



# Recycled plastic granules and demolition wastes as construction materials: Resilient moduli and strength characteristics



Arul Arulrajah<sup>a,\*</sup>, Ehsan Yaghoubi<sup>a</sup>, Yat Choy Wong<sup>b</sup>, Suksun Horpibulsuk<sup>a,c,\*</sup>

<sup>a</sup> Department of Civil and Construction Engineering, Swinburne University of Technology, Hawthorn VIC3122, Australia

<sup>b</sup> Department of Mechanical and Product Design Engineering, Swinburne University of Technology, Hawthorn VIC3122, Australia

<sup>c</sup> School of Civil Engineering, and Center of Excellence in Innovation for Sustainable Infrastructure Development, Suranaree University of Technology, Nakhon Ratchasima 30000, Thailand

## HIGHLIGHTS

- Plastics and demolition wastes evaluated as construction materials.
- 3 types of plastics and 2 types of demolition wastes were tested.
- Resilient moduli and strength tests.
- 5% plastics found to be optimum content as a construction material.

## ARTICLE INFO

### Article history:

Received 5 December 2016

Received in revised form 12 April 2017

Accepted 24 April 2017

Available online 6 May 2017

### Keywords:

Plastic  
Demolition  
Waste  
Recycling  
Stiffness  
Strength

## ABSTRACT

Vast quantities of plastic and demolition wastes are generated annually by municipal and commercial industries in all developed and developing countries. The sustainable usage of recycled plastic and demolition wastes as alternative construction materials has numerous environmental and economic advantages. New opportunities to recycle plastic and demolition wastes into alternative resource materials for construction industries would mitigate landfill issues and significantly reduce global carbon emissions. Infrastructure projects typically consume significant quantities of virgin quarry materials, hence the usage of plastic and demolition wastes as alternative construction materials will divert significant quantities of these wastes from landfills. In this research, three types of recycled plastic waste granules: Linear Low Density Polyethylene filled with Calcium Carbonate (LDCAL), High Density Polyethylene (HDPE) and Low Density Polyethylene (LDPE) were evaluated in blends with Crushed Brick (CB) and Reclaimed Asphalt Pavement (RAP). The blends prepared were evaluated in terms of strength, stiffness and resilient moduli. Resilient moduli prediction models were proposed using Repeated Load Triaxial (RLT) tests to characterize the stiffness properties of the plastic/demolition waste blends. Polyethylene plastic granules with up to 5% content were found to be suitable as a road construction material, when blended in supplementary amounts with demolition wastes. This research is significant, as the usage of plastics as a construction material, in combination with demolition wastes will expedite the adoption of recycled by-products by construction industries. Furthermore, the plastic blends were prepared without the requirement for any further operations, such as reshaping plastic granules into fibers, hence leading to significant energy and costs savings.

© 2017 Elsevier Ltd. All rights reserved.

## 1. Introduction

The production and landfilling of solid wastes has exacerbated carbon emissions and increased pollution in metropolitan cities worldwide. Management of wastes remains a global challenge for developed and developing countries alike [1]. The traditional approach of landfilling solid wastes is unsustainable and has become increasingly uneconomical, given the scarcity of land in urban precincts. Opportunities to recycle solid wastes into alterna-

\* Corresponding author at: Department of Civil and Construction Engineering, Swinburne University of Technology, PO Box 218, Hawthorn, VIC 3122, Australia (A. Arulrajah). School of Civil Engineering, Suranaree University of Technology, Nakhon Ratchasima 30000, Thailand (S. Horpibulsuk).

E-mail addresses: [arulrajah@swin.edu.au](mailto:arulrajah@swin.edu.au) (A. Arulrajah), [eyaghoubi@swin.edu.au](mailto:eyaghoubi@swin.edu.au) (E. Yaghoubi), [ywong@swin.edu.au](mailto:ywong@swin.edu.au) (Y.C. Wong), [suksun@g.sut.ac.th](mailto:suksun@g.sut.ac.th) (S. Horpibulsuk).

tive resource materials are increasingly being sought by construction industries. The successful use of recycled wastes as a valuable resource material would significantly reduce the carbon footprint of road construction industries and furthermore reduce the demand for virgin quarry materials.

Plastic wastes comprise 8–12% of the municipal waste stream with approximately 190 million tonnes generated annually [2]. In Australia alone, 2.24 million tonnes of plastic waste were generated in 2008, which comprised 16% of the municipal waste stream [3]. Factors such as population growth, low production cost, and the wide variety of applications has led to an increasing production of plastics [4], with polyethylene products primarily contributing to the large volumes of plastic wastes [2].

Three types of polyethylene granules generated by the plastic recycling industries are Linear Low Density Polyethylene filled with Calcium Carbonate (LDCAL), High Density Polyethylene (HDPE) and Low Density Polyethylene (LDPE). Mineral fillers, such as calcium carbonate are added to polymers to enhance properties, as well as to reduce production costs. The mechanical properties of LDCAL, HDPE and LDPE such as density, maximum using temperature and tensile strength have been reported previously by several researchers [4–6]. Research on application of HDPE as a construction material has been limited to the usage of this material as a reinforcement in the form of fibers or strips. Benson and Khire [7] researched on the usage of HDPE as a reinforcement material for sand and reported that improvement in terms of bearing capacity, stiffness, resilient and shear properties of the sand through geotechnical tests. Choudhari et al. [8,9] reported that improvement in geotechnical properties of pavement base, subbase and subgrade layers could be attained by using HDPE in the form of strips. Improvement of flexible pavement material in terms of bearing capacity by introducing HDPE strips was also reported by Jha et al. [10].

LDPE has been used in hot mix asphalt [11] and concrete [12,13]. HDPE and LDPE granules have been researched in combination with recycled concrete aggregates in pavement bases by Yaghoubi et al. [14], who reported that despite slight degradation in properties, the blends were comparable to conventional quarry materials. Application of LDCAL as a civil engineering construction material has been limited to reinforcing purposes, commonly in the form of geosynthetics [15,16]. Lack of understanding of the properties of recycled plastic wastes continues to limit their usage as a civil engineering construction material.

Crushed Brick (CB) and Reclaimed Asphalt Pavement (RCA) are generated by recycling the waste solids after demolition activities. CB is obtained from demolition of masonry buildings, while RAP is produced from the stockpiles of spent asphalt that has been removed from aged roads [17]. The mechanical properties of CB and RAP have been found to be comparable to conventional quarry materials in various civil engineering construction applications [18–24]. Utilizing the recycled plastics in the form of granules instead of fibers or strips would result in considerable energy and cost savings, as compared to the production of strips or fibers out of the plastic granules. Nevertheless, too much degradation of the properties could result in the need for traditional chemical stabilization to improve the mechanical properties of the pavement materials [25]. The usage of chemical stabilization to enhance the properties of construction materials have been reported by several authors [25–28].

The aim of this research was to evaluate the viability of using waste plastic granules in combination with demolition wastes as a road construction material, without the need for any form of further stabilization. The plastic granules and demolition wastes used in this research are by-products of recycling industries. The stiffness and strength of the blends of plastic granules/demolition wastes were evaluated in this research and resilient moduli models

proposed to characterize the recycled blends. The evaluation of plastic granules (LDCAL, HDPE or LDPE) in blends with demolition wastes (CB, RAP) will enable further understanding of the strength, stiffness and performance of these recycled by-products as a construction material. The optimum limits of the supplementary plastics content that can be used in combination with demolition wastes would bring new knowledge to civil engineering construction industries and expedite the adoption of recycled by-products.

## 2. Materials and methods

The materials used in this research were comprised of LDCAL, HDPE and LDPE plastic granules together with CB and RAP demolition wastes from the state of Victoria, Australia. The blends of plastics and demolition wastes used in this research are presented in Table 1. Plastic contents of 3% and 5% were selected based on past work on plastics with recycled concrete aggregates [14].

Gradation of the blends was investigated using Talbot and Richart [29] equation (aka Fuller's equation) as presented in Eq. (1), whereby PSD curves of the blends were fitted into the equation to obtain the  $n$  exponent of each blend.

$$P = 100 \times \left( \frac{d_i}{D_{\max}} \right)^n \quad (1)$$

where  $d_i$  is the size of the sieve in question,  $P$  is the total percent finer than the sieve in question,  $D_{\max}$  is the maximum particle size, and  $n$  is the exponent of the Fuller's Equation.

For a determined  $D_{\max}$ , and diameters of  $d_i$ , the  $n$  exponent is the only variable parameter that changes the gradation curve. Originally, Fuller and Thompson [30] reported a value of 0.5 for the  $n$  exponent in order to achieve the highest density. However, later research works showed that the  $n$  exponent of 0.5 might not be a fixed value for a gradation with the least voids. For instance, in the 1960 s Federal Highway Administration (FHWA), introduced an  $n$  exponent of 0.45 for a PSD leading to the highest density [31].

Optimum Moisture Content (OMC) and Maximum Dry Density (MDD) of blends were determined using modified Proctor method according to ASTM-D1557 [32]. A 152.4 mm diameter mold with a height of 116.43 mm was used and samples were compacted in five layers with 56 blows of the hammer on each layer. OMC and MDD were then obtained using the compaction curves plotted based on the test results. For a uniform distribution of plastic particles, the blends were mixed for several minutes. Also, for ensuring uniformity, a random sample consisting of 95% CB and 5% plastic was divided into four quarters using a riffle and the plastic content of each quarter was visually estimated. Segregation of aggregates was avoided, by keeping the scoop as close as possible to the bottom of the mold when placing the material.

California Bearing Ratio (CBR) was undertaken following ASTM-D1883 [33]. Samples were compacted in five layers, each under modified Proctor compaction effort using 56 blows in a 152.4 mm diameter mold. Care was taken to control the uniform distribution of plastics in the blends, as well as avoiding segregation while preparing and compacting the CBR samples.

Resilient properties of the blends due to the addition of supplementary amounts of LDCAL, HDPE and LDPE plastic granules were evaluated using specialized Repeated Load Triaxial (RLT) tests, and compared with typical values of resilient modulus for control (0% plastics) CB and RAP. RLT tests simulate the repeated loads on civil engineering infrastructures when subjected to traffic loads [34]. A triaxial cell was used with the universal testing machine to carry out the RLT tests. RLT samples were prepared using a split compaction mold, 100 mm in diameter and

**Table 1**  
Blends of demolition wastes/plastic granules used in this research.

Blend composition	Blend name
Control CB	CB
3%LDCAL + 97%CB	LDCAL3/CB97
3%HDPE + 97% CB	HDPE3/CB97
3%LDPE + 97%CB	LDPE3/CB97
5%LDCAL + 95%CB	LDCAL5/CB95
5%HDPE + 95%CB	HDPE5/CB95
5%LDPE + 95%CB	LDPE5/CB95
Control RAP	RAP
3%LDCAL + 97%RAP	LDCAL3/RAP97
3%HDPE + 97%RAP	HDPE3/RAP97
3%LDPE + 97%RAP	LDPE3/RAP97
5%LDCAL + 95%RAP	LDCAL5/RAP95
5%HDPE + 95%RAP	HDPE5/RAP95
5%LDPE + 95%RAP	LDPE5/RAP95

Download English Version:

<https://daneshyari.com/en/article/6480596>

Download Persian Version:

<https://daneshyari.com/article/6480596>

[Daneshyari.com](https://daneshyari.com)