Sustainable urban roads

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ABSTRACT

In recent years, within the current growing awareness and tightening of the environmental regulations, it has been attempting to correct the impacts that the manufacture and application of Asphalt Mixtures causes on the environment. The concept of sustainability has come to the field of bituminous mixtures with three main components: reducing costs, reducing emissions and reducing consumption of raw materials, preserving resources for the future.

Rehabilitation and Maintenance activities of road pavements generate an increasing amount of waste from the milling of the damaged layers of bituminous mixtures. This material, which has a high cost and its properties are exceptional, should be reused in manufacturing new mixtures of the same type and function. We are more obliged to provide solutions that will minimize the consumption of natural resources by using a new generation of Bituminous Mixtures.

This paper presents the efforts carried out to develop a technology for the construction, maintenance and rehabilitation of roads based on the use of Half-Warm Mix Asphalt, with a recovery rate up to 100% that applies low temperatures at the production (90-100 ºC) and compaction (70-80ºC) stages of road/street construction. These mixtures will contribute to improve the sustainability of urban areas by reusing materials of high quality, reduction in energy consumption and reduction in GHG emissions with a hefty lower impact on the environment.

Keywords: Emulsions, Low-Temperature, Milling, Reclaimed asphalt pavement (RAP) Recycling, Warm Asphalt Mixture

1. INTRODUCTION

The environmental impact of the hot mix asphalt industry is not all negligible or insignificant. Without undertaking any evaluation of the impacts produced during the process of manufacturing components (aggregates and binders) and equipment used in the manufacture and laying, the manufacturing of hot mix asphalt (HMA) requires significant energy consumption and generates a certain volume emissions of greenhouse gases.

In response to these two major issues of the urban road sustainability, it suggests that compared to hot mix asphalt manufactured at temperatures between 140ºC and 170 ºC, with a consumption of raw materials (95 percent aggregates and about 5 percent asphalt cement), a new type of bituminous asphalt that applies low temperatures at the production and compaction stages, without additional natural aggregates along with the minimal addition of bitumen must be developed.

With changes in construction materials economics, stricter environmental regulations, and an emphasis on “green” technologies and sustainable pavements, these innovative recycled mixtures for surface layers constitutes a “treasure trove” for the urban road heritage conservation.
The main goal of the study is to investigate and develop Half-Warm Mix Recycled asphalt for wearing courses in urban roads. In order to fulfil this objective, the study was divided into four phases.

- Reclaimed Asphalt Pavement (RAP) Samples Analysis and characterization.
- Characterization studies and development of specific emulsions.
- Mix design and the job-Mix formula.
- Validation of these mixtures through field trials.

2. LABORATORY STUDIES

2.1. Preparation, selection, analysis and characterization of samples of milling (RAP) and aggregates.

The recycled asphalt pavement (RAP) selected came from the wearing course of Madrid street. Once selected, we proceeded to treat the RAP in a Roll Mill. The mill has a device for RAP classification into two different fractions, a bulk (5/25 mm) and a fine (0/5 mm). Under normal conditions, particles >60 mm are rejected, between 25 and 60 mm are fed to the mill and <25 mm they go directly to the sorting sieve

Figure 1: RAP classification into two fractions.

Classification RAP into two fractions is essential for accurate and weight control of each fraction in the final composition of the mixture thus ensuring its consistency.

Background research was carried out to characterize the RAP samples obtained. The tests performed were:

- Particle size distribution, UNE EN 933-1 and UNE EN 12697-2
- Soluble binder content, 0/5 and 5/25 mm fraction, UNE EN 12697-1.
- Binder recovery: rotary evaporator, UNE EN 12697-3.
- Penetration graded recovery binder, UNE EN 1426.
- Softening point recovery binder, UNE EN 1427.
- Other chemical and physical characterizations recovered binder and aggregates.

-	5/25Fraction		0/5Fraction	
UNE EN 933-1	BLACK	WHITE	BLACK	WHITE
Sieve UNE EN (mm)	**% Passing**			
31,5	100,0	100,0	100,0	100,0
22,4	99.5	100,0	100,0	100,0
16	91.7	96.7	100,0	100,0
8	32.4	58.3	100,0	100,0
4	5.3	25.1	71.8	82.6
2	4.7	20.5	32.9	53.6
0,5	2.9	14.6	11.2	25.1
0,25	1.3	11.6	1.4	20.0
0,063	0.2	6.4	0.3	10.2
% Binder s/a	3.65±0.5		6.17±0.04	

Table 1: Fractions analysis RAP
Black fraction: RAP with binder White fraction: RAP without binder

RAP Physical Characterisation:

Los Angeles Abrasion	UNE-EN 1097-2
LAA:	**20**
Crushed and broken faces	Según UNE-EN 933-5
Crushed and broken, %	**28,0**
Completely crushed, %	**64,0**
Rounded, %	**7,7**
Completely Rounded, %	**0,2**
Flakiness index	UNE-EN 933-3
FI:	**7,1**
Relative density and absorption coarse aggregate	UNE-EN 1097-6
Bulk (g/cm^3)	**2,630**
s.s.s.(g/cm^3)	**2,647**
Real (g/cm^3)	**2,676**
Absorption %	**0,65**
Relative density and absorption fine aggregate	UNE-EN 1097-6
Bulk (g/cm^3)	**2,604**
s.s.s.(g/cm^3)	**2,652**
Real (g/cm^3)	**2,693**
Absorption %	**2,05**
Sand Equivalent	UNE-EN 933-8
S.E.	**51%**

Table 2: Fractions physic analysis aggregate recovery of RAP

BINDER RECOVERY (UNE EN 12697-3)			
Ensayo	**UniT**	**Standard**	**Valour**
Penetration 25 ºC	*0,1 mm*	UNE EN 1426	14
Softening point, Ring & Ball	*ºC*	UNE EN 1427	71.8
FRAGMENTATION RECOVERED BINDER			
ASPHALTEN (A)	%	ASTM D 2006	38.22
POLARS (N)	%	ASTM D 2006	21.71
1ª ACIDAFINES (A1)	%	ASTM D 2006	11.75
2ª ACIDAFINES (A2)	%	ASTM D 2006	17.80
SATURED (P)	%	ASTM D 2006	10.06
ReactivityChemical (CRR)	0.4 > CRR < 1.5		1.20
Colloidal instability (Ic)	Ic< 1.0		0.94
Chemical compatibility C	C > 0.5		2.16

Table 3: Physic and chemistry analysis binder recovery of RAP

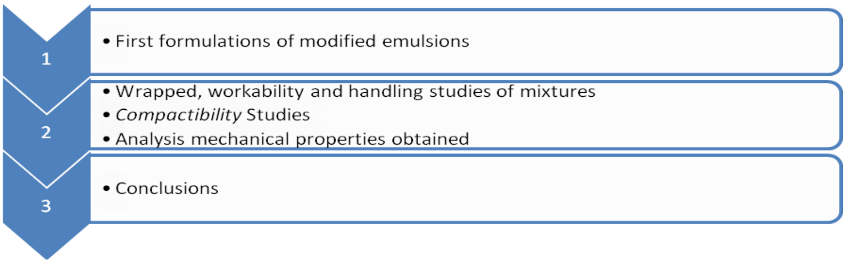
The virgin aggregates used in the studies of the half-warm mix recycled asphalt corresponded to fractions 12/18 , 6/12 and 0/6 mm of silicon origin (Madrid) , sand 0/6 mm limestone origin (Madrid) and 6/12 mylonite origin from Almonacid (Toledo).

The main conclusions obtained at this stage were:

- The recovery binder from the milled material wasn't excessively aged.
- The composition in two fractions generated from the milled material, are suitable to be used in Half-Warm Mix asphalt (HWMA) with a recovery rate of 100% and also in HWM with a recovery rate lower.
- The RAP may be suitable to be used for wearing courses, based on the results of tests performed on them.
- The virgin aggregates are suitable to be used in Half-warm mix recycled asphalt.

2.2. Characterization studies and development of specific emulsions.

The purpose of this phase consisted of characterization studies and development of specific emulsions for different types of mixtures. The methodology used is summarized in the following diagram:



The studies carried out at this stage provided the basis for the formulation of emulsions to be used for the design of the all Half-Warm mix recycled asphalt raised in this study.

All emulsification tests were made in pilot plant and the use of different emulsions in the proposed mixtures have allowed us to know what composition may be more favourable to get mechanical properties in half warm mix recycled asphalt (HWMRA) to meet the specifications and referenced in the statement technical requirements for Hot Mix Asphalt (HMA).

Emulsion formulations for HWMRA were based on:

- Find emulsions allow us an appropriate workability/handling in Half-Warm mix recycled asphalt to its laying and compaction. So it is important to define the type of binder based emulsions, in terms of physical, chemical and rheological properties.

- For Half-warm mix with total recycling rate (100%), it is not necessary emulsifiers that empowered the adhesiveness with the milling material. Even If there is loss of this properties in terms of indirect tensile strength (ITS) by the action of water, others emulsifiers can be used to improve this feature.

- For mixtures with lower recycling rate for the type of aggregates used in the study, it is necessary to use additives in the bitumen that would improve residual activity of active binder, in addition to strengthening the highest percentage that improved adhesiveness emulsifier

- Modified emulsions are designed with a concentration of 67% of final residual binder observed good coating and behavior. Unmodified emulsions are designed with concentrations above 65% of residual binder. They are emulsions type C65 / 67B3 or C67BP3, spontaneous rupture of the emulsion and binder foaming at manufacturing temperatures of HWRMA (100 ºC) and residual water remaining helps workability and compaction performance of the mixture.

2.3. Design of mixtures and obtaining Job-Mix Formula.

The compaction system chosen and used for the mixtures in this study was the gyratory press, according to UNE EN 12697- 31, using:

- contact pressure of 600 kPa,
- rotation angle of 0,82º,
- rotation speed of 30 rpm ,
- and 100 mm diameters moulds.

The system is considered suitable to obtain samples in the laboratory for the HWMRA technology and comes closest to the reality of what happens to real scale.

The conditions of manufacturing for such mixtures were:

- RAP Temperature 100ºC
- Virgin Aggregate temperature: 115-120 ºC
- Emulsions Temperature: 60 ºC
- Mix Temperature: 90-100 ºC
- Compaction Temperature: 70-80 ºC

Mixtures selected for this study were half-warm mix with a high recycling rate (50 % -80 %) and HWMA with total recycling rate (> 80 %) for wearing courses.

- HWMA for very thin layer type BBTM11B with a total recycling rate, (100%RAP) that we have called **BBTM 11B RT100.**
- HWMA type asphalt concrete (AC) with three different recycling rate (100%, 70% and 50% RAP), between dense and semi dense grading. That we have called **ACRT100, ACRT70 and ACRT50.**

BBTM11B RT100 was manufactured with course fraction of RAP (5/25 mm), to obtain a white grading curve **(without binder)** to put in place of target composition BBTM, except filler and bulk zones. This last detail could be improved if the process plant recycled would have been less than 25 mm.

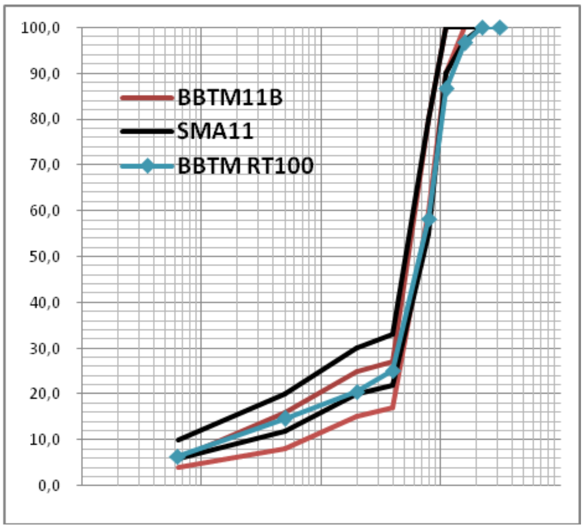


Figure 2: White grading curve BBTM11B RT100

Despite of these details, the results showed an effective and potentially highly innovative mix which fulfilled the study objectives in terms of environmental, technological and effectiveness in mechanical properties. Based on the results obtained in the design phase, an optimum emulsion and binder was set at 2.5-2.6 % and 5.45% about aggregates, respectively. Three modified emulsions (A1, A2 and A3) were designed, which was changing in the penetration rank binder of the emulsion and its grade of modification. The results obtained in terms of mechanical properties are shown in the following table:

Emulsion Type	% Total Binder	% Emulsion	Bulk Density, g/cm^3	% air voids content	Stiffness Module, MPa	ITSwater MPa	ITS dry, MPa	% Preserve Resistance	WTS, mm/10^{3}ciclos
BBTM 11B	5.45	2.60	2.098	13.7	3696	1.48	1.67	88.6	0.089

RT100. A 1									
BBTM 11B RT100. A 2	5.45	2.55	2.100	13.6	3342	1.45	1.61	90.1	0.091
BBTM 11B RT100. A 3	5.45	2.55	2.101	13.5	2757	1.36	1.49	91.3	0.100

Table 4: Mechanical results of BBTM RT 100% with the different modified emulsion.

From the results obtained it must be noted that we have a specific modified emulsions for the design of discontinuous mixtures (BBTM) with a high recycling rate and also with an important feature, its workability/ handling.

These mixtures have a good compactness, we needed a low energy value of compaction (65 cycles), obtaining a volumetric properties about 13-14% of voids content.

Very good mechanical properties were obtained, mainly emphasizing the values of slope deformation on tracking, with values ≤ 0.1 mm/10^3 cycles , conserved resistance to water sensitivity ≥ 90 % , with binder content above the minimum required in the Spanish standards (PG3) for discontinuous hot mix asphalt type B (≥ 5% about aggregates). Modulus stiffness is values some high for the type of mixture and cohesion values in terms of indirect tensile strength were very good.

In the case of Asphalt Concrete mixtures (type AC), the results of the three mixtures are showed with different recycling rates 100, 70 and 50 %, referred to AC RT100, AC RT70 and AC RT50.

The materials composition was:

Materials/Mix	ACRT100	ACRT70	ACRT50
RAP 0/5 mm	68	22,4	16
RAP 5/25 mm	32	47,6	34
% Old bindera/a	4,5	3,1	2,2
6/12 Siliceous	--	22	32
0/6 Limestone	--	8	10

Table 5: Mixtures Composition ACRT

Test have been carried out using different emulsions: hard, soft and modified emulsions for mixtures with a total recycling rate (100% RAP) and conventional and modified with additives for mixtures with a high recycling rate (50%-80% RAP).

Results/ Mixers	AC RT 100 Soft Emulsion	AC RT100 Hard Emulsion	AC RT100 Modified Emulsion	AC RT70 Conventional Emulsion with additives	AC RT70 Modified Emulsion with additives	AC RT50 Conventional Emulsion with additives	ACRT50 Modified Emulsion with additives
ITS dry (MPa)	1,87	2,10	2,07	2,10	1,81	1,59	1,35
ITS water (MPa)	1,67	1,70	1,87	1,80	1,56	1,30	1,20
ITSR %	89,2	81,2	90,6	85,2	86,2	82,0	88,9
WTS air (mm/100 cycles)	0,078	0,062	0,046	0,095	0,100	0,102	0,074
Modulus Stiffness (MPa)	3918	4120	3432	3186	3716	2889	2881
% Final Binder, m/m	6,0	6,2	6,3	6,0	6,0	5,5	5,5
Air Voids, %VM	4,3	4,4	4,3	4,2	4,3	4,9	5,3
Bulk Density (g/cm^3)	2,33	2,32	2,33	2,33	2,34	2,33	2,32

Table 6: Volumetric and mechanics results of ACRT mixtures.

The next graphic showed the empirical/fundamental results:

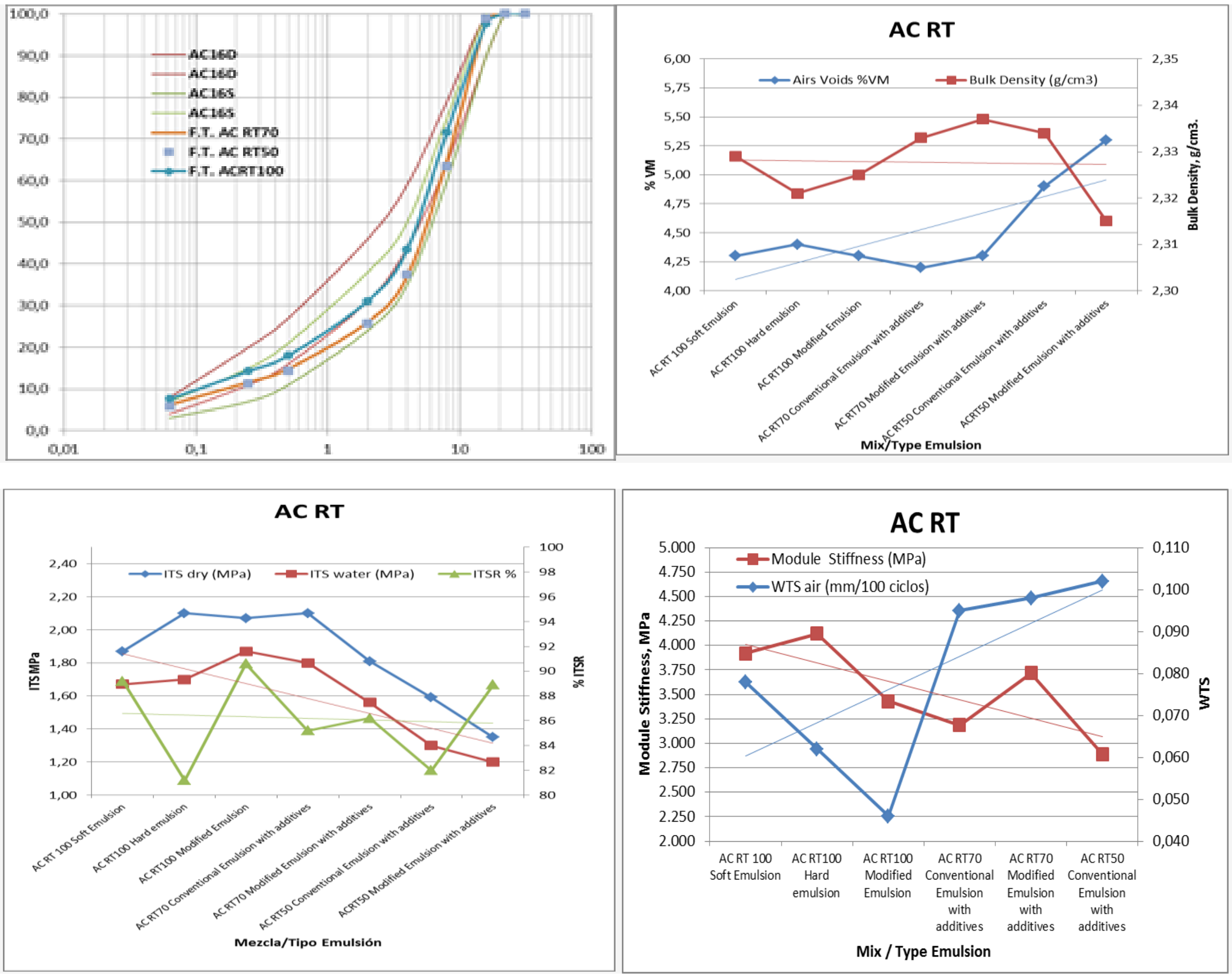


Figure 4, 5, 6 and 7: Graded Curves and mechanic results ACRT mixtures.

In the AC mixtures with total recycling rate, we can get high percentage of total binder in the mixers, about 6% a/a, value can be increased until 6,2-6,3 % a/a if we use residual modified or hard binder in the emulsion. This indicates us that the old binder has a significant weight in the total recycling rate mixers. The percentages of emulsion used were 2,5 to 2,75 % m/m, according to the emulsion concentration. Highlight good compaction of these mixtures with total recycling rate, with relatively low energy compaction (cycles lower than Hot Mix Asphalt (HMA), between 44 and 65 cycles) with good handling characteristics even with the modified emulsion, decreasing slightly with hard emulsion. In terms of mechanical properties, it should also be noted that deformation track values (WTS) were always below 0.1 mm / 10^3 cycles, which improved when we used hard and modified emulsions. Results from water sensitivity tests (ITSR) have been quite good, except with hard emulsion but always above 80%. The values of water sensitive requires for hot mix asphalt in wearing courses according to the Spanish Technical Specifications for Road (PG3) are ≥85%. It is important to point out that there is a possibility of using hard emulsion formulation with emulsifiers or additives that foster improved water sensitivity results. The values of indirect tensile strengths (ITS) are very good; these are like in the Hot Mix Asphalt mixtures (HMA), indicating good internal cohesions. Stiffness values are between 3500-4000 MPa, showing no excessive rigidity if it is compared with typical values of HMA and similar particle size and graded curve, moreover, taking into account that we are recycling 100 % of RAP, offsetting higher values of total binder in mixtures.

For mixtures with high recycling rate, we are able to keep the final percentages of binder 6% a/a for rates of 70 % RAP, being necessary to reduce the content of binder until 5.5% a/a for mixtures with 50% recycled material, because the new binder in this recycling rate has a representing weight in the new mixture.

Mixtures with 70% recycled rates are quite similar to those with total recycling rate. The virgin aggregate has not highlighted any testing feature, but they have shown the need to increase the compaction energy (about 90 cycles), less module stiffness, deformation track values higher than 100% RAP but with similar rutting deformation.

As for the mixtures with 50% recycling rates , a light increase in void content is observed , being necessary to increase the compaction energy (about 135 cycles) by higher amount virgin aggregates than other recycled rates, lower modulus stiffness, similar values rutting deformation slope and fewer cohesion in terms of indirect tensile strength.

2.4. Cracking and durability tests

In order to assess the mechanical properties of the Half-Warm mix recycled Asphalt in terms of ductility and crack resistance, two trials were performed: FENIX test and EBADE test.

The study consisted on analyzing the properties of different mixtures produced with different bituminous emulsions and different rates of RAP. To do two test procedures were considered, Fenix test and EBADE test, and three different test temperatures, +20, +5 and -5ºC. Additionally the Fenix tests were also conducted at -15ºC.

FENIX test

The Fenix test is a direct tension test to characterize the fracture properties of bituminous mixtures. Using and hydraulic press a 1 mm/min constant displacement rate is applied to a half cylindrical notched specimen.

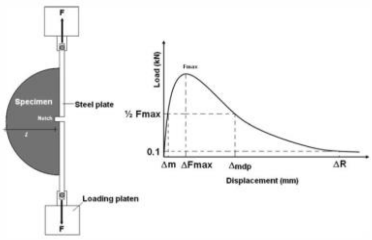


Figure 8: Fenix test setup and load-displacement .output curve (Pérez-Jiménez et al. 2010).

The two main parameters obtained from the test that are used to characterize mixtures are the tensile stiffness index (IRT) and the fracture energy defined by equation 1 and 2:

$$IRT = \frac{\frac{1}{4}F_{\max}}{\Delta_{\frac{1}{2}F\max} - \Delta_{\frac{1}{4}F\max}} \quad (1) \qquad G_F = \frac{W}{S_F} \quad (2)$$

Where, W is the work done during the test and S_F is the cross-section area of the specimen. The IRT parameter quantifies the stiffness of the mixture during the test, since it is the slope of the loading curve in the linear domain.

EBADE test

A cyclic uniaxial tension-compression strain sweep test that uses prismatic specimens carved from cylindrical ones also was used. The test is called EBADE that stands for strain sweep test in Spanish (Ensayo de BArrido de DEformaciones). In this test the strain amplitude is increased every 5,000 cycles, each block of 5,000 cycles is called a strain step. The first strain amplitude applied is $25·10^{-6}$ and it increases in the same amount every 5.000 cycles, i.e, in the second step the strain amplitude is $50·10^{-6}$, in the third $75·10^{-6}$ and so on. The tests frequency chosen for the test is 10 Hz. During the test the stress amplitude, the complex modulus and the dissipated energy density is recorded every 100 cycles. The dissipated energy density is calculated by computing the stress-strain loop area using the Gauss determinant formula.

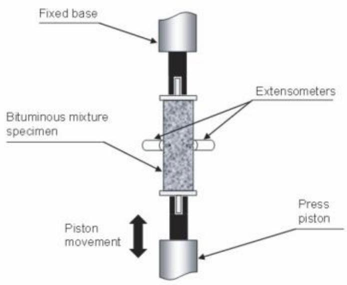


Figure 9: EBADE test set up (Pérez-Jiménez et al. 2011).

The stress amplitude, the complex modulus and the dissipated energy density is recorded every 100 cycles. From this data two parameters are calculated:

- Initial complex modulus: Average of the 50 complex modulus values recoded during the first 5.000 cycles of the test at which the strain applied is $25 \cdot 10^{-6}$.
- Failure strain: Strain amplitude at which the dissipated energy density drops below 50% the maximum value reached during the test.

Using these two parameters it is possible to compare the behaviour of different mixtures under cyclic conditions.

The results are divided in two subsections. One presents the results obtained in the Fenix tests and the other one the results obtained in the EBADE test.

<u>Fenix tests results</u>

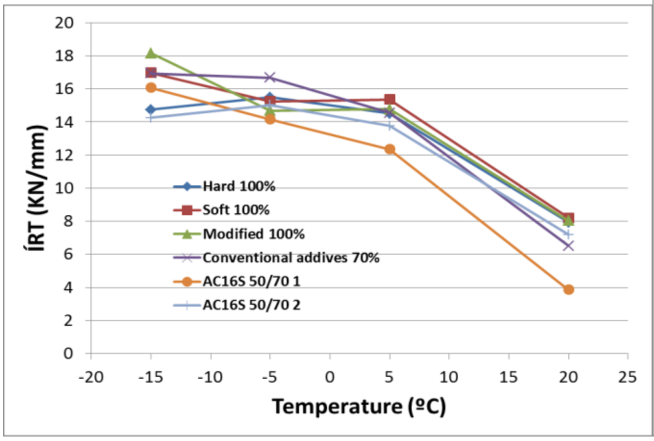
One of the main advantages of the Fenix test is capable of simulating the mechanism of cracking of bituminous mixtures when they are under thermal stresses and heavy traffic loading.

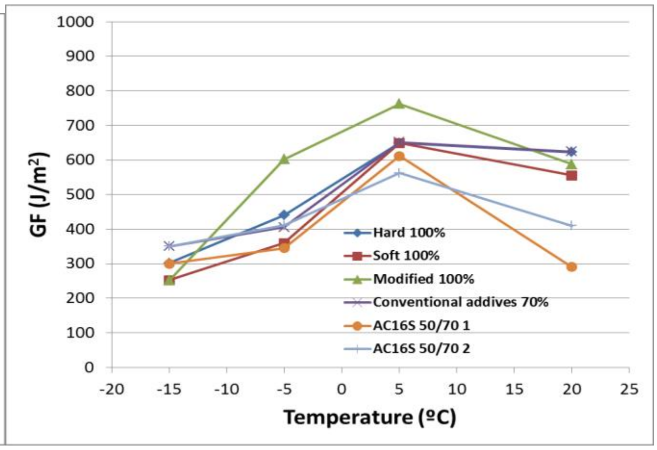
The parameters obtained from the Fenix test to ACRT mixtures with 70% and 100% recycled rates and compared with two hot mix asphalt (HMA) type AC22 with 50/70 binder are presented:

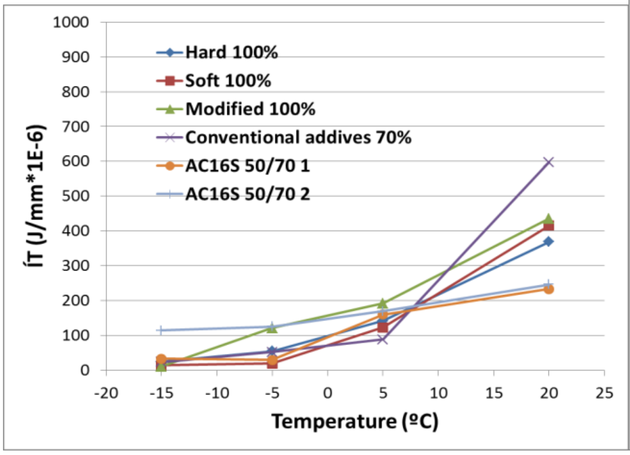
Emulsion	Temperature (ºC)	IRT (KN/mm)	G_F(J/m^2)	IT (J/mm*1 E-6)
HARD 100% RAP	20	8	622	369
	5	15	649	142
	-5	15	440	55
	-15	15	302	24
SOFT 100% RAP	20	8	555	416
	5	15	649	123
	-5	15	360	19
	-15	17	252	14
Modified 100% RAP	20	8	588	435
	5	15	762	192
	-5	15	602	121
	-15	18	251	11
Conventional with additives 70% RAP	20	7	624	598
	5	15	651	89
	-5	17	406	52
	-15	17	350	24
AC16S 50/70 1	20	4	290	233
	5	12	612	160
	-5	14	345	30
	-15	16	300	33
AC16S 50/70 2	20	7	409	246
	5	14	562	169
	-5	15	410	125
	-15	14	350	114

Table 7: Test Fénix results, AC RT mixtures.

The differences between mixtures and the effect of temperature can also be appreciated in the following figures (Figure 10, 11, 12 and 13), in which are plotted against the temperature test: Tensile Stiffness Index (IRT), the tensile strength (RT), the fracture energy (Gf) and the tenacity index (IT). The results corresponding to two HMA type AC with penetration bitumen 50/70 have also been presented. The results don't show differences as for IRT and RT, The values of Half-Warm Mix Recycled Asphalt (HWMRA) are similar to those obtained with hot mix asphalt (HMA).







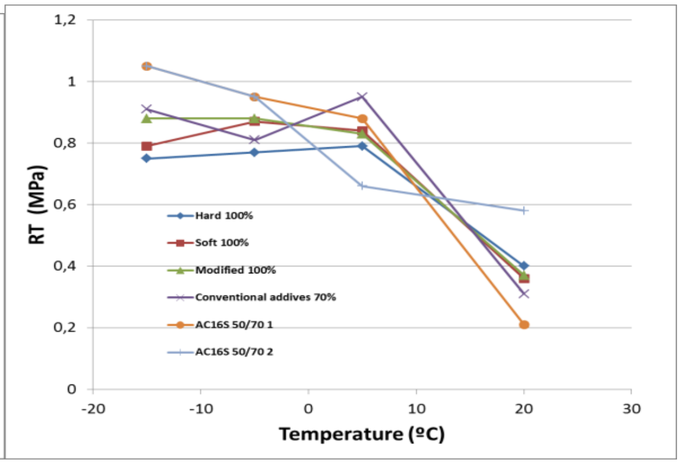


Figure 10, 11, 12 and 13. Test Fénix results, AC RT mixtures.

The differences are appreciated in the variation of energy and tenacity indices (Figures 12 and 13). The HMA show a pronounced decline in fracture energy from 5 to 20 ºC while the change is much less or not produced in HWMRA. The tenacity index is greater than 20 ° C to HWMRA. HWMRA at 20 ° C have the same modulus and strength than conventional but with greater fracture energy and tenacity than HMA. At low temperatures the HWMRA exhibit similar characteristic to HMA with 50/70 bitumen.

The parameters obtained from Fenix test to discontinuous mixture (BBTM RT100 type) were:

Emulsion	Temperature (ºC)	IRT (KN/mm)	G_F(J/m^2)	IT (J/mm*1E-6)
Emulsion A1	20	6	635	655
	5	13	651	143
	-5	15	402	51
	-15	16	321	20
Emulsion A3	20	6	766	800
	5	14	938	265
	-5	18	724	122
	-15	15	288	16

Tabla 8: FÉNIX Test Results, BBTM11B RT100.

These graphs show, as in the case of AC mixtures, an increasing rigidity of mixtures with decreasing temperature, this change is particularly significant from 20 to 5 ° C. A light ductile behavior is observed in the case of the modified emulsion A3 (softer).

To better observe these qualitative differences in behavior, the tensile stiffness index, cracking resistance, fracture energy and tenacity index versus temperature are shown (Figures 14, 15, 16 and 17). In these figures, we have also included the results of two hot mixtures of discontinuous grain (BBTM and SMA), both with modified bitumen PMB 45 / 80-65.

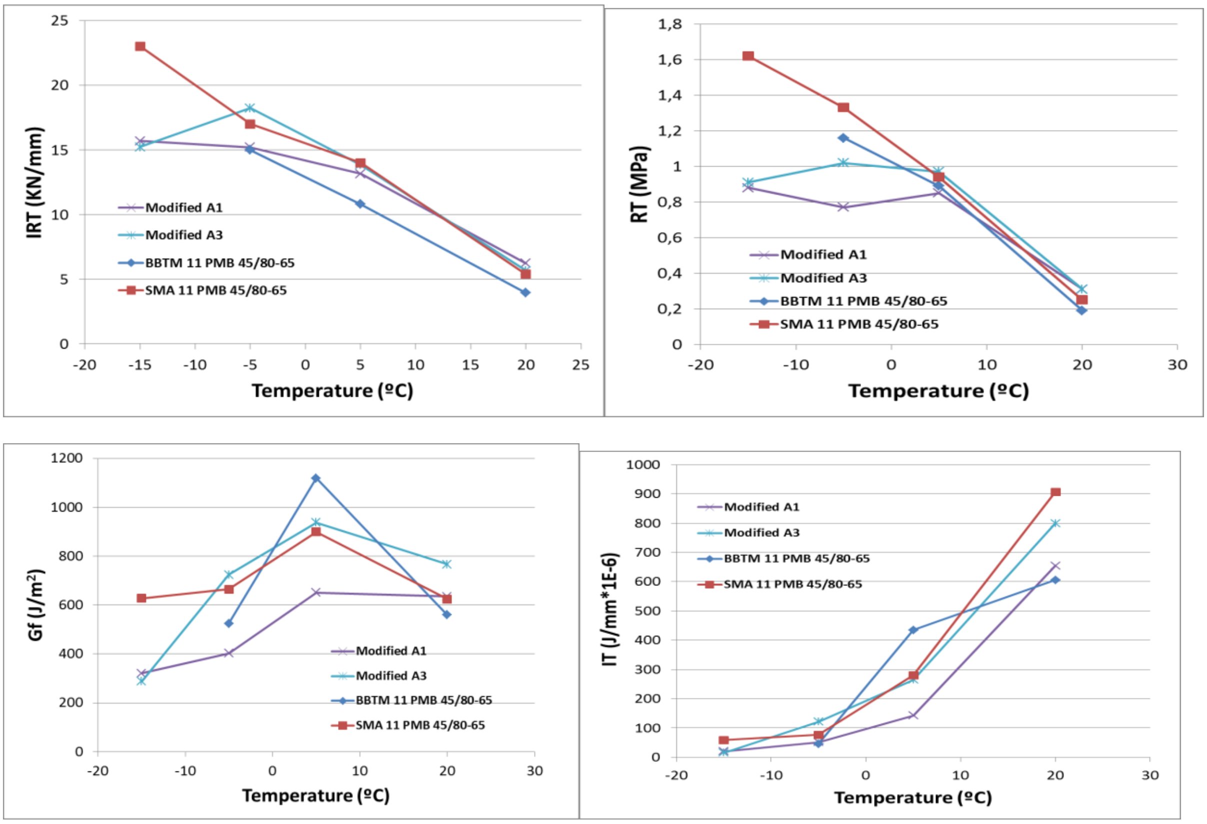
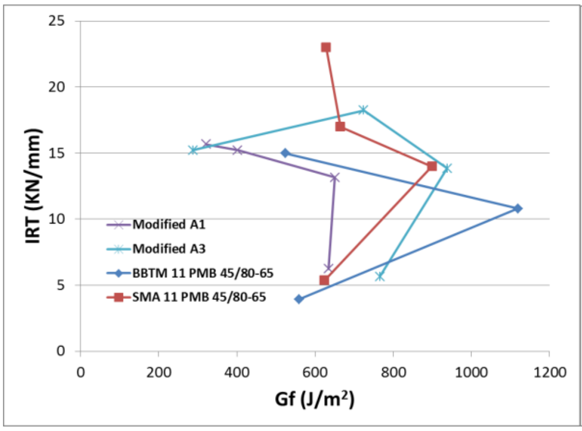


Figure 14, 15, 16, 17. Differences in behavior, the tensile stiffness index, cracking resistance, fracture energy and tenacity index versus temperature

HWMRA showed an intermediate response between the two hot mixtures taken as reference. Differences between HWMRA are also appreciated; HWMRA manufacture with modified emulsion A3 (softer) is more tenacious and ductile. For the same test temperature, rigidity index of the mixture with modified emulsion A3 is similar to the emulsion made with the modified A1 (harder) , but its fracture energy and tenacity index is higher (see Figures 18 and 19).



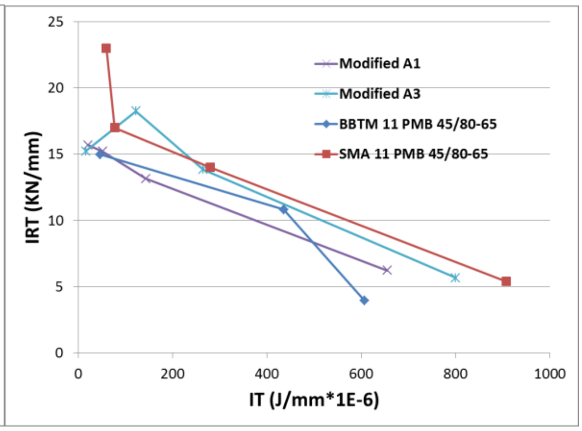


Figure 18

Figure 19

EBADE tests results

The parameters obtained from the AC EBADE test mixtures were:

Mixtures	Temperature (ºC)	Initial Module (MPa)	Failure strain ($1E^{-6}$)
AC RT100 HARD	20	6347	275
	5	10128	250
	-5	11471	200
AC RT100 SOFT	20	5483	275
	5	10991	200
	-5	13801	175
AC RT100 MODIFIED	20	5741	325
	5	--	--
	-5	12203	175
AC RT70 ADITTIVE CONVENTIONAL	20	6607	375
	5	12856	250
	-5	12796	175

Table 9: Test EBADE to ACRT

The different parameters obtained from the test EBADE, initial module and failure strain versus temperature test (Figure 14, 15 and 16) are shown. The tested mixtures modules have a similar variation with temperature and only failed strain higher is seen at 5 and 20 ºC to 70% of RAP and modified emulsion.

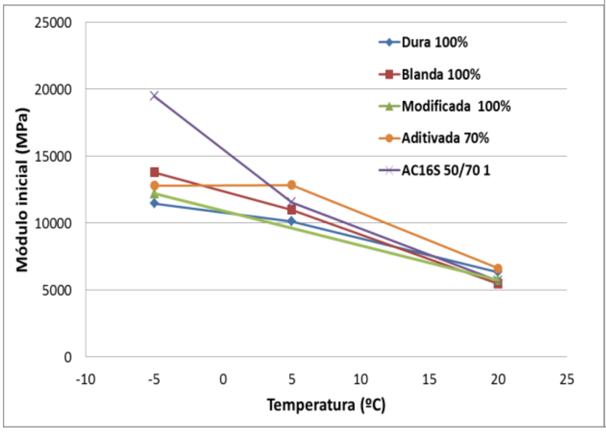


Figure 20

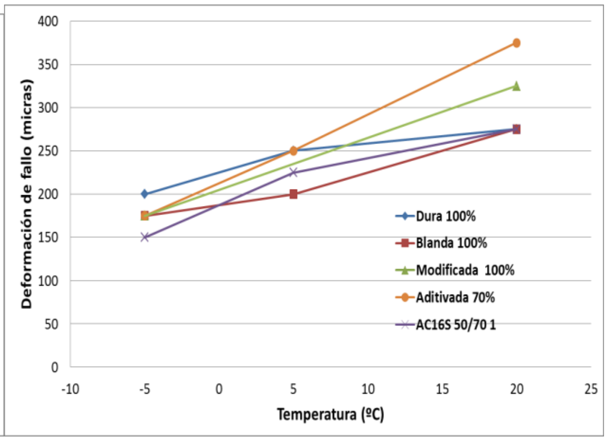


Figure 21

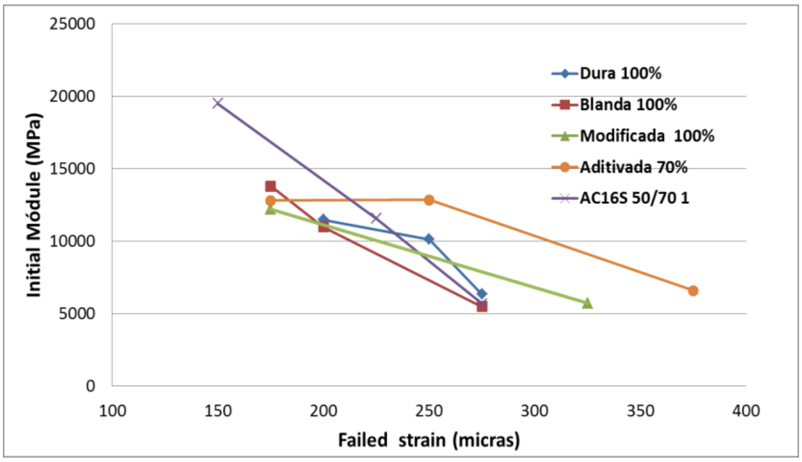


Figure 22

In these figures has been included the response of a AC16S hot mixture manufactured with 5% bitumen 50/70 on the mass of the mixture. It is appreciated that the HWMRA has greater ductility at 20ºC and lower module at low temperatures. This can be seen clearly in Figure 22, where the relationship module-failed strain is represented.

And finally the parameters obtained from the test EBADE to BBTM11B RT100 mixture are showed:

Mixtures	Temperature (ºC)	Initial Module (MPa)	Failure strain ($1E^{-6}$)
BBTM 11B RT100 Mod. A1Emulsion	20	5680	350
	5	9488	225
	-5	13025	150
BBTM 11B RT100 Mod. A3 Emulsion	20	6253	325
	5	--	--
	-5	10380	250

Table 10: Test EBADE Result, BBTM11B RT100 mixtures.

Results tests EBADE have shown a great similarity of behaviour to both mixtures at 20 °C, it has been observed as the modified emulsion A1 to +5 and -5 ºC has experienced greater stiffening, increasing module and decreasing deformation failure than modified emulsion A3 (see Figures 23 , 24 and 25) .

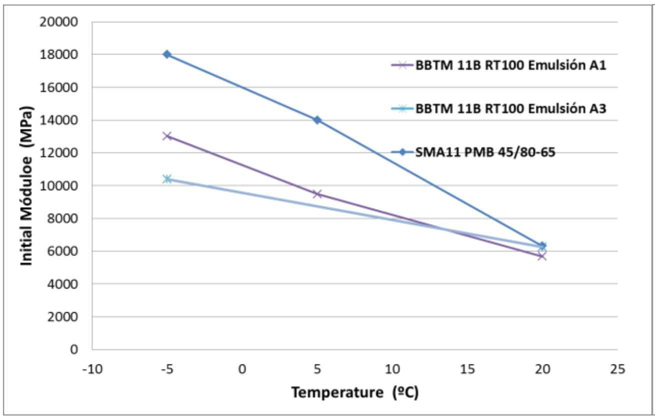


Figure 23

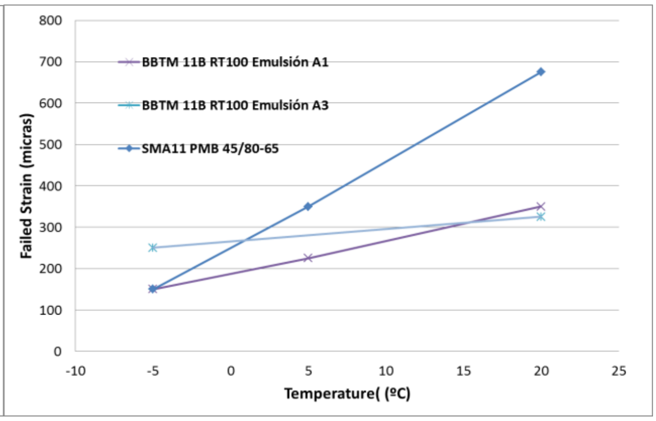


Figure 24

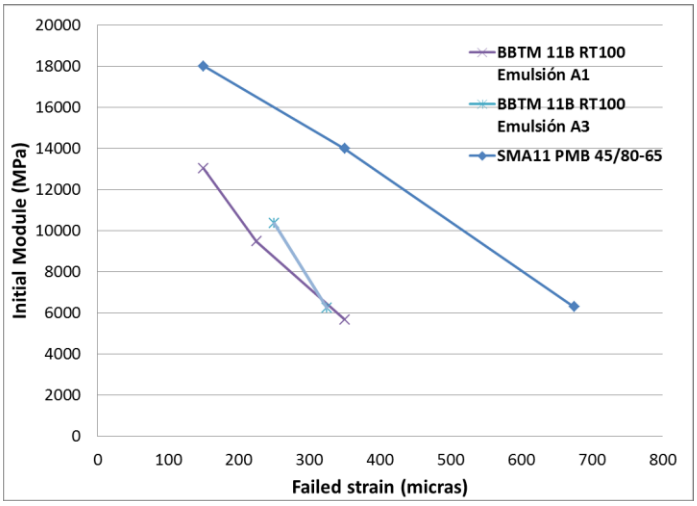


Figure 25

Both tests clearly shows that HWMRA behaviour is similar to conventional hot mixtures, having a stiffness and strength resistance of the same order in the range of temperatures tested, but showing equal or greater tenacity index and failed strain, pointing out a more ductile response to a similar stiffness.

Half-Warm Mix Recycled Asphalt (HWMRA) and Hot Mix Asphalt (HMA) are capable of temperature changes. When the temperature rises from -15 to 20 °C occurs a sharp decline of the dynamic module of type AC mixture about 13000 MPa to about 5,000 MPa , both HWMRA and HMA mixtures have showed similar variation. The ductility of these mixtures also varies with temperature, but in this case the variation ductility is higher in HWMRA, showing similar tenacity index at -15 to -5 ºC (less than 100 J/mm * 1E -6) and can get double at 20° C (250 J / mm * 1E- 6 to AC HMA and up to 600 J/mm * 1E -6 to HWMRA).

The BBTM half-warm mix recycled asphalt also exhibit a similar modulus to HMA in the range of temperatures studied and their behaviour is more ductile at 20 ºC, varying its tenacity index from 600 to 800 J/mm * 1E -6 .

There are also differences between the types of emulsions and formulations used. In the case of AC type mixtures manufactured with modified emulsion has a more ductile and tough response. The same applies to the A1 emulsion in the case of BBTM mixtures.

The Fenix and EBADE tests have provided very valuable information of the mechanical characteristics of the mixtures and have been able to compare and rank them on terms of their performance

3. CONCLUSIONS

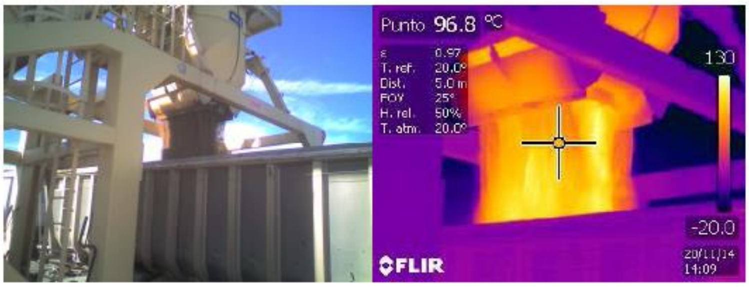
The main conclusions of this paper are:

- It is very important to take into account the treatment of the Reclaimed Asphalt Pavement (RAP) in at least two fractions for accurate and weight control of each fraction in the final composition of the mixture thus ensuring its consistency.
- It have been achieved to design modified emulsion for discontinues half-warm mix recycled asphalt (BBTM11B type) with high recycling rate of RAP, with good workability and compaction performance. For de design of AC half-warm mix recycled Asphalt (AC type), emulsion formulation with conventional binder was reinforced and modified emulsion was designed to improving the mechanical properties of HWMRA with high and total recycling rate.
- Laboratory testing of discontinuous HWMRA with total recycling rate (100% RAP) and high recycling rate (<80% RAP), have shown excellent mechanical properties and good compaction behavior compared to conventional mixtures (HMA).
- Durability and cracking testing performed have shown :
    a) HWMRA performance is similar to conventional HMA, giving a stiffness and strength of the same order in the range of temperatures tested, but showing equal or greater tenacity index and failed strain, which indicates a more ductile response to a similar stiffness.
    b) Differences between discontinuous HWMRA and AC HWMRA have been very small, and in some cases considerably lower than the dispersion test.
    c) Modified emulsions, have shown slightly higher performance than the rest of emulsions.
- This research has demonstrated the viability of obtaining a new type of bituminous mixtures (half-warm mix recycled asphalt) with a recovery rate up to 100%, manufacture a low temperature (<100ºC) more competitive and environmentally sustainable compared to conventional hot mix (HMA).
- This innovative technology opens up the possibility to produce Half-Warm Recycled Asphalt Mixtures, offering recycling rates of material up to 100% and maintaining the same high mechanics performance than conventional mixtures. HWRAM also have an important environmental benefit, which include reduced fossil fuel consumption and emissions (including greenhouse gas emissions) and also improving conditions for workers.

4. FIELD TRIALS

A test section was performed in an urban street, where two half- warm mix recycled asphalt (ACRT100 and ACRT70), with two different recovery rate (100% RAP and 70%RAP) were manufactured, placement and compaction at the temperatures that are shown in the thermographic pictures.

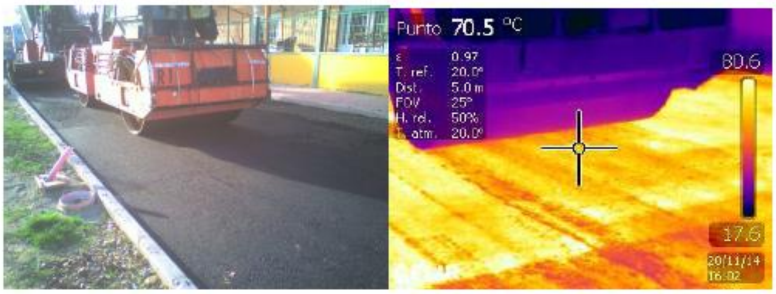
Manufactured temperatures



TrucksTemperature:

Mixture Temperature:

Compaction Temperature:



5. ACKNOWLEDGEMENTS

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