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Effects of recycled concrete aggregate on stiffness and rutting resistance of asphalt concrete

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HIGHLIGHTS

- Ten asphalt mixtures with partial substitution of natural aggregate by RCA produced.
- The optimum bitumen content increases with increasing RCA content.
- Volumetric compositions of asphalt mixtures meet relevant technical requirements.
- The amount of used RCA has no significant influence on the rutting resistance.
- Asphalt mixtures with RCA have a lower stiffness modulus.

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ABSTRACT

The objective of this research was to assess the possibility of using recycled concrete aggregate (RCA) in asphalt mixtures. The experimental research included 10 asphalt mixtures with partial natural aggregate substitution by RCA, which ranged from 15% to 45% of fine (⩽4 mm), coarse (4/22.4 mm) and both fine and coarse aggregate. The optimum bitumen content increased with increasing RCA content. The use of RCA had no significant influence on the permanent deformation, while the stiffness modulus of asphalt mixtures with RCA was lower compared with the control mixture, especially at high frequencies. The results indicate that RCA can be successfully used in asphalt mixtures.

1. Introduction

Managing construction and demolition (C&D) waste with the aim of reducing environmental pollution represents a huge challenge for the construction industry. Around 850 million tons of C&D waste is annually produced in the European Union, which is about 31% of total generated waste [1].

Cement based concrete represents a major part of C&D waste [2,3], and large quantities of recycled concrete aggregate (RCA) may be obtained by its crushing. So far, RCA has been used for the production of new concrete, and soil stabilization, as well as for materials for road pavement construction, primarily for unbound base and sub-base layers [4]. In the US, as much as 85% of RCA is used as roadbase [5]. The aggregate participates with over 90% in the total mass of asphalt, with a production of 435×10^6 - tons/year in the European Union [6]; hence, asphalt represents a very suitable composite for the application of RCA. However, research on the use of RCA in asphalt mixtures has been quite limited due to the disadvantages of RCA when compared with natural aggregate.

In general, RCA differs from natural aggregates because the newly created aggregate particles consist of natural aggregate combined with residual cementitious mortar. In addition, as a result of processing C&D waste, it may also contain different impurities such as ceramic products, wood, glass and plastic. This feature has significant influence on the design, properties and performance of both concrete and asphalt mixtures made with RCA.

When compared with natural aggregate, RCA particles have higher water absorption and lower strength, as well as lower density and abrasion resistance [7]. The presence of residual cementitious mortar makes the surface texture of RCA exceptionally rough,

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with sharp edges and favourably shaped particles, which is a result of the crushing of concrete [7]. These properties contribute to a better interaction and higher surface friction between aggregate particles. At the same time, the presence of residual cementitious mortar on the natural aggregate particles results in the formation of a more porous surface texture of RCA, when compared with natural aggregates. The results of a scanning electron microscope (SEM) analysis [8] showed that, because of its rougher surface, RCA possesses a significantly higher specific surface area than natural aggregate. Therefore, the absorption of water or bitumen in RCA will be considerably higher compared with natural aggregate.

The main advantages of possible RCA application are based on sustainable development principles, including the reduction of waste quantities, aesthetic impact on the environment, preservation of natural resources, collection of metal debris during concrete recycling and reduction of C&D waste disposal costs [7,9]. This resulted in a substantial increase in research on the use of RCA in hot asphalt mixtures (HMA) in recent years.

Approximately the same number of peer-reviewed research papers deals with the use of RCA in asphalt base course (17 papers) and in binder and wearing courses (19 papers). The influence of the used RCA percentage on the optimum bitumen content (OBC) in asphalt mixtures is presented in Figs. 1 and 2 for base, and binder and wearing courses, respectively.

The two regression lines have approximately the same slope, which indicates that both groups of asphalt mixtures have bitumen content proportional to the quantity of used RCA. A relatively wide dispersion of results is a consequence of the different composition of RCA, diverse types of applied fillers, bitumen and natural aggregate, various asphalt mix designs and laying procedures, etc. Although there are many differences between the analysed asphalt mixtures, there is a general consensus in the literature that with the increase of the RCA content, the OBC also displays a growing trend.

The analysis of results obtained by testing different asphalt mixtures, made with a partial or total substitution of natural aggregate with RCA, shows that the maximum size of RCA has a major influence on the stiffness of the asphalt mixture. Results of several studies showed that mixtures with 100% of fine RCA (⩽4.75 mm) instead of natural aggregate had a higher stiffness compared with a control mixture [10,11]. Contrary, the total substitution of natural aggregate with coarse RCA (>4.75 mm) led to less stiff asphalt mixtures [11,12]. The opposite conclusion was presented by Zulkati et al. [13]. For mixtures in which both fine and coarse natural

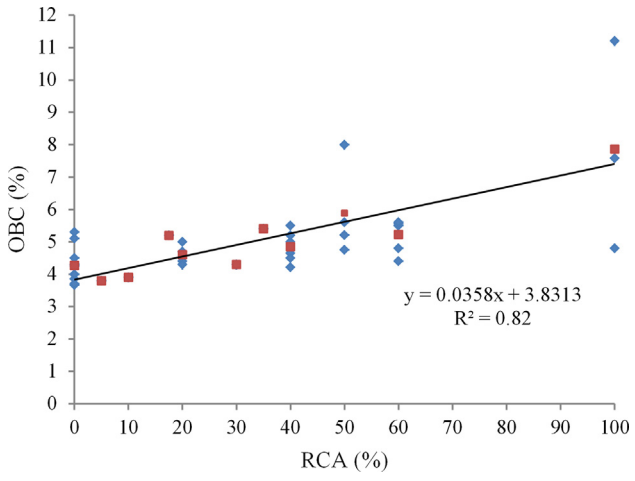

Fig. 1. Correlation between OBC and RCA content in HMA base course.

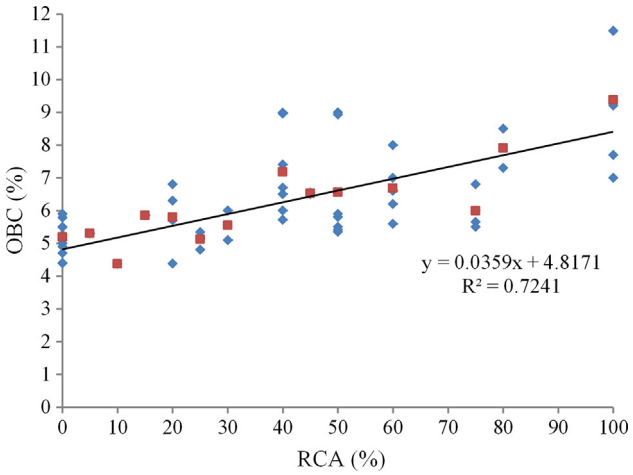

Fig. 2. Correlation between OBC and RCA content in HMA used for binder and wearing courses.

aggregate were replaced by RCA, it was observed that with the increase of the RCA content the stiffness of the asphalt mixtures decreased [14–16].

Wong et al. [10] showed that the use of filler acquired from RCA does not have any significant influence on the stiffness and permanent deformation of asphalt mixtures, while Chen et al. [8] and Arabani et al. [11] found that it increases the resistance of asphalt mixtures to permanent deformation.

In addition, Wong et al. [10] and Arabani et al. [11] discovered that the use of 100% fine RCA increases the resistance of asphalt mixtures to permanent deformation in comparison with control mixtures. However, findings regarding the resistance to permanent deformation of mixtures with high percentages of coarse RCA are not consistent. Wu at al. [17], Shen and Du [18] and Zhu at al. [19] confirmed that using 80% or 100% of coarse RCA improves the resistance to permanent deformation. Contrary, Arabani et al. [11] found that mixtures containing coarse RCA are more unstable than the control mixture, while Perez et al. [20] came to a similar conclusion for mixtures with up to 40% of coarse RCA.

Ektas and Karacasu [15] found that the simultaneous use of both fine and coarse RCA, in quantities up to 40%, can improve the resistance of asphalt mixtures to permanent deformation. Gul [21] tested two groups of asphalt mixtures with aggregate gradations that correspond to the lower and upper limit curves for Dense Mixtures D-6, according to the ASTM D3515 standard, which included up to 75% of fine and coarse RCA. For the lower-limit curve the permanent deformation increased, while for the upper-limit curve it decreased with the increase of the RCA content.

Based on the literature review, the size and quantity of the natural aggregate replaced with RCA have a substantial impact on the asphalt mixture's performance. However, most of the reviewed papers deals with some specific situation related to the quantity and gradation of the used RCA, which included either full substitution of fine or coarse aggregate with RCA, or a simultaneous replacement of fine and coarse aggregate. The stiffness analysis was mainly focused on mixtures for wearing courses and did not include a partial replacement of only fine or only coarse aggregate with RCA.

The main objective of the research presented in this paper was to evaluate the possible application of RCA in asphalt mixtures. Beside the quantity of the applied RCA, special attention was paid to the influence of RCA gradation (i.e. replacement of fine, coarse and both fine and coarse aggregate with RCA) on physical and mechanical properties of asphalt mixtures.