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Potential use of reclaimed asphalt pavement and recycled concrete aggregate in base/subbase layers of flexible pavements

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HIGHLIGHTS

- Addition of RAP contents can significantly increase the M_R value of the blended sample.
- Addition of RAP contents can significantly increase the residual strain of the blended sample.
- Under controlled conditions RAP can be used in base/subbase layer of the pavement.

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ABSTRACT

In current road and pavement engineering practices, the lack of fresh natural aggregate (granular material) supplies with increasing processing costs have led to use various reclaimed/recycled materials from old structures as a source of construction materials. Reclaimed Asphalt Pavement (RAP), and Recycled Concrete Aggregate (RCA) have been used as aggregates for pavement construction for some time. This study is focused on the characterization of blended materials containing 50% and 75% of RAP with fresh granular materials and RCA to evaluate whether they are suitable for granular base/subbase layers of flexible pavements. A series of laboratory tests was performed to determine the resilient modulus (M_R) and the constrained modulus (M_c) for both fresh granular materials and their blends. Statistically, the notable increase was found in the M_R values of the blended samples containing 75% RAP material and 25% fresh granular, particularly at higher levels of bulk stresses. It was also found that the accumulative strains during cyclic loading generally increase with an increase in the percentage of RAP contents in the blended samples. M_c test results show an increasing trend with the increasing level of axial stress, however, M_c value decreases with increasing percentage of the RAP content. Never-the-less, the *t*-test showed that accumulative strains during M_c tests were found to increase significantly with an increase in the percentage of RAP contents.

1. Introduction

Use of recycled materials for the construction of roads, pavements, footpaths is increasing all over the world due to their cost effectiveness and environmentally sustainable aspects. The most common recycled materials used in different layers of flexible pavements are Reclaimed Asphalt Pavement (RAP) [1–3], Recycled Concrete Aggregate (RCA) [4–6], recycled bricks [7,8], recycled glass [9–14] and fly-ash [15].

Data provided by European Asphalt Pavement Association (EAPA) show that in Europe, 47% of the available RAP was used in hot mix asphalt applications during 2011 [16]. In the US, statistics published by National Asphalt Pavement Association (NAPA) and documented by Hansen and Copeland, [17]; Zaumanis et al., [18] estimates a total of 71.8 million tonnes of RAP accepted in 2011, 84% of which were used in asphalt applications. Although nationally this is a high re-use rate, in urbanized areas the restrictions on the maximum allowed RAP content in mix design and technical capabilities of asphalt plants have created a high surplus of RAP. Several studies have shown that the RAP mixtures in hot mix asphalt have performed equal or better than the fresh granular material [18–23]. RAP has been used in hot mix asphalt pavements in various percentages that reached in some cases up to 80% [24]. Most studies have recommended the use in a range from 20–50% [15,25,26]. Hence in addition to using recycled materials as a replacement for fresh granular material in hot mix asphalt, there is a demand for them to be used as granular base/subbase materials.

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In recent years, efforts have been made to incorporate RAP into pavement base or subbase applications [1–4,27–32]. RAP stabilised with cement binders has been reported toperform satisfactorily in pavement base and subbase layers [2,3].The application of RAP and RCA in pavement base/subbase as an aggregate, however, has been limited due to the lack of reported laboratory testing and field-testing results [33].Most of the existing literature concludes that M_R value increases with RAP content; however, the majority of the studies have only considered low RAP contents in the blends. Moreover, the effects of other fundamental properties including accumulative deformation on the structural behaviour of the RAP are lacking. An extensive analysis of the characteristics of RAP to be incorporated into base/subbase layer is not available in the literature [33]. This situation demands the developing procedures/guidelines for the successful use of RAP and RCA as unbound materials within the framework of different design methods being applied for highway pavements.

The main objective of this research is to analyse the results of performance-based tests on selected fresh granular materials, RCA and RAP for the use in base/subbase layer of flexible pavement. In particular, the focus is placed on studying the impact of the variation of the resilient modulus and constrained modulus with RAP content when different types of RAP are mixed with a fresh granular material. In order to achieve this goal, the research emphases on the following tasks:

1. Carry out a literature review focusing on the use, testing, and evaluation of RAP and RCA materials in unbound pavement layers, taking into account various research findings, performance data, current practices and related specifications from other studies.
2. Conduct laboratory tests to determine the stiffness and compressibility of blended materials prepared by mixing fresh granular materials/RCA with RAP.
3. Characterise the dependency of resilient and constrained moduli and accumulative strain of blends containing RAP as a major constituent on the applied stress states under repeated loading.

2. Reclamation of RAP material

RAP is reclaimed when an existing hot mixed asphalt (HMA) layer is removed for reconstruction or resurfacing. The two methods generally used for RAP reclamation are (i) cold milling and (ii) ripping & breaking [34–38]. RAP properties are governed by milling and ripping/crushing operations, as well as the characteristics of the asphalt binder, age of the asphalt pavement and aggregates present from which the RAP is reclaimed [38]. RAP reclaimed from surface courses (compared to binder courses) is usually of higher quality because of the higher quality aggregates that were used in the original construction.

The cold milling method which is most commonly used in engineering practices generally removes up to 50 mm thick HMA in a single pass while restoring the surface to a specified grade and slope. A number of passes may be required, depending on the distress severity, to free the surface of any rutting, bumps or other defectiveness. The Asphalt Recycling and Reclaiming Association (ARRA) categorise cold milling into five classes [39]:

- Class I – Milling the existing HMA to the necessary depth to remove surface irregularities.
- Class II – Milling the existing surface to a uniform depth.
- Class III – Milling the existing surface to a uniform depth and cross slope.
- Class IV – Milling the entire thickness of the HMA layer.
- Class V – Milling the existing surface to variable depths.

Full-depth removal involves ripping and breaking the pavement using a rhino horn on a bulldozer and/or pneumatic pavement breakers. In most instances, the broken material (removed HMA blocks) is picked up by front-end loaders and loaded into haul trucks. The material is then hauled to a central facility for processing. At this facility, the RAP is processed using a series of operations, including crushing, screening, conveying, and stacking for later use [34,35,38].

Proper crushing and screening of RAP can yield well-graded aggregate particles that are partially or wholly coated with asphalt binder [35,39]. Although the majority of old asphalt pavements are recycled at central processing plants, asphalt pavements may also be pulverised in place and incorporated into granular or stabilised base courses using a self-propelled pulverising machine. Cold milling is generally more efficient than ripping and crushing because it is usually completed in-situ without hauling RAP to a crusher or at the central processing plant for processing. However, it is commonly accepted that cold milling produces more fines than ripping and crushing [35].

3. Aggregate degradation during RAP reclamation

RAP particles often consist of conglomerates of smaller aggregates glued together by mastic. The maximum size of RAP generally varies from 30 mm to 50 mm but has not been categorically defined in the literature [38]. Aggregate degradation occurs during milling and crushing operations, which causes the RAP gradation to be finer than the gradation of the original virgin aggregates. Aggregate degradation during milling is a function of the top size and the gradation of the aggregates used in asphalt pavements [39]. However, in most cases, RAP is well graded and slightly finer than crushed natural aggregates [37].

The crushing of HMA pavements at a central plant is carried out using compression and impact crushers. RAP breakers are used if crushed RAP starts to form a flat, dense mass, particularly on warm and humid days. Impact crushers may be one viable equipment for RAP reclamation, as there is less chance of the equipment getting plugged with RAP material, which sometimes happens when using jaw crushers. An impact crusher can also be treated as a secondary crusher when a jaw crusher is used as a primary crusher. In a combination crusher, the jaw crusher reduces the HMA slabs to more convenient size, which are then further reduced to useable sizes using the secondary roll crusher. RAP reclaimed using ripping is generally less fine than the RAP reclaimed using milling but the aggregate fraction is still finer than the original granular material. The equipment used during milling and ripping operations also affects the gradation of RAP. The RAP gradation is further influenced by the gradation of the underlying base/subbase layer if the depth of reclamation includes parts of these layers [40].

Table 1 Summaries the range of gradation of RAP materials obtained after milling or ripping as reported by different agencies [41].

4. Allowable RAP content in base/subbase layer

In different studies, it has been found that addition of the RAP contents in the fresh granular materials can change the mechanical properties of the granular material implicitly and hence the performance of the pavement layer (base and/or subbase layer) is also affected considerably. Table 2 lists the general trends for five engineering properties including dry density, optimum moisture content, permeability, CBR and resilient modulus as the percentage of RAP content was increased in the prepared blend. In this table, where the blending of RAP with the fresh granular material is