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Laboratory evaluation of hot-mix asphalt containing construction and demolition waste

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HIGHLIGHTS

- We studied hot-mix asphalt containing 0%, 5%, 10%, 20% and 30% of recycled concrete aggregate in place of virgin aggregate.
- To improve their water sensitivity the mixes were cured in an oven for 4 h before compaction at mixing temperature.
- Marshall mix design procedure was used.
- Optimized mixes comply with Spanish moisture damage specifications for base course.
- Resilient modulus, permanent deformation and fatigue life of optimized mixes also showed good results.

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ABSTRACT

A laboratory study of the use of recycled concrete aggregates (RCAs) from construction and demolition waste (CDW) in hot-mix asphalt (HMA) for base courses in pavements was conducted. HMA mixes containing 0%, 5%, 10%, 20% and 30% RCA in place of natural aggregate were evaluated. The Marshall mix design procedure was used to develop the mixes. To improve the moisture sensitivity of the mixes, they were cured in an oven for 4 h. The results indicated that the mixes comply with Spanish moisture damage specifications. The mechanical properties (stiffness, permanent deformation and fatigue) of the mixtures were studied. The mixtures exhibited good engineering properties. Although HMA with RCA requires further investigation, the results from this study were very promising.

1. Introduction

Concerns in recent decades about achieving sustainable growth has resulted in attempts to recycle or reuse a large portion of construction waste materials. This is the case for recycled concrete aggregate (RCA) from construction and demolition waste (CDW). Its use has been growing in recent years, particularly as aggregate for concrete [1,2] and unbound pavement layers [3–5]. However, further research is needed to diversify RCA applications and make its use a habitual practice.

Although RCA is most likely suitable for use as aggregate in hot-mix asphalt (HMA) for pavements in road building, to date only a few studies have been carried out dealing with the use of this type of waste material in HMA [6–23].

Many researchers have noted that the attached mortar (Fig. 1a), which is more porous and less dense than crushed stone, seems to be the principal reason for RCA being of unsatisfactory quality [6,10–12,14,22–24], but it is not the only reason. In fact, some studies have recommended removing impurities such as wood, rubber, and gypsum with the aim of making RCA more homogeneous [6,10,11,21,23]. The tiny fissures that appear during the crushing process [12] and the weak contact between the mortar and aggregate [22] are other factors to take into account. All of these reasons make RCA from CDW a poorer-quality aggregate than natural aggregate [22,24]. Obviously, differences between the properties of RCA and those of natural aggregates are going to influence the performance of HMA made with RCA. It is also expected that the RCA content (between 0% and 100%) will affect HMA performance.

It is particularly interesting to note that some studies have indicated that HMA mixes made with RCA have higher moisture sensitivity than those made with natural aggregates only [10,11,15,21,23]. Moisture sensitivity or moisture damage is a deterioration process that affects HMA and is defined as the degradation of mechanical properties of the mixture due to the presence of water [25]. There are many ways to improve the moisture sensitivity of conventional HMA, including the use of antistripping additives, the addition of selected fillers, avoidance of hydrophilic aggregates, etc. [26]. Previous research conducted with the same RCA used in this investigation [18,21,23] recommended allowing the HMA sufficient time at high temperature to complete the binder absorption by the aggregates. This could be a way to improve the moisture sensitivity of HMA made with RCA, since the bitumen

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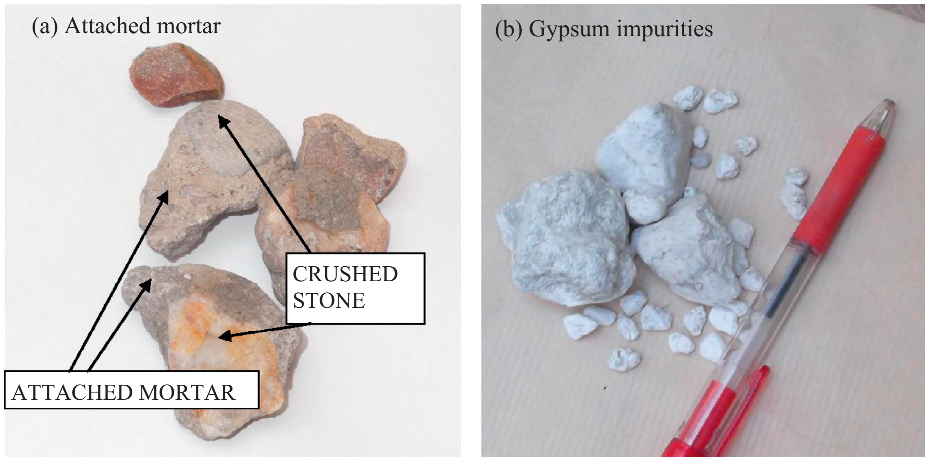

Fig. 1. RCA used in this investigation: (a) attached mortar and (b) gypsum impurities.

absorbed by RCA makes the whole aggregate surface be coated by the binder, leaving no fissures through which water could penetrate. Furthermore, it reduces the porosity decreasing at the same time water accessible voids.

Moisture sensitivity is not the only HMA property that could be affected by the use of CDW as recycled aggregate. Some researchers have stated that the use of RCA in HMA production leads to mixes with less stiffness than conventional mixes [10,15], while others suggest the opposite [8,11]. The literature on the permanent deformation of HMA made with RCA yields varied conclusions. Most researchers consider mixtures made with RCA to comply with specifications related to permanent deformation [9,11,15,18,21,23] and exhibit permanent deformation behavior similar to conventional mixes [10] or better [7,8,13,20]. However, other researchers indicate that despite meeting the specifications, permanent deformation performance worsens as the percentage of RCA in the mix increases [15]. Others indicate that permanent deformation performance is also influenced by the mixture gradation [14]. The fatigue life of HMA containing RCA has been studied less. The studies to date indicate that HMA with RCA are similar in fatigue life to conventional mixtures [11,17]. There is one exception: when RCA is used as filler, fatigue life improves [20].

This paper presents an investigation of the mechanical properties of HMA made with RCA from CDW for base courses. The aim of the investigation is to design HMA with RCA and achieve good mechanical properties and good moisture sensitivity performance. Following the example of previous studies [18,21,23], to improve the moisture sensitivity of the asphalt mixes used, they were cured in an oven at the mixing temperature for 4 h after mixing and before compaction. This made it possible for, the aggregate, particularly the RCA, to absorb a greater amount of bitumen. Not only improved mortar resistance but also less water absorption, and thus better moisture damage performance, is expected as a result. The moisture sensitivity, stiffness, permanent deformation and fatigue life of HMA mixes containing RCA were studied.

2. Materials and methods

2.1. Basic materials

2.1.1. Aggregates

Two types of aggregates were used: RCA and natural aggregate. RCA was obtained from demolition waste from residential buildings of different origins and qualities in Madrid (Spain) and was supplied by a CDW recycling plant. Aggregate, concrete, and similar materials constituted 89.3% of the mass of the RCA obtained for use in this study, and bituminous materials constituted 6.5%. The remainder of the constituents were impurities (ceramics, wood, rubber, gypsums, etc.) that could introduce variation in the test results. Gypsum (Fig. 1b) is an impurity that is polishable and has a poor affinity with bitumen, so it would be wise to remove it before using RCA in HMA production. The natural aggregate used was a hornfels that was supplied by a local contractor and is typically used in HMA production in Spain. The compositions of the natural and recycled aggregates were determined using X-ray fluorescence tests. The results indicated that the RCA (61.46% SiO_2) and hornfels (62.30% SiO_2) are siliceous aggregates. Consequently, both of them were expected to exhibit poor stripping performance.

The RCA and natural aggregate properties were evaluated according to the Spanish General Technical Specifications for Roads, also known as PG-3 [27]. The results (shown in Table 1) indicate that the RCA had a lower bulk specific gravity (ρa) than the natural aggregate as well as a higher water absorption (W_{24}). This is due to the mortar on 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. The RCA's Los Angeles (LA) abrasion coefficient only complied with the PG-3 for HMA as a base course material in low-volume roads in heavy traffic category T4. The LA abrasion coefficient of the hornfels aggregate complied with the PG-3 for HMA as a base course material in roads in heavy traffic category T00. The LA abrasion coefficient of a mix of RCA and natural aggregate was also determined. The results showed that for mixes of 0%, 5%, 10%, 20% and 30% replacement of natural aggregate by RCA, the combined (RCA + natural) LA abrasion coefficient complied with the PG-3 (LA < 25%) for HMA as a base course material in roads in heavy traffic category T00.

2.1.2. Binder and filler

A B50/70 binder from Venezuela was chosen for use in this study. Its engineering properties are presented in Table 2. Gray Portland cement (CEM II/B-M (V-L) 32.5 N) was obtained from a commercial source for use as mineral filler. Its Blaine surface area was equal to 3134 cm^2/g and its specific gravity was equal to 3.10 g/cm^3.

2.2. Testing program

2.2.1. Marshall mix design

The Marshall mix design procedure, as specified in NLT-159/86 [28], was used in this investigation. The laboratory mixing temperature was 170 °C and the compaction temperature was 165 °C. Percentages of 0%, 5%, 10%, 20% and 30% of RCA by weight of total aggregate were studied. The aggregate gradation, an AC 22 base G (Fig. 2), was chosen in accordance with the PG-3. The aggregate gradation had a

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.