Asphalt mixture performance and testing

Bituminous Mixtures Ultra-Thin-Layers (AUTL)

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Abstract

During 2017, a consortium was created between the companies CAMPEZO -the leading company-, PADECASA and REPSOL, to carry out a research project on the use and characterization of new type of bituminous mixtures which are developed in a new European standard prEN 13108-9. In this work, we consider the resources available in our country and study the use of different types of materials as well as manufacturing technologies that are less polluting and more sustainable. The ASFALTHIN project, with a duration of 3 years, has been approved in December 2017 by the Industrial Technological Development Center CDTI, within the "PID research and development projects" program, with a budget of 1 million euros. The project is divided in 6 activities, including a study of art and in-depth study of European regulations, laboratory studies necessary to identify the requirements required for materials and the proposal of grading for this type of mixtures with different structure and characteristics, for layering with thicknesses between 1-2 centimetres. In the final phase of the project, several test trials were carried out with the materials studied. This communication will present all the results obtained at the laboratory level (design and properties of the mixtures) with which several mixtures of AUTL mixtures have been defined, with different content of holes and possible applications, as well as manufactured with materials at a lower temperature and results of behavior of the mixture in service of several test sections executed throughout the project. The work will be completed with the publication of a guide of suggestions to use as a reference document in the sector where the procedures and appropriate methodologies are indicated to carry out the design and quality control of the AUTL mixtures, establishing the most suitable criteria and methodologies for the climatology and traffic conditions in Spain.

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1. INTRODUCTION

In recent years, the need to establish mechanisms and systems for the conservation of road pavements because of inadequate conservation actions and the increase in traffic in the roads has been detected.

An important percentage of the Spanish roads have pavements with inappropriate surface characteristics, however, in a lot of cases the structural properties of the pavement have not been lost. This wear mainly affects road safety, user comfort and a greater generation of CO_2 into the atmosphere, as well as if an action is not carried out on the pavement the road structure will suffer and could be needed actions more aggressive with higher economic cost and environmental.

If we are based on the evolution of the industrial sector in objectives such as circular economy and sustainability, we need to promise environmental respect, rational use of natural resources and socially accepted service.

The road construction sector focuses more and more efforts on developing processes and products that improve the environmental aspects, promoting more sustainable technologies and construction models with greater durability. The pavements are products that are subjected to progressive structural degradation by meteorological agents and by the vehicles traffic, which imply to carry out constant works of rehabilitation during their useful life.

AUTL ultrafine bituminous mixtures can be a suitable alternative to achieve the challenges defined above. These type of bituminous mixtures used in some countries of the European Union, have shown properties that allow defining regulatory requirements adapted to the European regulations for the CE marking, the result of which is the EN 13108-9 standard in which a series of properties are established that we will allow the CE marking of these type of mixtures in the next years.

The incorporation of these new bituminous mixtures family allow us to develop materials placed in small thickness. In the summer of 2017, ASFALTHIN was approved how to Research and Development in Cooperation Project - National Cooperation R&D Projects, thanks to ITDC (Industrial Technological Development Centre of the Ministry of Industry).

The project is being developed in collaboration between REPSOL, PADECASA and CAMPEZO. The budget approved by the ITDC for this project is almost one million euros.

The ASFALTHIN project expects to develop a new family of bituminous mixtures (AUTL), keeping to the requirements of Standard UNE-EN 13108-9, placed in small thicknesses (between 1 and 2 centimeters) with excellent performance and durability. This objective will be achieved through the development of new formulations with different materials, in order also to guarantee the environmental sustainability of the new mixtures, also developing with lower temperature manufacturing techniques and additives.

2. ASFALTHIN PROJECT

The general objective of ASFALTHIN project is developing new bituminous mixtures of type AUTL in Spain to allow laying them in 1-2 cm thickness and to improve the surface characteristics of pavements from a point of view of comfort, safety and environmental sustainability.

In order to achieve mixtures with a thickness of less 2 cm and high performance in skip resistance, you should start investigating or selecting the type of raw materials to allow you to achieve these high performances. High quality aggregates, high performance modified bituminous binders and tack coat emulsions what ensuring good surface characteristics.

Other environmental benefits will also be achieved with the development of these new AUTL mixtures such as:

- Maximum durability due to the incorporation of high quantity of binder in the mixture.
- Minimum consumption of raw materials per unit area.
- Minimal environmental impacts.

Finally, ASFALTHIN Project would like to conclude with the developing a recommendations guide that could serve as possible technical requirements specification in Spain for these mixes.

2.1 Task Project

ASFALTHIN project lasts 3 year and it is divided into 6 activities. Currently, activities 4 and 5 are being developed in more than 50%.

The six activities of the project are the following:

- Task 1. State of the art.
- Task 2. Raw materials.
- Task 3. Formulations. AUTL mix design
- Task 4. Characterization tests of the mixtures designed in activity 3.
- Task 5. Test sections.
- Task 6. Analysis of results and dissemination.

Task 1: State of art

The International, European and National regulations have been studied in depth [1,2,3,4].

Task 2. Raw material

The objective of this activity has been to select and analyze the characteristics of the components of the AUTL mixtures. The aggregates have been selected and analyzed and the most suitable bituminous binder for the purpose of this project has been studied and selected.

The binder analysis has been carried out from two perspectives:

1.- Develop binders that allow their use at different manufacturing and landing temperatures.

2.- Develop specific tack coat emulsions to create a strong adhesive .

Four types of modified bitumen have been studied, PMB 45/80-65 bitumen and three modified bitumen specially designed for this project to allow manufacturing at different temperatures. This paper presents only the tests of materials, aggregates and binders selected with the most interesting results.

For the design of binders for ultrafine mixtures (AUTL), manufacturing and compaction temperatures have been especially in mind. Due to its lower thickness, there are an important risk of cooling during its laying and it must be greater than 120 ° C (hot technology), in order to ensure adequate density and mechanical properties for durability of the mixes.

The reduction of manufacturing temperatures is actually the main objectives of the design of mixtures and its production is based on the use of specific manufacturing procedures or the use of binders with a very specific design / formulation, especially if they are modified binders. They constitute, without doubts, technologies of very current future, which are committed to reducing the environmental impacts of bituminous mixtures.

Even in the production of hot bituminous mixtures should be considered temperature reductions sufficiently significant so that certain aspects are taken into account with influence on the laying temperature (type of bitumen, additives, type of work, application, transport times and distances, construction management, worker comfort, workability, possible incidents, etc).. For example, extreme or specific situations may involve manufacturing temperatures of 20 to 30 ° C higher than the minimum necessary to ensure adequate compaction temperatures, that is values of the same order as the temperature reduction offered by warn mixt asphalt (WMA), so the first step is to set a maximum of 165 ºC

These considerations are what we have been considered in the manufacture technology of ultra-fine bituminous mixtures, which due to their characteristics in terms of thickness, binder content, type of binder (modified), range of workability temperatures and compactibility, make us to manage very important aspects to obtain the maximum benefits that they offer us.

Focusing on the different manufacturing technologies that employ temperatures above 100 ° C, and with the indications show before, we have:

HMA with manufacturing temperatures between 145 - 175 ºC depending on the type of mixture and binder used. It has been proposed to design a modified binder that allows the manufacture of ultra-fine mixtures at 165 ºC, and that allows adequately temperatures laying from 160 to 145 ºC to final values over 130 ºC. The modified binder called Asfalthin II has been developed.

WMA with manufacturing temperatures between 130-145 ° C depending on the type of mixture and binder used. A special binder with additives has been defined that allows manufacturing temperatures between 140-145 ºC, beginning of laying temperatures between 130-135 ºC and finishing it above 120 ºC. The modified binder called Asfalthin I has been developed.

The empirical and performance characteristics of the modified binders selected for HMA technology (Asfalthin II) and WMA (Asfalthin I) are the following. In addition, the characteristics of its homologous modified bitumen, PMB 45 / 80-65 and PMB 45 / 80-75 respectively are presented.

Table 1. Binder's characteristics

Properties	Standard	Unit	Asfalthin ii	Asfalthin i	PMB 45/80-65	PMB 45/80-75
Needle penetration, 25ºC, 100g, 5s.	EN 1426	1/10 mm	46	51	49	66
Softening point, ºC	EN 1427	ºC	89	80	68	78
Penetration Index		s/u	5.2	4.4	2.4	4.8
Brookfield Viscosity	AASTHO T316					
135ºC		cP	2430	1295	2980	3887
145ºC		cP	1467	777	1056	1690
165ºC		cP	635	356	454	552
Force Ductility 5ºC	EN 13589 plus EN 13703	J/cm^2 cm	7.6 >40	7,8 >40	6.3 >40	6.7 >40
Elastic Recovery	EN 13398	%	91	82	90	95
PG Grade	AASTHO T315		*PG 76-22 E PG 82-22 H*	*PG 76-22 H PG 82-22 S*	*PG 76-22 H*	*PG 82-28*

The aggregates selected and analyzed have been an offite and Cornean nature.

Fine aggregate was defined as the fraction that passes through the 2 millimeter sieve and retains the 0.063 millimeter sieve and had the function of providing cohesion to the mixture and improving the adhesiveness of material. Different tests have been carried out for the characterization of fine aggregates, such as the determination of density and absorption, equivalent of sand and methylene blue. The characteristics of the fine aggregates used are the following:

Table 2 Fine aggregate characteristics

Fine aggregate characteristics	Standard	Result
Bulk density, Mg/m^3	UNE EN 1097-6	2,85-2,70
Absorption, %	UNE EN 1097-6	1,1-0,5
Sand equivalent (size 0/2 mm)	UNE EN 933-8	65-60

The coarse aggregates provide resistance and surface characteristics, obtaining high values for skip resistance and hardness coefficient (LA). Aggregate fractions with size distribution 3/6 mm and 4/8 mm have been used, the characteristics for the smaller material are the following:

Table 3 Course aggregate characteristics

Course aggregate characteristics	Standard	3/6 and 4/8 mm
Bulk density, Mg/m^3	UNE EN 1097-6	2,75-2,95
Absorption, %		0,5-1,5
% Totally Crushed particle	UNE EN 933-5	100
% Rounded particle		0
Shape index, %	UNE EN 933-4	10-20
Resistance to fragmentation	UNE EN 1097-2	< 15

Micro-Deval	UNE EN 1097-1	<20

Task 3: Formulation. Design of AUTL mix

In order to study the characteristics of these new mixtures in a wide range of possibilities. The studying mixtures was divided into two parts, on the one hand, mixtures with air void content less than 10% and on the other hand open grade mixtures with air voids greater than 10%. In addition, two types of mixtures have been studied for each group where the maximum aggregate size has been 8 mm and 6 mm.

First, grading requirements of target composition have been defined in consideration of UNE EN 13108-9 standard. The grading composition established were the following:

Table 4. Grading composition AUTL

Mixture	Grading				
	11,2	8	5,6	2	0,063
AUTL 6 Open		100	90-100	15-25	5-10
AUTL 8 Open	100	90-100		10-25	5-10
AUTL 6 Dense		100	90-100	20-35	5-10
AUTL 8 Dense	100	90-100		20-35	5-10

The minimum bitumen content was set at 6% by weight over the total bituminous mixture, taking into account the necessary correction according to the density of the aggregate used. Based on these premises, the designed mixtures had the following size distribution curve:

Table 5. Final Grading composition

Size UNE (MM)	% Pass AUTL 6 Open	% Pass AUTL 6 Dense	% Pass AUTL 8 Open	% Pass AUTL 8 Dense
11.2	100	100	100	100
8	100	100	87	93
5.6	93	99	37	70
4	47	76	26	38
2	20	33	19	25
0.5	11	19	11	15
0.063	7.5	10,0	7.1	8.9

To determine the optimal binder content, air void content and binder drainage tests have been made to adjust them in the desired range. For AUTL dense mix, the air void content would be between 3-8% and for the open mix would be between 10-18%. For the compaction of the specimens, the impact compactor was used at 25 strokes per face, using approximately of 700 g to achieve a theoretical thickness of 35-45 mm. Also, the rotary compactor has been used using 40 spin, estimated energy to reach the reference density, but it is not ideal system to obtain AUTL specimen.

The optimum bitumen content defined for the mixtures has been 6.2% by weight over the total bituminous mixture. The two mixtures have an additive fibers in a proportion of 0.3-0.5%.

The mixtures were manufactured at 165 ° C with Asfalthin II and compacted at 150 ° C. Mixtures with Asfalthin I were manufactured at 140 ° C and compacted at 130 ° C. The results obtained were the following:

Table 6. Results of designed mixtures AUTL 6

Characteristics	Norma EN	AUTL 6 A Asfalthin I	AUTL 6 C Asfalthin I	AUTL 6 A Asfalthin II	AUTL 6 C Asfalthin II
Binder Drainage Schellenberg, %	12697-17	0.08	0.02	0.04	0.04
Impact 25*2					
Bulk Density, Kg/m^3	12697-6	2.206	2.418	2.205	2.404
Geometric Density, kg/m3		2.087	2.339	2.068	2.306
Maximum Density, kg/m^3	12697-5	2.489	2.581	2.508	2.578
Air Void Content,%	12697-8	16.2	6.3	17.5	6.8
VMA, %		28.7	20.9	30	21.2
Gyratory 40 spins					
Bulk Density, Kg/m^3	12697-6	-	2.294	-	2.289
Geometric Density, kg/m3		1.925	2.149	1.907	2.121
Air Void Content, %	12697-8	22.6	11.1	24	11.2
VMA, %		34.2	24.9	35.4	25

Table 7. Results of designed mixtures AUTL 8

Characteristic	Standard EN	AUTL 8 Open Asfalthin I	AUTL 8 Dense Asfalthin I	AUTL 8 Open Asfalthin II	AUTL 8 Dense Asfalthin II
Binder Drainage Schellenberg, %	12697-17	0.08	0.06	0.04	0.07
Impact 25*2					
Bulk Density, Kg/m^3	12697-6	2.264	2.458	2.255	2.479
Geometric Density, kg/m3		2.113	2.325	2.083	2.351
Maximum Density, kg/m^3	12697-5	2.474	2.569	2.481	2.580
Air Void Content,%	12697-8	14.5	4.3	15.7	3.9
VMA, %		27.2	19.1	28.4	18.8
Gyratory 40 spins					
Bulk Density, Kg/m^3	12697-6	2.195	2.430	2.112	2.322
Geometric Density, kg/m3		1.918	2.174	1.923	2.124
Air Void Content,%	12697-8	22.5	5.4	22.2	10
VMA, %		34.0	20	33.8	24

Likewise, the compactibility of the mixtures with gyratory compactor was studied, compacting specimens at 250 turns. The values of K and n (1) are the following:

Table 8. Value compactibility Gyratory compactor.

	K Value	N (1) Value
AUTL 6 Open Asfatlhin I	-2.811	31.43
AUTL 6 Dense Asfalthin I	-2.285	24.14
AUTL 6 Open Asfalthin II	-2.802	34.03
AUTL 6 Dense Asfalthin II	-2.023	22.38
AUTL 8 Dense Asfalthin I	-2.144	20.65
AUTL 8 Dense Asfalthin II	-2.129	24.04

Task 4: Characterization of mixtures type AUTL

As for the mechanical properties, according to EN 13108-9, the tests performance to obtain the mechanical properties were:

• Water sensitivity (EN 12697-12) that includes the categories for method A, values between 75 and 95 and also the compression immersion test (values between 75-95%).

• Low temperature properties according to EN 12697-46. The specimens must be compacted according to EN 13108-20 Table C1, where the range between the maximum and minimum limits selected must be 2% for the degree of compaction and 3% for the air void content, TSRTS maximum values between -15 to -30 depending on the breaking temperature.

• Friction after polishing (EN 12697-49). This test can be avoided by declaring the PSV of the aggregate.

• And then certain specific properties for application in airports such as resistance to fuel according to EN 12697-43 and resistance to de-icing fluids according to EN 12697-41.

In this task, the properties indicated in standard EN 13108-9 are being studied, but other tests are being carried out that they can provide important information about their behavior in service, as particle loss dry and water test in designed AUTL open mixtures.

Likewise, macro-textural and Coefficient of friction measurement tests are carried out on wheel tracking specimens, resistance cracking test, adhesion between layers test to define the most suitable tack coat emulsion. The most relevant results are presented below.

The results obtained in the water sensitivity test with the Asfalthin I and Asfalthin II binders for some of the mixtures studied, as Indirect tensile strength resistance (ITSR) was above 90%, whether impact or gyratory manufactured compactor. Indirect tensile strengths was slightly above for dense mixture than for the open mixture. And the results obtained in the loss particle test, both dry and water, was less than 10% loss in.

Uniaxial tensile tests to characterize low temperature cracking resistance to Asfalthin I´s Asfalthin II´s binder was evaluated through thermal relaxation test (TSRST), standardized test in UNE EN 12697-44. Asfalthin I binder gave values close to -30 ° C and Asfalthin II binder gave higher than -31.

Cracking tests have been carried out to evaluate the tenacity, ductility and stiffness of the mixtures, using the Fenix test [5,6,7]. The specimens were made with impact compaction machine at 25 strokes per face with heights between 30-60 mm have been used.

Table 9. Fénix Cracking Test Values.

FENIX TEST to 5ºC	**AUTL 8 C ASPHALTIN 2**	**AUTL 6 C ASFALTHIN 1**	
IRT, Stiffness Traction Index (MPa/mm)	---	1,8	
GF, Cracking Energy (J/m2)	---	911	
IT, Tenacity Index (mN)	---	448	
d0,5Pm, displacement to 50 % of load (mm)	---	1,1	
FENIX TEST to 25ºC			**Reference Values to BBTM B**
IRT, Stiffness Traction Index (MPa/mm)	0,71	0,9	>0.4
GF, Cracking Energy (J/m2)	403	415	>300
IT, Tenacity Index (mN)	587	577	>600
d0,5Pm, displacement to 50 % of load (mm)	2,14	2,0	-

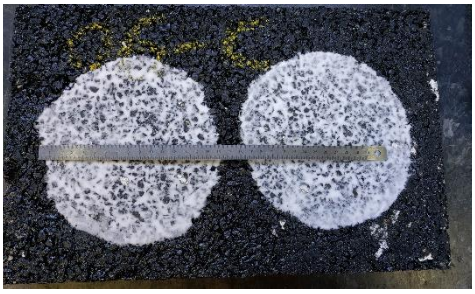
Track deformation tests have been carried out, tests that do not characterize these mixtures, but values of slope deformation below 0.07 have been obtained.

Macrotextures tests have also been carried out according to UNE EN 13036-1 and measurement of the coefficient of friction (pendulum).

Table 10. Values of surface characteristics on track specimens

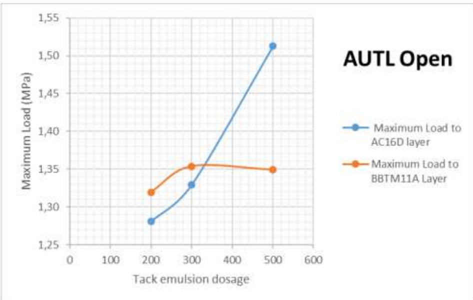
	AUTL 8 C ASFALTHIN 1		AUTL 8 C ASFALTHIN 2	AUTL 6C ASFALTHIN 1	AUTL 6 A ASFALTHIN 1	AUTL 8 A ASFALTHIN 1
Thickness specimen, mm	**20**	**40**	**20**	**20**	**20**	**20**
MACROTEXTURE	**1,1**	**1,3**	**1,1**	**0.7**	**1.15**	**1.15**
Coefficient of friction (PENDULUM)	**-**	**74**	**61**	**56**	**--**	**--**

Figure 1: Macrotexture test and pendulum.

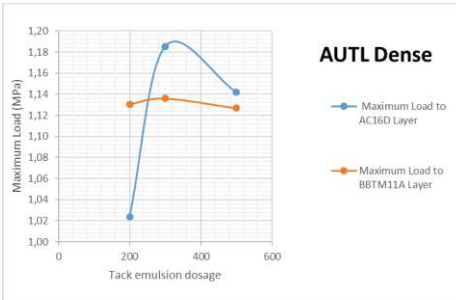



Adhesion tests between layers have been performed. For this purpose, two base layers, dense and open grade (AC16D and BBTM11B), and several tack emulsion dosages (C60BP3 ADH Asfalthin) have been used, and using an AUTL mixture with PMB 45/80-65 and Asfalthin II´s binders. The results obtained were:

Figure 2 Adhesion tests



PMB 45/80-5 and C60BP3 ADH Asfalthin I task emulsion



Asfalthin II binder and C60BP3 ADH Asfalthin I task emulsion

Task 5: Test section.

At the end of June 2019, a work section was carried out in the tunnel of Santa Maria de la Cabeza (Madrid City Council) to be used in an urban pavement with the mixture type AUTL6 D. Aggregates of a cornean nature (two sizes of 0/3 mm and 2/6 mm) and the Asfalthin I binder have been used. The theoretical dosage used in the asphalt plant is as follows:

Table 11. Dosage of material to trail section

Material	Type	Dosage (%)
0/3 mm	Cornean	23.0
2/6 mm	Cornean	65.4
Filler	Calcium carbonate	5
Fiber	Cellulose	0.3
Binder s/m	Asfalthin I	6.3

Cellulose fibers and the limestone mineral powder have been used. The tack coat emulsion, fundamental aspect for these technologies, was C60BP3 TER ASFALTHIN type.

The mixture was manufactured in a discontinuous plant for bituminous mixtures, using two hoppers for 2/6 mm and one hopper for 0/3 mm.

The laying equipment used in the work were: two high capacity Dumper, a mobile transfer silo placed at the entrance of the tunnel to achieve thermal homogenization before unloading in the paver, a special paver for the ultra-thin mix landing, Vogüele Super 1900 3i, metal roller, tack coat truck and transfer silo, SB2500E.

The mixture was placed in a theoretical thickness of 1.5 centimeters in an area of approximately 10,000 m2. The results obtained from the quality control performed were the following:

Table 12: Binder Content and distribution size

Size, UNE	8	5,6	4	2	0,5	0,063	Binder content o/m
Pass objective (%)	100	97	57	27	15	7,6	6.30 %
Specifications (%)	100	90-100	-	20-35	-	5-10	>6,1%
Average obtained (%)	100	98	61	32	14	7,0	6.44%

Specimens with the impact compactor were manufactured by applying an energy of 25 strokes for each face of the specimen. Density determination was carried out by the saturated dry surface procedure. The results obtained are the following:

Table 13: Results of the volumetric characteristics

	Max. Density Kg/m3	Bulk Density, ssd Kg/m3	VM, %	VMA %	VFB %
Average	**2.508**	**2.339**	**6.7**	**21.3**	**68.7**

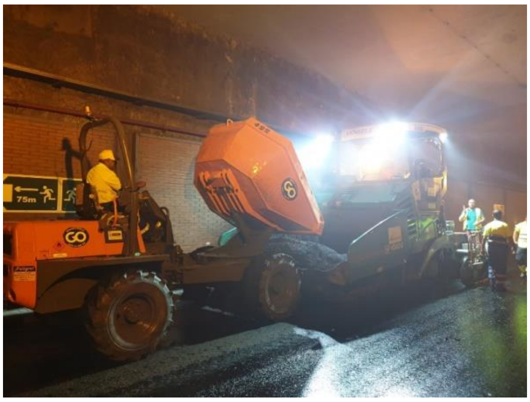
Water sensitivity tests of specimens manufactured with the gyratory compactor were performed. The results obtained were:

Table 14: Water sensitivity tests

	ITS dry, kPa	ITS water, kPa	ITSR
Average	1623	1593	98%

Surface characteristics tests were performed, obtaining values between 0.8 and 1.1 mm of macrotexture. Visually, an adequate macrotexture was observed, with gaps smaller dimensions than mixtures with thick aggregate size.

Figure 3: (Left) transfer silo outside the tunnel picture feds Dumper, (right) Dumper feeds the paver into the tunnel.



Laying temperature have been made to analyze the thermal homogeneity of the extended mixture, using thermal image camera.

Figure 4. Thermal image

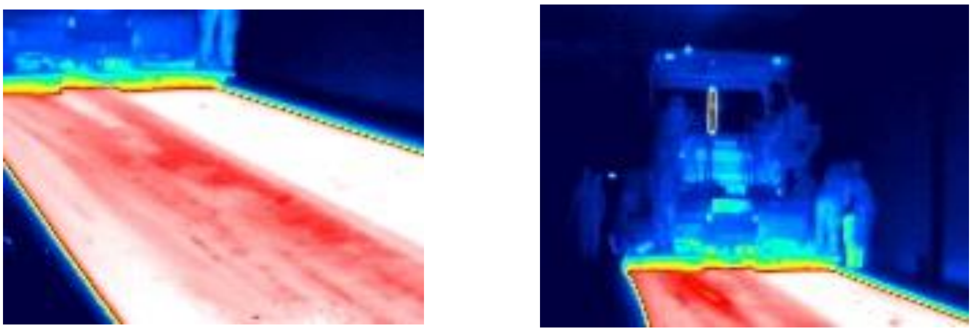
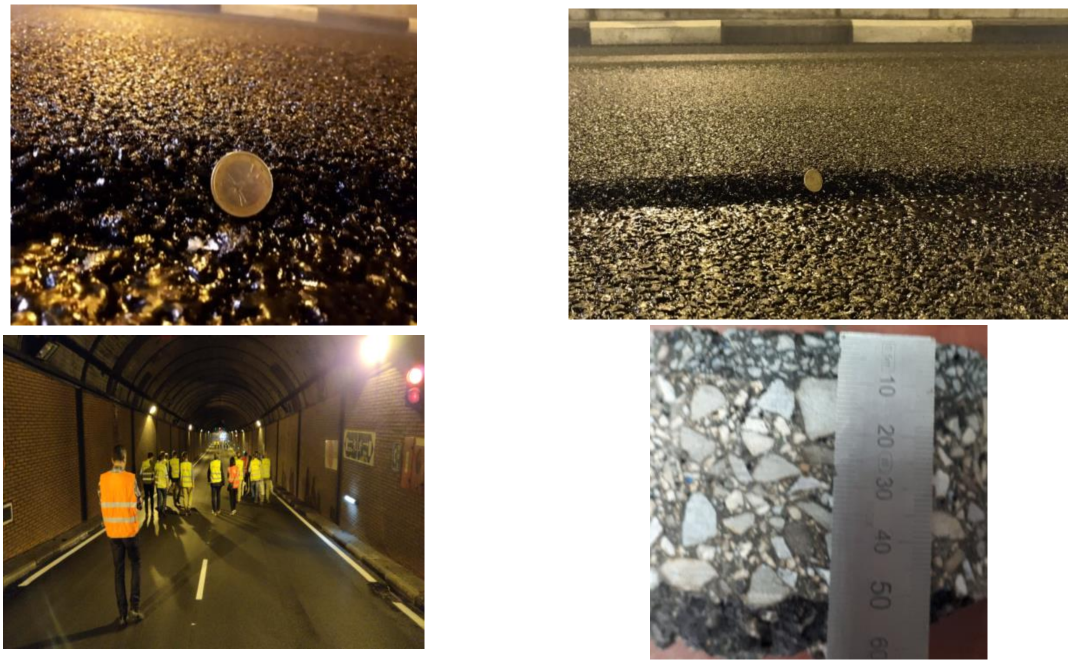


Figure 5. Final appearance of the mixture and core.



3. CONCLUSIONS

Of the results currently obtained we highlight the following:

- A study of the characteristics of the constituent materials has been carried out to make a valuation proposal for the future selection of aggregates and binders.
- Subsequently, a complete characterization has been carried out for two types of different mixtures, closed and open grade, for use in different types of roads.
- Different criteria have been established in the methodology of any of the tests used, obtaining good results.
- Different modified binders have been evaluated for HMA and WMA technologies, which allow versatility / workability in manufacturing and compaction temperatures.
- Proposals for particle size grade to obtain macrotextures appropriate for use in different types of roads, use of modified binders with special technology that allow wide paving and compaction temperature in elevated percentages that ensure the maintenance of the characteristics over time.
- The results obtained in the first test section have been very satisfactory.
- The final objective of this research project is to produce proposals and recommendations for the manufacture of ultra-thin mixes in accordance with European standards for renovation on the surface characteristics of pavements.

4.- ACKNOWLEDGMENTS

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