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Binder–aggregate adhesion and resistance to permanent deformation of bitumen-emulsion-stabilized materials made with construction and demolition waste aggregates

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ABSTRACT

Bitumen-stabilized materials with emulsion (BSM-E) are gaining increasing importance within the scope of road pavement engineering and the fight against climate change. Both environmental and economic aspects of BSM-E can be further improved by substituting the natural aggregates (NA) with recycled construction and demolition waste aggregates (CDWA). The objective of the present paper is to analyze how such substitution affects the two critical properties that mostly define the durability and long-term performance of BSM-E: resistance to stripping and resistance to permanent deformation. The stripping phenomena were analyzed in terms of binder–aggregate affinity through the Rolling Bottle Test and Boiling Water Test. The results showed that the weak mortar that attached to the aggregate surface produced poorer binder–aggregate affinity when the samples were subjected to mechanical agitation. However, the recycled aggregates did not affect the affinity at high temperatures and improved the resistance to permanent deformation, leading to failure of the material after many loading cycles.

1. Introduction

Bitumen-stabilized materials with emulsion (BSM-E[1]) are the result of mixing aggregates, asphalt emulsion and water. The use of asphalt emulsion instead of bitumen enables the mix to be blended, laid and compacted at room temperature, reducing economic and environmental costs; thus, it is gaining popularity within the scope of the fight against climate change in civil engineering. These materials once were considered inferior to hot mix asphalt (HMA[2]) owing to their high air void content after compaction and weak early life strength; however, their current uses cover a great range of applications in addition to the conventional ones, including surface treatments and reinstatement work on low-traffic roads and walkways (Nageim et al., 2012; Read and Whiteoak, 2003; HAUC, 1992; James, 2006).

Both environmental and economic aspects of BSM-E can be improved by substituting the natural aggregates (NA[3]) with recycled construction and demolition waste aggregates (CDWA[4]), an approach that is currently being applied, with successful results, to other kinds of infrastructure materials, such as road bases (Xuan et al., 2015), concrete (Bravo et al., 2015; Rodríguez et al., 2016), mortar (Ledesma et al., 2015; Saiz Martínez et al., 2016) or geosynthetic reinforced structures (Vieira et al., 2016). However, the great heterogeneity of this type of aggregate, especially in terms of their composition, makes it very difficult to predict how they will affect the properties of asphalt mixtures. In the limited literature published on HMA with CDWA, certain common trends were found, such as higher air void content but lower content of voids filled with bitumen (Shen and Du, 2005; Paranavithana and Mohajerani, 2006; Wong et al., 2007; Pérez et al., 2010); lower densities (Huang et al., 2002; Li, 2004; Paranavithana and Mohajerani, 2006; Pérez et al., 2007; Melbouci, 2009; Mills-Beale and You, 2010; Gokce et al., 2011); higher optimal binder content (Paranavithana and Mohajerani, 2006; Wong et al.,

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[1] BSM-E: Bitumen Stabilized Materials with Emulsion.
[2] HMA: Hot Mix Asphalt.
[3] NA: Natural Aggregates.
[4] CDWA: Construction and Demolition Waste Aggregates.

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2007; Pérez et al., 2010); higher resistance to cracking at low temperature (Mills-Beale and You, 2010); and lower resistance to water damage and stripping phenomena (Shen and Du, 2005; Paranavithana and Mohajerani, 2006; Pasandín and Pérez, 2013, 2014b; Pérez et al., 2007, 2010, 2012a, 2012b). In addition, contradictory results were found on other properties, such as indirect tensile strength and stiffness (Shen and Du, 2005; Paranavithana and Mohajerani, 2006; Mills-Beale and You, 2010; Chen et al., 2011a, 2011b; Pasandín and Pérez, 2013, 2014b), resistance to permanent deformation (Shen and Du, 2005; Paranavithana and Mohajerani, 2006; Wong et al., 2007; Mills-Beale and You, 2010; Chen et al., 2011a; Pérez et al., 2012; Bhusal and Wen, 2013; Pasandín and Pérez, 2013, 2014b), and fatigue (Pérez et al., 2010; Chen et al., 2011a, 2011b; Chen et al.; Bhusal and Wen, 2013; Pasandín and Pérez, 2013, 2014b), without sufficient clarity regarding whether the incorporation of CDWA produce positive or negative effects on these properties.

Regarding BSM-E with CDWA, the published literature is even shorter, but works including Thanaya (2003, 2010); Gómez-Meijide and Pérez (2014a, 2014b, 2015); and Gómez-Meijide et al. (2015a, 2015b) confirmed the abovementioned trends and improvements in some mechanical properties, such as compression strength, indirect tensile strength, stiffness and stability to temperature variations. Some weaknesses were also found (especially the behavior at early curing stages), but none of the previous publications studied the two phenomena that mostly define the durability and long-term performance of BSM-E: the resistance to stripping and the resistance to permanent deformations (it must be noted that owing to the higher flexibility of this type of mixture, fatigue is not usually the critical failure mechanism). The objective of the present study is precisely to determine, for BSM-E, how the addition of CDWA affects these two critical properties.

2. Materials and method

2.1. Materials and production of specimens

The samples were made with two different sources of aggregates. On the one hand, aggregate from construction and demolition waste was recycled, mainly composed of concrete, mortar and stone with a certain proportion of impurities including ceramics, metal pieces, gypsum, plastics and glass (Table 1). On the other hand, a hornfels, a common metamorphic siliceous NA extracted from a local quarry in Ourense (Spain), was used to produce the control mixes. In Table 2, the main characteristics of both aggregates can be seen, of which the high water absorption and low specific gravity of CDWA are especially remarkable.

The selected binder for all samples was a cationic slow-setting bitumen emulsion (60% bitumen content) with 100 pen grade base bitumen.

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%

Following the recommendations of the Spanish Technical Association of Bituminous Emulsions (ATEB) (ATEB, 2015), all samples were made with the same gradation, corresponding to a grave emulsion GE1. The fine part of the gradation curve was adjusted to the lower limit because of the trend observed in CDWA to increase the amount of fine particles after the mixing and compaction processes (Fig. 1).

For the rutting tests, the mixtures were composed according to Standard NLT-161, derived from the French Duriez test (NF P98-251) and widely used for BSM-E. Thus, 101.6-mm height × 101.6-mm diameter cylindrical specimens were obtained after applying a static compaction of 1 MPa for 1 min (preload) followed by 21 MPa for 2 min. The samples were then cut with a radial saw blade, maintaining the diameter in 101.6 mm but reducing the height to 50 mm.

Because rutting is a long-term phenomenon, which especially occurs after many cycles, the BSM-E samples were fully cured until the mass remained constant. With this aim, and as specified by ATEB (ATEB, 2015), a 3-day curing time was applied in an oven at 50 °C. However, after the process, it was found that the weight was still not constant. Therefore, and to avoid premature aging of the binder, the samples were stored at room temperature (20 ± 2 °C) for 18 months.

2.2. Testing program

2.2.1. Aggregate–binder affinity

Aggregate–binder affinity is an indicator of the susceptibility of a certain mix to stripping phenomena. This susceptibility, as treated in the present paper, is an indirect measure of the capacity of a given binder to adhere to different aggregates used for the present investigation.

For this purpose, two different methods were used:

a) First, the rolling bottle test was applied. In this test, the aggregate–binder bond is assessed by means of visual inspection of the aggregate coating grade, once the loose mix has been subjected to mechanical agitation in the presence of water. This test was performed according to Standard UNE-EN 12697-11.
b) The second method was the boiling water test, which also involves the visual inspection of the coating grade of aggregates but only after having immersed the loose mix in boiling water under controlled conditions. This test is described in the American standard ASTM D 3625.

Although both tests fix a given amount of binder to be added to the mix, the present investigation went beyond this point, repeating the procedures with different binder contents (given a fixed water content) and with different water contents (given a binder content). Furthermore, to assess how the curing processes may affect the aggregate–binder adhesion, the tests were repeated with samples cured for 0 (control mixes), 3 and 7 days. A curing time of 3 days was selected because it is a common process included in a great deal of standards and investigations on BSM-E (ATEB, 2015). In addition, 7 days was considered as enough time to completely develop the curing of the mixes. The whole range of tests is summarized in Table 3.

2.2.1.1. Rolling bottle test. Standard UNE-EN 12697-11, specific for HMA, was modified in this investigation to test BSM-E. Thus, 510 ± 2 g of dry aggregate of the fraction 8/11.2 mm were mixed with the proper binder amount (although the standard specifies 3% binder over mix weight, this test was repeated with different residual bitumen contents; owing to the high absorption of CDWA, it was observed that 3% was insufficient to completely coat the