Maintenance and Rehabilitation

High performance ultra-thin asphalt layer

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Abstract

For 10 years we have been developing a technique to consolidate and improve the performance of ultra-thin asphalt layers. This achievement satisfies the necessity of re-establishing the surface properties of worn-out pavements with good structural and evenness conditions to increase safety and maintain these features over time. It is the result of the synergy among different fields. The emulsion used as bond coat is made from polymer modified bitumen; it is specially designed to guarantee adherence with the underlay and merge with the asphalt mix to reinforce the binder performance. The hot bituminous mix is costumed in each case to meet the needs of each road. Small changes in the formulation lead to textures from 0.8 to 1.5 mm. Lastly, the paver integrates a spraying ramp where the emulsion is uniformly sprayed before the screed. The outcome is the joint implementation of this emulsion with high irrigation dosage (0.8 to 1.5 kg/m2), followed by the spread of 1-1.5 cm thick asphalt layer. The high bitumen content provided from both, the bituminous mix and the emulsion, avoids aggregate relocation and improves frost resistance. Mix endowments between 20 and 35 kg/m2 involve no previous milling works and benefit road users minimizing execution times and traffic congestion. This sustainable technique reduces the volume of asphalt produced and raw materials consumption, cutting CO2 emissions. Cubic shaped aggregates of maximum size 12 mm provide a single grained structure with negative texture to maintain the initial properties regarding contact patch, surface drainage and noise absorption. Thereby, we reach greater skid resistance and safer conditions for longer time than conventional methods. Its smoothness reduces rolling resistance and fuel consumption. Our experience of 1.5 million m2 executed supports the suitability of this system for Administrations who work on preventive road maintenance programs to obtain long-lasting high performance pavements.

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1. INTRODUCTION

Flexible and semi-flexible pavements have been designed based on three types of layers: the base, the intermediate and the wearing course. Historically they have been thicker and with less bitumen from bottom to top, delivering rigidity at the base and ductility at the top. As it states the article [1] from FOM/3460/2003 *Secciones de Firme 6.1.IC*, in the last decades the volume of road traffic has increased, being necessary the creation of a new traffic category T00. At the same time, this article denotes the social demand for more comfortable and safe roads in rain conditions, implying the use of higher quality aggregates, modified bitumen, fibers, etc. Nowadays design criteria seek solutions resistant to fatigue in the base layers and durability against climatic agents, safety and comfort for users in the upper layers. All together optimizing environmental and economic features. In this way it has evolved to a greater specialization in the materials, composition of the asphalt and thicknesses of the layers.

The wearing course, historically with finer aggregate and more bitumen, is the one that has evolved the most considering that it is the one entrusted with the safety and comfort of road users. In addition, it must withstand meteorological agents offering the maximum operational life as possible. Suitable solutions have been sought for both, new construction and maintenance works to restore the surface properties of the layer. As it is shown in "*Evolution of the need for wearing courses*" by Yves Brosseaud [2], design criteria for asphalt upper layers lead to the development of discontinuous asphalt mixes and thinner layers. In this context, asphalt for upper layers has evolved from layers of continuous granulometry and thickness from 2.5 to 3 times the maximum size of the aggregate, to discontinuous layers of greater macrotexture and smaller thickness. Depending on the type of road and the type of traffic, from the AC16 S or D, passing through the SMA (Stone Mast Asphalt), to very fine mixes BBTM (Beton Bitumineux Tres Mince), and the most modern and fine such as the BBUM [3] (Beton Bitumineux Ultra Mince) equivalent to the AUTL (Asphalt for Ultra-Thin Layer) of the European standard EN 13108-9 [4].

In this work we present a system which belongs to the set of asphalts for ultra-thin upper layers. It consists of the joint implementation of high endowments of a highly modified emulsion, specially designed for this use, followed by a single-grained layer of asphalt offering a high performance wearing course . The result is a structure of minimal thickness (Figure 1) with a high bitumen content provided by both the hot bituminous mixture and the residual binder of the emulsion. We began its development more than 10 years ago, due to the need for improving the behavior and long-term evolution of conventional road wearing courses. They conform the upper part of the road section, and must withstand the efforts of traffic and wear produced by weather agents. Their main function is to provide safety and comfort to users with regularity, surface texture, surface drainage and waterproof. The mastic covering the surface aggregates is weakened by the efforts of traffic and meteorological agents. From the point of view of its design and based on our experience, we can confirm that over the years the binder content of conventional microagglomerate is not enough. This generates a lack of adhesiveness that can evolve in loss of particles, relocation of the aggregates from its initial structure, changes of texture from negative to positive and loss of the initial surface properties of the pavement. This adverse development forces to carry out early maintenance and rehabilitation road works.

The aim of this system is to mitigate these deficiencies and offer ultra-thin asphalt layers with high-performance surface properties to provide safer roads for longer time. It is based on a higher binder content single-grained structure that maintains the initial surface negative textures. This sustainable system reduces road maintenance costs and offers a new concept for preventive road conservation. Nowadays it is presented as a consolidated tecnique with more than 1,500,000 square meters executed in Spain with satisfactory results.

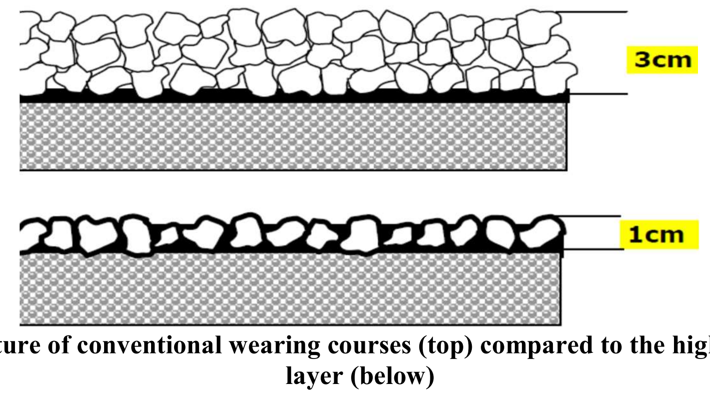

Figure 1: Internal structure of conventional wearing courses (top) compared to the high-performance ultra-thin layer (below)

2. HIGH PERFORMANCE ULTRA-THIN ASPHALT LAYER FOR WEARING COURSES

This system is the result of the combination of three essential elements: an updated asphalt paving machine, a specially designed high-performance emulsions and the properties of the aggregates used in the mixture.

2.1 Application system

The implementation method is part of the requirements to achieve the results sought with this system. It consists of the joint application of a homogeneous irrigation of a specially designed emulsion, with endowments of the order of 4 times greater than conventional techniques (between 0.8 and 1.5 kg/m^2), immediately followed by the spread of an ultra-thin asphalt layer, all in one single process. Mixture endowments are between 25 and 35 kg/m^2. Emulsion and asphalt endowments depend on the condition and texture of the existing pavement. This process is obtained with an updated asphalt paver (Figure 2) that incorporates an irrigation ramp where the emulsion is sprayed on the entire surface just before it's covered by the spread of the asphalt (Figure 3).

Figure 2: Asphalt paving system with integrated spraying ramp to apply the emulsion and spread the asphalt in one single process

Figure 3: Detail of the spraying system integrated in the updated asphalt paver machine

It is not necessary to wait for the curing time of the emulsion. The time elapsed between the application of the emulsion and the spread of the asphalt is less than 5 seconds. When the asphalt, at 150-170ºC of temperature, comes into contact with the modified emulsion, its breakage occurs. The immediate evaporation of the water produces an effect of ascension. It allows the resultant modified binder of the emulsion to wrap the aggregates of the mixture. In this way, the bitumen of the emulsion merges with the one of the asphalt. The sum of both modified binders results into a reinforced mastic. This fact ensures the adhesion between layers, improves the waterproofing of the upper layer being more resistant to frosts, it is less affected by dirtiness and more feasible to be cleaned in order to maintain surface properties such as skid resistance. That's how this system increases road safety.

No vehicle of the work site can step on the emulsion before this is covered. Therefore, this system preserves the cleaning of the surrounding roads, reduces the affection to their users and avoids road mark repainting works. Moreover, it guarantees a uniform and stablished emulsion endowment in the whole applicable area.

This system is applied directly on the existing pavement, being necessary a cleaning of the surface and a good regularity of itself. It avoids some of the previous paving works such as milling and waiting curing time of the emulsion. This significantly reduces the impact on road users in time and space availability, improves traffic flow due to works, and offers greater safety during works. With all this, performances with this system are greater than in conventional paving systems, with the same number of paving machines.

After the paving process, this system requires the use of one or two metallic rollers and one pneumatic roller. This ultra-thin asphalt layer does not need compaction due to its minimum thickness and its single grained structure. The main role of the rollers is to ensure the full contact of the emulsion with the mixture in the entire paved surface (Figure 4).

Figure 4: Final stage with metallic and pneumatic rollers

Because of its thickness, asphalt reduces its temperature faster than conventional wearing layers. Road marking works can be performed earlier than in conventional paving systems. In addition, the non-compactness of the mixture reduces commissioning times, not exceeding 20 minutes once extended, being even favorable its passage through the newly extended surface.

2.2 High performance bituminous emulsion

Another essential element for this system is the high modified bituminous emulsion specially designed for this use, based on SBS polymer modified bitumen, with higher elastic features than conventional ones. After being sprayed, the breakage of the emulsion takes place and then a large amount of highly modified residual bitumen remains as bonding coat (Figure 5). The reinforced properties of this residual modified bitumen ensure the adherence of the ultra-thin layer with the base. In this system, the emulsion has a double function: being the bonding coat between layers ensuring its adherence and, due to its high endowment, it also integrates into the asphalt and strengthens its binder in quality and quantity. So, finally, a much richer mastic is achieved and provides high resistance to efforts caused by linear traffic and shear forces generated by turns and lateral displacements.

Figure 5: High elastic performance of the special emulsion designed for this system

Below are the main properties of this singular adhesion emulsion, customized and designed for this application. It satisfies the specifications included in UNE EN 13808 standard for an emulsion type C60BP3 and stands out for its elastic feature.

Specially designed emulsion properties (Table 1):

Table 1. Highly modified emulsion properties specially designed for this system

Properties	Units	Guide	Requirement	
			Min.	Max.
Binder content by water content	%	UNE EN 1428	58	62
Stiffness (of the binder recovered by evaporation)	0.1 mm	UNE EN 1426	-	≤100
Softening point (of the binder recovered by evaporation)	ºC	UNE EN 1427	≥50	-
Elastic recovery at 25ºC (of the binder recovered by evaporation)	%	UNE EN 13398	≥70	-
Elastic recovery by torsion (of the binder recovered by evaporation)	%	NLT 329/91	≥50	-
Cohesion strength-ductility at 5ºC (of the binder recovered by evaporation)	J/cm^2	UNE EN 13589-13703	≥2	-

To evaluate the elastic behaviour of the emulsion residue, the strength-ductility test was carried out at 5ºC (UNE EN 13589) and compared with the results of other binders. In Figure 6 we can see the results collected. With the residue of this highly modified emulsion, we've obtained values higher than 2 J/cm^2. As a reference, article 212 of the PG-3 calls for strength-ductility cohesion values > 2 J/cm^2 for a modified bitumen type PMB 45 / 80-60 and > 3 J/cm^2 for a PMB 45 / 80-65 polymer modified bitumen. In the same figure we can observe the behaviour of a bitumen type PMB 75 / 130-60 and that of the residue of a standard modified emulsion type C60BP4 TER. The last one was carried out at 15ºC, since at lower temperatures the sample breaks before even finishing the test.

Therefore, this indicates that once the emulsion is broken, the residual binder that merges into the asphalt is the most similar to a polymer modified bitumen.

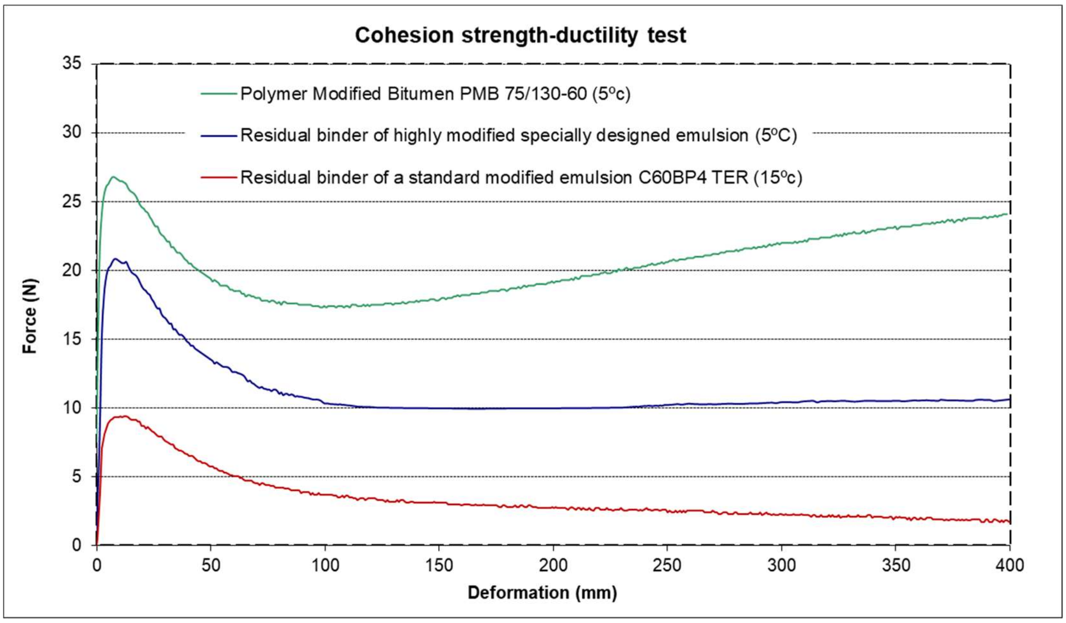

Figure 6: Cohesion strength-ductility test

The viscosity of the emulsion is a feature to be taken into account for the application of this system. This property allows higher doses of emulsion endowments, offering a greater adherence interface thickness and being able to integrate into the asphalt. The factors that directly influence the viscosity of any emulsion are the concentration of the dispersed phase, the size distribution of the particles and the mechanical means used for manufacturing [5]. An emulsion with a small droplet size (d (0.5)) and with a narrow granulometric distribution will have a high viscosity and optimum properties for the system that is presented.

Those emulsions manufactured from a high content of polymer modified binder tend to have a larger particle size than unmodified ones, due to the difficulty of emulsifying this type of bitumen. For this system we obtain a highly modified emulsion with a narrower particle distribution and a smaller particle size than standard modified emulsions of the same range (Figure 7). From bibliographical references [6] and based on the experience that we have as emulsion manufacturers, it is considered that the common particle size in bituminous emulsions ranges between 5 and 10 µm.

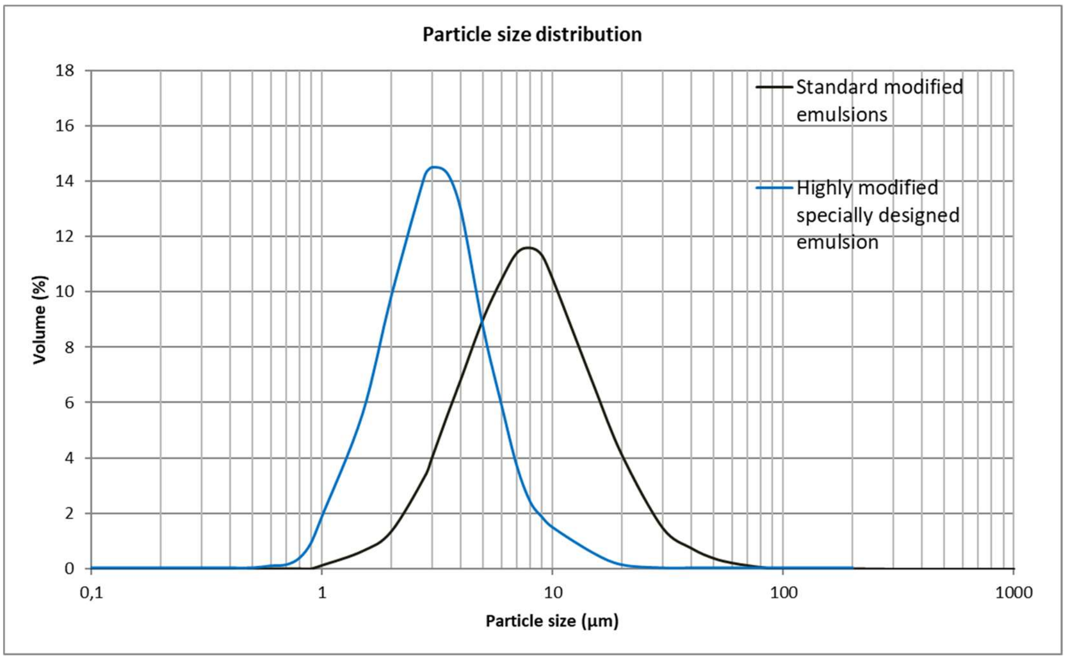

Figure 7: Particle size distribution of the emulsion used in the system in comparison with a standard modified emulsion

The final modified binder content, the one contributed by the asphalt itself merged with the one that the emulsion provides, is about 7% by weight on mixture. This generates a reinforced internal structure that complies with the objective of improving the durability of the upper layer while maintaining its initial surface characteristics. This amount of bitumen in the asphalt cannot be obtained through conventional paving systems.

In order to value the modification degree of the original bitumen, the binder of the mixture has been recovered before and after the integration of the emulsion and has been analysed, comparing the results with those of the asphalt original bitumen. The tests carried out have been: UNE-EN 1426 Needle penetration test, UNE-EN 1427 Softening point Test. Rig-ball method and NLT 329/91 Identification of modified bitumen elastic recovery by torsion.

The results of Figure 8 show how the incorporation of the modified emulsion into the asphalt favours the properties of the resultant binder. It improves its thermal sensitivity and at the same time it recovers part of the hardness and the elastic recovery that had been lost because of aging due to the manufacture and transportation processes.

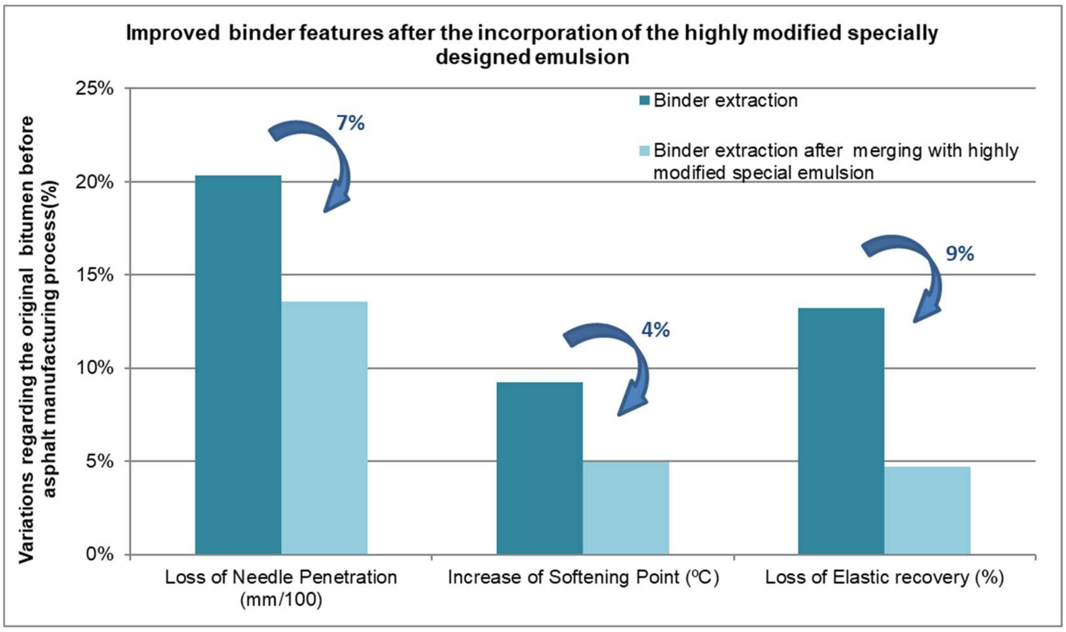

Figure 8: Improvement of the properties of the ultra-thin layer resultant binder due to the contribution of the highly modified emulsion integrated during the spread process

2.3 Asphalt component properties

Shape properties of those aggregate used in asphalt upper layers have an important impact on road safety as they have the role of offering negative texture, superficial drainage and the durability of these properties. Its mineral composition will define the micro-texture and the shape coefficient will relate to the macro-texture (Figure 9). An accurate selection of these two properties will provide a successful skid resistance over time and increase the contact patch between the tyres and the pavement. In addition, a coefficient of shape demanding a cubic aggregate will favour the achievement of a wearing course with a long-lasting negative texture (Figure 10).

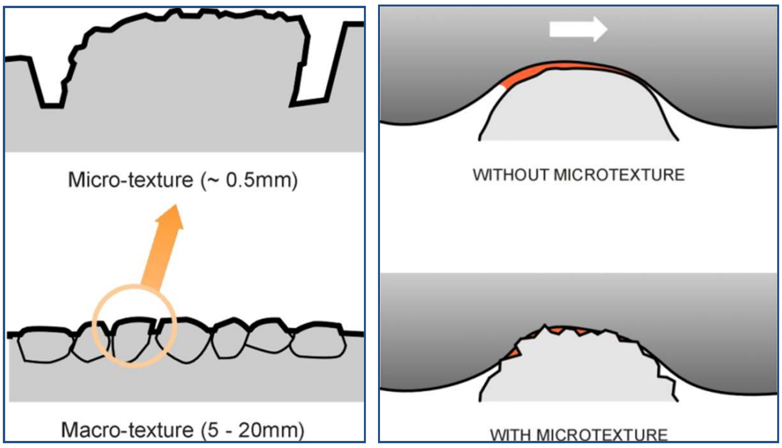

Figure 9: Detail of micro-texture and macro-texture defined by the aggregate properties

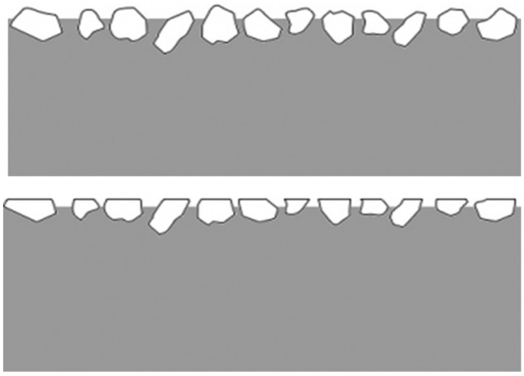

Figure 10: Positive texture (above) and negative texture (under) in different wearing courses

Regarding the type of aggregate used in this system, its hardness and shape are key features. A cubic aggregate with a maximum particle size of 5/11 mm is used in order to achieve a single-grained layer. The long-lasting negative texture generated by aggregates cubicity increases the contact patch between road surface and vehicle tyres, improving safety (Figure 11). Its reduced thickness and high binder content avoid further granular particles relocation due to traffic effort and wear. So initial surface properties such as negative texture, sound-reducing capacity or superficial drainage remain effective for much longer than conventional methods.

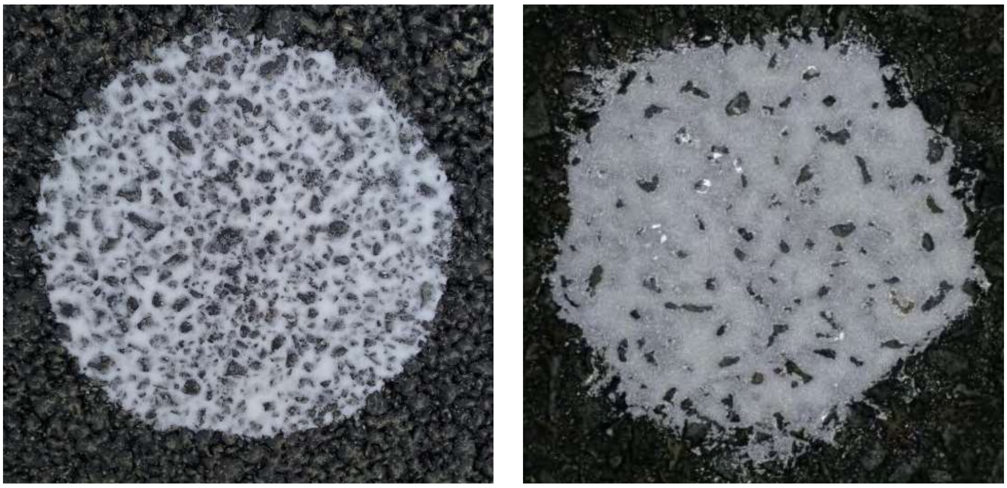

Figure 11: Sand patch test and effective contact patch offered by each technique after their first operational year. High performance ultra-thin layer (left) and conventional discontinuous gradated wearing course (right)

Conventional discontinuous grated asphalts such as BBTM tend to lose their initial negative texture as the thickness they are designed for enables the relocation of aggregates progressively from its commissioning. This fact is emphasized by some asphalt design guidelines related to undemanding aggregate shape and limitations in the binder content to meet the content of gaps.

3. APPLICATION AND RESULTS

3.1 Commissioning performances and applications

After more than 10 years of development and over 1,5M square meters performed (Figure 12), we've come up with the following statements and results.

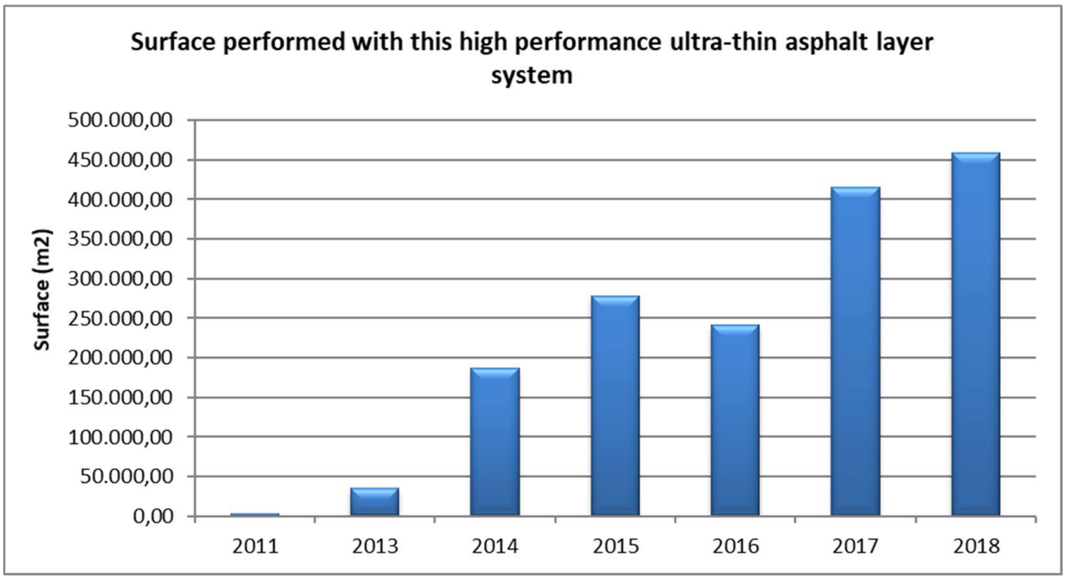

Figure 12: Annual area of action with the system presented

This technique is designed for pavements with a correct structural condition and good transversal regularity, but with the need for restoring its surface properties to offer safety and comfort to users. It is also designed to withstand the demands of high-speed traffic, as well as the aging caused by weather agents.

In addition, it is a system adaptable to each road requirements. Due to its thickness, with small variations in the formulation we can obtain a wide range of properties such as surface textures between 0.8 and 2 mm and SFC (Sideways-Force Coefficient) values of up to 80. This technique is suitable for all kind of traffic volumes and has already been implemented in urban, conventional and high-speed roads (Figure 13). It can also be customized for each road requirements to achieve for example greater impermeability, sound-reducing features, improved skid resistance or increased contact patch with tires, reducing texture.

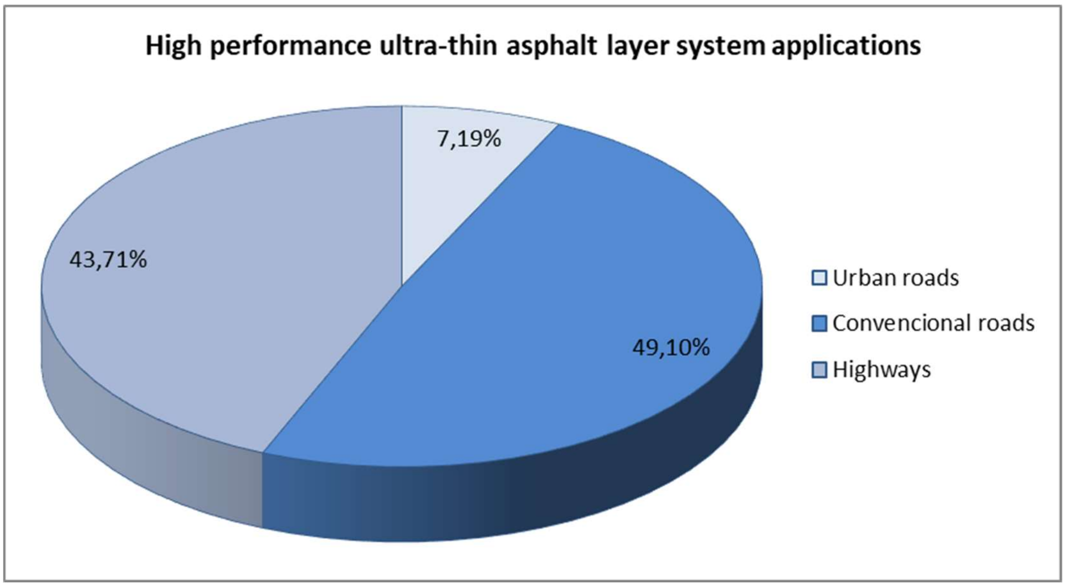

Figure 13: Different types of roads where the system has been implemented

This innovative system allows the restoration and maintenance over time of the main parameters required in a wearing course with half the volume of material required in conventional systems (Figure 14). This cuts the volume of raw material used and means lower energy consumption during its manufacturing. Consequently, there will be less presence of heavy vehicles for its transportation what will reduce the congestion of the roads nearby. On the other hand, as it is not necessary to carry out previous milling works on the existing pavement, significant economic and environmental savings owing to the whole milling process must be taken into account. That makes it a more sustainable system. In addition, the innovative application method allows higher performances minimizing the impact on traffic and road users.

With all that mentioned, we achieve a thinner wearing course rather than those that common discontinuous asphalts can offer, with higher binder content and suitable surface textures for all kind of traffic. Moreover, it improves the pavement performance and safety properties, especially in the long-term, and reduces the cost of the operation.

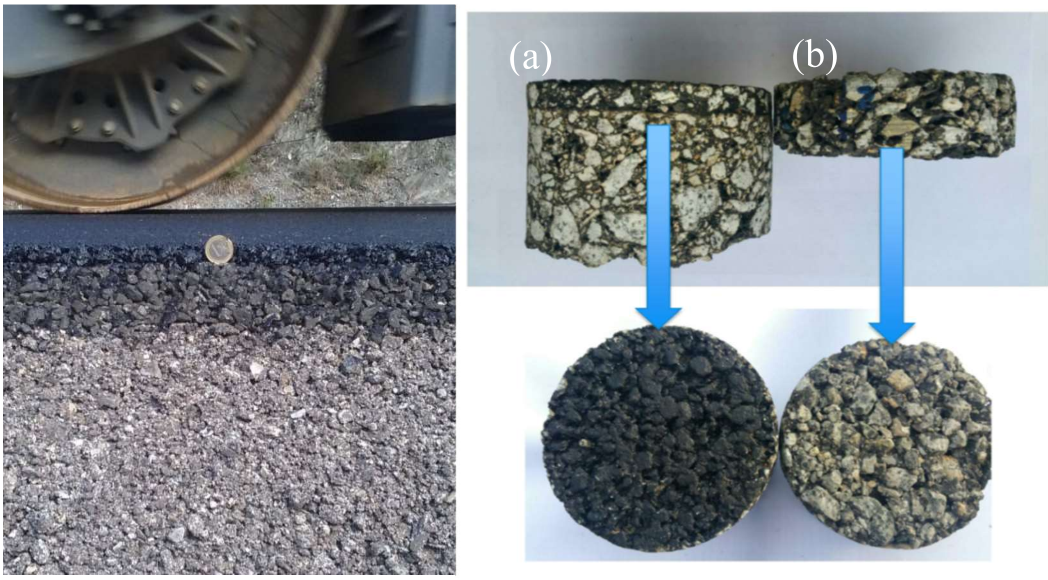

Figure 14: Reduced thickness of the innovative system compared to the conventional wearing course underneath. (a) High performance ultra-thin asphalt layer, single grained structure, minimum thickness and high bitumen content; (b) common discontinuous wearing course (BBTM) 2,5cm thick

3.2 Results

To evaluate the behaviour of the cracking resistance of this innovative technique, we carried out a study with the Fénix Test [7] (Figure 15), in charge of the UPC Civil Engineering Professorship. We compared the performance of this system with conventional cross section upper layer pavements. The conclusion determines that the high performance ultra-thin layer delays the fissure opening and maintains the load for a longer time, leading to a much more ductile break than a conventional asphalt (Figure 16). The tenacity index value with the ultra-thin mixture (1000mN) was in the order of three times greater than with the conventional layer (300mN). And with the same method it has been able to corroborate the good adhesion with the lower layer offered by this system, thanks to binder provided by the integrated spraying system.

Figure 15: Fénix Test performed on cores with the high-performance ultra-thin asphalt layer

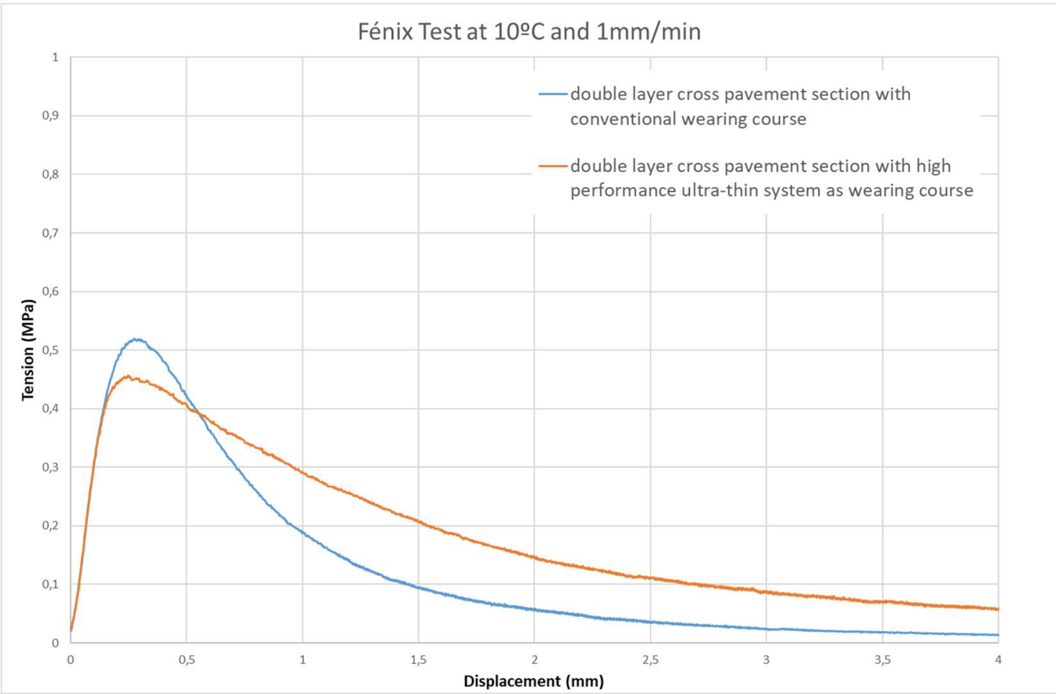

Figure 16: Fénix Test results in bilayer cores with conventional and innovative ultra-thin wearing courses

We've carried out a continuous monitoring of all the works performed regarding: the asphalt layer performance, skid resistance results (figure 17) and graphic reviews on site with sand patch tests (such as figure 11). This information collected along 10 years of application leads us to notice that this technique achieves its main target: maintaining the layer initial granular structure over time. Our experience with more than 1,5M m^2 implemented backs us up. When the aggregates are cubic (values under 10% according to UNE-EN 933-4), the layer has a single grained structure and there's a higher content of modified bitumen in the mix (over 7% by weight of mix), aggregate relocation is avoided because its lack of space. Our next goal is to carry out a study to confirm empirically that this technique maintains an increased contact patch between firm and vehicle tires over the time, in comparison with conventional asphalt upper layers.

This is also reflected with greater and lasting skid resistance features it offers. Regarding the SCRIM test, with this system the mixture can be designed to obtain high Sideway-Force Coefficient values since commissioning, improving from 5 to 15 points in comparison with conventional wearing courses. It's also highlighted how these initial values hold for longer, while those of the conventional layers decay along while they lose its initial surface properties (Figure 17). The results obtained in the following graphic are subject to the methodology of the SCRIM test system.

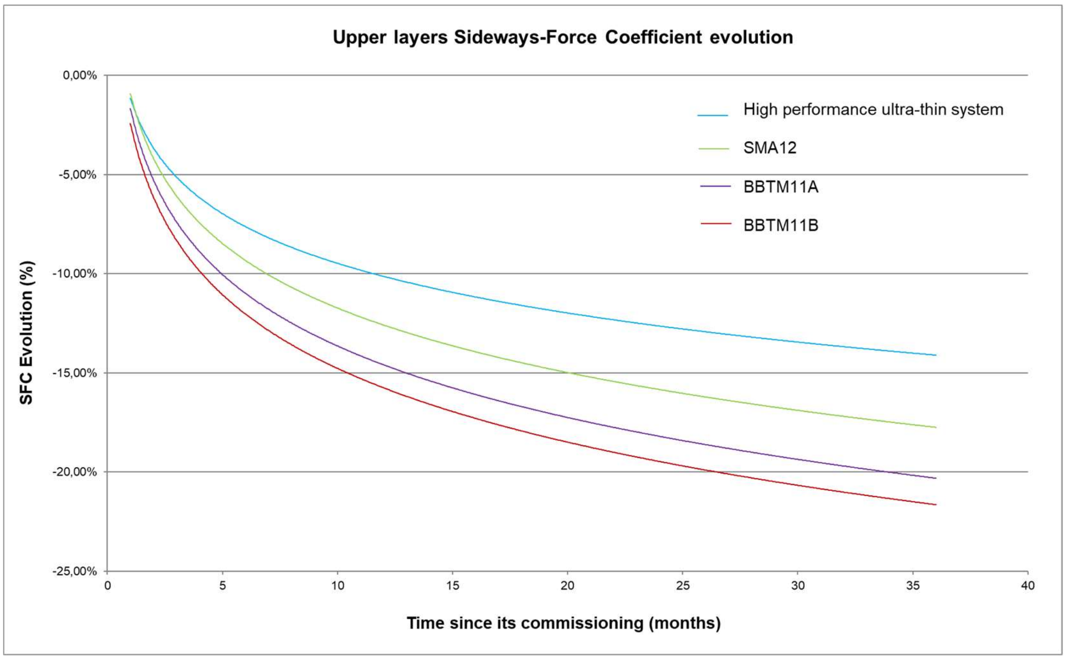

Figure 17: Sideways-Force Coefficient evolution of several upper layers

4. CONCLUSIONS

In this regard, we present a consolidated system as a new concept for rolling asphalt layers consisting in the application of a high-performance ultra-thin wearing course. It states the evolution of conventional 3-4cm thickness upper layers to a more sustainable and high-quality applications, offering a new solution for preventive road conservation works.

This innovative technique restores the surface of worn-out roads offering durable safety properties and improves and maintains skid resistance for longer than conventional methods. In this way we obtain safer road conditions for longer time with a sustainable system that reduces environmental and operational costs. It uses less volume of raw material and reduces energy consumption in manufacturing and transport processes. The updated application system allows to minimize the impact on road users during the works and preserves the cleanness of the surrounding roads.

The mechanical properties tested in the asphalt demonstrate a good resistance to the action of the water, crack delaying performance and a good adherence between layers.

It has been evidenced that the integration of part of the modified bitumen emulsion in the asphalt improves the features of the resultant binder. It exerts a rejuvenating effect after the manufacturing process, lengthens its durability and improves thermal susceptibility to weather changes.

Due to the single-grained structure of the layer we obtain long-lasting negative texture which maintains sound-reducing features, surface drainage, enhanced effective contact patch and high skid resistance over time.

To sum up, the technique presented offers safer pavements for longer time reducing environmental and operational costs.

Figure 18: Innovative paving system with integrated spraying ramp

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