Bituminous emulsions

High performance recycling with bituminous emulsions

Marimar Colás, Vicente Pérez, Antonio García
CEPSA

Abstract

The structural rehabilitation of asphalt pavements using techniques such as recycling with emulsion is framed on the principles of the Circular Economy and therefore its use should be strengthened in comparison with other options. This technique has clear environmental and economic advantages as the saving of a significant percentage of quality aggregates, since a good part of the asphalt mixes to be recycled generally come from the milling of the top layers, and the decrease of the dosage of binder, based on to the regeneration that can be obtained from the aged binder existing in the pavement to be recycled, thanks to the contribution of a specific bituminous emulsion. Despite these advantages, one of the disadvantages that have limited its use is that cold recycled mixtures with emulsion, require a curing period to remove the water from the mixture and achieve the final mechanical properties. This drawback is avoided with the half-warm recycling but even so, in the current regulations, there are limitations that prevent its use for new surface layers. The objective must be to ensure that the final performances of the half-warm recycling are similar to those of the AC type bituminous mixtures that would be put in place, in the case of milling and replacement with hot mixes. This paper presents the development of high performance modified emulsions, suitable for use in emulsion half-warm recycling that can satisfy the requirements demanded to the surface layers, at least for low trafficked roads surfaces. The improvements to be achieved will not only allow the economic and environmental benefit of the recycled ones, but also an improvement in the performance of the mixture and in its durability, thanks to the use of half-warm recycling techniques and high performance emulsions.

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4. INTRODUCTION

The main target of half-warm mix asphalts is to reduce manufacturing and application temperature in order to save an important amount of money due to the lesser fuel consumption, which also implies a reduction on greenhouse effect emissions (CO2). Also the temperature reduction translates into a much better working conditions during laying operations, without a significant effect on the quality and characteristics of the asphalt mixes. Therefore, road paving through warm techniques may be considered as one of the most outstanding innovations for industrialized nations. [1]
Several lines of research have been developed around this objective among which we highlight, given its influence in our country, the use of half-warm mix asphalts which contain a bituminous emulsion as a binder. They are manufactured in a hot mix plant, lowering temperature down to 100 ºC (see Figure 1, how these mixes behave in comparison to the others in terms of manufacturing temperature). The intention is none other than manufacturing asphalt mixes which may gather the advantages of both hot and cold techniques.

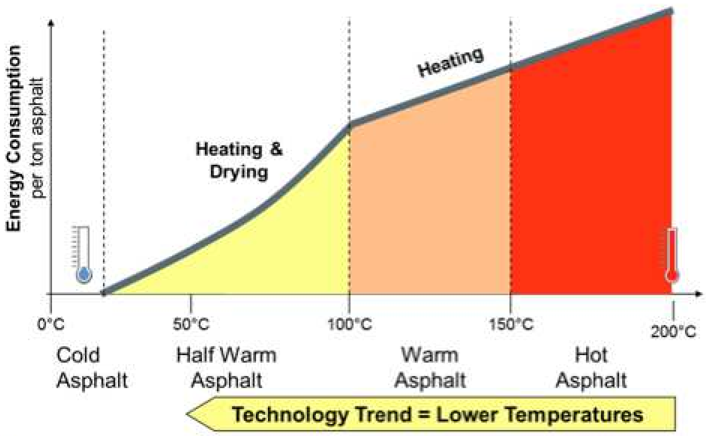

Figure 1: Classification of types of asphalt mixtures by their manufacturing temperature (Source: EAPA)

Half-Warm mixtures with bituminous emulsion allow for drastically reducing manufacturing and commissioning temperatures, since they are manufactured, extended and compacted at temperatures below 100 ° C. The technology of warm mixes is applicable to all types of existing mixtures, although in this work we will focus on recycled mixtures, whose application in firm rehabilitation actions has shown that they can present a satisfactory mechanical behavior which makes them suitable to support heavy traffic loads and that can be taken into account as an innovative and environmental solution very interesting for asphalt paving.

Albeit, despite the investment in product development and improving the knowledge of warm techniques, in some cases, the performance achieved is not as good as with hot mixes, mainly because the residual binder of conventional emulsions used in the manufacturing of half-warm mixes usually presents less consistency than the bitumens used to make hot mixes.

This paper presents the development of high-performance modified emulsions, suitable for use in half-warm recycled mixes with emulsion that can meet the requirements of the surface layers, at least on roads with low traffic intensity. The improvements will permit not only the economic and environmental benefit of recycled products, but also an improvement in the features of the mixture and its durability, thanks to the use of half-warm techniques and high-performance emulsions.

5. HIGH-PERFORMANCE HALF-WARM MIXES

They are bituminous mixtures manufactured in hot mix plants but using as a binder a cationic bituminous emulsion modified with elastomeric polymers, type C60BP4 according to EN 13808 [2]. The emulsion may or may not contain fluxing agents depending on the type of mixture and layer of the firm to which it is intended. In any case, the residual binder of the emulsion will be a modified bitumen that will not show running off at the manufacturing temperatures of the mixture and will provide good cohesion to the half-warm mix.

The crushed aggregates will meet the same requirements that are demanded to hot bituminous mixtures intended for surface layers. They will usually be heated up to 100 ° C, carrying out the coating with the emulsion whether in the dryer drum of the continuous plant or in the mixer of a batch mixing plant. Half-warm mixtures allow reuse of milling material from aged pavements, in different percentages depending on the manufacturing process and materials used, hence the recycling rates will vary up to 100% [3].

The emulsion will be introduced by means of a conventional pump since its temperature will be between 20ºC-60ºC depending on the viscosity of the emulsion to be used.

An important aspect to consider will be the residual moisture of the half-warm mixes that usually presents values close to 0.5% of the mass of the mixture when the temperature is reduced to 100 ° C [4]. The greater water content into the half-warm mixes with emulsion can lead to somewhat higher residual humidity results. According to the ratios represented in the Figure 2, half-warm mixes with emulsion are assigned a moisture that exceeds the levels of the warm mixes with bitumen by 0.5% on aggregate mass.

In general, residual moisture is considered harmful for hot or warm bituminous mixtures. However, in half-warm mixes, this moisture is expected to improve its workability, facilitating the coating and positioning at lower temperatures. The residual humidity of the temperate mixtures must be sufficient for this purpose without negatively affecting their mechanical properties.

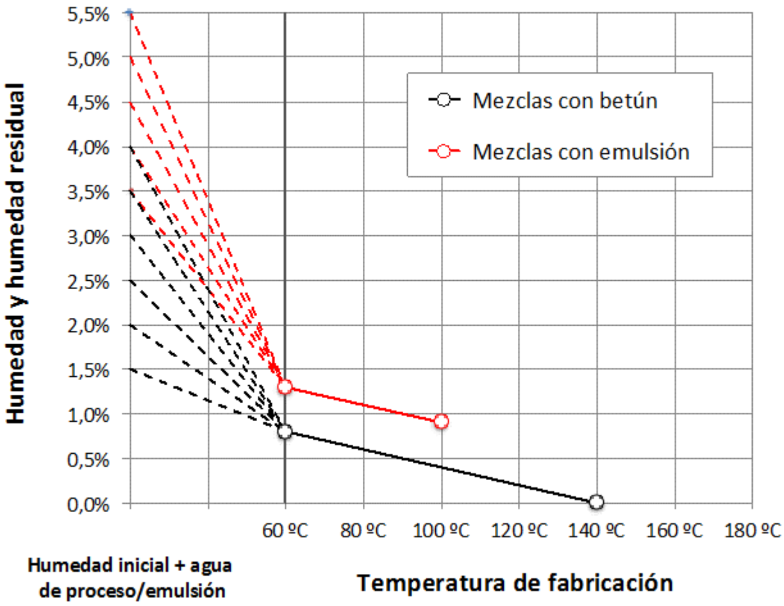

Figure 2: Retained moisture in the mixture depending on aggregates moisture + process or emulsion water and manufacturing temperature [5]

The minimum temperature for laying and compacting the mixture, which may vary depending on the type, is around 60 ° C, being storable for 24 hours in some cases, before proceeding to the laying.

6. STUDY OF HIGH-PERFORMANCE HALF-WARM MIXES

The starting line is the definition of the virgin granular materials to be used in the mixture and also of a milled material from aged pavements (RAP). In the study carried out in the laboratory, these materials are heated to 90 ° C before mixing with the emulsion though coating tests. Series of test samples with different emulsion dosages are then manufactured, which are subjected to the usual tests for asphalt mixtures, to determine the optimum residual binder to be used in the mixture.

Eventually, there are results obtained and represented for two mixtures type AC, manufactured with ophitic aggregates and different rates of milled material from old pavements (RAP).

6.1 Materials

In these half-warm recycled mixes, the main components are aggregates, milled material and bituminous binder (conventional or modified cationic emulsion), and additives regulating breakage of the emulsion and / or adhesiveness can be admitted, if necessary.

Aggregates:

- Coarse gravel 12/20 ophitic nature
- Fine Gravel 5/11 ophitic nature
- Sand 0/6 ophitic nature

Milled material:

The milled material corresponds to a blend of different layers of asphaltic firm, classified in three different fractions and of which one or more will be used depending on the type of mixture.

Binder content was 4,7% on the aggregate mass presenting the following characteristics
- Penetration: 5 x 0,1 mm
- Softening Point: 80ºC

The results of the granulometric analysis of the milled material (after the binder extraction) and of the virgin aggregates are shown in the Figure 3.

ANALISIS GRANULOMETRICO

PORCENTAJES ACUMULADOS QUE PASAN POR LOS TAMICES:

TAMIZ UNE	**ARIDO1** *Fresado extracc.*	**ARIDO 2** *12/20*	**ARIDO 3** *5/11*	**ARIDO 4** *0/6*	**ARIDO 5** *0/6 desfillerizac*
60	100	100	100	100	100
45	100	100	100	100	100
32	100	100	100	100	100
22	100	100	100	100	100
16	100	90	100	100	100
8	88	3	60	100	100
4	58,3	1,1	2,5	88,2	87,4
2	42,8	1,1	0,7	60,8	58,1
0,5	24,3	1,0	0,6	29,9	25,0
0,25	18,5	1,0	0,6	23,9	18,5
0,063	10,3	0,9	0,4	13,0	7,0
Equivalente de arena →				53	

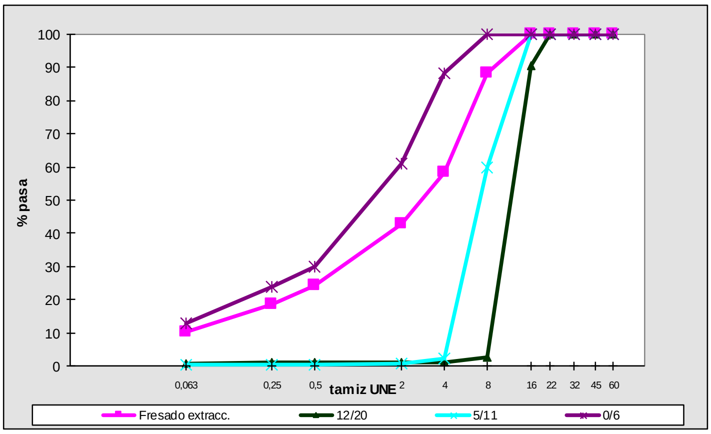

Figure 3. Granulometry of the aggregates and milling products

<u>Bituminous Emulsion</u>

This work presents the result of the development of a special emulsion, capable of coating the blend of virgin aggregates and milling, without deteriorating due to thermal shock and, at the same time, providing the mixture with a great initial cohesion, a high active and passive adhesiveness and sufficient manageability for use with conventional equipment.

It consists of a cationic bitumen emulsion modified with polymers type C60BP4, manufactured from a special modified bitumen for application by means of the warm technique.

The characteristics of this modified emulsion designed specifically for use in half-warm mixes are set out in Table 1 and Figures 4 and 5, while its specifications are set out in the attached Table 2.

Tabla 1. Characteristics of the emulsion C60BP4

Charasteristic on emulsion as such	**Standard UNE-EN**	**Value**
Binder content per water content,%	1428	60.3
Residue on sieving residue (0,5 mm), %	1429	0.02
pH	12850	2.05
Efflux time at 40ºC (2 mm),s	12846-1	35
Breaking value	13075-1	164
Adhesivity with reference aggregate, %	13614	90
Method of Recovery: **by distillation**		
Binder content, %	1431	61
Penetration, dmm	1426	52

Softening point, ºC	1427	58
Cohesion (pendulum test)*, J/cm2	13588	0,89
Elastic recovery at 25ºC,%	13398	60
Method of Recovery: **by evaporation**		
Penetration, dmm	1426	55
Softening point, ºC	1427	60
Cohesion (pendulum test)*, J/cm2	13588	0,97
Elastic recovery,%	13398	58

*See results on the figure attached:

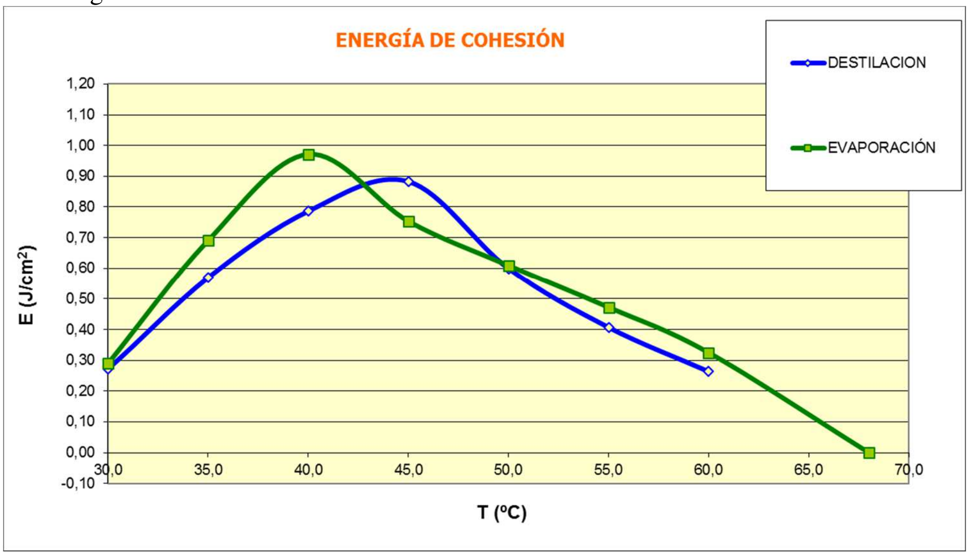

Figure 4. Results of cohesion test through Vialit pendulum (UNE-EN 13588) for the different residual binders

Additionally, the emulsion particle size has been analyzed with a laser granulometer (applying the Mie dispersion model). As Figure 4 shows, it is a modified bituminous emulsion with an average particle size of 4.43 microns that will have enough stability and aggregate coating capacity.

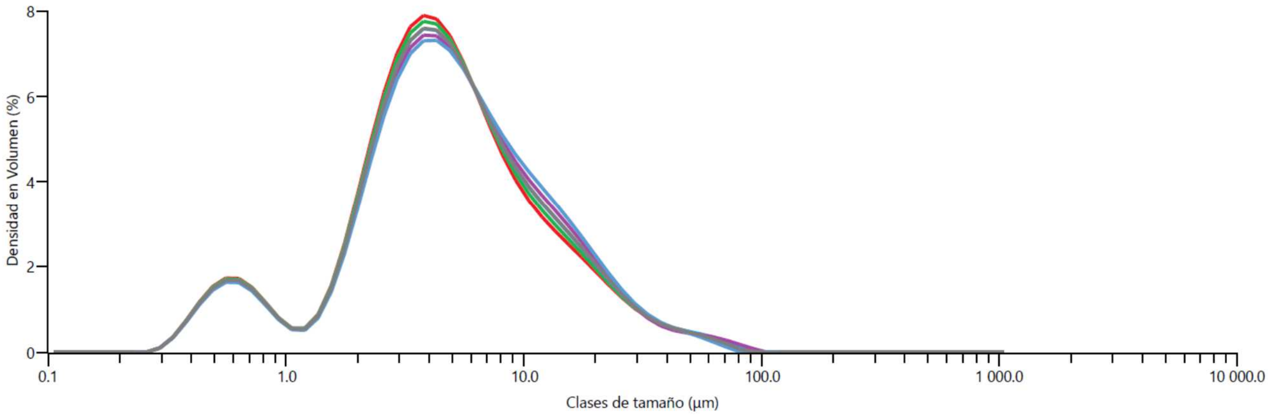

Figure 5. Granulometric distribution of the bitumen particles inside the emulsion

Tabla 2.Emulsion specifications C60BP4

Characteristics	**Unit**	**Standard UNE EN**	**Min.**	**Max.**
Original emulsion				
Particle polarity	-	1430	Positive	
Breaking value	g	13075-1	110	195
Binder content per water content	%	1428	58	62
Efflux time (2 mm, 40 ºC)	s	12846-1	15	70
Settling tendency (7 days)	%	12847	-	10
Residue on sieving (0,5 mm)	%	1429	-	0,1
Adhesiviness	%	13614	90	-

Binder after distillation as per UNE EN 1431				
Penetration (25ºC)	0,1mm.	1426	-	100
Softening point	ºC	1427	50	-
Cohesion (Pendulum test)	J/cm^2	13588	0,5	-
Elastic recovery at 25ºC	%	13398	DV	
Binder after evaporation as per UNE EN 13074-1				
Penetration (25ºC)	0,1mm.	1426	-	100
Softening point	ºC	1427	50	-
Cohesion (Pendulum test)	J/cm^2	13588	0,5	-
Elastic recovery at 25ºC	%	13398	DV	

6.2. Half-warm recycled mixes composition [6]

Below, Table 3 and Figure 6 show the composition and granulometric curve of the recycled mixture with 20% RAP, screened by 14 mm.

Table 3.Half-warm recycled mix AC 16 S R20

	AC 16 S R20
Sand 0/6 [%]	25 (*)
Fine gravel 5/12 [%]	30
Coarse gravel 12/20 [%]	25
Milled material [% on agreggate]	20
Emulsion [% on agreggate]	6.5

(*) Filler partially removed from sand

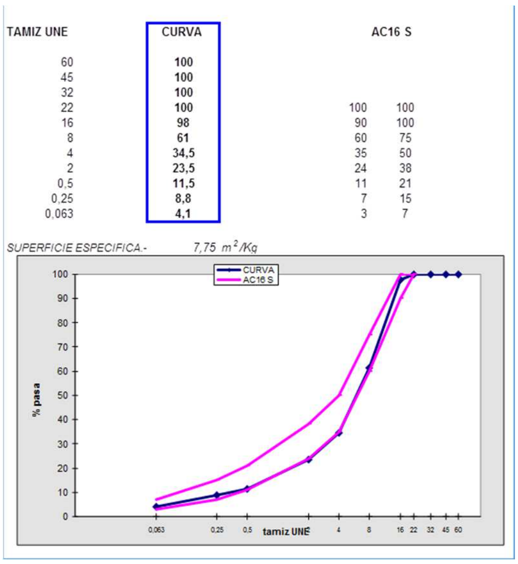

Figure 6. Composition and granulometric curve of mix type AC 16S

The recycled mixture with 80% RAP (type AC22 S R80) is considered a full rate recycle with only 20% limestone aggregate, which is used as a granulometric correction. To produce this half-warm recycled mixture is needed to have the milled material classified in three different fractions, using 40% 14/32, 20% 5/14 and 20% 0/5.

6.3. Tests on the asphalt mixes

In order to simulate a hot mix plant process in the laboratory, the mixes were manufactured with virgin aggregates sorted as per the granulometric results, as shown in Figure 6, then heated to 125 ºC to facilitate the heat transfer when blended with the milled material at room temperature resulting in a blend of aggregates and RAP at 90-100 ºC. Then, the emulsion is added and blended, coating the aggregates so the asphalt mix cylinders can be built for the subsequent tests.

The asphalt cylinders and the tests procedures are conducted similarly as in a hot mix with the only difference of the compaction temperature, which will be comprised between 85-95 ºC. On Table 4 is shown a summary of the results obtained.

Table 4. Results for studied mixes

Characteristics	**AC16 S R20**	**AC22 S R80**
Emulsion.[% on aggregate]-	6,6	3,5
% total binder	4,8	4,9
Moisture induced damage:		
- RTI dry (MPa)	1,431	1,920
- RTI wet (MPa)	1,238	1,66
- ITSR(%)	86,5	86
Geometric density g/cm3	2,364	2,372
Density SSD. g/cm3	2,494	2,533
Rotary compaction:		
- Rotations required to achieve a density at 90ºC similar to the geometric.	47	40
Estimated mix voids (%)	5	4
Wheel tracking test		
- WTS	0.18	0,07
- PRD (%)	8.4	6,5
Rigidity module at 20ºC(MPa)	3540	5838

Dry resistance values are lower than those obtained in hot mixes that are usually greater than 2.0 MPa. However, for low traffic intensity roads, the values obtained are considered adequate. [7]

In the wheel tracking test, the specifications required for hot mixes are not always met but it might be considered acceptable for these mixtures when the value of the average slope of deformation within a range of 5,000 to 10,000 cycles is less than 0,10, both in base and surface layers. In addition, values higher than indicated for low trafficked roads may be accepted, to the opinion of the works management [8].

Although the rigidity module is not a determining test for the surface layers, it can give us an idea of its behavior as a pavement. As expected, the module of the half-warm recycled mix with 20% RAP is quite similar to a hot AC 16 G type mix while the AC 22 S R80 type mixture is in the range of 5000-7000 MPa typical of semi-dense and dense asphalt concrete [9].

7. APTATIONS OF A HOT MIX PLANT CENTER FOR THE PRODUCTION OF HALF-WARM RECYCLED MIXES

Although there are some plants that have been specifically designed for the production of half-warm mixtures, it is still common for this technology to be used in bituminous hot mix plants that have been adapted for the indistinct production of both types of mixtures (hot and warm). The necessary adaptations must be studied in each specific case, as they depend on the configuration of the plant (continuous or batch), the type of burner and the fuel used, and even the configuration of the suction and purification equipment of the combustion gases. They also depend, of course, on the intended temperature reduction and the milling rate to be used in recycled mixtures. [10]
Overall, the following aspects must be taken into account:

1. The plant must have a mixing system that can be regulated so that it is suitable for working with different mixing times both dry (combined aggregates and milling material) and wet (mixing of the former with the emulsion). In this way it is possible to adapt the process for an adequate coating of the aggregates and the milling product in the mixture. As for batch plants, it is necessary to have a pre-aggregate storage system, hot hopper type (at least three) to which the material previously classified by fractions will arrive and will consist of a system of independent weight dosage. In the case of continuous processes, there should be a weight control of the mass of aggregates and milling material and its moisture, prior to the dosing of the bituminous emulsion.

2. The plant must heat aggregates to temperatures below those of a conventional hot production. This fact may require adjustments or modifications to the dryer drum burner, reducing the standard production per hour level of hot production. Figure 7 shows the conduit arranged for the additional extraction of hot air from the drying drum in a batch plant.

3. It should be foreseen that the introduction of the bitumen emulsion, from the storage tank to the mixer of the manufacturing plant, is not carried out by a line heated with thermal oil since this would cause premature rupture of the emulsion. The circulation of thermal oil through the necessary coils or sectors of the plant must be canceled, or the bitumen emulsion must be directed and weighed through ducts and scales independent of those used when bitumen.

4. Despite the temperature reduction in the manufacture of these mixtures, the combustion gases must reach the bag filter at sufficiently high temperatures (> 100 ° C) so that condensations that prevent their normal operation do not take place. For this, it may be necessary to drive a certain proportion of hotter air directly to the bag filter than is obtained after the thermal exchange with the aggregates, sucking it from other points closer to the central burner.

5. In the case of half-warm recycled mixtures, especially at medium or high rates (> 50%), the milled material should be classified into several fractions (usually 3) so that the finest fraction is treated at room temperature and can be fed directly to the plant mixer (see Figure 8)

Figure 7: Adittional hot air extraction conduct in a batch plant

Figure 8: Hopper for milling material fraction at room temperature that goes straight to the mixer..

In order to carry out the RAP material heating, there are three possible methods:

1) Direct method. It consists of directly heating the treated RAP or the different fractions of the treated RAP, through a specific dryer drum at a temperature around 100° C. The RAP, once hot, would go directly to the mixer not going through avoiding hot sieves.
In this case, it is possible to heat the RAP by direct heat input with the use of specific heating systems in which direct contact with the flame of the dryer drum burner is avoided, and that does not run through areas of excessive gas temperature, to preserve the characteristics of the RAP binder.

2) Indirect method. It consists of heating the RAP by heat transfer from the aggregates. In this case, the treated RAP is fed cold, with its moisture, directly to the mixer. The RAP binds to the overheated compensating aggregates, at a temperature such that the final mixture is around 100 ° C, but considering the limitation of never overheating the aggregates above 220 ° C.
This way of manufacturing MBRTE determines the maximum rate of RAP to be used, which will depend on the moisture of the RAP, its granulometric characteristics and the type of final mixture desired.

As shown in Figure 9, the maximum rate to be used by this method is 60% RAP

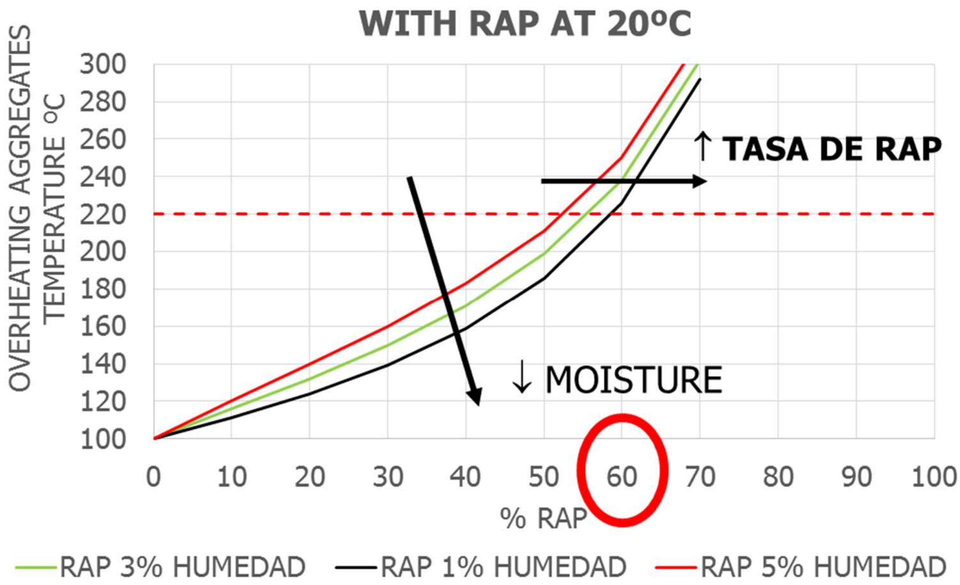

Figure 9: Maximum RAP content in half-warm recycled mixes based on their moisture and aggregate overheating

3) Combination of both methods. It consists of a combination of both systems for the manufacture of the half-warm recycled mixture

In general, RAP heating systems with excessive exposure to high temperatures, such as conventional counter flow drying drums, are not suitable, and therefore should be avoided, as the RAP passes in front of the flame of the burner through the zone of maximum temperature, what would degrade the binder in an excessive way, besides promoting stickiness issues in other parts of the plant due to the fusion of the binder from the RAP.

Other obstacles to be solved are:

- Clog in different parts of the plants (depending on the type) such as in the belts towards the mixer, bucket elevator, entrance of the by-pass, etc. on which there should be a special attention.
- Dirt in the bag filter, since moisture is not adequately removed due to the low temperatures of the production process itself, which can cause deterioration of the bag filters.

8. RESULTS OF MANUFACTURING AND LAYING TESTS

This section includes the results of manufacturing half-warm mixtures with a cationic emulsion modified with polymers type C60BP4 specially designed for half-warm recycled mixtures with an average percentage of milling (20-50%), which meets the specifications set out in table 2.

Remarks:
The mixtures were manufactured at 95 ° C and were extended around 75 ° C
The high performance bituminous emulsion was fed to the mixer at a temperature around 60 ° C
The half-warm recycled mix was manufactured with 6.6% emulsion on the basis of aggregate's mass.
In the manufacture of the mixture with 20% milling, this is introduced cold (passed through the drum without ignition) in the hot silo of the plant where temperature rises to 58 ° C.
In the first mix production, the aggregates were overheated to 140 ° C (over the design temperature) so that the mixture of these with the milled material was at 117 ° C. In the following fabrications, the temperature of the mixture was reduced below 100 ° C.

The granulometric curve of the materials and the manufactured mixtures are shown below in Figure 10. Table 5 shows the results obtained in the quality control tests carried out on the half-warm mixture type AC16 S R20.

Productos	% Ligante s/mezcla	% Ligante s/aridos	Referencia del componente (origen de los resultados)
FILLER RECUPERACION alfintrame	3.0 %	3.2 %	CEMOSA 3983
0/6 alfintrame	22.6 %	23.1 %	alfarras B5092912
6/14 alfintrame	29.2 %	31.6 %	alfarras B5092910
14/22 alfintrame	20.3 %	22.1 %	alfarras B5092911
Fresado 0/12.5 alfintrame	18.8 %	20.0 %	
STYEMUL CL-2 90 (C60 BP4) PROAS	6.1 %	6.5 % s/a	

Obligación	0.063	0.25	0.5	2	4	8	16	22.4
Media	4.00	8.62	12.39	25.08	37.16	63.14	95.06	100.00
Máximo	7	15	21	38	50	75	100	100
Visado	4.1	8.8	11.5	23.5	34.5	61	98	100
Mínimo	3	7	11	24	35	60	90	100
Desviación	0.10	0.18	0.89	1.58	2.66	2.14	2.94	0.00
Coef.	1	1	1	1	1	1	1	1

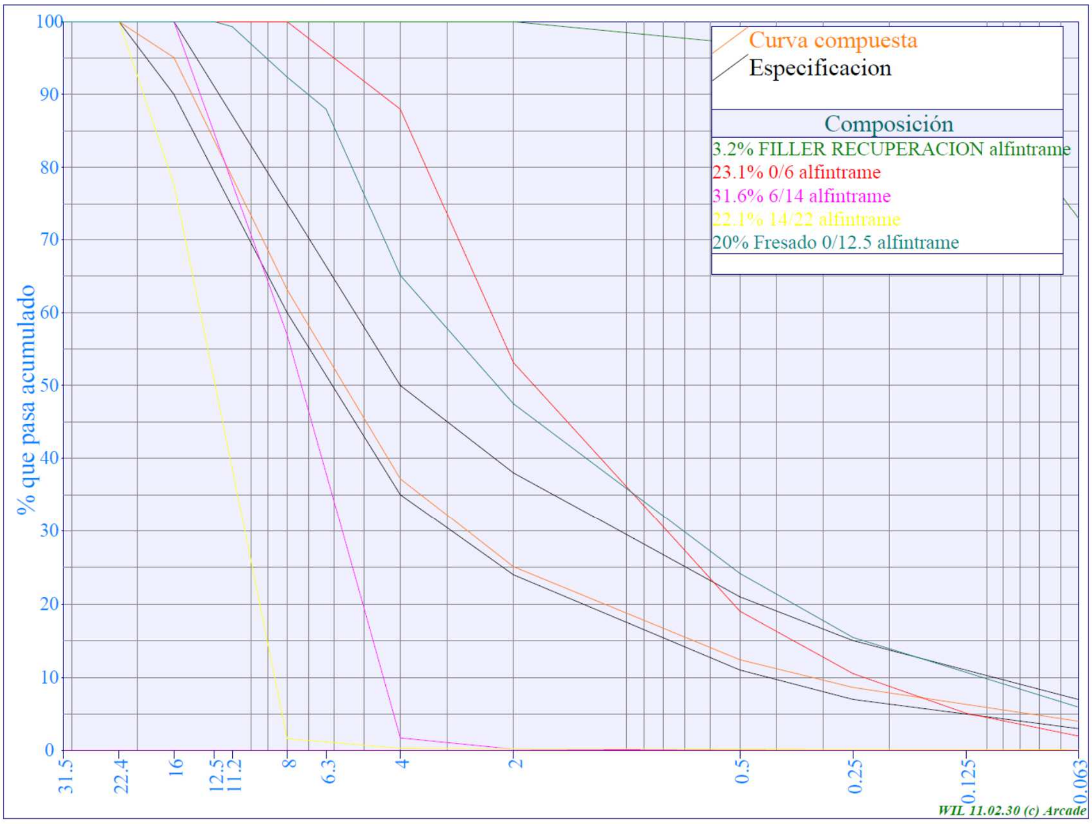

Figure 10: Granulometric analysis of aggregates, milled material and mixture

Table 5. Results obtained for mixtures AC16 R20

Test	Results on site	Results in the laboratory
Extracted binder content UNE-EN 12697-1	4,63% s/m	4,8% s/a
Voids Volume,%	5,1	5,0
Density SSD., kg/m3	2507	2494(*)
Filler/bitumen ratio	1,2	
Granulometry after extraction	Sieve - % through 22,4--100 16—90,3 8—63,6 4—42,2 2—29,7	Sieve - % through 22,4--100 16—98 8—61 4—34,5 2—23,5

	0,5—15,3 0,25—11,4 0,063--6	0,5—11,5 0,25—8,8 0,063—4,1
Binder characterization after extraction UNE-EN 12697-3		
Penetration a 25 ºC UNE-EN 1426		23 . 0,1 mm
Softening point UNE-EN 1427		65,3 ºC
Dynamic module. UNE-EN 12697-26 (Annex C)		3540 MPa
Geometric density	2507 kg/m^3	2369 kg/m^3
Wheel tracking test.-		
WTS	0,13	0,18
RD	3,5 mm	3,2 mm

In general, it presents a good aspect all over the manufactured mixes. In the attached photographs you can see some details of the application on site and appearance of these half-warm recycled mixtures (see figures 11 to 14)

Figure 11: Laying AC16 R20

Figure 12: Laying AC22 R80

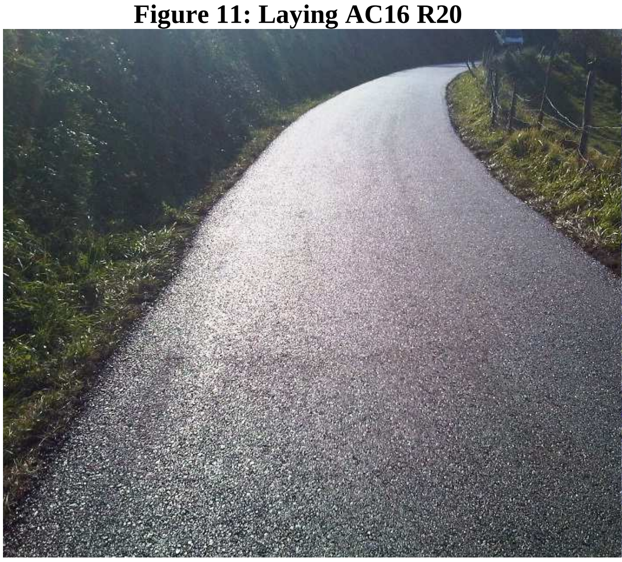

Figure 11: Laying AC16 R20

Figure 14: Laying AC22 R80

Two months after the tests were carried out, a core extraction and a texture measurement of the manufactured half-warm mixes were planned.

The measurement of the macro surface texture of the pavement was carried out through a sand circle test according to EN 13036-1. In the attached table 6 are represented the results of the measurements obtained for each type of half-warm mixture and in figures 15 and 16, some photographs taken during the finished unit control. It is appreciated that the final texture of the half-warm recycled mixes with 80% RAP is slightly rough, superior to those of semi-dense mixes such as AC 16S R20, manufactured using the half-warm technique bur using only 20% RAP.

Table 6. Texture results of the mixtures

Characteristics	Standard UNE- EN	Half-warm mix type	
		AC16 R20	AC22 R80
Surface macrotexture* (mm)	13036-1	0,8-1,1	1,1-1,5
(*) Measurements taken on the cores extracted two months after the test.			

Figure 15: Core extraction for texture measurement

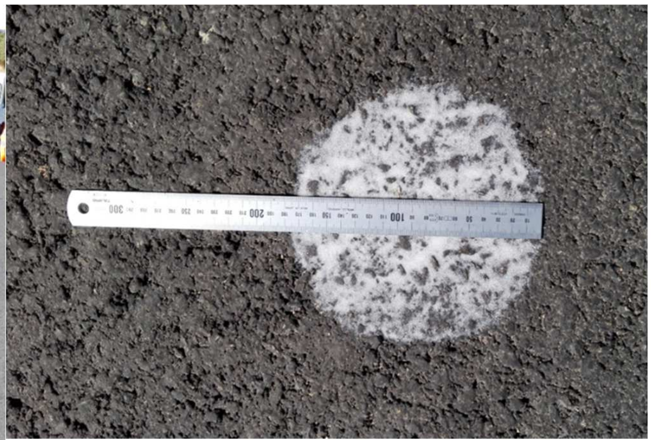

Figure 16: Detail of the measurement with sand circle test

9. CONCLUSIONS

The following conclusions are drawn from the work presented:

-The technology of production of temperate recycled mixtures allows working at temperatures around 100 ºC, obtaining mixtures with good performance, thanks to the use of bituminous emulsions specially designed for these mixtures. In some cases, these are polymers modified emulsions, produced from bitumen of somewhat higher consistency and cohesion than usual in conventional recycling emulsions.

-The reduction of the manufacturing and extension temperatures of these mixtures allows reducing greenhouse gas emissions as well as considerable energy savings, as well as allowing better working conditions for the workforce, especially valued when used in warm areas and in summer.

-The results obtained in the industrial manufacture of half-warm recycled mixtures type AC with milled material and polymers modified emulsions are, for all parameters tested, suitable for this type of mixtures.

-Half-warm recycled mixtures with polymer modified emulsions can meet the requirements of the surface layers, at least on low trafficked roads. The improvements achieved allow not only the economic and environmental benefit of the recycled products to be achieved, but also an improvement in the performance of the mixture and its durability, thanks to the use of high-performance emulsions.

-Half-warm recycled mixes with emulsion are an alternative to take into account in the structural rehabilitation of pavements. In principle, its use is recommended on roads that support medium and low traffic intensities.

The use of polymer modified emulsions in this type of mixtures is interesting to contemplate their use on site also in surface layers, where their resistance to plastic deformations and better initial cohesion of these mixtures will be validated for future use on roads with greater traffic of heavy vehicles.

10. ACKNOWLEDGEMENTS

We thank the Companies BENITO ARNÓ and CAMPEZO for the access to information on half-warm recycled mixes manufactured in their plants and studied in their laboratories.
Thanks also to the Technical Association of Emulsions and, especially, to the members of its GT3 on half-warm mixes, for the work done to spread their knowledge.

11. REFERENCES

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