Warm Mix Asphalt / Low temperature asphalt

STRIPPING POTENTIAL OF HALF-WARM MIX ASPHALT MADE WITH RECYCLED CONCRETE AGGREGATES

Ana María Rodríguez Pasandín, Ignacio Pérez Pérez, Lidia Caamaño Caamaño
Universidade da Coruña (UDC)

Abstract

Warm-mix asphalt (WMA) and half-warm-mix asphalt (HWMA) are relatively new and sustainable techniques for the manufacture of bituminous mixtures for flexible road pavements. The use of recycled concrete aggregates (RCA) from construction and demolition waste (C&DW) as aggregate in bituminous mixtures could also contribute to the sustainable construction of such pavements. Nevertheless, the use of RCA as raw material lead to bituminous mixtures with low moisture damage resistance, particularly when used in hot-mix asphalt (HMA). In the present investigation HWMA for road binder course type AC 22 bin S has been manufactured replacing the coarse fraction of the natural aggregate by RCA. That is, 55% of RCA and 45% of hornfels have been used as aggregate. The mixture has been manufactured using low setting cationic bitumen emulsion type C60B4 as binder. The air voids, adhesion and stripping potential of the mixtures have been analyzed. The results have been compared with those obtained for a control mixture (0% RCA). As was expected, the stripping potential of the HWMA made with 55% RCA is higher than that obtained for the control mixture. Nevertheless, higher bitumen content, lead to HWMA made with RCA that comply with the Spanish Technical specifications for moisture damage resistance. A cost effective analysis has been also conducted with the aim of quantifying the economical drawbacks of using RCA in HWMA.

This paper was first published in 2020 in version 1.0 of the proceedings of the 7th E&E Congress. This second edition (version 1.1.) of the proceedings is published in June 2021. The content of this paper has not changed, but the author(s) may have provided additional information in the form of an annex.

1. INTRODUCTION

In line with the target of 1.5ºC of global warming above pre-industrial levels proposed by the Intergovernmental Panel on Climate Change (IPCC, 2018) of United Nations, the road pavement industry has developed new environmentally friendly technologies, such as the use of warm mix asphalt (WMA) and half-warm mix asphalt (HWMA). Particularly, according to Rubio et al. (2012), HWMA exhibited mixing and laying temperatures ranging from 60 ºC to 100 ºC. This temperature reduction could lead to CO_2 emissions reduction up to 58% when compared to conventional hot bituminous mixtures. Also, fossil fuel consumption is reduced due to the lower temperature used during all the process, leading not only to environmental benefits but economic benefits.

In addition, the recycled concrete aggregates (RCA) from construction and demolition waste (C&DW) are a potential source of aggregates for bituminous mixtures that can promote the circular economy in the construction industry. Only in Spain in the period 2009-2013 a total of 139.62 million tons of C&DW (GERD, 2018) were generated, which is indicative of the important flow of this kind of waste.

The technical and environmental requirements for the use of RCA in bituminous mixtures can be found in the existing technical standards for natural aggregates (GERD, 2018; AENOR, 2003). Nevertheless, the rough nature of the RCA, the porous attached mortar and the heterogeneity of its composition make that the RCA display properties that lead to bituminous mixtures with poor properties than that made only with natural aggregates. In this regard, when these aggregates are used for hot bituminous mixtures, the stripping potential of the mixtures is higher than that of the mixtures made with conventional virgin aggregates (Paranavithana and Mohajerani, 2006; Diew et al., 2007; Mills-Beale and You, 2010; Wen and Bhusal, 2011; Lee et al., 2012; Pérez et al., 2012a and 2012b; Wu et al., 2012; Zhu et al., 2012).

For all these reasons, in this research, the feasibility of using RCA for the manufacture of HWMA is analysed. Particularly, this research focuses on the stripping performance of HWMA mixtures made with RCA in the coarse fraction (55% RCA) and natural aggregates in the fine fraction. The current Spanish specifications and a control mixture (100% natural aggregate) were used to analyse and compare the results. The final aim of this investigation is to achieve environmental and economic benefits whilst ensuring a reduction in the labour risks and increased comfort for workers.

2. MATERIALS AND METHODS

2.1. Recycled concrete aggregate

Recycled concrete aggregates (RCA) from construction and demolition waste have been used in this investigation. These aggregates are different from the recycled asphalt pavement (RAP) due to the RAP comes from the demolition of bituminous pavements, while the RCA comes from the demolition of buildings. The RCA used in this investigation, was supplied by a C&DW recycling plant in Spain. Figure 1 shows the RCA composition obtained according to EN 933-11. As can be seen, the majority components are concrete, aggregate and mortar.

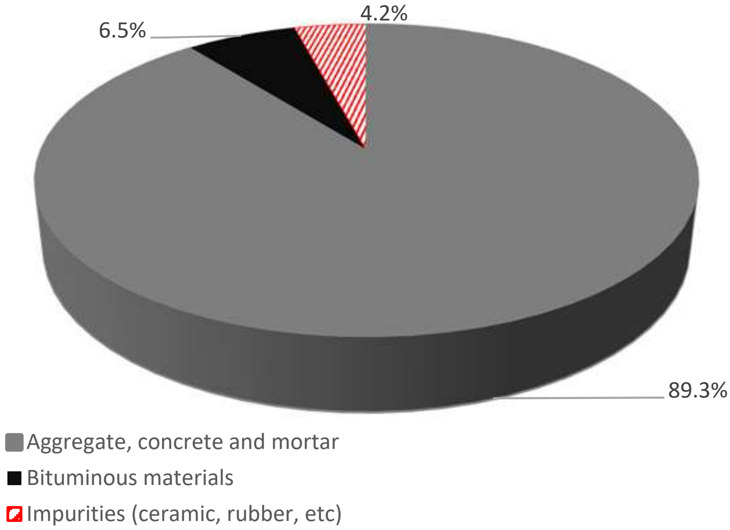

Figure 1: RCA main constituents

According to the Spanish General Technical Specifications for Road and Bridges (known as PG-3) (MFOM, 2015), the only property that makes the RCA suitable for only heavy traffic category T2 (Annual Average Daily Heavy Traffic: 200-800), is that it has a high Los Angeles (LA) coefficient (LA = 32%).

2.2. Natural aggregate

As natural aggregate, a siliceous hornfels, typically used in the road pavement construction, has been chosen to conduct this research. In this case, its properties makes it suitable for T1 heavy traffic category (Annual Average Daily ≥ 4,000).

2.3. Bitumen emulsion

A commercial cationic medium setting bitumen emulsion C60B4 was selected as bituminous binder (MFOM, 2015).

2.4. Half warm mix asphalt type and manufacture process

Based on the gradation limits given by the Technical Association of Bituminous Emulsions (ATEB) (2014), a HWMA type AC22binS for binder course of road pavements was selected to conduct this study (figure 2).

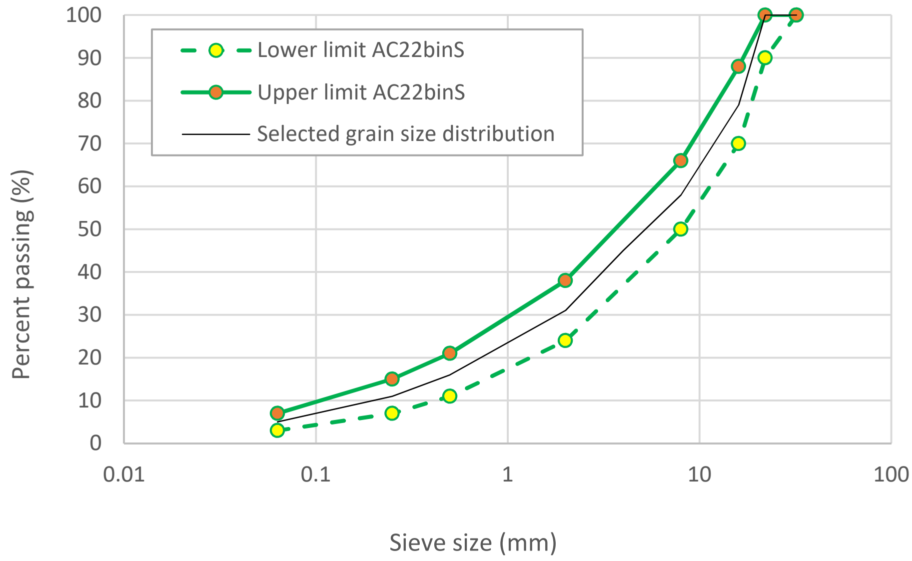

Figure 2: Grain size distribution of AC22binS

Two different HWMA were manufactured: a mixture with 0% RCA (i.e. 100% natural aggregate as control mixture) and a mixture made with 55% of RCA (i.e. all the coarse fraction with RCA and the fine fraction with natural aggregate).
In order to achieve a proper coating, in the control mixture the aggregates were heated at 105ºC and the bitumen emulsion at 60ºC. In the mixture made with 55% of RCA, the aggregates were heated at 100ºC and the bitumen emulsion at 65ºC. The mixing time was of 120 seconds.

2.5. Air voids

In order to determine the air voids content (Va), the EN 12697-8 was followed. The bulk specific gravity (ρb) (on Marshall specimens compacted with 75 blows per face) and the maximum specific gravity (ρm) were determined following the EN-12697-6 and the EN-12697-5 respectively. Then, the following equation was used to calculate Va:

$$Va = \frac{\rho_m - \rho_b}{\rho_m} \times 100$$

The Va was determined for HWMA made with 0% (control) and 55% of RCA that were manufactured with different residual bitumen contents. In order to satisfy the Spanish requirements (ATEB, 2014; MFOM, 2015), the Va for HWMA binder courses must be from 5% to 7% for traffic categories T1 and T2 and from 4% to 7% for traffic categories T3 (Annual Average Daily Heavy Traffic: 50-200) and T4 (Annual Average Daily Heavy Traffic: 0-50).

2.6. Stripping potential

The EN 12697-12 was followed to evaluate moisture damage resistance of HWMA made with 0% and 55% RCA. The mixtures were manufactured with the same residual bitumen content indicated in the section 2.5.
In this test, for the control mixture and for the HWMA made with 55% RCA, a series of ten cylindrical Marshall samples compacted with 50 blows per face was manufactured. Each series was subdivided into two subseries, with 5 samples each, namely the ‘dry’ and ‘wet’ subseries. The samples of the ‘dry’ subseries were maintained at room temperature while the samples of the ‘wet’ subseries were saturated and then held in a water bath for 3 d at 40°C. Then, the ‘dry’ and ‘wet’ subseries were left for 2 h at 15 °C and the tensile strength ratio of each set was determined as indicated in the next equation:

$$\mathrm{TSR} = \frac{\mathrm{ITS_w}}{\mathrm{ITS_D}} \times 100$$

where TSR denotes the tensile strength ratio (%), ITS_W denotes the average tensile strength of the ‘wet’ specimens (MPa), and ITS_D denotes the average tensile strength of the ‘dry’ specimens (MPa). Additionally, TSR ≥ 80% is required by the Spanish specifications (ATEB, 2014; MFORM, 2015) for HWMA for use in binder courses.

2.7. Cost effective analysis

A cost-effectiveness analysis taking into account the cost per ton of mixture and the energy consumption of both mixtures (0% and 55% RCA) was conducted.

2.8. Life cycle analysis

The ECCO2 free online software by Arnó Company (2019) has been used to perform a life cycle analysis (LCA). This program carries out a "cradle to gate" LCA analysis, since it takes into account the impacts due to the extraction, transformation and transportation of raw materials, as well as those derived from the manufacture, transport and positioning of the bituminous mixtures. In this analysis, an indicator of the climate change was obtained for the control mixture (0% RCA) and for the mixture made with 55% RCA.

3. RESULTS AND DISCUSSION

3.1. Air voids

Table 1 shows the air voids contents (Va) for the HWMA made with 0% RCA (control mixture) and the HWMA made with 55% RCA. As was expected, in both cases, the Va decreases as the residual binder content increases. The lower and the upper limits of the Spanish standards (ATEB, 2014; MFOM, 2015) in terms of Va are also included in Table 1. The values that fulfil the national specifications are highlighted by means of shaded boxes. As can be seen, the first residual bitumen content that achieves compliance with the specifications is 4.1% for the control mixture and 6.5% for the HWMA made with 55%RCA. The rough RCA surface and its absorptive nature, make HWMA made with 55% RCA demand a residual bitumen content 58.5 % higher than the control mixture.

Table 1. Air voids content

Residual bitumen content (%)	Va (%)				
	0% RCA	55% RCA	Lower limit		Upper limit
			T3 and T4	T1 and T2	T1, T2, T3 and T4
3.7	8.4	-	4	5	7
3.9	8.2	-			
4.1	6.5	-			
4.3	5.0	13.1			
4.5	4.3	12.8			
4.8	-	12.3			
5.0	-	11.0			
5.2	-	10.7			
5.4	3.0	10.3			
5.7	-	10.0			
5.9	-	9.2			
6.1	-	8.4			
6.3	-	8.1			
6.5	-	6.8			

3.2. Stripping potential

Figure 3 shows the TSR, ITS_D and ITS_W obtained for HWMA made with 0%RCA and 55% RCA, at the minimum residual bitumen content indicated previously: 4.1% for the control mixture and 6.5% for the mixture made with 55% RCA. As can be seen, the stripping potential is adequate (TSR≥80%) and very similar in both cases but the indirect tensile strength is lower in the case of the HWMA made with 55% RCA. That is, the RCA reduces the resistance of the mixture in terms of indirect tensile stress: 31.5% in the case of the dry group and 35.8% in the case of the wet group. Probably the higher air voids content is mainly responsible for this performance. Also, the weak attached mortar onto the RCA surface could aid to produce this low resistance.

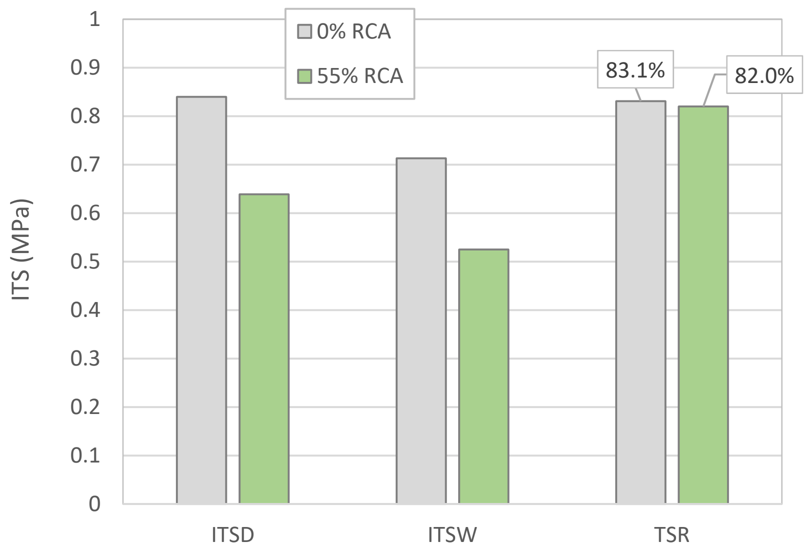

Figure 3: Stripping potential results

3.3. Cost effective analysis

A cost-effectiveness analysis was conducted. In this analysis, the control HWMA (0% RCA) and the HWMA made with 55% RCA were compared. Both mixtures were analysed at their optimum bitumen content: 4.1 % for the control mixture and 6.5 % for the mixture made with 55%RCA. As is shown in table 2, the cost of manufacture the HWMA made with 55% RCA t is 35.0% higher than that of the control mixture, due to the higher residual binder content used to manufacture this mixture.

Table 2. Cost-effective analysis

Component	**Cost (€/t)**	**Cost per ton of HWMA (€)**	
		HWMA 0% RCA (4.1% residual binder)	**HWMA 55% RCA** (6.5% residual binder)
C60B4	360	24.60	39.00
Aggregate (hornfels)	8.21	7.65	3.29
Aggregate (RCA)	2.50	0.00	1.23
Total		32.25	43.52

3.4. Life cycle analysis

Figure 4 shows the climate change indicator (kg of CO_2 equivalent) for the HWMA made with 0% RCA (control mixture) and for the HWMA made with 55% RCA. As can be seen, despite 55% RCA is used in place of natural aggregate, the higher residual bitumen consumption of the HWMA made with 55% RCA lead to mixtures with a 24.1% higher climate change impact: 38.4 kg of CO_2 for the control mixture and 43.2 kg of CO_2 for the HWMA made with 55% RCA.

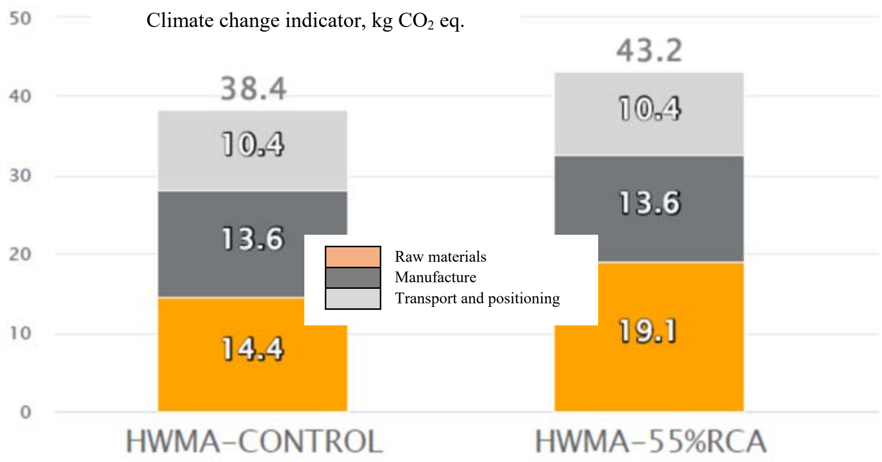

Figure 4: Climate change indicator for the control HWMA and the HWMA made with 55% RCA obtained by ECCO2

4. CONCLUSIONS

The use of RCA for the manufacture of HWMA type AC22binS with bitumen emulsion for low traffic roads is possible, but currently it has two main inconveniences:

- A minimum of 31.5% of indirect tensile strength reduction compared with a control mixture
- A 58.5% of increased residual bitumen consumption compared with a control mixture (0% RCA), that lead to mixtures with higher climate change impact (24.1% higher CO_2 emissions) and higher cost (35.0% higher).

Thus, the economic and environmental benefits on the use of RCA in place of natural aggregates, are totally mitigated by the increased bitumen emulsion consumption, that lead to environmental drawbacks, such as increased CO_2 emissions.

ACKNOWLEDGEMENTS

The authors want to thank the Spanish Ministry of Education and Science for sponsoring this research through Project BIA2013-47987-C3-2-R.

The authors would also like to thank Ecoasfalt S.A. for supplying the bitumen emulsion, Tec-Rec for supplying the recycled concrete aggregates, and Probigasa for supplying the hornfels.

REFERENCES

- AENOR (Spanish Association for Standardization and Certification), 2003. Aggregates for bituminous mixtures and surface treatments for roads, airfields and other trafficked areas (in Spanish).
- Arnó. Tool for Calculating the Environmental Impact of Bituminous Mixtures. Manual. http://www.arno.es/es/ecco2/ (Accessed 24 July 2019) (in Spanish).
- ATEB. Technical Association of Bituminous Emulsions. Half-Warm Mix Asphalt with bitumen emulsion. Madrid, Spain (in Spanish), 2014.
- Diew, W.Y., Delai, S.D. and Dickson, L. Value-added utilisation of recycled concrete in hot-mix asphalt. Waste Manage, 2007, 27(2), 294-299. http://dx.doi.org/10.1016/j.wasman.2006.02.001.
- GERD (Spanish Association of Construction and Demolition Waste Managers). Spanish Guide of Recycled Aggregates from Construction and Demolition Wastes, 2018 (*in Spanish*).
- IPCC, Special Report on Global Warming of 1.5°C, IPCC Special Report, 2018.
- Lee C.H., Du J.C., Shen D.H. Evaluation of pre-coated recycled concrete aggregate for hot mix asphalt. Construction and Building Materials, 2012, 28, 66-71. http://dx.doi.org/10.1016/j.conbuildmat.2011.08.025.
- MFOM. Ministry of Public Works. Article 542 (Asphalt Concrete) of the General Technical Specifications for Road and Bridge Works (PG3) from the Spanish Ministry of Public Works. Madrid, Spain (in Spanish), 2015.
- Mills-Beale J., You Z. The mechanical properties of asphalt mixtures with recycled concrete aggregates. Construction and Building Materials, 2010, 24, 340-345. http://dx.doi.org/10.1016/j.conbuildmat.2009.08.046.
- Paranavithana S., Mohajerani A. Effects of recycled concrete aggregates on properties of asphalt concrete. Resources Conservation and Recycling, 2006, 48, 1 - 12. http://dx.doi.org/10.1016/j.resconrec.2005.12.009.
- Pérez I., Pasandín A.R and Gallego J. Stripping in hot mix asphalt produced by aggregates from construction and demolition waste. Waste Management Research, 2012b, 30 (1), 3 - 11.
- Pérez I., Pasandín A.R, Medina L. Hot mix asphalt using C&D waste as coarse aggregates. Matererials and Design, 2012a, 36, 840-846. http://dx.doi.org/10.1016/j.matdes.2010.12.058.
- Rubio, M.C., Martínez, G., Baena, L. and Moreno, F.,Warm mix asphalt: an overview. Journal of Cleaner Production, 2012, 24, 76-84.http://dx.doi.org/10.1016/j.jclepro.2011.11.053
- Wen H., Bhusal S. Evaluate Recycled Concrete as Hot Mix Asphalt Aggregate. Transportation Northwest (TRANSNOW). 2011. University of Washington.
- Wu, S., Zhong, J., Zhu, J. and Wang, D. Influence of demolition waste used as recycled aggregate on performance of asphalt mixture. Road Materials and Pavement Design, 2013, 14(3), 679-688. http://dx.doi.org/10.1080/14680629.2013.779304
- Zhu J.; Wu S.; Zhong J., Wang D. Investigation of asphalt mixture containing demolition waste obtained from earthquake-damaged buildings. Construction and Building Materials, 2012, 29, 466-475. http://dx.doi.org/10.1016/j.conbuildmat.2011.09.023.