wheel path was collected by gently brushing for a specified time period. As expected, loosened material quantity was significantly higher in samples tracked with treaded tyre compared to smooth tyre. The quantity of loosened material reduced as the binder content increased. The results demonstrate a noteworthy reduction in the quantity of loosened material within the wheel path as a direct consequence of the bitumen emulsion treatment, thereby leading to a substantial decrease in dust generation.

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Evaluation of Rutting Using Extra-large Wheel Tracker

A significant challenge was finding a tyre that can withstand loads in the wheel tracker and conform to tread patterns in the actual vehicles. A smooth solid rubber tyre, a solid tyre with fine treads, and a solid tyre with coarser treads were used. These tyres are capable of taking loads up to 20 kN. These tread patterns were manually carved to conform to the design criteria of the tread pattern which are:

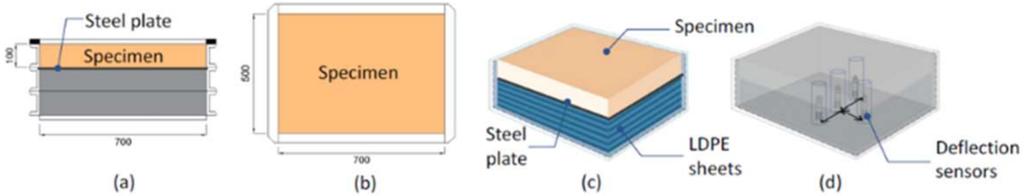
1) Create channels for water and liquid debris to be evacuated from under the contact patch allowing for adhesion with the surface.
2) And to provide a 'biting edge' for traction in off-road conditions

And there are other features, such as asymmetry, that are all designed around the need to reduce vibration, noise and harmonics that can disrupt driving pleasure or, enhance performance whilst still achieving those 2 points.

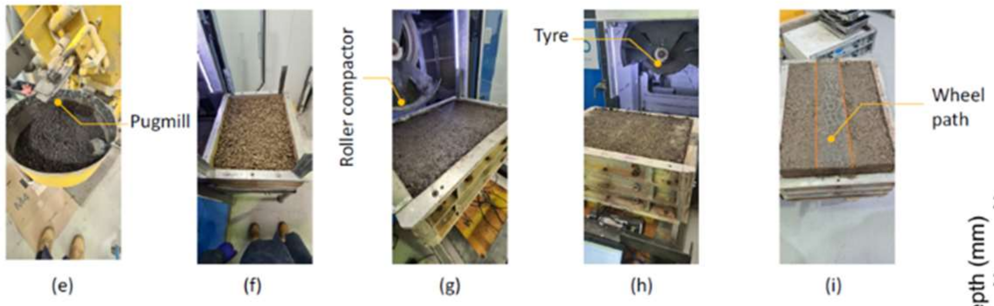
The designs here are hand cut and rough, would achieve the key principles of the design need.

Evaluation of Rutting Using Extra-large Wheel Tracker

Extra large wheel tracker @NTRO

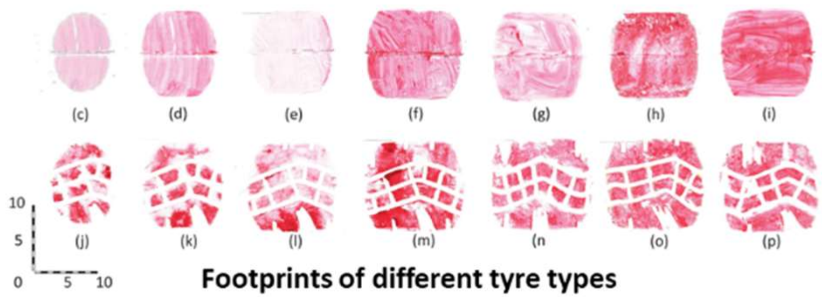


(a) to (d): Wheel tracker instrumentation

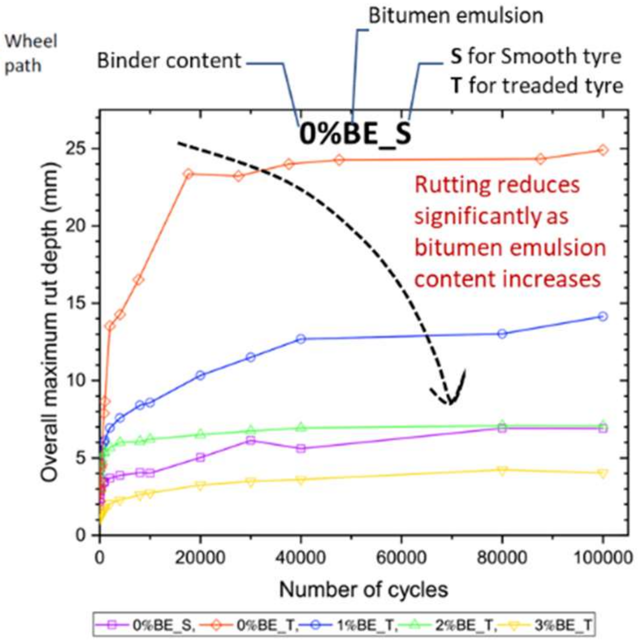


(e) to (i): Wheel tracker sample preparation

Different tyre types used in wheel-tracker testing



Footprints of different tyre types used in wheel-tracking



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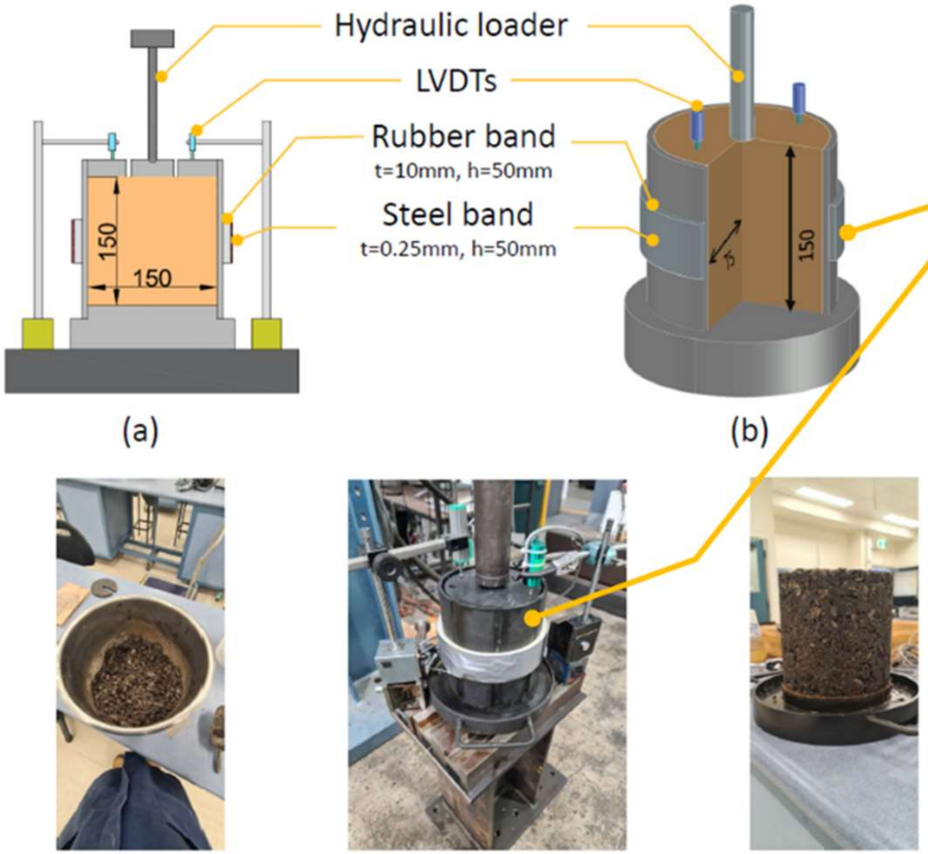
Rutting Assessment Using a Novel Device

We have used a novel rut measuring device to investigate the rutting performance of crushed rock treated with different bitumen emulsion contents. Samples were compacted in 5 layers with 25 blows per layer. The compacted specimens were cured for 3 days at 40^{o}C. After that, each sample was subjected for haversine load pulses up to 100,000 load cycles.

Results show that the rutting has decreased by 25%, 40%, and 56% with 1%, 2%, and 3% bitumen emulsion respectively, which means that the treatment is effective in terms of rutting that is the primary deterioration mechanism of unsealed roads under repeated heavy traffic loads.

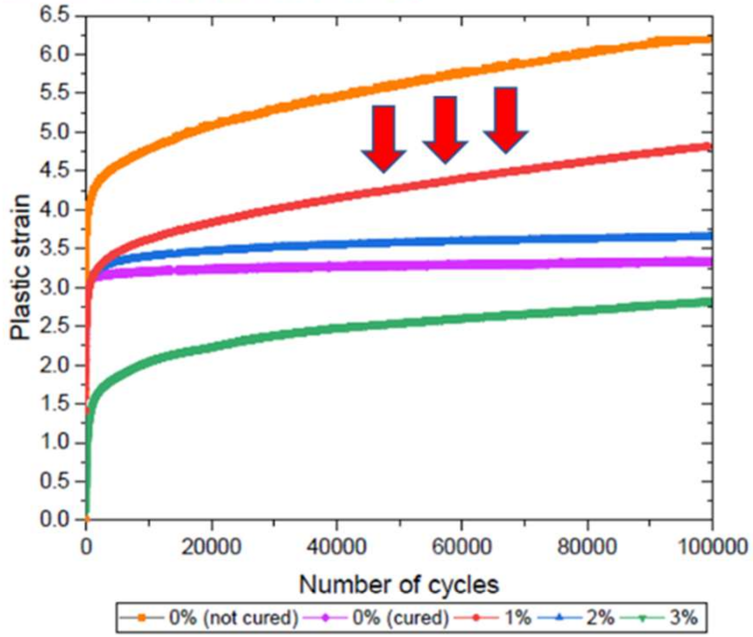
Rutting Assessment Using a Novel Device

Smart rational evaluation of material resilience



(a) (b) (c) (d) (e)

Expandable compaction mould: *simulating the actual field conditions*



The rutting of the crushed rock has decreased by 25%, 40%, and 56% with 1%, 2%, and 3% bitumen emulsion treatment, respectively.

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Field Application

The video clips (5 clips) on the next slide (not available in this PDF) show the real-world application of the bitumen emulsion treatment in an unsealed road segment in Victoria. The process begins by watering the surface so it facilitates easy loosening. The grader loosened the material to the required depth. The sprayer applied the desired binder content onto the loosened material uniformly. The combined material is then compacted using available compactors. Finally, to obtain a more dust-resistant surface, a more diluted bitumen emulsion was applied to the surface.

The bitumen emulsion treatment was conducted in late 2019. The performance of the treated unsealed road, in terms of dust control and rutting, was monitored for approximately 18 months. It is noteworthy that no visible rutting or dust emissions were observed from the treated road surface throughout the monitoring period, despite the road section being exposed to diverse traffic and environmental conditions.

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Field Application

Tobruk Road at Benalla–Tocumwal Road
Moira Shire Council, Vic

- Length : 450 m
- Base : Unbound granular material
- Treatment : bitumen emulsion stabilisation at ~1.5%
- Field monitoring: Dust and rutting monitoring over 18 months





Watering → Facilitates easy loosening of the surface

Surface loosening → Loosens the surface layer

Spraying → Adding the bitumen emulsion at the desired content

Compaction → Compaction of the treated layer

Capping layer → Diluted bitumen emulsion on to the surface