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Stiffness of cold asphalt mixtures with recycled aggregates from construction and demolition waste

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HIGHLIGHTS

- The stiffness of cold asphalt mixtures (CAM) containing CDW as aggregate were studied.
- CAMs with CDWA frequently achieved higher stiffness than control mixes.
- CAMs with CDWA were less temperature susceptible and more fatigue resistant.
- CAMs with CDWA were more complicated to design.
- Clear dependency of stiffness on the compaction process (static and gyratory).

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ABSTRACT

The stiffness of cold asphalt mixtures (CAM) with 100% recycled construction and demolition waste aggregates (CDWA) was studied from three different points of view: the indirect tensile stiffness modulus (ITSM), the dynamic modulus at different temperatures and frequencies and the correlation between them. It was found that CAM with CDWA frequently achieved higher stiffness than control mixes using natural aggregate (NA), but that they required significantly higher bitumen and water contents. They were less temperature susceptible, therefore potentially more fatigue resistant, but more complicated to design. Finally, a clear dependency on the compaction process (static and gyratory) was also found.

1. Introduction

Cold asphalt mixtures (CAM) are bituminous materials normally made by mixing cold aggregates with an asphalt emulsion and water. Due to their remaining high air-void content once compacted, weak early life strength and long curing times required to achieve an optimal performance, they have been traditionally considered inferior to hot mix asphalt (HMA) over recent decades [1]. Thus, the use of CAM is still restricted in many cases to surface treatment and reinstatement work on low trafficked roads and walkways, being less commonly found in structural layers [2–5].

On the other hand, wide research is being carried out nowadays in order to minimize these mechanical disadvantages, for instance, by modifying the emulsified asphalt binders or incorporating a certain amount of cement into the mixture [6–9]. Thus, these mixtures are regaining their importance within the asphalt world market, having currently reached annual production levels of 1.5 million tones in France or 2 million tones in Turkey, for example [10]. Besides, there are numerous properties that make them more suitable than HMA under certain circumstances. For instance, they have lower energy consumption, reduced ecological impact, less occupational hazards for operators, lower economic costs, and a reduced tendency to cracking thanks to their flexibility. Furthermore, they are storable at ambient temperature prior to use, which makes them especially suitable for low/medium traffic local roads, often located far from manufacturing plants.

In order to improve the ecological and environmental aspects of CAM, numerous researchers have lately been studying the use and incorporation of waste and by-product materials such as steel slag,

Abbreviations: CAM, cold asphalt mixtures; HMA, hot mix asphalt; CDWA, construction and demolition waste aggregates; ITSM, indirect tensile stiffness modulus; NA, natural aggregate.

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crushed glass and used cylinder oil [11,12]. According to Al-Busaltan et al. [13] four main benefits can theoretically be achieved when utilizing by-product materials in CAM: absorption of trapped water via the hydration process, improvement in mixture mechanical properties, cost effectiveness and the ecological benefit factor.

Following this trend and based on the extensive, growing and successful research on HMA with recycled aggregates from waste materials [14–22], which reinforces this new approach in pavement engineering, CAM with recycled construction and demolition waste aggregates (CDWA) was studied in terms of stiffness, arguably the key property behind other related phenomena, such as the fatigue cracking or the appearance of permanent deformation under different load and environmental conditions. In this regard, this paper continues a research already described in previous publications [23,24], by analyzing the stiffness of these mixtures using different measures, such as indirect tensile stiffness modulus (ITSM) and Dynamic Modulus $|E^*|$, the latter being tested according to a new proposed protocol which allows a better correlation between the two moduli.

From previous research, the results of ITSM obtained for specimens containing 100% of CDWA and 100% of natural aggregate (NA) and compacted with static uniaxial pressure have already been published [23,24]. The aim of this paper, on the other hand, is to compare these results with those obtained from a series of new specimens of the same mixes, but compacted by using a gyratory compactor, which nowadays is one of the most common compaction methods for cylindrical specimens. Thus, the influence of the compaction system on the stiffness could be assessed. Additionally, these latter samples were used to determine the dynamic modulus and to model the stiffness behavior by means of master curves.

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, plastic, glass)	<0.1%	0.1%

Table 2
Characterization of recycled and natural aggregates.

Property	Recycled aggregate	Natural aggregate
Flakiness index (UNE EN 933-3 [26])	4.5%	19.8%
Crushed particles (UNE EN 933-5 [27])	89%	94%
Sand equivalent (UNE EN 933-8 [28])	77	78
Los angeles coefficient (UNE EN 1097-2 [29])	38	14
Bulk specific gravity (UNE EN 1097-6 [30])	2.64 t/m^3	2.78 t/m^3
Dry specific gravity (UNE EN 1097-6 [30])	2.23 t/m^3	2.74 t/m^3
SSD specific gravity (UNE EN 1097-6 [30])	2.39 t/m^3	2.75 t/m^3
Absorption (UNE EN 1097-6 [30])	7.0%	0.5%

2. Materials

For this investigation the same aggregate gradation was batched for all the samples. This gradation was based on the recommendations given by the Spanish Technical Association of Bituminous Emulsions (ATEB) [25] for GE1 grave-emulsions but slightly modified with less fine particles in order to keep it within the recommended upper and lower limits after compaction. As can be seen in Fig. 1, the gradation of the construction and demolition waste aggregates (hereafter CDWA) tended to get modified during mixing and compaction, increasing the amount of fine and medium sized particles.

The CDWA used for this research was a 100% recycled aggregate, whose composition is given in Table 1. As can be seen, the main part of it is concrete and mortar as well as natural aggregates. To a lesser extent, it includes a certain amount of impurities, such as ceramics, metal pieces, gypsum, plastics or glass. Some of these required the use of an X-ray diffractogram in order to truly define their source. A natural aggregate (NA) was also used to give a control mix, subjected to the same tests, comparing the results with the ones obtained for mixes with 100% of CDWA. In this case, the chosen NA was a hornfels, a metamorphic siliceous aggregate extracted from a natural stone quarry. The different properties of both natural and recycled aggregates can be seen in Table 2, notably the low specific gravity and high water absorption of CDWA which will clearly affect the mechanical and rheological properties of the bituminous mixtures made from it.

Finally, the binder used was a cationic bitumen emulsion (60% bitumen content) with 100 pen. grade base bitumen.

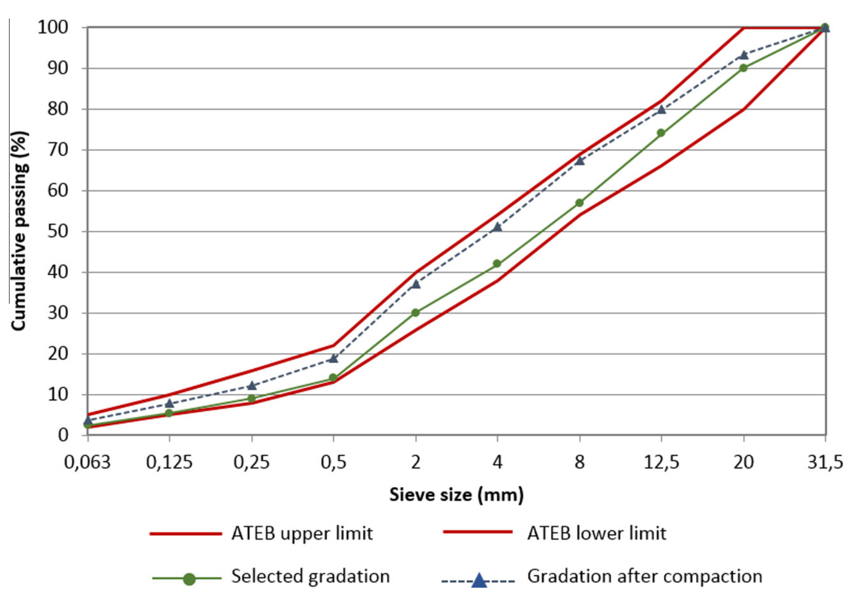

Fig. 1. Aggregate gradation of CDWA before and after compaction compared with ATEB recommendations.