Category 2: Industry Excellence in Consulting, Research or Education

Transforming Municipal Solid Waste-to-Energy Incineration (MSWI) Ash into a Sustainable Solution for Pavement Stabilisation

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and SPARC Hub

2023 AustStab Awards of Excellence

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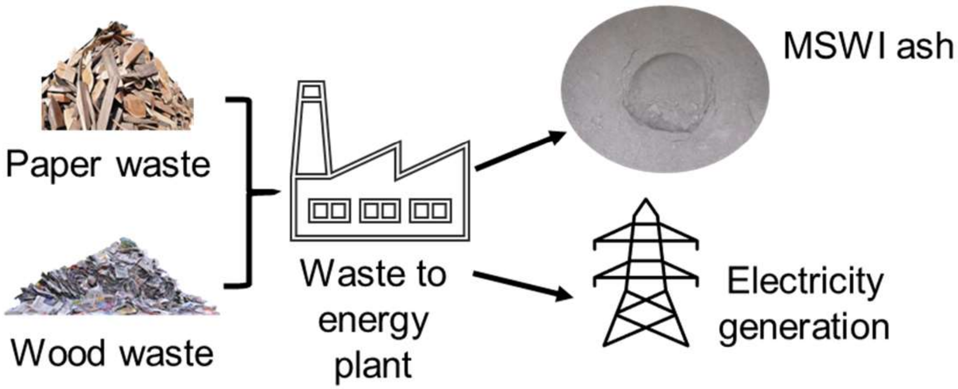
Overview

- Over 2,000 waste-to-energy (WTE) plants globally, generating millions of tons of MSWI fly ash.
- Western Europe alone accounts for an estimated annual production of 1.2 million tons of MSWI fly ash
- MSWI fly ash is unsuitable for cement and concrete production due to its high chlorine content.
- Limited research exists in the literature regarding the durability and in-depth microstructural analysis of MSWI fly ash used as road material, which restricts its potential application for soil treatment.



Objectives

- Investigate the mechanical performance of MSWI fly ash to be used as a subgrade stabiliser
- Evaluating the micro-level mechanism of the stabilisation process
- Evaluating the durability performance of MSWI fly ash treatment
- Assessing the environmental impacts of using MSWI fly ash for mine roads
- Investigate hydraulic and shear strength characteristics during the seasonal moisture variation
- Predicting the pavement performance using numerical simulation
- Contribute design guidelines for sustainable mine haul road construction

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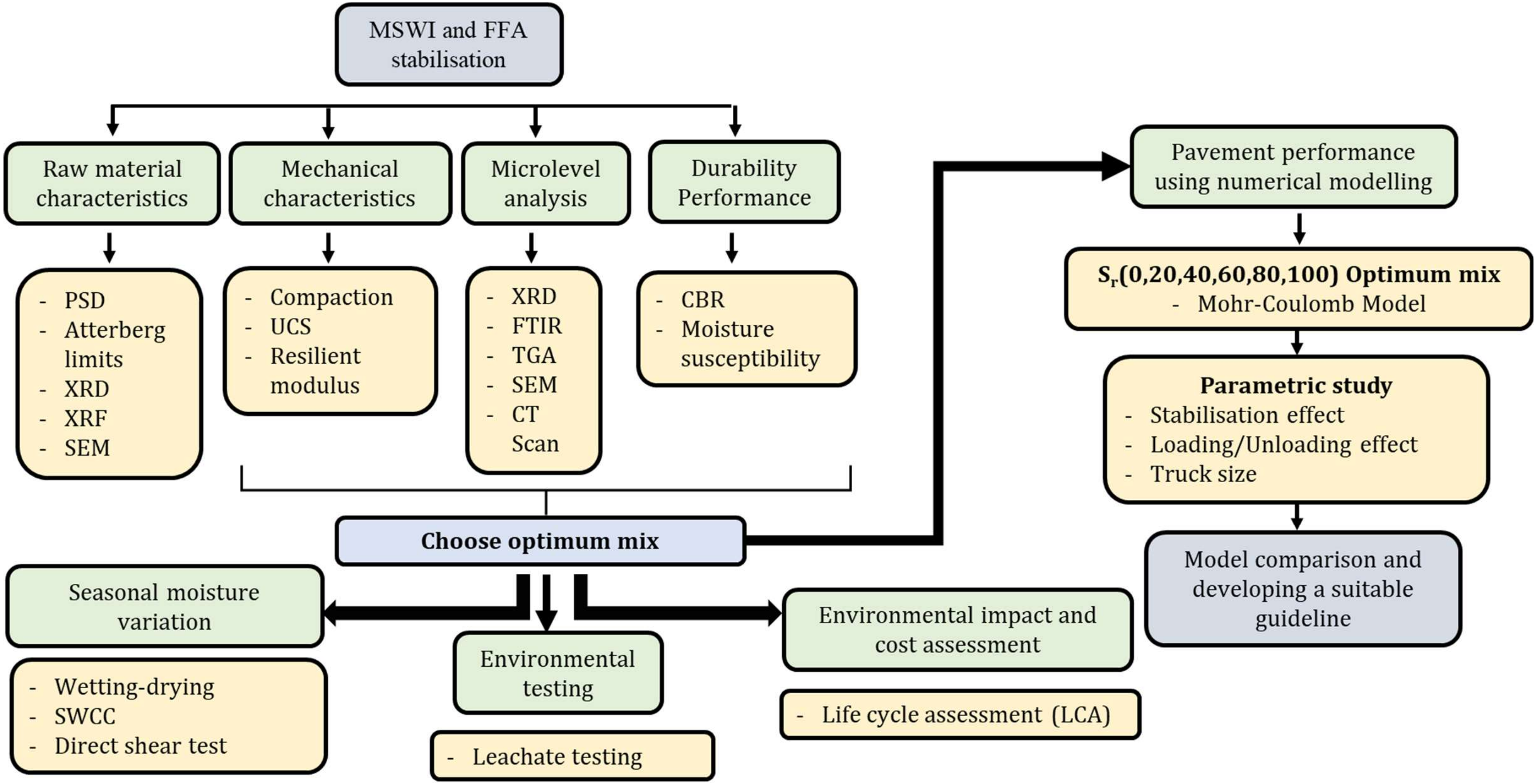
Initiatives undertaken

- The figure on the next page shows the flow chart of the testing program. MSWI Fly ashes were mixed in 10%, 15% and 20% dosages by weight of dry soil. Most of the tests were conducted after 7 and 28-day air curing. CBR tests were performed after 4 and 10 days of soaking as recommended in the Austroads guidelines. Following the tests for physical properties of raw materials, mechanical and durability tests were conducted for stabilised samples. Then, wet-dry and environmental testings were performed for the control soil and optimum mix (20% MSWI fly ash). Microlevel investigations (XRD, FTIR, TGA and SEM) were conducted for all the stabilised samples to understand the stabilisation mechanism and weathering process.

- UCS=Unconfined compressive strength, CBR=California bearing ratio, XRD=X-ray Diffraction, FTIR=Fourier transform infrared spectroscopy, TGA=Thermogravimetric analysis, SEM=Scanning Electron Microscopy, MSWI fly ash=Municipal solid waste incineration fly ash, FFA= Class F fly ash, WD=Wet-dry cycles, 24SD=24 hours soaking and 24h drying

Initiatives undertaken



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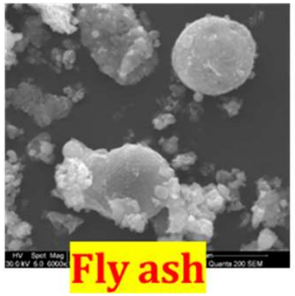
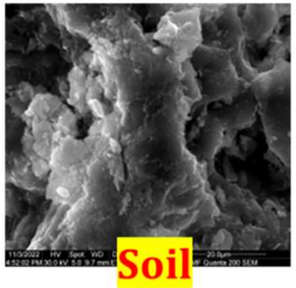
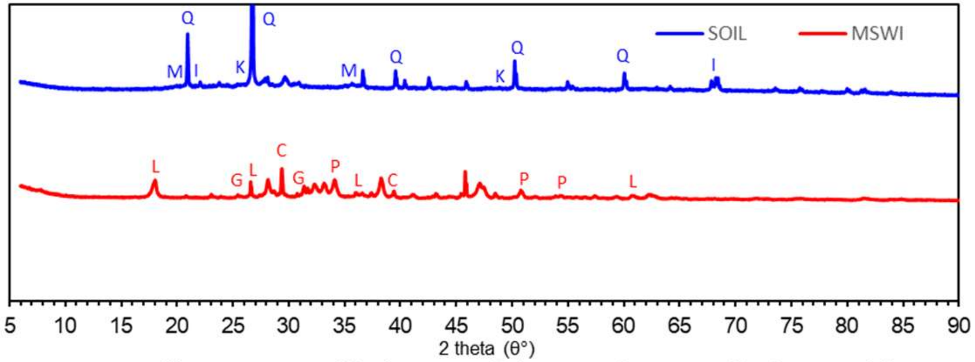
Initiatives undertaken

Physical properties of raw materials





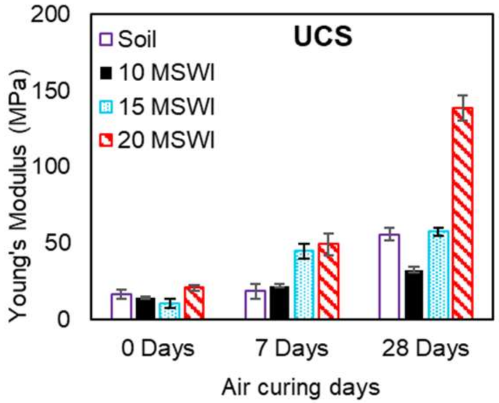
Atterberg limits	
LL	62
PL	28
PI	34

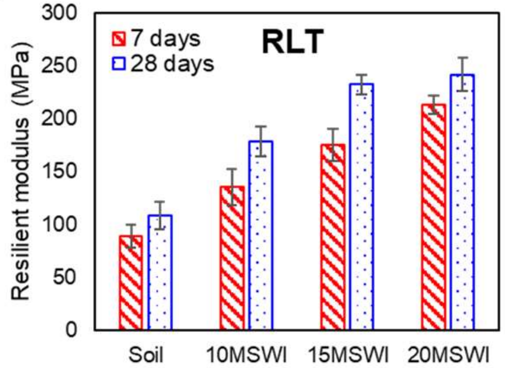


Q-Quartz, I-Illite, M-Montmorillonite, K-Kaolinite, L-CaclOH, G-Gehlenite, C-Calcite, P-Portlandite, T-Mullite, H-Hematite

- MSWI fly ash consists of irregular unbound carbons and hollow spheres
- Soil is classified as High plasticity clay

Mechanical properties





- After 7 days of curing, the UCS of the 10% and 20% MSWI fly ash stabilised samples increases to 0.7 MPa and 0.83 MPa, 17% and 36% higher than the control samples
- Resilient modulus of the clay increased from 89 MPa (control soil) to 213 MPa in 7 days of curing.
- MSWI fly ash contained more than 50% CaO and a greater CaO/SiO2 and CaO/(SiO2+Al2O3) ratio. Therefore, MSWI can provide a stronger cationic exchange reaction and crystalline formation.

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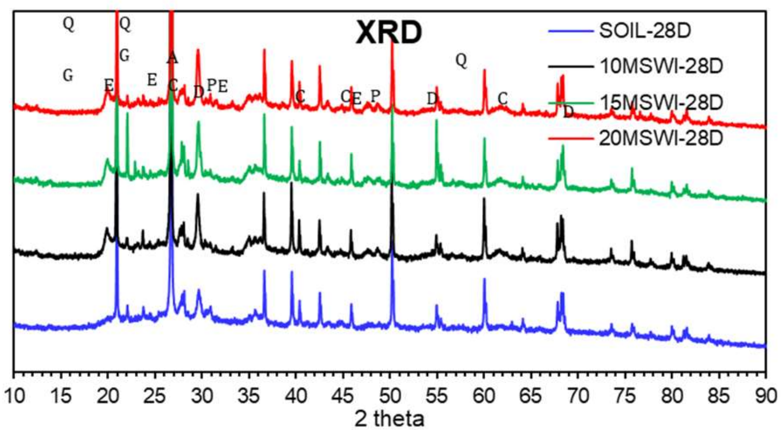
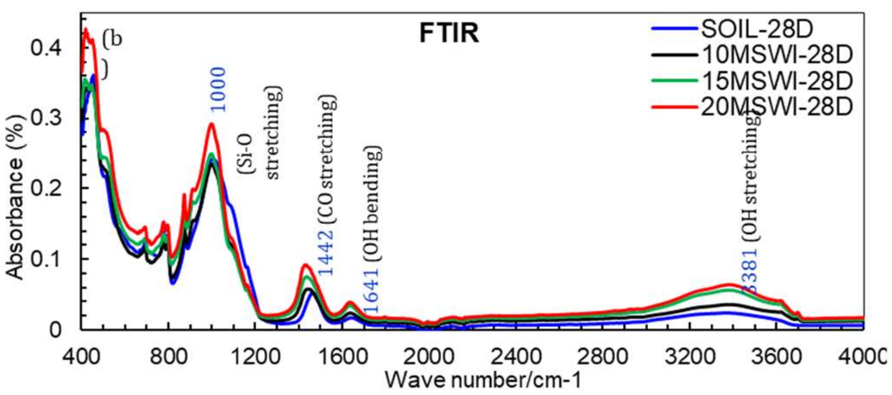
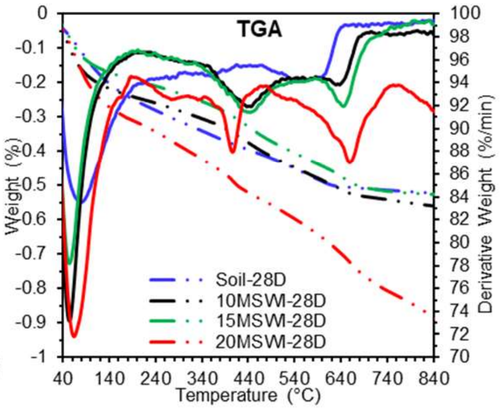
Initiatives undertaken

Microlevel investigation (XRD, FTIR, TGA, CT SCAN AND SEM)





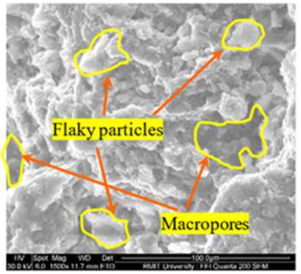


- XRD results showed that the main crystalline formations during the MSWI fly ash stabilisation are quartz, gismondine, albite, calcite, portlandite, andradite and ettringite.
- FTIR and TGA results confirmed the presence of portlandite, calcite, and ettringite phases.
- SEM and micro-CT scanning confirm reduced porosity with MSWI fly ash dosage and curing time.

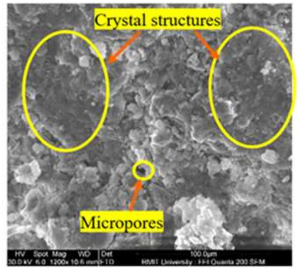
Soil

20MSWI

CT Scanning



Soil



20MSWI

SEM analysis

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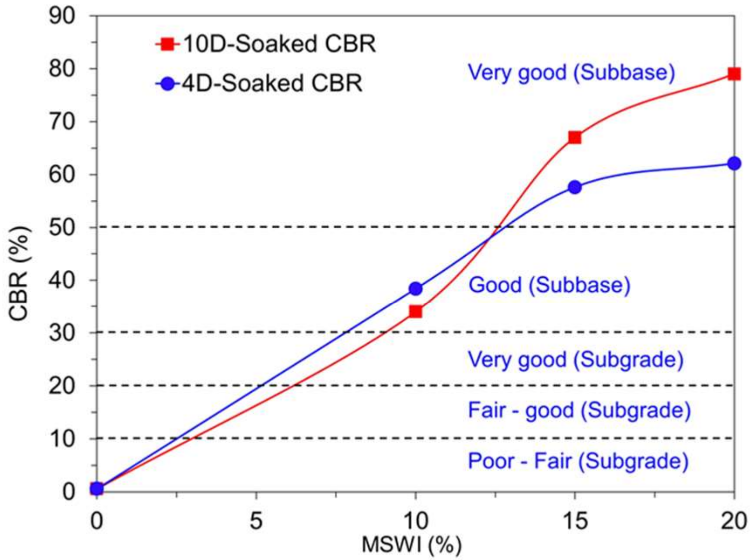
Challenges of the operating environment

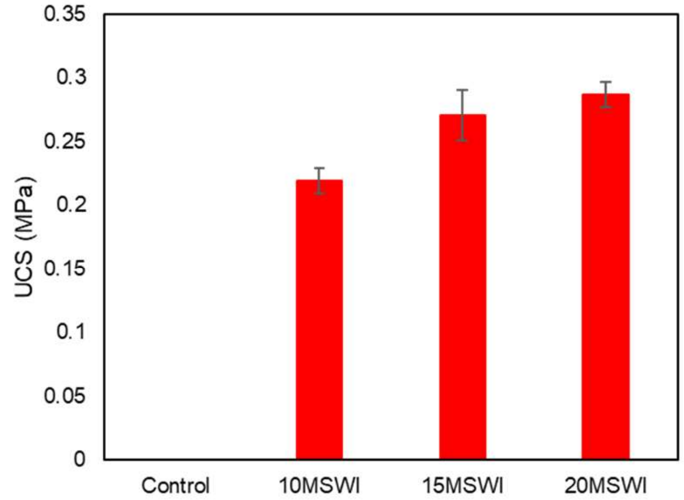
- Durability and environmental performance assessment required prior to project implementation.
- Durability performance was assessed through soaked CBR, moisture susceptibility, and wetting-drying testing.
- Environmental performance evaluated through leachate testing.

Soaked CBR tests



- Wet conditions enhance hydration and crystalline phase formation, resulting in increased strength and CBR of MSWI fly ash-stabilized samples in the subgrade.

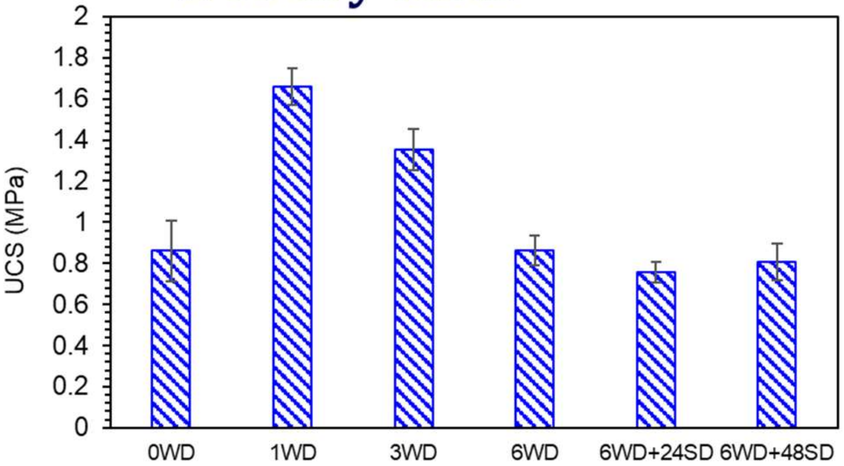
Moisture susceptibility tests



- MSWI fly ash stabilized samples exhibited no visual degradation after soaking, with compressive strengths of 10%, 15%, and 20% MSWI fly ash treated samples measured at 0.22, 0.27, and 0.29 MPa, respectively.

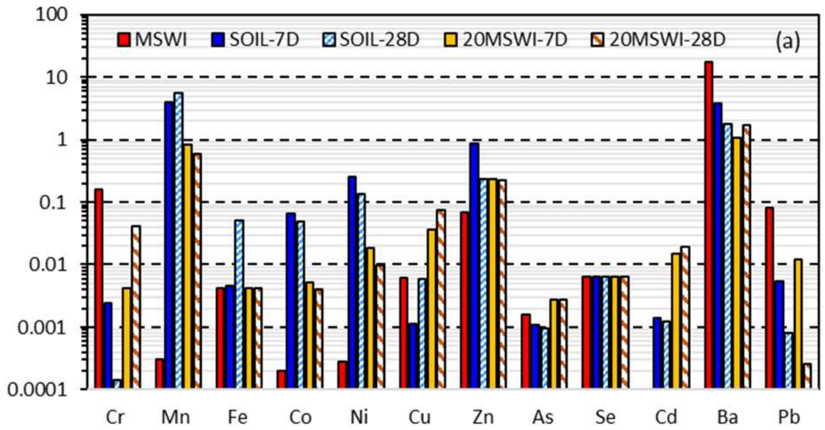
Challenges of the operating environment

Wet dry tests



- Control sample failed in the first wet cycle
- During the first drying cycle, minor cracks formed in 20MSWI treated sample
- After 6WD, samples were soaked and dried for 24 hours (6WD+24SD). UCS strength of the samples reduced slightly to 0.76 MPa.

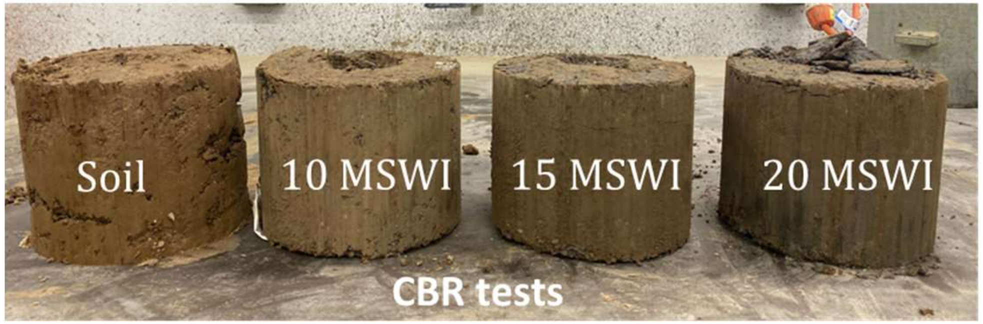
Leachate testing

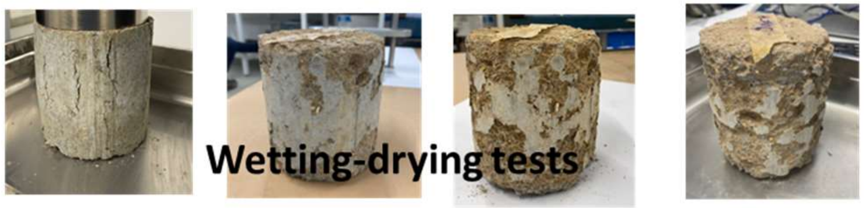


- After the stabilization, 20MSWI samples exhibit a satisfactory level of heavy metal concentration which is within the maximum allowable limit mentioned by all the states in Australia.
- No additional treatment process is required to reduce the trace metal concentration of MSWI fly ash

Evidence of success

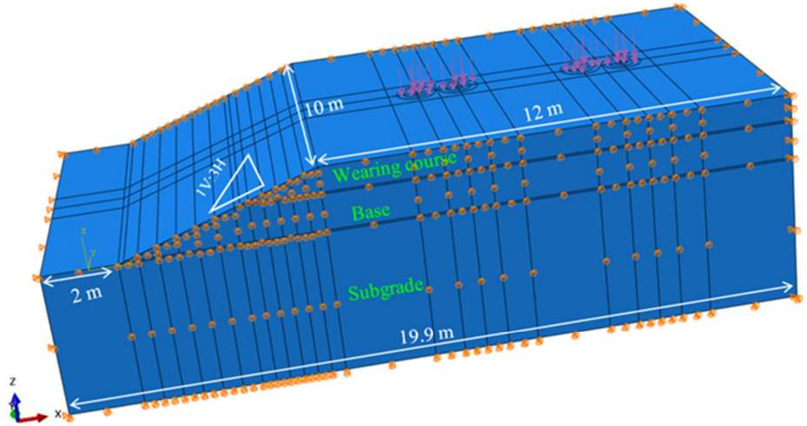
Supporting data





1WD 3WD 6WD 6WD+24SD

Supporting data-Numerical simulation



- Using the experiment data, the performance of stabilised pavement is investigated using numerical simulation.
- In addition to the data presented in this slides, direct shear test and SWCC testings were conducted and the pavement is modelled using Mohr-Coulomb model using the Abaqus software.
- Mine road is modelled for different saturation levels such as 20%, 40%, 60%, 80%, OMC (optimum moisture content) and 100% saturation levels

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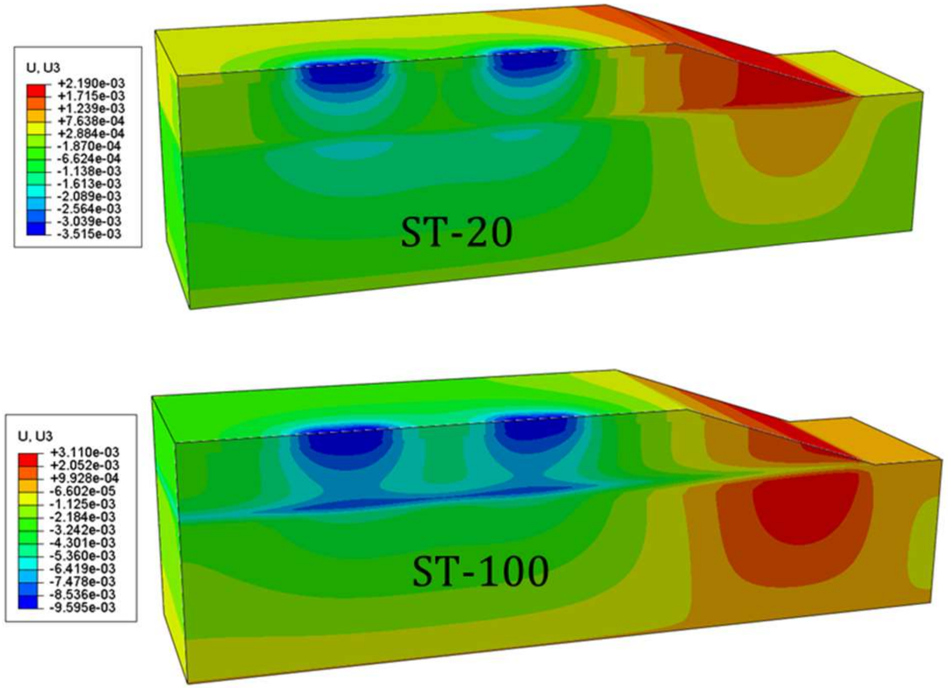
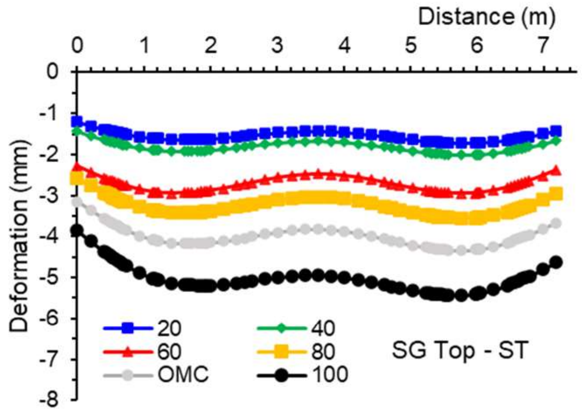
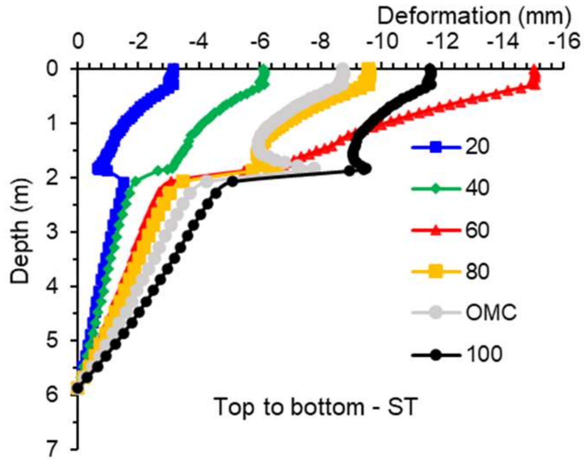
Evidence of success

Supporting data – Numerical simulation results







- The stabilized pavement exhibits a distinct settlement pattern with varying saturation levels.
- The ST-20 model, with high suction, demonstrates the least deformation, while the ST-60 model exhibits the highest settlement.
- The behaviour is influenced by soil suction, moisture content, and the pozzolanic reaction between MSWI fly ash and soil.

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Key points of interest

- MSWI fly ash contains more irregular unbound carbons and fewer hollow spheres. The major oxides in MSWI fly ash are CaO, SiO2, Al2O3, TiO2, Fe2O3 and MgO.

- UCS results show that Young's modulus and compressive strength increased significantly for the 15MSWI and 20MSWI fly ashes due to the formation of hydration products.

- 20% MSWI fly ash treated sample exhibited 0.86 and 2 MPa after 7 and 28 days curing, while the resilient modulus of the clay increased from 89 MPa (control soil) to 213 MPa in 7 days curing.

- 4 days and 10 days CBR test results reveal that the CBR value of the MSWI fly ash stabilised subgrade is higher than that of class C fly ash stabilised subgrades. The MSWI fly ash can be used as a very good subbase and subgrade material.

- Wet and drying test results at optimum mix (20MSWI) showed that the samples were durable even after 6 wet dry cycles, followed by 48 hours soaking and drying.

- Leachate testing results from MSWI ash revealed that the heavy metal concentrations in pH 5 and 7 after stabilisation are within the maximum allowable limit mentioned by the different states in Australia.

- The ST-60 model exhibited the highest settlement, while the ST-80 and ST-OMC models showed reduced settlement due to increased stiffness resulting from the pozzolanic reaction.

- Overall, 15% and 20% MSWI fly ash treated subgrades perform well for dry and wet weather conditions.