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# Mechanical behaviour and load bearing mechanism of high porosity permeable pavements utilizing recycled tire aggregates

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## HIGHLIGHTS

- The high hydraulic conductivity of tire-rock blends was dominated by rock aggregates with smaller mean diameter.
- The rigid skeleton controls the behavior for $V_{TDA} < 0.3$ while the tire skeleton prevails at $V_{TDA} \geq 0.5$.
- The rigid particles loose effective contact after $V_{TDA}$ of 0.5 and load bearing is controlled through tire skeleton.
- The transitional range between soft and rigid aggregates can be utilized to adjust flexibility of final mixture.

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## ABSTRACT

The benefits of Permeable Paving Systems (PPS) in minimizing surface water run-off which in turn reduces the imposed pressure on stormwater collection systems at the time of flash flooding have been recently remarked profoundly. In addition, the PPS have additional advantages such as filtering the pollutants for downstream water collection systems and accommodating transformation of nutrients and water to the surrounding vegetation. Inclusion of end-of-life tire products in the mixture of PPS can adjust the flexibility of the final product. Tire aggregates will potentially enhance the final product performance in areas where the ground movement or intrusion of roots can cause damage to conventional rigid pavement systems. The effect of addition of waste tire and rubber aggregates to solid granular material have been investigated in the past; however, their focus have been mainly on creating highly compacted mixtures. In contrast; in this study; mixtures of soft (end-of-life tire aggregates) and rigid aggregates (crushed rock) with a relatively high porosity was tested to evaluate their suitability for construction of permeable pavements which require high porosity. The flexibility of mixtures and their stress dependant behaviour was investigated based on the volumetric fraction of soft aggregates in the blend. The transitional soft-rigid behaviour of the mixture can be utilized to mitigate the unexpected deformation induced on the pavement. The compressive behaviour of highly permeable mixtures under $k_o$ loading and deviatoric shear provides an insight on the formation of force chains in the mixtures between the rigid particles. In addition, monitoring the compressive behaviour of rigid-soft aggregates under $k_o$ loading explains soft aggregates cushioning impact on improving the compressibility and shear behaviour of the mixture.

## 1. Introduction

The rapid economic development of modern societies comes with consequences such as dramatic rise in waste generation. Disposal of scrap tires generated from end of life tires is continually increasing globally and in Australia. Mountjoy, et al. [1] reported that 51 million equivalent passenger units (EPU) of Australian tires is entering the waste stream annually of which approximately 5% are recovered through recycling chains. Aside from the negative environmental impacts of landfilling end of life tires, a serious safety concern is recognized by councils and EPA Victoria for tire stockpiles near residential areas. A recent fire incident in a small recycling facility near Melbourne raised the alarm regarding the safety of stockpiling tires for long periods of time. The fired stockpile yard was 18 km north of Melbourne CBD which effected 15 suburbs by toxic fumes. Despite prompt action of authorities, 70% of the stockpile (approximately 130,000 end-of-life tires)

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## List of Notations

| | |
|---|---|
| $C_s = -\Delta e_z/\Delta(\log \sigma'_v)$ | Swelling indices (−) |
| $D_{50}$ | Mean diameter of the aggregates (mm) |
| $D_r$ | Relative density (−) |
| $\Delta e_z$ | Changes in void ratio (−) |
| $G_s$ | The specific gravity of aggregates (−) |
| $h_n$ | The height of the specimen at nth layer (mm) |
| $h_t$ | The total height of the specimen (mm) |
| $K_o$ | Coefficient of earth pressure at rest (−) |
| $m$ | Exponent indicating the sensitivity of the mixture stiffness to stress levels (−) |
| $M = \Delta\sigma_v/\Delta\varepsilon_z$ | Constrained modulus (MPa) |
| $M_1$ | The constrained modulus at $\sigma'_v = 1$ kPa (MPa) |
| $n_t$ | The number of specimen layers to be compacted (−) |
| $p'$ | Mean effective stress (kPa) |
| $q$ | Deviatoric stress (kPa) |
| $S_r = D_{50\ \mathrm{soft}}/D_{50\ \mathrm{rigid}}$ | Soft to rigid aggregate size ratio (−) |
| $U_n$ | The under-compaction percentage at the layer being compacted (%) |
| $V_s$ | Shear-wave velocity (m s$^{-1}$) |
| $V_{TDA}$ | Volume fraction of TDA (−) |
| $\alpha$ | The shear wave velocity at a confinement of 1 kPa (m s$^{-1}$) |
| $\beta$ | Indicates the stress dependency of $V_s$ (−) |
| $\gamma_{max}$ | Maximum dry density (kg m$^{-3}$) |
| $\gamma_{min}$ | Minimum dry density (kg m$^{-3}$) |
| $\sigma'_c$ | Confining pressure of triaxial test (kPa) |
| $\sigma'_v$ | Effective vertical stress (kPa) |
| $\phi$ | The angle of internal friction (degree) |

burnt and the fire was came under control only after 48 h (Fig. 1). Apart from air pollution concerns from the incident, EPA also considered potential impacts to nearby waterways and soil [2]. The wake-up alarm of the Melbourne incident on importance of city safety management and serious environmental penalties of such incidents raise the concern for councils of cities near similar stockpiles. The massive tire stockpile near Longford in Tasmania is 13 times bigger than the tire dump yard in Melbourne with an estimated 1,400,000 units of end-of-life tires. This stockpile is continuously increasing and not only wasting valuable lands and imposing environmental penalties on nature, but also can be a serious threat to the nearby communities. The environmental impacts of landfilling the waste tires calls for innovative solutions of recycling these wastes back into engineering applications. In addition, the safety risk associated with maintenance of the landfills against fire hazards is a strong motivation for pursuing novel recycling alternatives. There has been intensive research dedicated to assessment of hazards of disposing tires to landfills [3–5].

The mechanical properties of tire scraps have been investigated for utilization in civil engineering applications such as concrete manufacturing, pavement constructions, earthfills and highway embankments [6–8]. However, the inferior mechanical properties of tire-derived aggregates (TDA) such as excessive deformation under design loads limits the use of these end-of-life tire aggregates to marginal applications with low percentages of tire. Considering the high costs of recycling tire compared to the low costs of natural quarried aggregates; there is limited use of recycled tire in marginal applications. This means large volumes of tire still end up in landfills. It is important to note that although the load bearing capacity of TDA aggregates is relatively low, their high elastic flexibility can be utilized in construction of low-volume roads. In addition, TDA can be useful where excessive differential settlement (caused by reactive clays or induced by vegetation in footpaths and roads) is an engineering challenge.

Conventional road pavements and footpaths in urban areas are typically rigid to semi-rigid impervious structures. Impermeable surfaces result in augmented surface runoff leading to flash flooding and pollution of waterways. Permeable pavement is an innovative solution to postpone flash flooding of paved surfaces. Permeable surfaces is currently used for stormwater management of footpaths though in a very limited scale. However, lack of technical knowledge and legislation in the area of pavement technology has led to insufficient application within the Australian road construction industry [9].

Contrary to traditional impervious surfaces; permeable pavements permit percolation of water through surface layers

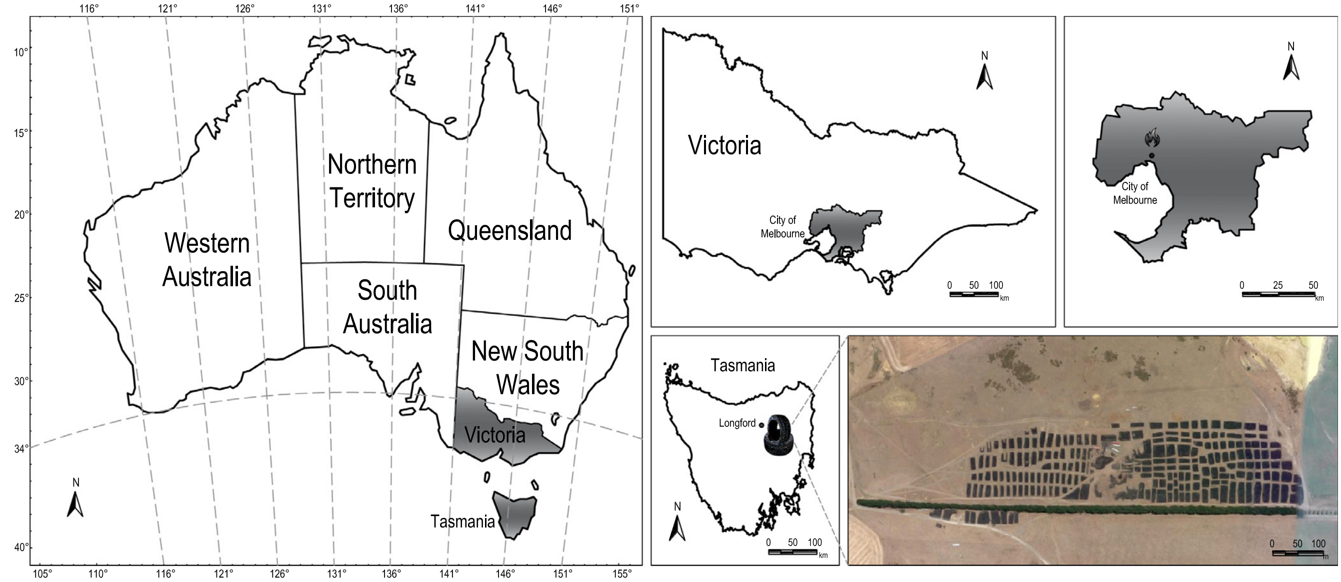

Fig. 1. Location of tire stockpiles near major cities at Melbourne and Longford.