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Effects of the use of construction and demolition waste aggregates in cold asphalt mixtures

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HIGHLIGHTS

- Cold asphalt mixtures containing CDW as aggregate were studied.
- UCS, ITS and ITSM results improved by introducing CDW in the mixes.
- Mixtures containing CDW aggregates perform better against moisture and temperature.
- Classical design methods become inaccurate with CDWA cold mixes.
- The Addition of CDW to cold asphalt mixes is an effective tool of sustainable engineering.

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ABSTRACT

Cold asphalt mixtures (CAM) with 100% recycled aggregates from construction and demolition waste (CDW) were researched to ecologically and economically improve cold asphalt mixtures. The present study indicates that the UCS, ITS, ITSM and moisture susceptibility were very satisfactory not only compared with a control mix with 100% natural aggregates (NA) but also with values given by different standards and recommendations. A new global approach to design these aggregates has also been explored because conventional methods are inaccurate in this case.

1. Introduction

Cold asphalt mixes (CAM) have been considered inferior to hot-mix asphalt (HMA) in the last several decades, mainly due the high air-void content of the compacted mixtures, their weak early life strength and the long curing times required to achieve an optimal performance [1].

After lay-down, these mixtures need to pass through a number of stages in which the binder and mastic cohesion, binder-aggregate adhesion and mixture shear strength develop. During these stages, cold asphalt does not lend itself to studies of the influence of material and/or process variables, e.g., moisture condition, on its mechanical properties [2]. This drawback is due to the associated peculiarities of cold asphalt, which include the presence of water, emulsion-aggregate reactivity, evolving characteristics with time and an undeveloped internal structure [3].

Many studies have been conducted to minimise these considerations and approximate hot asphalt mixtures, such as incorporating a certain amount of cement, as well as modified asphalt emulsions in the mixture [4–6]. In addition, cold mixes have features that make them preferable to hot mixes, such as a lower energy consumption, ecological impact, economic costs or occupational hazards for operators. Moreover, cold mixes are storable at room temperature until lay-down, non-polluting and show a lower tendency for cracking, due to their flexibility when the subgrade is not of great quality. Thus, cold mixes are especially suitable for low/medium traffic local roads, which are normally placed far away from the manufacturing plants.

Cold asphalt mixtures are currently regaining their importance within the asphalt world market, reaching annual production levels of 1.5 million tonnes in France or 2 million tonnes in Turkey in recent years [7]. Nevertheless, researchers and producers continue to improve these mixtures in an attempt to increase their competitiveness.

As such, and to improve the ecological and economic properties of CAM, CAM containing 100% recycled aggregates from

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construction and demolition waste (CDW) were studied. An extensive, growing and successful body of research on hot asphalt mixes with recycled aggregates from waste materials [8–16] reinforces this new approach in pavement engineering.

This research was focused on the mechanical properties of CAM containing 100% construction and demolition waste aggregates (CDWA) once they have already reached a high curing degree. The results obtained were satisfactory not only compared with a control mix containing 100% natural aggregates (NA) but also with values given by different standards and recommendations.

An ANOVA statistical analysis was performed to test and support the experimental results. Because the interaction between water and bitumen is unclear, one 2-way ANOVA and two 1-way ANOVA (one for each fixed variable water/bitumen) were performed for each studied property. As explained, both analyses served to confirm the results because the conclusions drawn from both follow the same direction and did not contradict in any of the cases.

2. Materials used

Two different aggregates were used: a hornfels, a metamorphic siliceous aggregate from a natural quarry used to produce the control mixes (hereafter, natural aggregate or NA) and a 100% recycled aggregate from construction and demolition waste (hereafter CDWA), whose composition is given in Table 1 for the received coarse and medium fractions. This composition was used to analyse the potential behaviour of this material in CAM. Most of this aggregate was concrete and natural stone but also contained other materials (Fig. 1) that required the use of an X-ray diffractogram to truly define their source in some cases. In this way, materials such as asphalt materials, plaster, aerated concrete or limestone with quartzite particles were identified.

The different properties of both natural and recycled aggregates are shown in Table 2. CDWA materials are weaker because they have a lower Los Angeles coefficient, Flakiness Index and Crushed Particles after the crushing process. However, the most characteristic feature is the low specific gravity and the extensive water absorption, which clearly affect the mechanical and rheological properties of the bituminous mixtures they comprise.

The binder used was a cationic bitumen emulsion (60% bitumen content) with 100 pen grade base bitumen. The other relevant properties are shown in Table 3.

The aggregate gradations of all the design mixtures used in this investigation were based on the technical recommendations given by the Spanish Technical Association of Bituminous Emulsions [22] for grave-emulsions. The initial gradation, which corresponds to a grave-emulsion GE1, required modification to be maintained within the upper and lower limits after compaction because the recycled aggregate tended to break, as shown in Fig. 2.

Table 1
Components of recycled aggregate (% of total dry weight).

Material	% In coarse aggregate (12/24 mm)	% In medium aggregate (6/12 mm)
Concrete and mortar	70	55
Natural aggregates	25	40
Ceramics and masonry materials	3.7	4.1
Concrete with metal pieces	1.121	<0.001
Concrete with textile fibers	0.146	0.042
Plaster/gypsum	0.103	0.012
Other materials (metal, paper, plastics, glass)	<0.1	<0.1

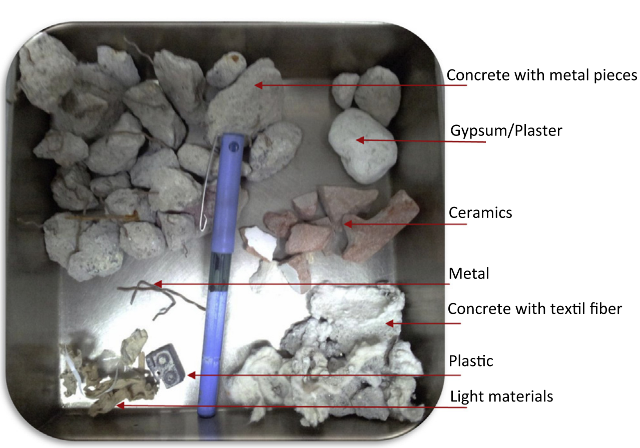

Fig. 1. Some of the materials found in the recycled aggregate.

Table 2
Characterization of recycled and natural aggregates.

Property	Recycled aggregate	Natural aggregate
Flakiness Index (UNE EN 933-3 [17])	4.5%	19.8%
Crushed Particles (UNE EN 933-5 [18])	89%	94%
Sand equivalent (UNE EN 933-8 [19])	77	78
Los Angeles coefficient (UNE EN 1097-2 [20])	38	14
Bulk specific gravity (UNE EN 1097-6 [21])	2.64 t/m^3	2.78 t/m^3
Dry specific gravity (UNE EN 1097-6 [21])	2.23 t/m^3	2.74 t/m^3
SSD specific gravity (UNE EN 1097-6 [21])	2.39 t/m^3	2.75 t/m^3
Absorption (UNE EN 1097-6 [21])	7.0%	0.5%

Table 3
Properties of the asphalt emulsion used during the present investigation.

Properties	Unit	Standard	Value	Class
Original emulsion				
Perceptible properties	–	1425	OK	–
Temperature	°C	N.A.	15–35	–
Bitumen content	%	1428	58–62	Class 5
Flow time (40 °C, 2 mm)	s	12846-1	15–45	Class 3
Residue (sieve), (Sieve 0.5 mm)	%	1429	⩽0.1	Class 2
pH	–	12850	⩽7	–
Storage stability	%	12847	⩽10	Class 3
Setting index	g	13075-1	120–180	Class 5
Adhesiveness	%	13614	⩾90	Class 3
Bitumen recovered by evaporation (UNE EN 13074-1)				
Penetration 25 °C	0.1 mm	1426	⩽100	Class 3
Softening point	°C	1427	⩾43	Class 4
Stabilized binders (UNE EN 13074-1 + UNE EN 13074-2)				
Penetration 25 °C	0.1 mm	1426	⩽100	Class 1
Softening point	°C	1427	⩾43	Class 1
Aged bitumen (UNE EN 13074-1 + 13074-2 + UNE EN 14769)				
Penetration 25 °C	0.1 mm	1426	⩽100	Class 2
Softening point	°C	1427	⩾43	Class 2

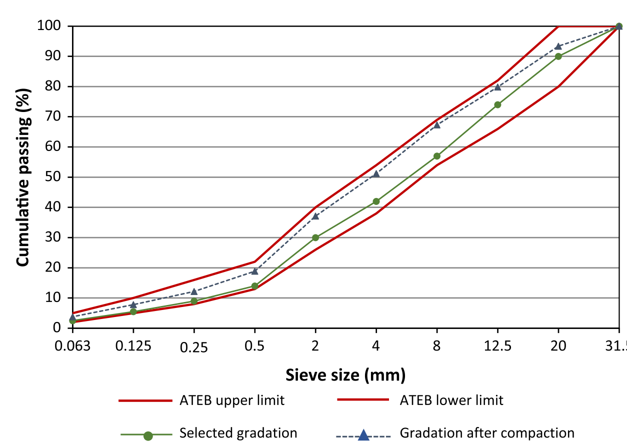

Fig. 2. Aggregate gradation of CDWA before and after compaction compared with ATEB recommendations.