Category 2: Industry Excellence in Consulting, Research or Education

Development of Geopolymer Concrete using Waste Clay Brick as Binder for Pavement Construction

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Project Overview

- Currently, both base and subbase layers of concrete pavements are made using ordinary Portland cement (OPC)-based concrete.
- The primary challenge regarding the sustainability in the concrete pavement industry is the high energy consumption and greenhouse gas emissions (i.e. CO_2) during OPC manufacture. In fact, OPC manufacturing is responsible for almost 8% of global anthropogenic CO_2 emission.
- To reduce the negative impacts associated with OPC production, sustainable concrete can be alternatively developed using geopolymer technology – two types of raw materials can be used to produce geopolymer binders.
- No. 1 is precursors, which are materials rich in alumina and silica – these materials are often referred to as aluminosilicate materials with fly ash and slag being the most common examples.
- In this study, as a new concept, waste clay brick (WCB) powder is used as a precursor.
- No. 2 is activators, which are strong alkali solutions, like sodium hydroxide.
- When precursors and activators are combined, alternative cementitious binders are obtained which are called geopolymer binders. These binders can be used instead of cement to obtain geopolymer concrete.
- In summary, this work combines WCB, fly ash and slag with sodium silicate activator in solid form to produce one-part geopolymer binders.
- Then, using these binders, we develop, optimize and assess geopolymer concrete to use as a pavement construction material.

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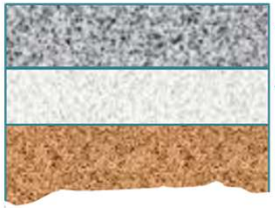
Project Overview

Concrete pavement structure



- Base
- Subbase
- Subgrade

Constructed with ordinary Portland cement (OPC) based concrete.

OPC manufacturing is highly carbon intensive and energy consuming

- Responsible for 8% of global anthropogenic CO_2 emissions
- Seconds only to emissions by fossil fuels

Alternative sustainable concrete can be produced using geopolymer binders

Waste clay brick (WCB) powder as a cement alternative → New concept explored in this study

WCB

Fly ash

Slag

Aluminosilicate precursor

+

Sodium silicate (Na_2SiO_3)

Activator (in solid form)

→ *WCB based one-part binders*

↑ *WCB based geopolymer concrete (GPC)*

→ *Pavement construction material*

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Availability of WCB in Australia

- WCB can be obtained mainly from construction and demolition (C&D) waste, which contributes up to 40% of annual waste generated in Australia.
- Under the C&D waste category, around 17 megatons of masonry waste are generated annually within the country, which mainly includes concrete, bricks and rubble.
- A significant amount of this waste is recycled and reused – however, in the recycling process priority is given to concrete and rubble.
- The second graph on the next page shows that the majority of bricks are going to landfill. The aim of this project is to show that a considerable percentage of the WCB can be used to produce geopolymers.
- Thereby, this research will contribute to reducing the carbon footprint of the construction industry while providing a sustainable and profitable solution for solid waste management.

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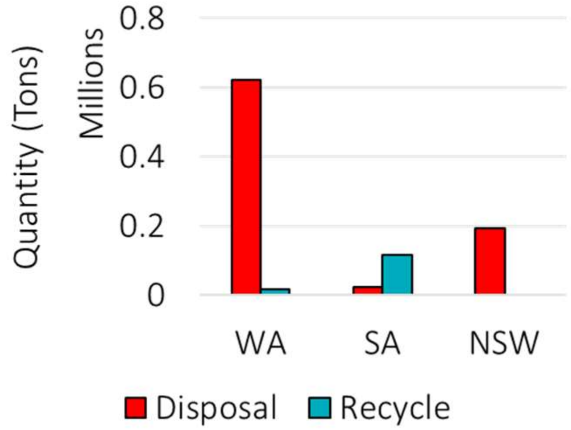
Availability of WCB in Australia

- Construction and demolition waste contributes up to 40% of total waste generated in Australia
- Around 17MT of masonry waste are generated annually → Includes WCB, concrete, rubble

Masonry Waste

Priority is given to concrete

Brick Waste



WCB are mainly going to landfills

This research will contribute to

- Reduce carbon footprint in pavement industry
- Provide sustainable and profitable solution for solid waste management

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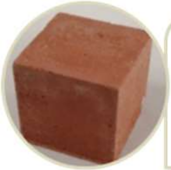
Research Objectives and Scope

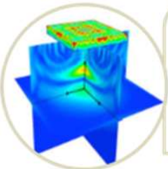
- The research was planned with 5 main objectives.
- The first was to develop and optimize one-part geopolymer binders using WCB, fly ash, slag and sodium silicate as the sole activator.
- Then, these binders were used to develop and optimize pavement grade concrete to satisfy the Australian pavement design requirements.
- Afterwards, the performance and durability of these concretes was investigated to identify their suitability for use in pavement construction.
- The next goal was to correlate properties of geopolymer concrete (GPC) to design standards developed for OPC concrete and identify possible modifications to OPC-based design methods and test standards to make them more suitable for GPC.
- The final objective was to compare and quantify the environmental impacts of using these low carbon concrete as an alternative to OPC concrete.
- Over 50 binder mixes were developed and optimised considering strength, different production parameters like activator content, particle size, mineralogical and macrostructural properties.

Research Objectives and Scope


To develop and optimise one-part WCB based geopolymer binders

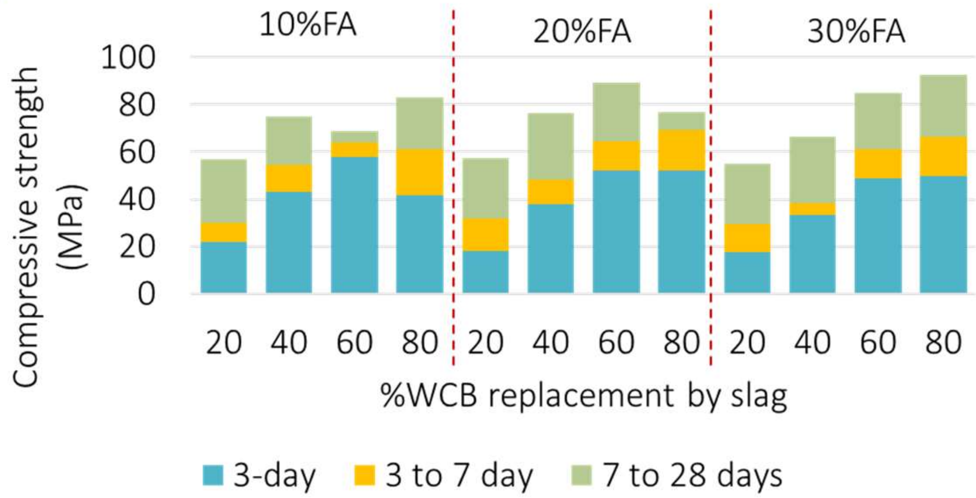

To develop and optimise one-part WCB based GPC

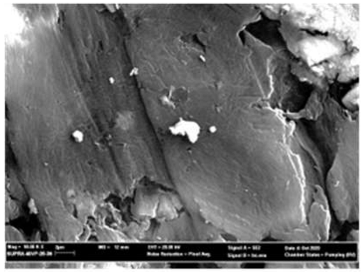

To investigate durability and performance of WCB based GPC

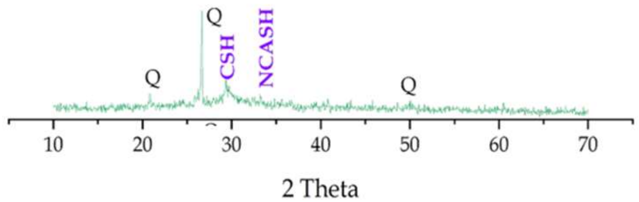

To analyse and correlate properties of WCB based GPC with OPC concrete


To compare and quantify environmental impacts when using geopolymer and OPC

Developed over 50 binder mixes







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Development of WCB-based GPC

- Using optimised binders, different concrete mix designs were developed.
- According to the Australian guidelines, laboratory target strength for a pavement grade concrete is 40MPa at 28 days.
- The first graph on the next page shows the 28-day compressive strength for some selected GPC mixes developed using WCB binders.
- Similar to the water curing used for OPC concrete, for the GPC we used ambient sealed curing, where samples were kept sealed with polythene until the test date.
- These mixes were able to satisfy the basic strength requirement of pavement concrete. For example, as shown in the middle figure on the next page, all mixes exceeded the concrete flexural strength minimum requirement of 4.5MPa at 28 days.
- The maximum allowable volume of permeable voids for pavement concrete is given as 14%. The mixes showed maximum permeable voids less than 11%, which was also excellent for strength and durability.

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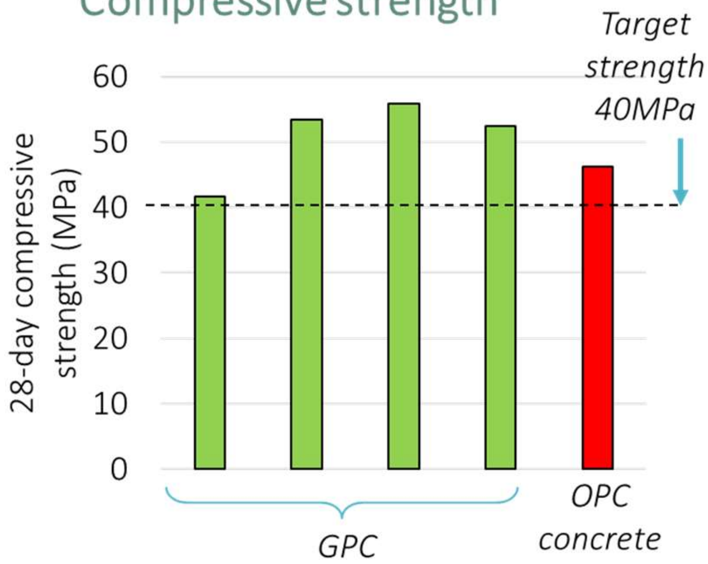
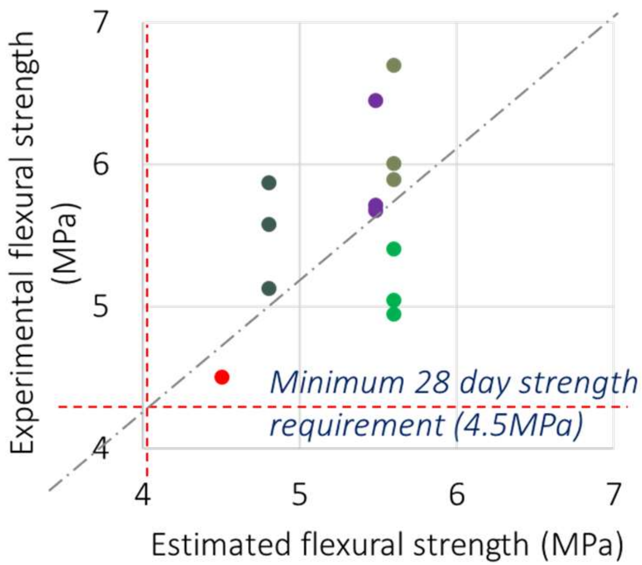
Development of WCB-based GPC

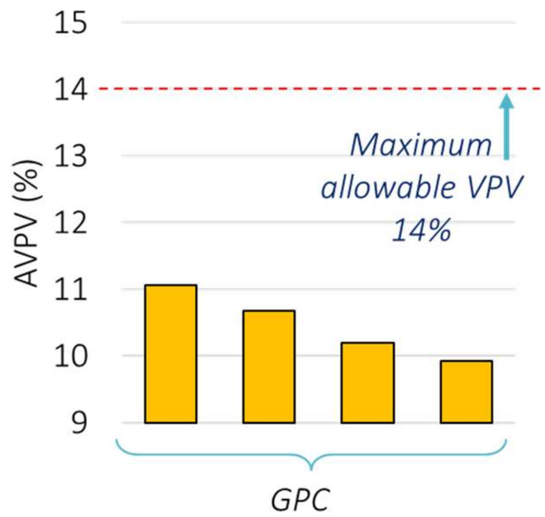
Compressive strength

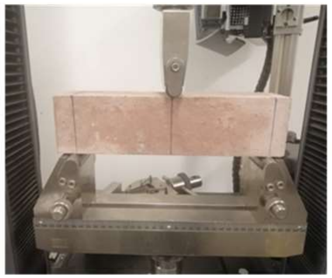


Flexural strength



Volume of permeable voids





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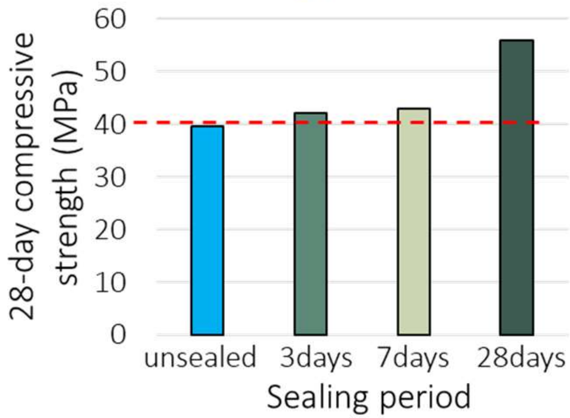
Optimised WCB-based GPC

- The concrete mix designs were optimised in terms of different production parameters and Australian design requirements – some of the results for the optimised mixes are shown on the next page.
- The first figure shows the variation of strength under different sealing conditions, which helps to identify and predict the field strength of concrete.
- Generally, OPC concrete test cylinders are cured in water for 28 days (of course, actual pavement is not subjected to the such perfect curing conditions). Similarly, for these GPC structures, lesser sealing periods in the field should be considered and compared to the laboratory curing. In this case, even covering with polythene only for 3 days still gave enough strength to exceed the required laboratory target strength.
- As shown in the next two figures on the next page, WCB-based GPC showed a high early strength development, which is a critical factor in pavement construction.
- Shrinkage for GPC under different curing conditions are given in the bottom figure on the next page.
- The unsealed sample shows the worst exposure for shrinkage, where the sample is kept in contact with the air from the first day after demoulding. This allows the sample to release more water, causing drying shrinkage. However, even for this sample, the shrinkage values were still less than the maximum allowable limits.

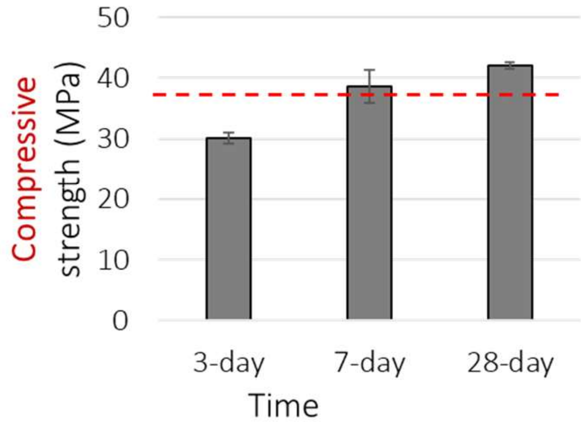
Optimised WCB-based GPC

Prediction of in-situ strength through laboratory trials

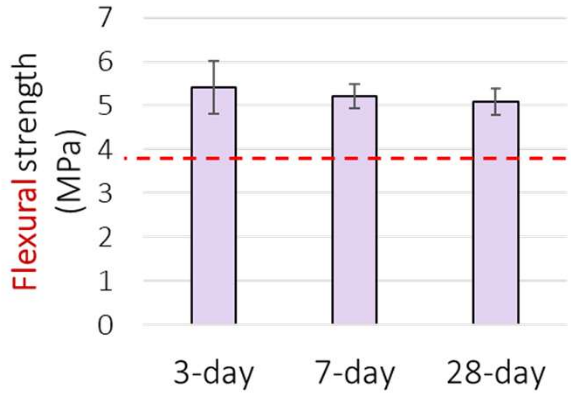
Effect of sealing period



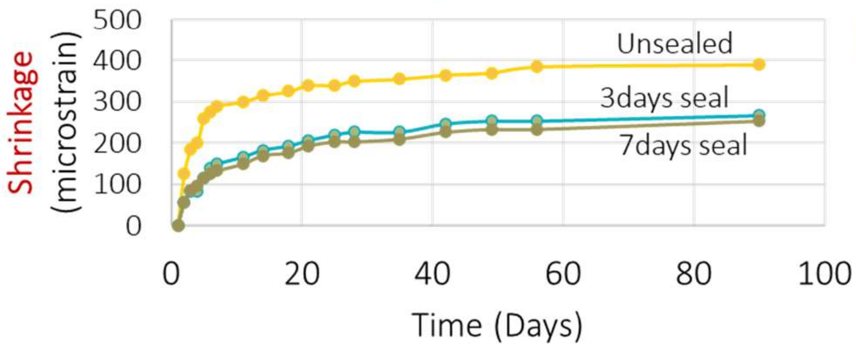
Compressive strength development



Flexural strength development



Total shrinkage



- Maximum allowable shrinkage for mixes with slag
  → @21 days 580µε
  @56 days 680µε

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Durability and Performance of GPC

- Some durability and performance test results for WCB-based GPC are shown on the next page.
- After exposure to constant wetting and drying cycles, these concrete samples showed only a 3% reduction in compressive strength. At the same time, mass loss was also only around 2.5%, which indicates a stable and strong structure of WCB-based GPC.
- Pavements are always under traffic loads where abrasion is a critical consideration. Therefore, abrasion resistance of concrete was evaluated in the laboratory by the standard test method. The concrete samples showed good abrasion resistance where, even after 2850 cycles, top surface abrasion was only 1.08mm.
- Wearing depth of the bottom surface was 0.91mm, which is not significantly lower than that of the top surface. This indicated the proper compaction ability of the concrete.
- The restrained shrinkage and cracking tendency of these GPC were also evaluated, including the change of maximum crack width with time. To position the crack in the middle of the beam and restrain the beam at the ends, a special reinforcement arrangement was used with a crack inducer in the middle. With this test setup, the initial crack appeared 4 days after casting.
- More investigations are currently being undertaken related to cracking tendency and hopefully more comprehensive results will also be obtained in the near future.

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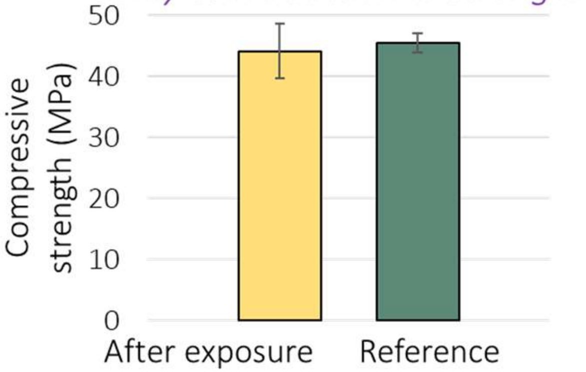
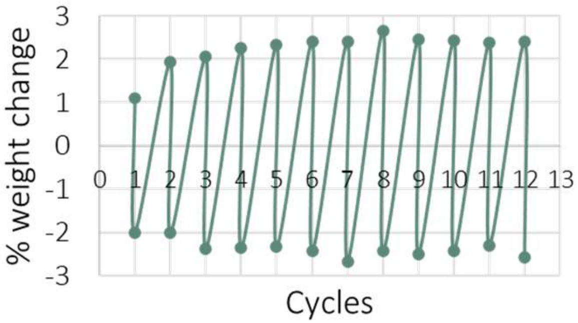
Durability and Performance of GPC

Cyclic wetting and drying

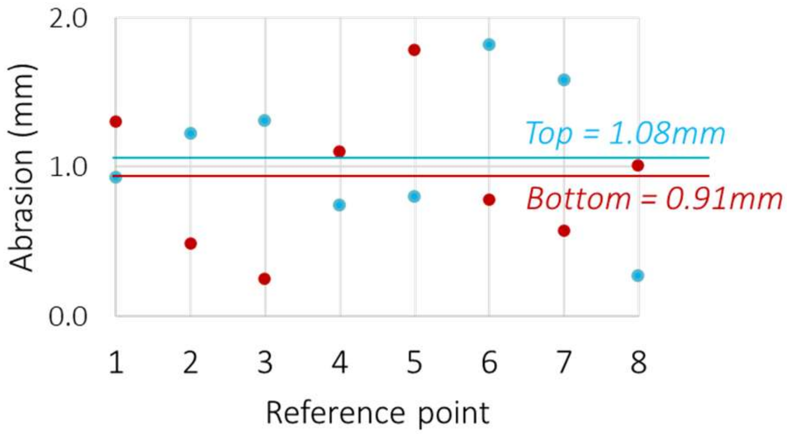
Only 3% reduction in strength

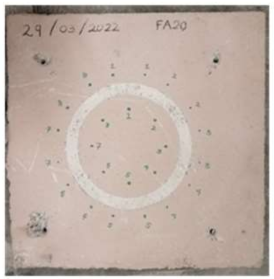




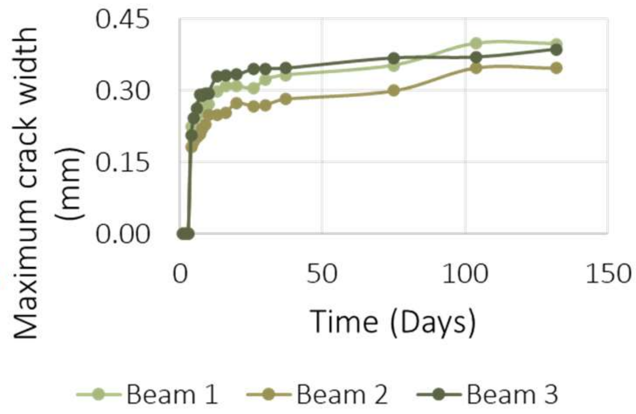
Abrasion

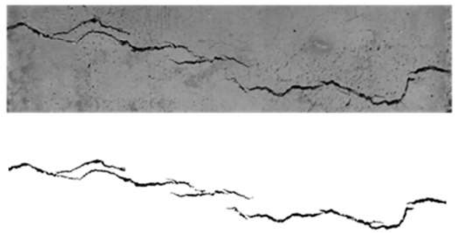
After 2850 rotations





Cracking tendency





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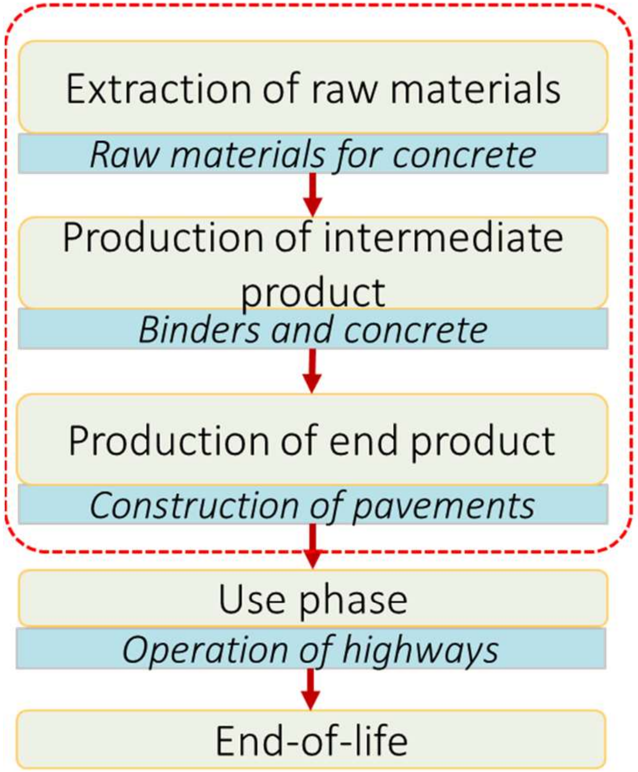
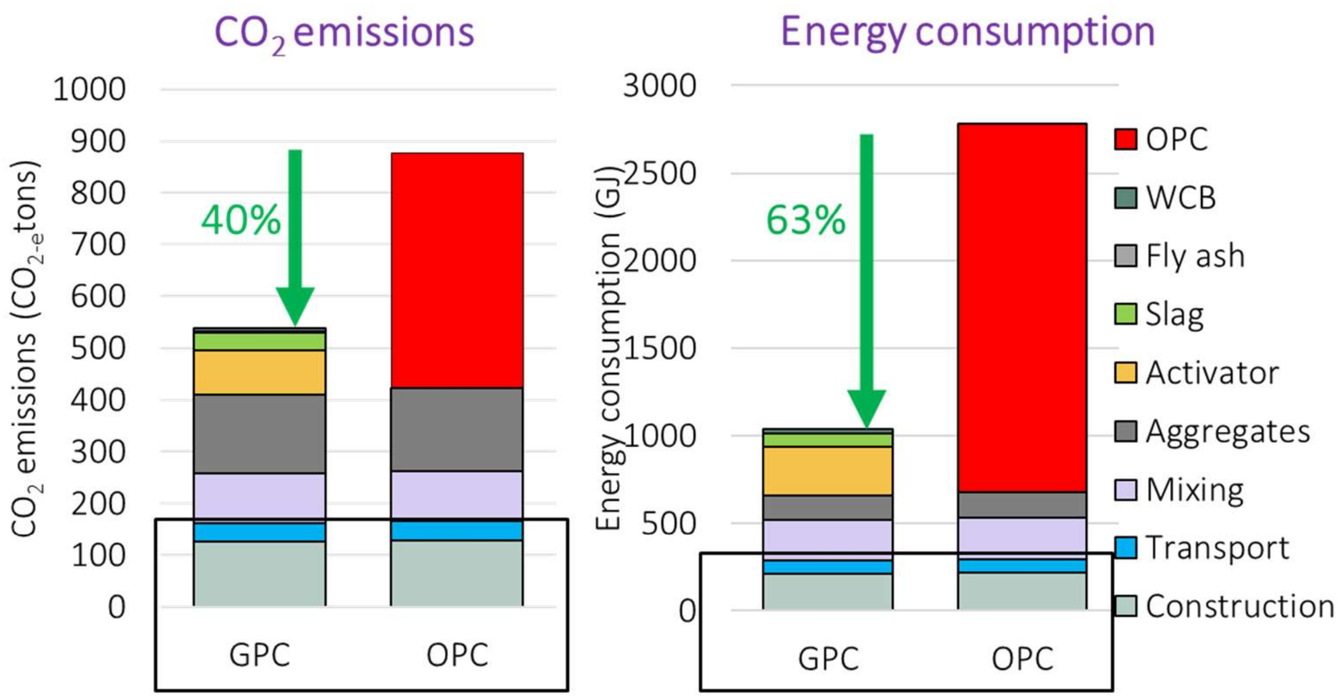
Environmental Impacts

- To evaluate the environmental impacts of producing our concrete, the CO_2 emissions and energy consumption that occurs when using GPC were quantified and compared with OPC concrete.
- Due to the unavailability of data related to the field performance and end life of WCB-based GPC, the assessment was limited from the raw material extraction phase to the pavement construction phase.
- As shown in the graphs on the next page, it can be seen that by using GPC instead of OPC concrete, the carbon emissions can be reduced down by 40% and energy consumption down by 63%.
- Here, impacts from transportation and construction are common for both concrete pavement types and there is no significant difference.
- Therefore, its clear the main reduction is associated with the materials themselves.

Environmental Impacts



Construction of 1km of plain concrete pavement



Transportation and construction impacts are common for both concrete types

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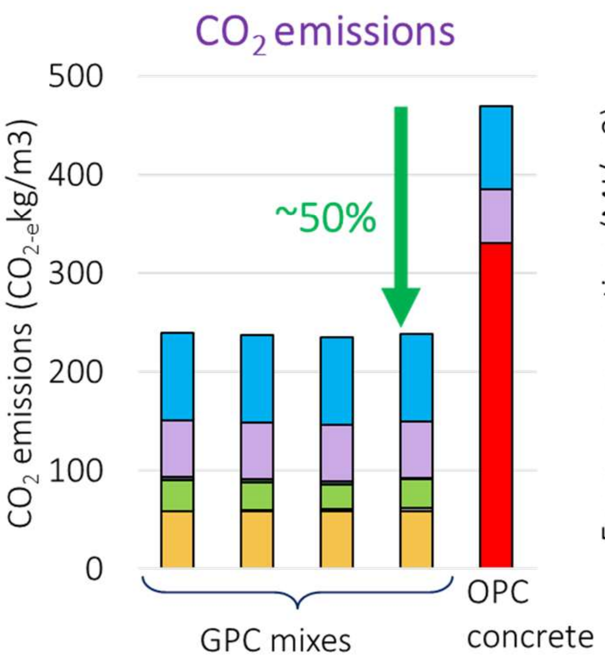
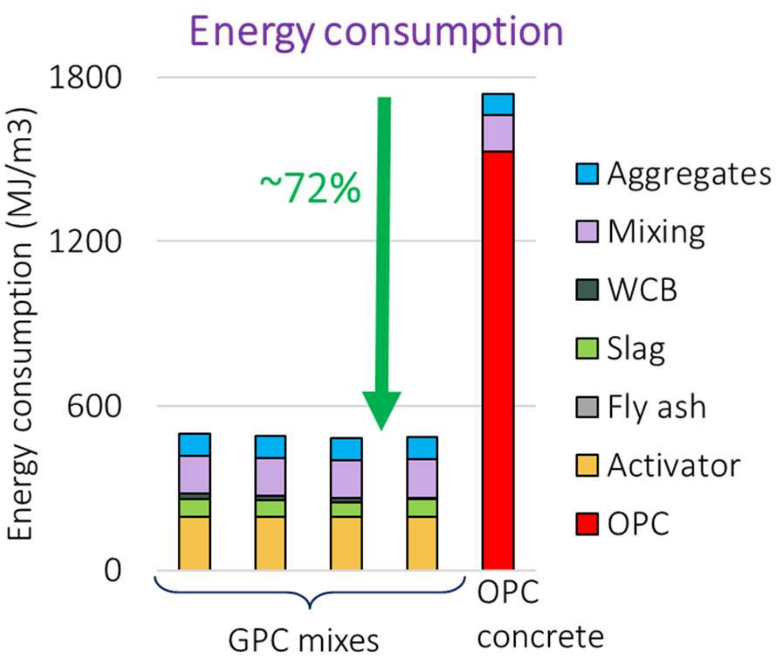
Impacts from Concrete Production

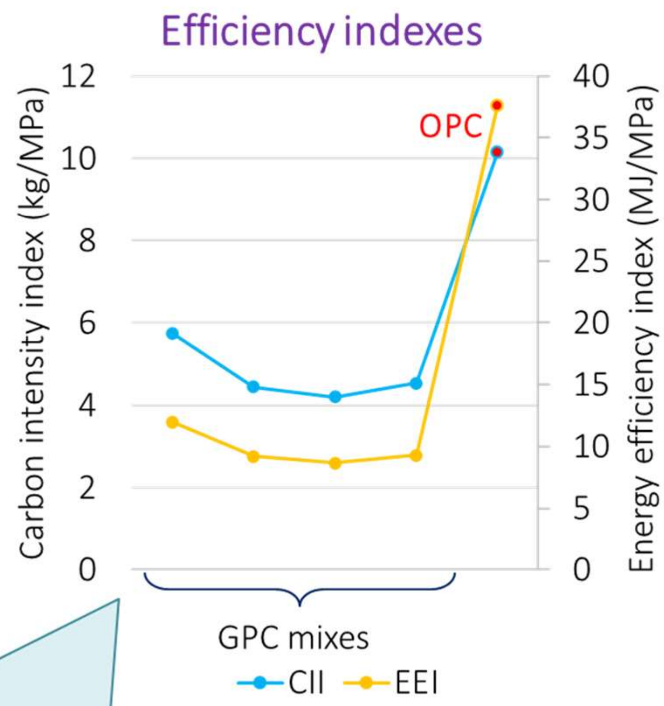
- On the next page the environmental impacts during concrete production can be seen – this includes impacts during raw material extraction, raw material processing and mixing.
- Compared to OPC concrete, GPC developed in this study is 50% less CO_2 emitting and 72% less energy consuming.
- Here also, the impacts from aggregates and mixing components can be seen to be almost similar for both concrete types.
- However, even with those included, total impacts from GPC are much less than the cement component in OPC concrete alone.
- Finally, the environmental and mechanical performance for all concrete types were combined and the carbon intensity index and energy efficiency index were calculated.
- Simply put, these efficiency indexes show the environmental impacts that are traded off to gain the same performance of concrete.
- It is very clear that the use of OPC will result in double the carbon emissions and almost four times the energy consumption compared to GPC to achieve the same performance.

Impacts from Concrete Production

- Highest environmental impacts arise during the binder and concrete production phases







Show the environmental impacts traded off for gaining a 1MPa of compressive strength in concrete

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Summary

- In summary, it can be said that compared to conventionally used OPC concrete, GPC concretes are chemically very different. However, it is possible to achieve the same mechanical performance whilst at the same time, they are more sustainable than OPC concrete.
- More information on this work is available through our recent publications.
- Two technical reports have been successfully completed for our main industrial partner Austroads and SPARC Hub. These reports were peer-reviewed by the Austroads Pavements Task Force Committee.
- In addition, our findings related to WCB-based geopolymer binder development and optimisation, feasibility of developing pavement grade concrete through WCB-based binders and environmental performance of WCB-based geopolymer concrete compared to OPC concrete have been published in international journals.

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Summary

Compared to OPC concrete, GPC is

- Chemically very different
- Mechanically same
- More sustainable

International Publications

Migunthanna, J., Rajeev, P. & Sanjayan, J. (2022). Waste Clay Bricks as a Geopolymer Binder for Pavement Construction. *Sustainability. Sustainable Roads and Airfields: Pavement Materials and Pavement Engineering.*

Migunthanna, J., Rajeev, P. & Sanjayan, J. (2021). Investigation of waste clay brick as partial replacement of geopolymer binders for rigid pavement application. *Construction and Building Materials* .

Migunthanna, J., Rajeev, P. & Sanjayan, J. (2022). Waste clay brick binders for rigid pavement subbase and base concretes. *Road and Airfield Pavement Technology.*

Migunthanna, J., Manjunatha, N.T., Shatagar, V.G., Raghu, D.H., Zinzala, R.S., Rajeev, P. and Sanjayan, J. (2022). Simplified life cycle analysis for rigid pavements constructed using waste materials as binders in concrete. *International Journal of Student Project Reporting.* (Under review)

Migunthanna, J., Rajeev, P. & Sanjayan, J. (2022). Waste clay brick as a part binder for pavement grade geopolymer concrete. *International Journal of Pavement Engineering.* (Under review)

Industry Technical Reports

Austroads Technical Report-**SPARC2020.04.2-1**, Project IH18.4.2, Migunthanna, J., Rajeev, P. & Sanjayan, J. (2020). Long-lasting and environmentally sustainable pavements through geopolymer concrete and composites, SPARC Hub, Notting Hill, VIC, Australia

Austroads Technical Report-**SPARC2021.04.2-1**, Project IH18.4.2, Migunthanna, J., Rajeev, P. & Sanjayan, J. (2021). Long-lasting and environmentally sustainable pavements through geopolymer concrete and composites, SPARC Hub, Notting Hill, VIC, Australia

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