EFFECT OF HYDRATED LIME ON THE BOND BETWEEN ASPHALT AND RECYCLED CONCRETE AGGREGATES

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Abstract

In this investigation, rolling bottle tests and boiling water tests were performed to evaluate the effect of hydrated lime on the adhesion between recycled concrete aggregates (RCA) and the asphalt binder. RCA from construction and demolition waste (C&DW) were used in this investigation. To generalize the findings, three asphalt penetration grades were analysed: B40/50, B60/70 and B150/200. The results indicate that the use of hydrated lime does not improve the RCA-aggregate bond. Additionally, the results indicate that a higher asphalt-aggregate adhesion correlates to a lower asphalt penetration grade.

Keywords: asphalt, FTIR-ATR, recycled concrete aggregates, hydrated lime, bond.

1. Introduction

The use of recycled concrete aggregates (RCA) from construction and demolition waste (C&DW) in place of natural aggregates in hot-mix asphalt (HMA) promote sustainable road pavement construction. Nevertheless, several studies have observed that because of an insufficient bond between the RCA and asphalt binder, HMA designed with RCA have shown poor water resistance (Paranavithana and Mohajerani, 2006; Pérez et al., 2007, 2010, 2012a and 2012b). Properly coating RCA with bitumen is more difficult than coating natural aggregates with bitumen because of the rough surface texture of the RCA. This surface texture can also affect the water resistance of the mixture. Water damage is one of main causes of the premature deterioration of flexible pavements (Caro et al., 2008); this damage causes stripping that negatively affects the durability of the mixtures. Thus, this poor moisture damage resistance of HMA composed of RCA must be improved to guarantee the sufficient durability of such mixtures. These improvements will promote their use in the road pavement construction industry and therefore their environmental benefits.

Numerous products and treatments that can improve the water resistance of HMA are available in the market, including liquid surfactants, fly ash, Portland cement or hydrated lime. The most utilized product is hydrated lime (Epps et al., 2003; Airey et al., 2008; Kim et al., 2012). Hydrated lime can be introduced in the mixture in three different methods (Button and Epps, 1983):

- Addition of hydrated lime to dry aggregates;
- Addition of hydrated lime to wet aggregates; and
- Addition of hydrated lime slurry to dry aggregates.

The present investigation analyses the effect hydrated lime on the bond between RCA and asphalt and the water damage resistance and durability of HMA composed of RCA. To conduct the analysis, three samples using hydrated lime and Portland cement as filler were manufactured. The hydrated lime was introduced in the samples by the three above mentioned techniques. A fourth sample, using only Portland cement as filler (without the introduction of hydrated lime), was used as a control sample. RCA from C&DW have been used to conduct the investigation. To generalize the findings, three penetration grade asphalt binders were used: B40/50, B60/70 and B150/200. To perform the research, two types of laboratory tests were selected because of their rapidity and simplicity (Jo et al., 1997): the rolling bottle method (AENOR, 2011) and the boiling water test (ASTM, 2005).

2. Materials and methods

2.1. Materials characterisation

2.1.1. Recycled concrete aggregates

As stated above, the laboratory evaluation was conducted with RCA from C&DW from residential buildings. The material was supplied by a recycling site in Madrid (Spain). RCA is mainly composed of petrous materials (89.3%) (such as aggregates, concrete and mortar), particles of asphalt (6.5%), masonry (3.6%) and other components (0.6%).

Table 1 describes the main properties of the RCA. The RCA water absorption is high, and the resistance to fragmentation is poor because of the attached mortar onto the RCA surface.

2.1.2. Asphalt binder

B40/50, B60/70 and B150/200 asphalt penetration grades were used in this investigation. Fourier Transform infrared spectroscopy by attenuated total reflectance (FTIR-ATR) (Bruker Vector 22) was conducted to determine the functional group differences between the three tested bitumen. Figure 1 shows the spectra obtained in wavenumbers ranging from 1900 to 500 cm^{-1} (Lu and Isacsson, 2002). In this range, two wavenumber values are particularly important. On the one hand, the absorbance band at approximately 1700 cm^{-1} is related to the carbonyl compounds (C=O), such as ketones, carboxylic acids and anhydrides. On the other hand, the absorbance band at approximately 1030 cm^{-1} is related to the sulphoxide compounds (S=0). An increase in carbonyl and sulphoxide compounds is generally observed in aged bitumen (Qin et al., 2014; Zhu et al., 2014) and thus in harder bitumen. As shown in figure 1 and as expected, bitumen B40/50 and B60/70 display FTIR-ATR spectra peaks at wavenumbers of approximately 1700 cm^{-1}; these wavelengths were 1030 cm^{-1} higher and more similar than those obtained for B150/200, which is the softer bitumen.

2.1.3. Portland cement

Commercial grey Portland cement CEM II/B-M (V-L) 32.5 R was used as control filler (mineral powder with size passing through the 0.063 mm sieve).

2.1.4. Hydrated lime

Commercial hydrated lime CL-90 S (minimum content of CaO and MgO: 90%), with a grain size distribution shown in figure 2, was used as an anti-stripping additive. As noted above, hydrated lime was introduced into the mixture in the three abovementioned ways, which are described in detail below:

- In total, 1% of hydrated lime (Lesueur et al., 2013) by weight of the dry aggregates was added to the dry RCA; and 2% of Portland cement by weight of the dry RCA was also added.

- In total, 1% of hydrated lime by weight of the dry aggregates was added to the saturated-surface-dry (SSD) condition RCA; 2% of Portland cement by weight of the dry RCA was also added (figure 3a).
- In total, 1% of hydrated lime by weight of the dry RCA was added in the form of slurry (82.4% of distilled water and 17.6% of hydrated lime); 2% of Portland cement by weight of the dry RCA was also added (figure 3b).

2.2. Testing program

As mentioned above, to conduct the asphalt-aggregate adhesion analysis, two tests were performed: the rolling bottle method and the boiling water test.

The rolling bottle method consists of introducing a sample of loose bituminous mixture into a glass bottle filled with distilled water and rotating the sample for 24 hours. The percentage of asphalt that remains after rotation is determined. The results of this test are only useful in comparisons between samples because the rolling bottle method has no requirements for asphalt coating.

The boiling water test consists of introducing a sample of a loose bituminous mixture into distilled water and boiling the sample for 10 minutes. The percentage of aggregate that remains attached after boiling is determined. In this test, a minimum asphalt coating of 85%-90% is required to determine whether the asphalt-aggregate bond is satisfactory (Kiggundu and Roberts, 1988).

3. Test results and discussion

A total of twelve loose mixtures were studied following the two laboratory methods described above. Figure 4 shows the RCA-bitumen adhesion results for both laboratory methods.

In the first analysis, the boiling water test displays better RCA-bitumen affinity results than the rolling bottle method. This is because of the different detachment mechanism prevailing in each of the two performance tests. In both tests, the water interacts with the sample. However, in the rolling bottle method, the beating of the aggregates during the rolling causes the detachment of bitumen. In the boiling water test, the detachment is caused by heating. The high temperatures during the boiling water test likely promote chemical reactions between the bitumen and the hydrated lime, resulting in a better adhesion with the RCA.

In general, lower penetration grade bitumen causes higher RCA-bitumen bonds. Therefore, as expected (Liu et al., 2014; Pasandín and Pérez, in press), the B40/50 displays a higher remaining bitumen coating for both tests, and the B150/200 displays the worst bitumen coverage.

From this laboratory evaluation, the use of hydrated lime in general does not improve the RCA-bitumen adhesion. Notably, the control mixture (the sample comprised of only with Portland cement as filler) displays similar or better bitumen coverage results than those using hydrated lime. This result seems to contradict the conclusions obtained by other studies (Hicks, 1991) in which hydrated lime is the most effective additive against the action of water. Nevertheless, this conclusion was obtained for virgin aggregates and not for RCA. Thus, RCA seems to not follow the identical rules of virgin aggregates. This deviation is likely because of the attached mortar onto the RCA surface, which is mainly composed of Portland cement.

For the boiling water test, the hydrated lime applied to the SSD RCA displayed better coverage results (figure 5a), similar or slightly better than those obtained for the control mixture. Contrary to the rolling bottle method, this treatment displays the worst coverage results (figure 5b). Again, the prevailing detachment mechanisms in each performance test may explain this finding.

Three-way ANOVA (analysis of variance) was conducted using SPSS software (PASW Statistics 18) to determine the effect of the performance test, the penetration grade of the bitumen and the method of introducing hydrated lime in the mixture on the adhesion between asphalt and RCA. The remaining asphalt coating was the dependent quantitative variable, whereas the type of test (rolling bottle method or boiling water test), the asphalt penetration grade (B40/50, B60/70 and B150/200) and the method of introducing the hydrated lime in the mixture (as filler, applied to SSD RCA and as slurry) were qualitative factors.

The ANOVA results are displayed in table 2. Statistical analysis indicated that the type of test ($p \leq 0.0001 \leq 0.05$) and the use of treatment ($p=0.026 \leq 0.05$) significantly affects the asphalt-RCA adhesion, confirming the results observed in figure 4. Nevertheless, the bitumen penetration grade is not statistically significant in the RCA-bitumen bond ($p=0.051 \geq 0.05$), contradicting the results observed in figure 4. To refine the results, a Tuckey post hoc analysis was also conducted to analyse the influence of the bitumen penetration grade. The results are shown in table 3. The penetration grade is statistically significant ($p=0.05$) only between the extreme penetration grades analysed, that is, between B40/50 and B150/200. Thus, to detect the effect of the grades, the differences between penetrations must be noticeable.

4. Conclusions

Based on the results of this research, the following conclusions can be drawn:

- Aggregate-asphalt bond tests influence the bitumen coverage results. Therefore, when analysing the RCA-bitumen bond, is recommended to conduct at least two different tests to generalize the findings.
- As was expected, a higher asphalt penetration grade correlates to a lower RCA-asphalt adhesion. Nevertheless, these differences are significant when the penetration grades differences are noticeable (for example B40/50 versus B150/200).
- Unexpectedly, conclusions from other studies were not confirmed; in general, mixtures composed of Portland cement display better RCA-asphalt bond than mixtures in which hydrated lime is introduced.

These findings were obtained from the limited research conducted. Therefore, further investigations are required to resolve issues such as why the RCA functions differently than natural aggregates when using hydrated lime as an anti-stripping agent.

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Table 1
RCA properties

Property (*)	Standard	Result
ρa (g/cm^3)	EN-1097-6	2.63
WA_{24} (%)	EN 1097-6	5.08
SE (%)	EN 933-8	67
LA (%)	EN 1097-2	32

(*) ρa: bulk specific gravity
WA_{24}: water absorption
SE: sand equivalent
LA: Los Angeles abrasion coefficient

Table 2
ANOVA results: the effects of the type of test, bitumen penetration grade and use of hydrated lime in the RCA-asphalt bond

Source of Variation	**SS**	**DF**	**MS**	**F**	**p-value**
MAIN EFFECTS					
A: type of test	1,276.042	1	1,276.042	53.261	0.000
B: bitumen penetration grade	243.750	2	121.875	5.087	0.051
C: use of hydrated lime	469.792	3	156.597	6.536	0.026
INTERACTIONS					
A*B	189.586	2	94.792	3.957	0.080
A*C	803.125	3	267.708	11.174	0.007
B*T	139.583	6	23.264	0.971	0.514
RESIDUAL	143.750	6	23.958		
TOTAL	3,265.628				

(*) SS: sum of squares; DF: degrees of freedom and MS: mean square

Table 3
Tuckey post-hoc analysis: the effects of the bitumen penetration grade on the RCA-asphalt bond

Bitumen		p
B40/50	B60/70	0.736
	B150/200	0.050
B60/70	B40/50	0.736
	B150/200	0.132
B150/200	B40/50	0.05
	B60/70	0.132

Figure 1
FTIR-ATR spectra for B40/50, B60/70 and B150/200

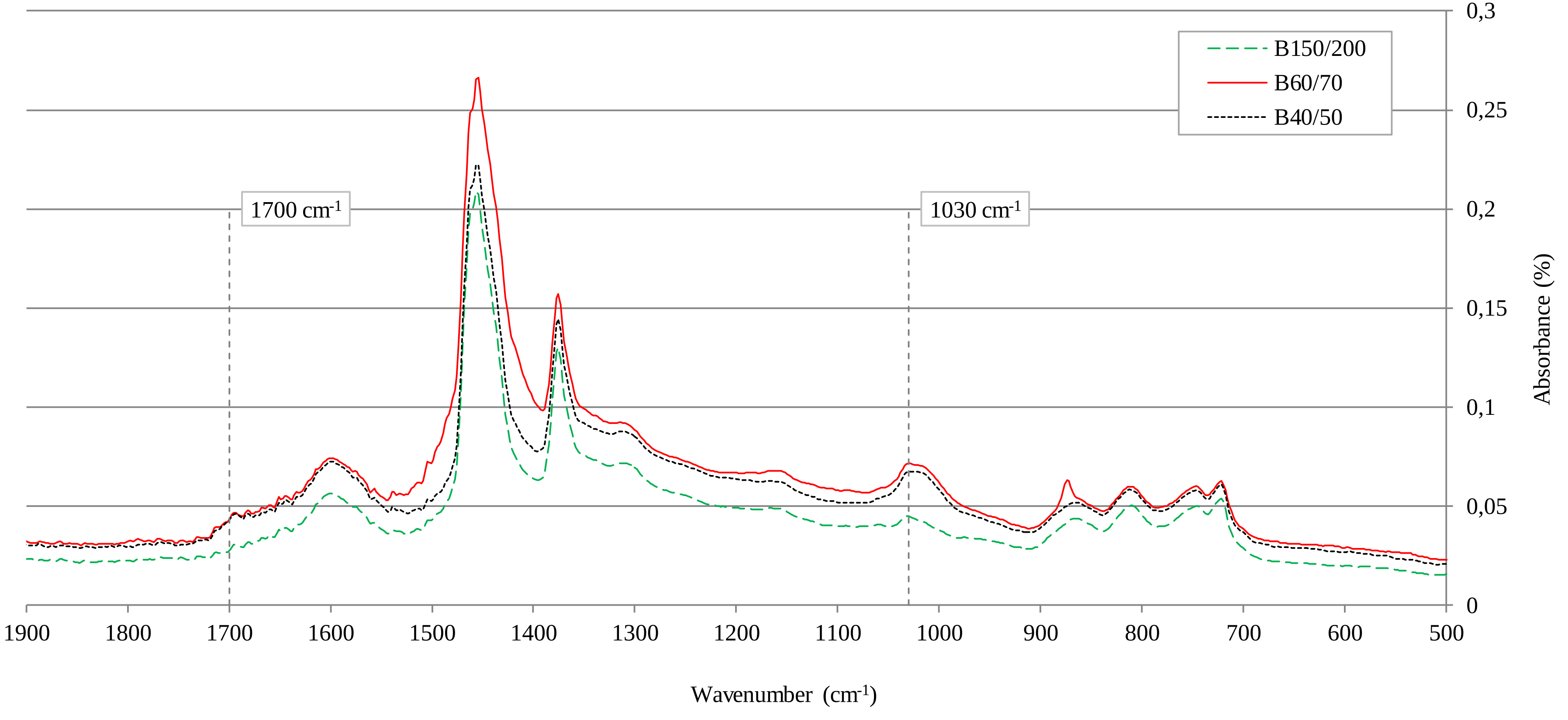

Figure 2
CL-90-S grain size distribution

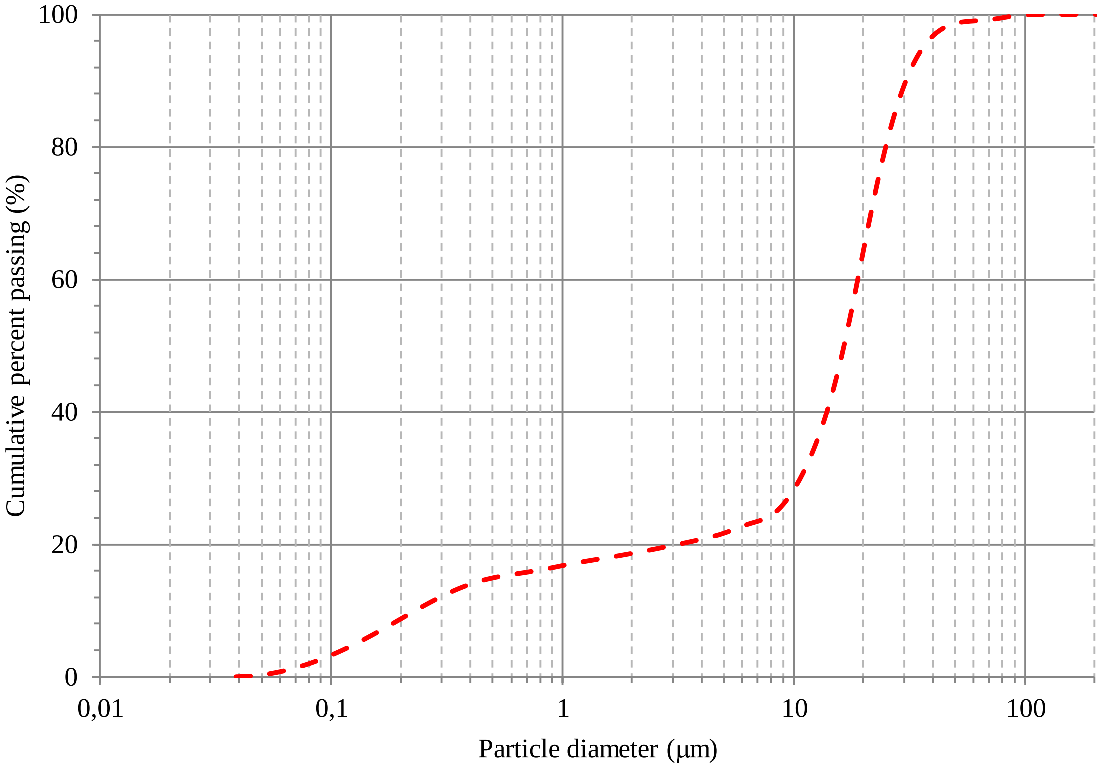

Figure 3
Pretreated RCA before mixing with bitumen: a) 1% of hydrated lime to SSD condition RCA and b) RCA with hydrated lime in the form of slurry

Figure 4
RCA-bitumen adhesion results

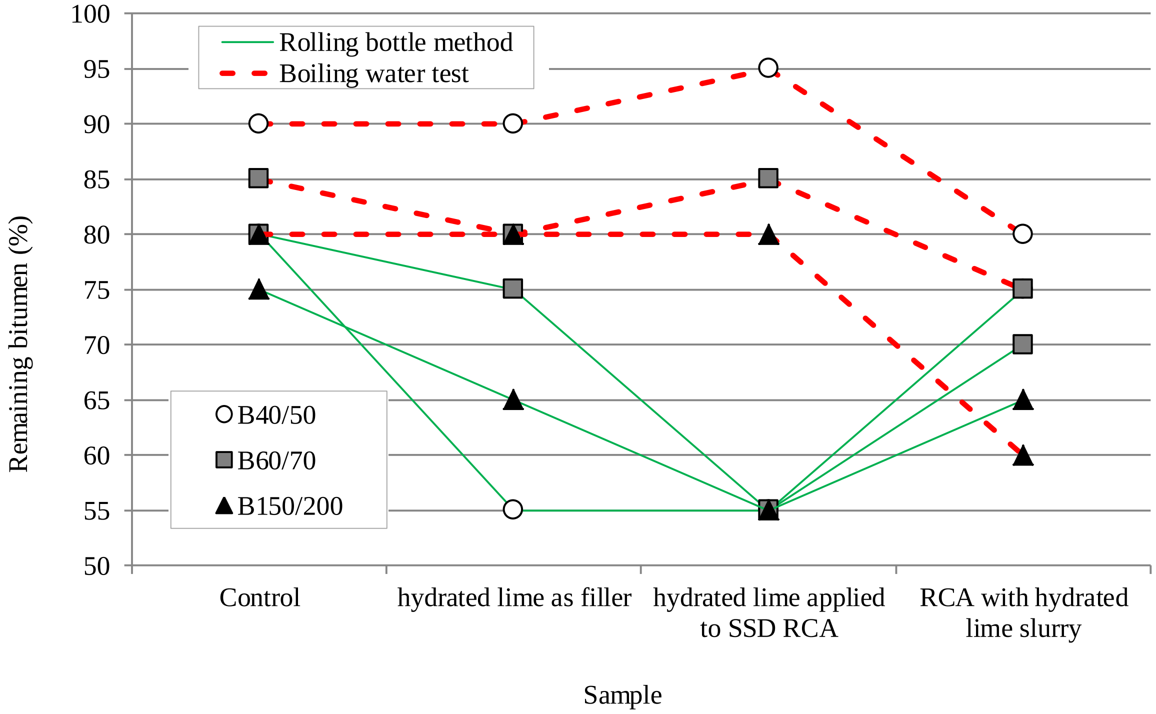

Figure 5
Hydrated lime applied to SSD RCA using B40/50: a) boiling water test results and b) rolling bottle method results