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Moisture damage resistance of hot-mix asphalt made with recycled concrete aggregates and crumb rubber

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ABSTRACT

To guarantee sustainable construction, we investigated the reuse of construction and demolition waste (CDW) as recycled concrete aggregate (RCA) for the manufacture of hot-mix asphalt (HMA) in place of natural aggregates. The use of waste tire rubber as a bitumen modifier could be a means of improving the water resistance of these mixtures. In this investigation, moisture damage resistance of HMA for binder course, type AC 22 bin S, was analysed. Percentages of 0% (control mixture), 35% and 42% RCA were used in place of natural aggregates. Two types of bitumen have also been used: a conventional B35/50 penetration grade bitumen and BC35/50, a crumb rubber modified bitumen. Volumetric properties and water resistance were determined by means of indirect tensile tests. The results indicate that contrary to expectations, mixtures made with BC35/50 do not display better water resistance than mixtures made with B35/50. Nevertheless, a mixture made with B35/50 or BC35/50 does comply with Spanish requirements. Additionally, reversibility of moisture damage resistance was clearly demonstrated in this research. This research may help to better understand the performance of HMA made with RCA and the drawbacks of using waste tire rubber as a bitumen modifier.

1. Introduction

In the last several decades, the construction industry has experienced a notable growth that has caused the generation of high construction and demolition waste (CDW) (Ossa et al., 2016). CDW are one of the most voluminous and heaviest residues generated in the European Union (European Commission, 2016), as well as throughout the rest of the world. For this reason, the landfilling of these wastes has significant environmental impact, such as the occupation of large land areas with the associated visual and scenic degradation.

For these reasons and, in order to guarantee sustainable construction, the proper management of CDW is a priority. Diverse investigations have tried to reuse this waste material as recycled concrete aggregate (RCA) for the manufacture of hot-mix asphalt (HMA) in place of natural aggregates.

Despite the variability of the results, mainly due to the various origins of the RCA used, most authors agreed that the use of RCA in place of natural aggregate when manufacturing HMA leads to worse water resistance of the mixtures. In this regard, Paranavithana and Mohajerani (2006) concluded that the stripping potential of mixtures made with RCA in the coarse fraction is significantly higher. These authors attributed this behaviour to the easy separation of the mortar attached onto the RCA surface. In fact, they notice a significant change in the particle size distribution of mixtures containing RCA as a consequence of the mixing and compaction process.

Mills-Beale and You (2010) stated that as the RCA percentage increases, the moisture susceptibility of HMA also increases. Wen and Bhusal (2011) obtained an increase in the moisture susceptibility of the mixture as the RCA content grew. They attributed this performance to the higher asphalt content of mixtures made with RCA and to the crushing of RCA. Zhu et al. (2012), Pérez et al. (2012a, 2012b) and Wu et al. (2013) also confirm that the use of RCA produces HMA with lower moisture damage resistance. Ossa et al. (2016) stated that up to 20% of RCA is suitable for use in the wearing courses of urban road pavements. Percentages up to 40% of RCA will be suitable only when using anti-stripping additives. Qasrawi and Asi (2016) indicate that RCA replacement up to 50% leads to mixtures that comply with water resistance requirements. Nevertheless, these authors also stated that RCA leads to mixtures with lower stripping resistance.

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To improve the water resistance of mixtures made with RCA, some researchers applied various treatments. For example, Lee et al. (2012) precoated the RCA with a slag cement paste. Zhu et al. (2012) found that precoating the RCA with a patented liquid silicon resin led to mixtures with higher water resistance than mixtures made using untreated RCA. Pasandín and Pérez (2013, 2014) tested two treatments: coat the RCA with 5% of bitumen emulsion prior to the mixing process, then keep the loose mixture in an oven for 4 h at 170 °C after mixing and before compaction. Both of them showed successful water resistance results.

Among the factors that may affect the water resistance of bituminous mixtures, binder properties play a crucial role. In particular, some investigations have demonstrated that the use of bitumen with higher viscosities improves the moisture damage resistance of HMA (Abo-Qudais and Mulqi, 2005). As a consequence, when HMA is in service, the higher asphalt viscosity leads to better moisture damage resistance (Bagampadde, 2004; Xiao and Amirkhanian, 2009).

In this regard, it is interesting to note that waste tire rubber has been used in asphalt pavement since 1960s (Lo Presti, 2013) in order to promote energy savings and to reduce environmental impacts (Rodríguez-Alloza et al., 2013).

As is well known, one of the main effects of adding rubber to bitumen is that it produces an increase in its viscosity which causes the manufacturing of rubberized asphalt mixtures to need higher mixing temperatures (Rodríguez-Alloza et al., 2013; Hossain et al., 2015; Rodríguez-Alloza and Gallego, 2017).

Regarding the performance of rubberized asphalt mixtures, some investigations indicate that the use of rubberized asphalt in HMA reduces noise from tire/pavement interactions (Paje et al., 2010; Vázquez et al., 2016), is cost effective (Hicks and Epps, 2000) and reduces the rutting potential, the thermal susceptibility and the appearance of fissures (CEDEX, 2007). Additionally, waste tire rubber modified bitumen leads to mixtures with higher elasticity and resilience at higher temperatures (MFOM, 2007).

Nevertheless, despite the increased viscosity of the rubberized asphalt, its effect on the moisture damage resistance of HMA is still not clear. On one hand, some authors stated that rubberized asphalt improves water resistance (Partl et al., 2010; Hossain et al., 2015). On the other hand, Xiao and Amirkhanian (2009) stated that the use of rubberized asphalt slightly worsens HMA water sensitivity.

The potential for improving water sensitivity during its in service life suggests that the use of rubberized asphalt in the manufacture of HMA made with a partial substitution of RCA could be a successful way of increasing its water resistance, which must be investigated.

2. Aims and objectives

The aim of this investigation is to manufacture HMA with various percentages of RCA and to compare their water resistance when manufactured with conventional bitumen versus when manufactured with rubber modified bitumen.

The present research has two primary objectives:

- The first one is to strengthen the knowledge about the performance of HMA made with a partial substitution of RCA in place of natural aggregates. Particularly, the research focuses on its performance against the action of water, which is one of the most important drawbacks of these mixtures. This first objective could be useful to those researchers who are currently focused on the study of this type of bituminous mixtures.
- The second objective is to check whether the use of rubberized asphalt may improve the water sensitivity of HMA made with a partial substitution of RCA. As a result of the technical literature review, a potential of improving water resistance of these mixtures by using rubberized asphalt has been detected. This second objective could be useful not only for researchers but for a large number of construction industry actors, particularly those who currently use or recommend the use of this type of bitumen. In this regard, this research can help to deepen the knowledge of the advantages and disadvantages of rubberized asphalt.

3. Materials and methods

3.1. Aggregates

In this investigation, RCA and natural aggregate were used. The RCA (Fig. 1a) came from the demolition of diverse residential housing in Madrid (Spain) and was supplied by a CDW recycling plant. A local contractor supplied the natural aggregate (Fig. 1b) that is a limestone which is typically used in HMA production in Spain due to its expected adequate water sensitivity.

The main properties of the RCA and limestone were evaluated according to the Spanish General Technical Specifications for Roads, usually known as PG-3 (MFOM, 2015). Table 1 summarizes the results of this characterization.

As was expected, when comparing both aggregates, the RCA presented a lower bulk specific gravity (ρa) (AENOR, 2014) as well as higher water absorption (W_{24}) (AENOR, 2014), particularly in the finest fraction. The attachment of mortar onto the RCA surface and the higher mortar content in the finest fractions (de Juan and Gutiérrez, 2009) are mainly responsible for this low value. The flakiness index (FI) (AENOR, 2012a) and the sand equivalent (SE) (AENOR, 2012b) of both types of aggregate complied with the Spanish Specifications for all traffic categories. The Los Angeles (LA) abrasion coefficient (AENOR, 2010a) only complies with T3 and T2 heavy traffic categories.

3.2. Bitumen

A B35/50 penetration bitumen was chosen to prepare the HMA test pieces. The B35/50 had a penetration of 41 × 0.1 mm at 25 °C and a softening point of 53 °C.

The same bitumen, modified with waste tire rubber (Fig. 2), BC35/50, was also used. To prepare the BC35/50, a B50/70 sample of 600 g was heated in an oil bath at 180 °C and then 10% by weight of rubber was added. This mixture was blended for 60 min at 4000 rpm at a constant temperature of 180 °C. The resultant BC35/50 had a penetration of 38 × 0.1 mm at 25 °C and a softening point of 64 °C.

The viscosity of B35/50 and BC35/50, determined by using a Brookfield rotational viscometer (AENOR, 2010c), can be seen in Fig. 3. As was expected, BC35/50 displays higher dynamic viscosities.

3.3. Specimen preparation

The HMA aggregate gradation, corresponding to AC 22 bin S (Fig. 4), for road pavement binder course was chosen according to the gradations limits given by PG-3 (MFOM, 2015).

The volumetric properties and the water resistance were evaluated on Marshall specimens manufactured according to NLT-159/86 (MOPT, 2002). The aggregates were heated for 8 h at 175 °C before mixing and compaction. The B35/50 was heated for 3 h at the temperature of 165 °C and the BC35/50 was heated for the same time at the temperature of 170 °C. The mixing and compaction temperature was 140 °C for mixtures made with B35/50 and 145 °C