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Permanent deformation behaviour of pavement base and subbase containing recycle concrete aggregate, coarse and fine crumb rubber

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HIGHLIGHTS

- Two types of recycled materials were used in the study.
- Fine and coarse crumb rubbers were added to the recycled concrete and crushed rock aggregates.
- Permanent deformation tests were performed.
- Permanent deformation performance of the aggregates with the crumb rubbers has been analysed.
- The suitability of recycled materials for use in base/subbase pavement applications are elaborated.

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ABSTRACT

Pavement layers must be sufficiently strong to carry all traffic loads and resist the accumulation of permanent deformations such as rutting and avoid premature failures including top-down cracking during their service lives. In recent years, the utilization of recycled construction and demolition (C&D) materials in civil and transportation infrastructure construction has been considered as a significant solution to replace conventional and natural aggregates, therefore to achieve the goal of building low-carbon footprint constructed facilities. Unfortunately, limited data have yet reported on the permanent deformation behaviour of the recycled materials in pavement, especially the effect of crumb rubber and rubber size with C&D aggregates on the permanent deformation behaviour in base and subbase layers. This paper provides unique laboratory information and testing results in this regard. In this study, two different groups of crumb rubber particles with sizes ranged from 400 to 600 μm (fine) and 15–20 mm (coarse) were separately added to 20 mm recycled concrete aggregate (RCA) and 20 mm crushed rock (CR) at 0.5, 1 and 2% by weight of the aggregates to study the effects of crumb rubber and rubber size on permanent deformation behaviour of RCA and CR aggregates. In particular, the permanent deformation behaviour of the RCA/CR with crumb rubber was investigated through the repeated load triaxial tests. It was observed that the CR samples should be avoided for use in base and subbase courses.

1. Introduction

Global climate change caused by human activities releasing an overabundance of greenhouse gases into the atmosphere is the critical challenge human beings are facing on Earth in the 21st century. Construction is one of the largest industries in the world. Tremendous amounts of materials are consumed in construction activities and huge amount energy is used. Greenhouse gas emission takes place in these activities. Reusing recycled construction and demolition (C&D) materials in civil and transportation infrastructure construction can benefit environmental, social, and economic aspects. The benefits of sustainable design and construction offer the potential to change the way in which we as humans face the challenges in the future. The utilization of nonconventional materials has been considered as a significant solution to replace natural aggregates, therefore to achieve the goal of building low-carbon footprint constructed facilities. The C&D and other recycled or nonconventional materials that are extensively available and can be used in pavement construction include, but not limited to, recycled concrete aggregate (RCA), scrap tire crumb rubber, varied ferrous, nonferrous and nonmetallurgical slags, municipal incineration waste, phosphogypsum, and other

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postindustrial recycled materials that serve as additives for construction applications [2,18,21,22,29,30].

The amount of waste materials generated from construction and demolition accounts for about half of the wastes generated in the world. The consumption rate of building materials is dramatically increasing [9]. Reducing the generation of C&D wastes has huge environmental benefits as well as cost-saving benefits. Also, it has been reported that reusing construction and demolition wastes could reduce the CO_2 emissions up to 65% [8]. RCA is one of the most well-known C&D wastes that has been used for civil and transportation infrastructure projects. It is noted that about 8.7 million tons of RCA are stockpiled in Australia every year [3].

Scrap tyres do not degrade and they are bulky and difficult to dispose of; therefore treatment of the scrap tyres has recently become an environmental problem [17,21,24]. It was reported that the brittleness index decreased by the inclusion of rubber [13,33]. Pettinari et al. [16] concluded that addition of rubber could improve the toughness, impact resistance and fatigue performance of base and subbase of pavements. Furthermore, crumb rubber has high impact resistance, very low water absorption, low shrinkage, acid resistance, excellent thermal insulation and good sound insulation. It also can undergo large deformations and absorb significant plastic energy. However, it is reported that the inclusion of rubber decreases the compressive and tensile strength [23,34].

Using a by-product in construction is a complicated process which requires a thorough understanding of the virgin material, by-product, end product, and their interactions. Special testing and investigation are needed. This originated this study: the permanent deformation behaviour of granular material containing recycled concrete aggregate, natural crushed rock, and coarse and fine crumb rubber. Li et al. [15] reported that RCA and CR had CBR values of 140% and 130%, respectively. They found that the CBR values of RCA and CR increased with the fine rubber content and decreased with the coarse rubber content. The results show that the combination of the wastes can be considered for pavement applications in terms of resilient modulus.

The objective of this research is to understand the effects of crumb rubber content and crumb rubber size on the permanent deformation behaviour of RCA and CR aggregates as base/subbase layers of pavements in order to evaluate whether they are feasibly useful in the base or subbase layers of road pavement. In particular, the permanent deformation behaviour of the materials (i.e., RCA and CR) along with crumb rubber was investigated through the repeated load triaxial tests.

Flexible pavement consists of asphalt layers over one or more unbound granular layers known as base and subbase layers. The unbound granular base and subbase layers that are compacted over a suitable subgrade soil play important roles as structural components of the entire pavement to support traffic loads and resist permanent deformation. The resilient deformation of the unbound granular layers should be sufficiently minimal to bear the cyclic loadings and avoid the fatigue cracking of overlying asphalt layers. Permanent deformation of pavement, i.e., rutting, a surface depression in the asphalt pavement along the wheel paths, stems from permanent deformation in any of the pavement layers, hot-mix asphalt layer, granular base and subbase, or subgrade soil. It is usually caused by densification and/or lateral movement of the materials due to traffic loading stress/strains. Pavement uplift may occur along the sides of the rut but, in many instances, ruts are noticeable only after a rainfall when the wheel paths are filled with water. There are three types of rutting based on the causes of rutting, i.e., (i) structural rutting, caused by base courses or subgrade; (ii) instability rutting, caused by asphalt concrete layers; and (iii) surface wear or densification. Fig. 1 shows the structural rutting due to weak granular base and granular subbase.

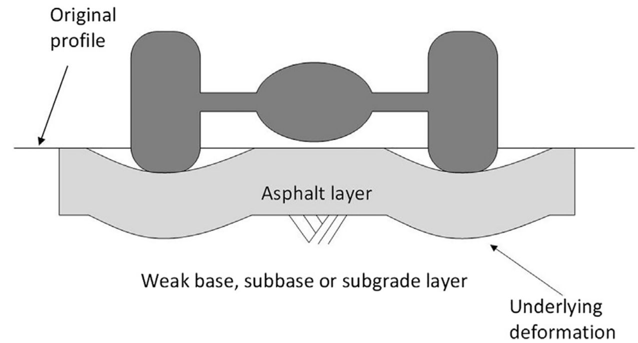

Fig. 1. Rutting due to permanent deformation of granular base and subbase layers (structural rutting).

Structural rutting is obviously of concern, this is a matter of an appropriate pavement design, materials specification and construction quality. To mitigate rutting, it is critical understand the characteristics of base course materials, especially when recycled materials are involved.

Safety is the paramount concern of rutting. For vehicles, there is reduced frictional characteristics, e.g., wheel path flushing, changing lanes becomes hazardous, there is the risk of loss of control, water ponds in wheel paths, potentially forming ice, and snow and ice removal becomes more difficult. For pedestrians, vehicle stopping distances increase at crosswalks during inclement weather, and tripping on the ruts becomes a potential hazard.

The gradual accumulation of permanent deformation of granular layers is very small during each loading cycle but its accumulation can lead to the collapse of the pavement layers due to excessive rutting. In addition, rutting can decrease the service life of pavement, lower road drivability, as well as affect the basic vehicle handling manoeuvers, therefore increase accidents. Rutting due to weak granular base and subbase layers is caused by shear and densification deformation, and develops marginally by increasing the number of loadings. Thus, pavement layers including hot-mix asphalt, granular materials, and subgrade soil must be strong enough to bear the accumulation of permanent deformations and avoid premature failures during their service lives [5,7,11,14,20,19,28]. Therefore, long-term permanent deformation is one of the most important factors to consider in adequate pavement design. In this study, the permanent deformation behaviour of the RCA/CR with crumb rubber was investigated through the repeated load triaxial tests. The test procedure employed in this study is time-consuming and very challenging. Sample preparation and testing process may take up to three days depending on the number of loading and unloading cycles.

2. Theoretical background

Laboratory repeated load triaxial (RLT) test is currently the most popular method to evaluate the permanent deformation properties of unbound granular materials. The shakedown theory is widely used to determine the permanent deformation behaviour of unbound granular materials [10,12,26]. Based on the shakedown theory (Fig. 2), the unbound granular materials are categorized into three groups [32]:

- Range A: plastic shakedown: unbound granular material response is plastic for a finite number of load cycles, with a rapid decrease in permanent strain rate; afterward the response becomes purely elastic (i.e. becomes resilient after post-compaction).