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Mechanical properties of hot-mix asphalt made with recycled concrete aggregates coated with bitumen emulsion

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HIGHLIGHTS

- We made a laboratory evaluation of hot-mix asphalt.
- Contents of 5%, 10%, 20% and 30% of recycled concrete aggregates were used.
- Recycled concrete aggregates were coated with bitumen emulsion.
- The mixes complied with Spanish water resistance specifications for base layers.
- Resilient modulus, permanent deformation and fatigue life also showed good results.

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ABSTRACT

The incorporation of recycled concrete aggregates (RCA) in hot-mix asphalt (HMA) could be a way to promote sustainable construction. To date, several investigations have examined the use of this type of waste material in HMA. Several researchers have observed that due to the action of water, the use of this material proved to have insufficient durability. In this investigation, a laboratory characterisation of HMA made with RCA from construction and demolition waste (CDW) for base layers in road pavements was conducted. Percentages of 5%, 10%, 20% and 30% of RCA in place of natural aggregates were analysed. To improve the water resistance of the mixes, the RCA were coated with 5% of bitumen emulsion prior to the mixing process. The results indicated that the mixes comply with the Spanish water resistance specifications required for base layers. The stiffness, permanent deformation and fatigue of the mixtures were also studied. The results indicated that HMA made with RCA coated with bitumen emulsion exhibited mechanical properties similar to those obtained for conventional mixtures.

1. Introduction

Several investigations examining the use of recycled concrete aggregates (RCA) from construction and demolition waste (CDW) in hot-mix asphalt (HMA) have been conducted in recent years to pursue sustainable development. In these investigations, the mortar attached to the RCA surface caused the properties of RCA to be different from those of natural aggregates [1–6]. Thus, the performance of HMA made with RCA will be different from that of conventional HMA.

After a review of the technical literature, we observed that the results of the research were quite variable. Particularly, the water resistance of HMA made with RCA is a property about which there is a wide disparity of opinions: some authors affirm that HMA made with RCA present an adequate water resistance performance [7–10]; nevertheless, other authors see the need to limit the percentage of RCA [11] and/or treat the RCA prior to manufacturing HMA [5,12,13] to achieve a satisfactory water resistance of such mixtures. In this regard, Lee et al. [5] used a slag cement paste to coat the RCA, obtaining moisture damage results within the Taiwanese range of specification requirements. In addition, Zhu et al. [12] showed that RCA coated with a liquid silicone resin improved the water resistance of HMA made with RCA. Moreover, Pasandín and Pérez [13] found that leaving the mixture in the oven for four hours at a mixing temperature before compaction improves the water resistance of HMA made with RCA.

In addition to providing these conclusions regarding water resistance, the review of the technical literature allows us to confirm that other HMA properties are affected by the use of RCA in place of natural aggregates. In this way, some researchers have stated that HMA made with RCA are stiffer than conventional mixes [9,13,14], while others suggest the opposite [11,15]. The resistance to permanent deformation has also been studied. In this sense, most investigators stated that HMA made with RCA exhibit a per-

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manent deformation performance similar to [13,15] or better than [2,7,8,10] that of conventional mixes. On the contrary, other researchers indicate that despite meeting these specifications, the resistance to permanent deformation decreases as the percentage of RCA in the mix increases [11]. The fatigue life of HMA containing RCA is the mechanical property that has been least studied in the literature. The few studies conducted on this topic indicate that the fatigue life of HMA made with RCA is similar to [13,14,16] or better than [10] that obtained for conventional mixtures.

This paper presents a laboratory study on the water resistance and mechanical properties of HMA made with RCA from CDW for base layers on road pavements. The aim of the investigation is to design HMA with RCA that achieves an adequate water resistance performance and satisfactory mechanical properties. To achieve these objectives, RCA were coated with a bitumen emulsion prior to the mixing process. On the one hand, it is expected that due to the action of bitumen emulsion, the RCA pores become obstructed, preventing the entry of water and therefore improving the mixture's resistance to moisture damage. Conversely, a better chemical affinity between the RCA coated with a bitumen emulsion and the bitumen is expected, thus preventing the mixture from suffering from stripping. The water resistance, stiffness, resistance to permanent deformation and fatigue life of the mixtures were analysed.

2. Materials and methods

2.1. Basic materials

2.1.1. Aggregates

In this investigation, RCA and natural aggregates were used. The RCA were obtained from the waste generated during the demolition of residential buildings in Madrid (Spain). The EN-933-11 [17] was followed to determine the constituents of RCA. The results showed that concrete and petrous materials constituted 89.3% of the mass of the RCA. The remainder of the constituents were bituminous materials (6.5%), ceramics (3.6%) and impurities (0.6%) such as wood, rubber or gypsum. These impurities were manually removed before the manufacture of RCA to avoid dispersions in the results. A hornfels supplied by a local contractor was used as natural aggregate. The mineralogical compositions of the RCA and the natural aggregates were determined using X-ray fluorescence tests. The results indicated that both the RCA (61.46% SiO_2) and the hornfels (62.30% SiO_2) are siliceous aggregates. Consequently, both of them were expected to exhibit an inadequate resistance to water damage.

As seen in Table 1 [13], the RCA and natural aggregate properties were evaluated according to the Spanish General Technical Specifications for Roads, also known as PG-3 [18]. The results indicate that, as expected, the RCA had a lower bulk specific gravity (ρa) than the hornfels as well as higher water absorption (WA_{24}). The mortar attached to the RCA surface is mainly responsible for the RCA's behaviour. The sand equivalent (SE) of the RCA and the hornfels complied with the PG-3 for HMA as a base layer material. The Los Angeles (LA) abrasion coefficient was determined for recycled and natural aggregates. As seen in Table 1, the RCA's LA only complied with the PG-3 for HMA as a base layer material in low-volume roads in heavy traffic category T4, while the LA of the natural aggregate complied with the PG-3 for HMA as a base layer material in roads in heavy traffic category T00. As seen in Fig. 1, the LA abrasion coefficient of a mix of RCA and natural aggregate was also determined. The results showed that for RCA percentages up to 58.5%, the resulting LA (RCA + natural aggregate) complied with the PG-3 (LA < 25%) for HMA as a base layer material in roads in heavy traffic category T00.

Table 1
Characterisation of aggregates.

Aggregate	Standard	RCA	Hornfels	PG-3 specifications[a]		
				T00–T1	T3–T2	T4
ρa (g/cm^3)	EN-1097-6	2.63	2.79	–	–	–
WA_{24} (%)	EN 1097-6	5.08	1.08	–	–	–
SE (%)	EN 933-8	67	61	⩾50	⩾50	⩾50
LA abrasion (%)	EN 1097-2	32	14.1	⩽25	⩽30	–

Traffic category T0 refers to 4000 > AADHT ⩾ 2000.
Traffic category T1 refers to 2000 > AADHT ⩾ 800.
Traffic category T2 refers to 800 > AADHT ⩾ 200.
Traffic category T3 refers to 200 > AADHT ⩾ 50.
Traffic category T4 refers to AADHT < 50.
[a] Traffic category T00 refers to AADHT (Annual Average Daily Heavy Traffic) ⩾ 4000.

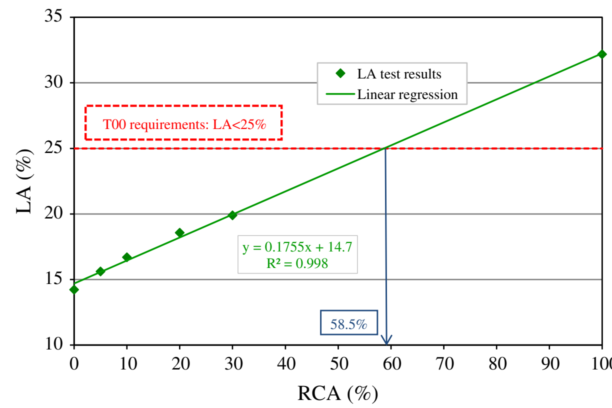

Fig. 1. LA of a mixture of RCA and hornfels.

2.1.2. Binder, bitumen emulsion and filler

A B50/70 penetration grade bitumen from Venezuela was chosen in this investigation. Its engineering properties are presented in Table 2 [13]. To coat the RCA before the mixing process, a bitumen emulsion type ECL-2d was used. ECL-2d is a slow-setting cationic asphalt emulsion that has a bitumen content of 61.2%.

Grey Portland cement (CEM II/B-M (V-L) 32.5 N) was used as mineral filler. Its specific gravity was equal to 3.10 g/cm^3 and its Blaine surface area was equal to 3.134 cm^2/g.

2.2. Testing program

2.2.1. Specimen preparation

The HMA aggregate gradation, corresponding to an AC 22 base G (Fig. 2) [13], was chosen according to the gradations limits given by the PG-3 [18].

The water resistance and mechanical properties were evaluated on Marshall specimens compacted with 75 blows per face according to NLT-159/86 [19]. Cylindrical asphalt specimens of 101.6 mm in diameter and 63.5 mm in height were manufactured with the bitumen content of 3.5%, 4.0% and 4.5% of the total weight of the mixture.

Percentages of 5%, 10%, 20% and 30% of RCA in place of hornfels were used. Following previous research [6,16] and with the aim of producing environmentally friendly materials, a maximum replacement ratio of 30% of RCA was chosen, because the high absorptive nature of RCA [13] can lead to excessive bitumen consumption. As a consequence of the higher mortar content of the RCA fine fraction, which negatively affects the properties of RCA [4], the replacement of RCA was made in the coarse fraction. In addition, in the coarse fraction, it is easier to remove the impurities by hand. The 8/16 mm coarse fraction (replacement of 5%, 10%, 20% and 30%) and the 4/8 mm coarse fraction (replacement of 30%) were chosen. Due to the heterogeneity of the RCA, it was not considered appropriate to include RCA in coarser fractions. As previously mentioned, RCA was coated with a bitumen emulsion to improve the water resistance of the HMA. A 5% of ECL-2d in total weight of the mass of the RCA was used, because it is the bitumen emulsion percentage that reached the best bond results in the affinity test conducted prior to the performance of this research [20]. As shown in Table 3, as a consequence of the bitumen emulsion coating, the bitumen content of the HMA increases.

2.2.2. Water resistance

To evaluate the stripping potential of HMA made with RCA, the UNE-EN 12697-12 [21] was followed. In this test, the loss of indirect tensile strength, expressed in terms of the tensile strength ratio (TSR), was determined. A set of 10 cylindrical Marshall samples is subdivided into two subsets with 5 specimens in each subset. The "dry" subset was kept at room temperature, while the "wet" subset was saturated and was held in a water bath for 3 days at 40 °C. After that time, the specimens of each subset were left a minimum of 2 h at 15 °C: the "dry" subset in air and the "wet" subset in water. The tensile strength of the two subsets was then determined.

Four RCA percentages (5%, 10%, 20% and 30%) were evaluated. The samples were produced at bitumen contents of 3.5%, 4.0% and 4.5% for each RCA percentage. As previously mentioned, the RCA were coated with a 5% of bitumen emulsion. Emulsion breaking occurs prior to the HMA mixing process. Cylindrical specimens were compacted with 50 blows on each side. The stripping potential of the mixture was evaluated as follows:

$$TSR = \frac{ITS_W}{ITS_D} \times 100 \quad (1)$$