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Effect of ageing time on properties of hot-mix asphalt containing recycled concrete aggregates

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HIGHLIGHTS

- We studied hot-mix asphalt containing recycled concrete aggregate (RCA).
- Percentages of 0%, 5%, 10%, 20% and 30% of RCA were used.
- Bitumen contents of 3.5%, 4.0% and 4.5% were used.
- Mixes were cured in an oven for 4 h, 2 h and 0 h before compaction.
- Volumetric and mechanical properties of mixes showed good results.

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ABSTRACT

This study describes a laboratory evaluation on the effect of ageing time on the primary properties of hot-mix asphalt (HMA) containing recycled concrete aggregates (RCA) from construction and demolition waste (CDW). The mixtures were left in an oven for 0 h, 2 h and 4 h at the mixing temperature prior to compaction. The volumetric properties, stiffness and resistance to the permanent deformation of HMA containing 0%, 5%, 10%, 20% and 30% RCA instead of natural aggregate were studied. The results showed that increasing the ageing time of HMA containing RCA increased the number of air voids, the stiffness at ambient temperature and the initial permanent deformation.

1. Introduction

In recent years, the use of recycled concrete aggregates (RCA) from construction and demolition waste (CDW) as coarse aggregates in hot-mix asphalt (HMA) has been studied as a sustainability practice. These studies have produced encouraging but widely differing results. However, the great variability in the results is not surprising. In these different studies, RCA was combined with natural aggregates and bitumens of different types; thus, different performances were to be expected. However, although a substantial contingent of the studies used RCA from the demolition of structures formed exclusively of concrete (e.g., concrete pavements) [1,2], other studies used RCA from the demolition of residential buildings [3–13] or natural disaster debris [14]. In the latter two cases, the quality of the original concrete was sufficiently different to negatively affect the performance of the mixtures. Furthermore, the RCA contained concrete fragments as well as other materials (e.g., ceramic and gypsum), which may also have affected the results.

In the literature, various authors have recommended that RCA should be treated prior to manufacturing HMA [11,13,14] to produce mixtures with good water resistance. Consequently, Lee et al. [11] coated RCA with a slag cement paste and obtained water resistances within the range of the Taiwanese specification requirements. Laboratory results by Zhu et al. [14] also showed that RCA coated with a liquid silicone resin improved moisture damage resistance. Pasandín and Pérez [13] found that mixtures containing RCA that were left in the oven for 4 h at the mixing temperature before compaction complied with the Spanish moisture damage resistance specifications.

The Superpave mix design short-term ageing procedure for paving mixtures simulates the ageing that takes place during the plant mixing phase, transportation and construction of pavement [15]. In the Superpave mix design method, the loose mixture is usually left in the oven at 135 °C for 4 h [15]. The short-term ageing process used in the Superpave mix design method is similar to the last treatment (mixtures left in the oven for four hours at the mixing temperature) mentioned above but has a different purpose, i.e., to improve the moisture damage resistance [13]. The RCA absorbs bitumen, which enables the binder to coat the entire aggregate surface, leaving no fissures through which water can penetrate,

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thereby reducing the porosity and the water-accessible voids at the same time [13]. The bitumen absorbed by the pores of the mortar attached to the surface of RCA also strengthens the mortar and, thus, the RCA [13]. However, it is well known that while the mixture is in the oven, oxidation and loss of volatile fractions occurs within the bitumen, resulting in bitumen hardening [16]. The aforementioned discussion shows that this treatment improves the moisture damage properties of HMA made with recycled concrete aggregates and also modifies the volumetric properties and service performance of these materials. Thus, the effect of the bitumen absorption and bitumen hardening on the properties of HMA containing RCA should be investigated.

In this study, we analyse the volumetric properties, stiffness and resistance to permanent deformation of HMA containing RCA from CDW as a base course material. To investigate the effect of the ageing time, asphalt mixes were left in the oven after mixing and before compaction for 0 h, 2 h and 4 h at the mixing temperature. Increasing the curing time was expected to cause the aggregate, particularly RCA, to absorb more bitumen. Increasing the ageing time was also expected to increase the loss of volatile compounds. Therefore, increasing the ageing time in the oven was predicted to increase the mortar resistance and change the volumetric properties and performance of HMA containing RCA. Mixtures containing 0% (control mixture), 5%, 10%, 20% and 30% of RCA were tested. To produce environmentally friendly materials, the RCA replacement was limited to 30%, because the high absorption capacity of RCA for bitumen [13] can lead to excessive bitumen consumption.

2. Materials and methods

2.1. Basic materials

2.1.1. Aggregates

Two types of aggregates were used in this study: RCA and natural aggregate. The RCA (Fig. 1) were supplied by a CDW recycling plant in Madrid (Spain). The RCA composition was as follows: 89.3% stone, mortar, concrete or similar materials; 6.5% bituminous materials and 3.6% ceramics. Fig. 1 shows that 0.6% of impurities, such as gypsum plaster, wood, metals and crystal, were carefully removed. Hornfels, which was supplied by a local contractor, was used as the natural aggregate. X-ray fluorescence tests (XRF) have shown that RCA (61.46% of SiO_2) and hornfels (62.30% of SiO_2) are siliceous aggregates. Moreover, X-ray diffraction tests (XRD) have shown that RCA and hornfels contain quartz in their mineralogical composition. Quartz is known to adhere poorly to the binder [17]. For all of these reasons, both aggregates, i.e., RCA and hornfels, were expected to exhibit poor moisture damage resistance.

The properties of the RCA and the natural aggregate were evaluated following the Spanish General Technical Specifications for Roads, which is also known as PG-3 [18]. The results are summarised in Table 1 [13]. As expected, RCA had a lower bulk specific gravity (ρa) than the natural aggregate and a higher water absorption (W_{24}) because of the mortar attached to the RCA surface. The sand equivalent (SE) values of the RCA and the natural aggregate complied with the PG-3 for HMA as a base course material. However, note that the Los Angeles abrasion coefficient (LA)

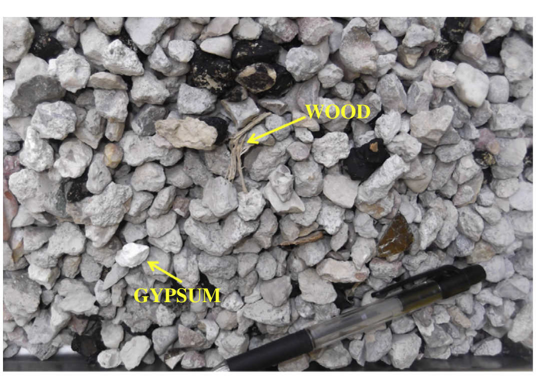

Fig. 1. Details of impurities in the 8/16 mm RCA fraction used in this study.

Table 1
Properties of RCA and hornfels.

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	–

[a] Traffic category T00 refers to AADHT (Annual Average Daily Heavy Traffic) ⩾ 4000.
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.

for RCA exceeded the PG-3 specifications; thus, the RCA are only suitable for the lighter heavy traffic categories. In contrast, the LA for natural aggregates was adequate for all of the heavy traffic categories.

2.1.2. Binder and filler

A B50/70 penetration bitumen from Venezuela was chosen to prepare the HMA specimens. The B50/70 had a penetration of 52 × 0.1 mm (at 25 °C, 100 g and 5 s), a softening point of 54.9 °C, a flash point above 290 °C, a density of 1.009 g/cm^3 (at 25 °C), a penetration following a rolling thin-film oven test of 68 × 0.1 mm and a Δ softening point following a rolling thin-film oven test of 6.5 °C. Grey Portland cement (CEM II/B-M (V-L) 32.5N) was obtained from a commercial source for use as a mineral filler. The cement had a Blaine surface area of 3134 cm^2/g and a specific gravity of 3.10 g/cm^3.

2.2. Test program

2.2.1. Specimen preparation

A continuous grading HMA for a base course type material, AC 22 base G (Fig. 2) [13], was chosen to comply with the gradation limits given by the PG-3 [18]. The HMA had a maximum aggregate size of 22 mm and a 4% filler content.

As previously stated, the samples were manufactured using 0% (control mixture), 5%, 10%, 20% and 30% RCA instead of hornfels. Impurities in the RCA coarse fraction can be most easily removed by hand. Note that when HMA is produced on an industrial scale, the impurities are removed by magnetic separation, water-floatation or air-sieving [19], thereby avoiding the inconvenient use of manual methods. Moreover, the RCA fine fraction has a higher mortar content than the RCA coarse fraction, which negatively impacts the RCA properties [20]. For all of these reasons, RCA replaced the natural aggregate for the coarse fractions of 8/16 mm (at replacement contents of 5%, 10%, 20% and 30%) and 4/8 mm (at a replacement content of 30%). In this study, the RCA was heterogeneous and was therefore not considered in the coarser fractions. Experimental tests were conducted on Marshall specimens that were compacted with 75 blows per face according to NLT-159/86 [21]. Asphalt specimens of 101.6 mm in diameter and 63.5 mm in height were manufactured with binder contents of 3.5%, 4.0% and 4.5% of the total weight of the mixture. The mixtures were left in the oven at the traditional mixing temperature (170 °C) for 0 h, 2 h and 4 h after mixing and before compaction.

2.2.2. Volumetric properties

The volumetric properties of the HMA samples, i.e., the content of the air voids (Va), the voids in the mineral aggregate (VMA), and the voids filled with asphalt (VFA), were obtained. The bulk specific density (ρb) was measured using the

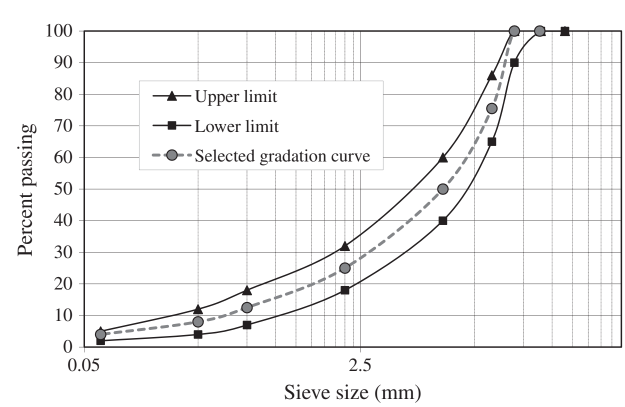

Fig. 2. Gradation curve for AC 22 base G.