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Rutting susceptibility of asphalt concrete with recycled concrete aggregate using revised Marshall procedure

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HIGHLIGHTS

- Marshall design method is revised for specimen size and aspect ratio requirement.
- Design number of blows are calculated based on concept of energy density.
- Effect of mixture gradation is more significant than that of RCA content.
- Slope constant and flow number describe rutting susceptibility of asphalt mixtures.
- RCA addition increases permanent deformation resistance of coarse graded mixtures.

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ABSTRACT

Natural aggregate is the primary ingredient of asphalt concrete and Portland cement concrete mixtures. Recycled concrete aggregate (RCA) derived from demolition wastes can be used in asphalt mixtures to eliminate potential problems arising from disposing these materials and conserve natural aggregate resources. This study presents methods for using RCA in asphalt mixtures based on repeated creep tests. The standard Marshall mixture design method is revised to prepare specimens satisfying the minimum size and aspect ratio requirement in uniaxial testing. The study shows that addition of RCA can improve the resistance of mixtures to permanent deformation and hence, rutting depending on mixture gradation.

1. Introduction

Natural aggregate is one of the main constituents for asphalt mixtures, base and subbase course of roadways, airports, sidewalks and parking lots. It is also an equally important material for Portland cement concrete mixtures used in the construction of rigid pavements, buildings, industrial facilities, and earthen structures. Aggregate and its processed fractions thus become an important industrial commodity for the construction sector [1]; in fact, it is the second most consumed material per capita in the world according to a recent statistics [2]. In Turkey, around 290 million tons of aggregate is produced every year, around 35% of which is used for road construction. Even though quality aggregate resources are generally abundant in Turkey and materials cost is lower, the newly developed sites for aggregate production has become increasingly distant, i.e., as far as 100–150 km, to major urban areas, thus increasing the transportation costs to the construction sector [2]. Moreover, the proximity of aggregate quarries to nearby cities also raised the concerns of environmentalists in the country by their adverse effects on vegetation, and increased dust emission, noise and visual pollution [3]. As a result, generation of alternative resources for natural aggregate becomes crucial to fulfill the continuous demands of the construction sector while minimizing the transportation costs and production related problems in the environment.

The use of recycled concrete aggregate (RCA) in road construction, that is, as aggregate in asphalt mixtures or Portland cement concrete mixtures, is one way of reducing the need for natural aggregate due to its considerable economic and environmental advantages. Because of the limited use of Portland cement concrete pavements in Turkey, most of the RCA materials are obtained from reclaimed Portland cement concretes derived from demolition wastes as a result of either earthquakes or reconstruction activities. On the other hand, it is almost universally accepted that

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disposing waste concrete in landfills is not a feasible solution due to the dwindling landfill sites, and the resulting environmental problems, such as degradation of vegetation, contamination of underground water, and solubility of certain components in the waste concrete. Because of its adverse effects on environment, waste concrete is considered as hazardous material in the *Hazardous Waste Control Regulations* document published by the Turkish Ministry of Urbanization and Environment [4]. Moreover, local agencies in Turkey concern that major urban transformation projects will be put in action throughout the major cities in the next ten years, causing renewal of around five million buildings, from which an enormous amount of demolition wastes will be generated from the wrecked buildings. It is obvious that the disposal of these waste materials will result in additional transportation costs and tipping fee charges for the construction sector when they are transferred to the landfill regions. Because of its large amount of aggregate demand, the asphalt road construction that is supplied with RCA seems to be a good alternative to reduce the waste concrete disposal, thereby minimizing the additional transportation costs and potential environmental problems, and at the same time preserving the natural resources for virgin aggregate [5].

Studies investigating the effect of RCA use on the mechanical properties of asphalt mixtures are limited and governed by the availability of waste concrete in each country and the imposed restrictions in the design specifications and environmental regulations. In recent years, studies show that the use of fine RCA in base and subbase layers may pose some problems such as increasing pH of water, which may harm the nearby vegetation, and the resulting precipitation of calcium carbonate content, which can cause clog up of the drainage systems [1]. However, when these materials are recycled into asphalt mixtures, the aggregate particles will be coated with bitumen and become impermeable, thus eliminating all these potential problems [6]. RCA materials, in general, have higher absorption, rougher surface texture, porous structure, and lower specific gravity than natural aggregates. Because of large variations in the composition of these materials, the measured properties of asphalt mixtures fabricated with RCA can show significant deviations from their equivalents with natural aggregate. There are several studies investigating the permanent deformation characteristics of asphalt mixtures containing RCA contents from 25% to 100% [7,8]. Results of dynamic repeated creep tests in these studies indicated that better mixture resistance to permanent deformation can be obtained with the increasing amount of RCA, thus improved rutting resistance. Contrary to these findings, the study conducted by Beale and You [9] showed a higher rate of permanent deformation developed when the RCA amount is increased. The use of fine RCA as filler material was also found to contribute to the permanent deformation resistance of asphalt mixtures, showing behavior that is essentially similar to coarse RCA [10].

Permanent deformation characteristics of asphalt mixtures can be studied using compacted cylindrical specimens produced from either Superpave or Marshall compactor device regardless of the mixture design method and the type of aggregate, e.g., natural aggregate or RCA, used. However, when the specimen preparation is done according to the Marshall method, there is an issue of specimen size and proportion of geometrical dimensions on the results of common mixture tests, in particular repeated creep tests, which is mainly used to evaluate the permanent deformation characteristics of asphalt concrete. Past studies indicate that there are certain geometrical requirements to be satisfied by laboratory specimens before utilizing in uniaxial testing to measure relevant material properties [11]. As a result, laboratory procedures used to prepare test specimens become an important issue to satisfy the specimen size and at the same time the boundary condition requirements. However, the current mixture design methods, i.e., Superpave and Marshall, do not produce such specimens satisfying the dimensional requirements of test specimens. In the Superpave design method, specimen coring is utilized to obtain 100 mm diameter specimen, so that a height to diameter ratio of 1.5 is achieved, requiring a minimum compacted specimen height of 150 mm. Although specimen stacking method is one way to overcome this geometrical constraint, it is not possible to produce such specimens in the Marshall method, in which only a small amount of mixture is used for compaction. The Marshall mixture design can be performed by two different procedures: First the standard procedure as described in ASTM D6926, where a compacted specimen of 100 mm diameter and 63.5 mm height is produced; Second the modified procedure as described in ASTM D5581, where a compacted specimen of 150 mm diameter and 93.2 mm height is produced, both of which do not still satisfy the homogeneity and the boundary effect requirements for uniaxial testing. Although the modified procedure specimen is large enough to regard as homogenous, its aspect ratio, however, remains far less than 1.5 to minimize the boundary effects in uniaxial testing.

In this study, experimental programs were set up to investigate the rutting susceptibility of asphalt concrete samples containing RCA using a revised Marshall procedure. The study was carried out in two phases. In the first phase, a procedure was suggested to revise the standard Marshall mixture design method, which can fulfill the requirements of minimum specimen size and aspect ratio. To achieve this, laboratory mixtures were prepared at varying gradations and asphalt contents to determine the design number of blows necessary for the revised Marshall procedure. In the second phase, laboratory specimens were prepared with varying percentages of RCA using the revised Marshall procedure. Uniaxial repeated creep tests were then conducted to calculate several parameters characterizing the rutting susceptibility of the test mixtures.

1.1. Specimen size and aspect ratio requirement in uniaxial testing of asphalt mixtures

To achieve reliable results from any laboratory testing, measured material properties should be independent of specimen size and boundary effects. While homogeneity is related to the minimum specimen dimension, which is governed by the maximum aggregate size for composite materials, such as asphalt concrete mixtures, the boundary condition requirement is related to the height to diameter ratio (aspect ratio) of test specimen. For Portland cement concrete and soils, the minimum specimen diameter that is 4 times the nominal aggregate size is proposed to meet the size requirement. As for the boundary condition, the aspect ratio should be at least 2 to minimize the boundary effects on the measured properties [11]. For asphalt concrete specimens that are tested in the uniaxial mode, the minimum size requirement is reported according to whether the specimen is obtained from field cores or fabricated in the laboratory. The minimum size can be as low as 2 times the nominal aggregate size for field cores, and at least 4 times for the laboratory prepared specimens. An aspect ratio near unity can also be suggested if the specimen's ends are lubricated during uniaxial testing [12,13]. Witczak et al. [11] conducted extensive research investigating the effect of specimen size and aspect ratio on permanent deformation behavior of asphalt concrete. They selected flow number as one of the best indicators of rutting susceptibility of mixtures under uniaxial creep testing. Their research outcomes regarding the effect of specimen diameter and aspect ratio on flow number can be seen in Fig. 1(a) and (b). It can be observed from Fig. 1(a) that the flow number increases with the specimen diameter; however, the rate of increase decays around a diameter of 100 mm, and remains nearly constant around 120 mm, indicating that the minimum