SUSTAINABLE PAVEMENTS: WARM ASPHALT MIXTURES MADE WITH RECYCLED AGGREGATES FROM DIFFERENT INDUSTRIAL BY-PRODUCTS

Fernando C. G. Martinho
FM Consult - Infrastructures and Roads Engineering / IST - PhD student
Lisbon, Portugal
E-mail: fernando.martinho@ist.utl.pt

Silvino Capitão
Department of Civil Engineering Transportation Infrastructures, ISEC
Coimbra, Portugal
E-mail: capitao@isec.pt

Luís de Picado Santos
Dep. of Civil Engineering, Architecture and Georesources, IST, Techn. University of Lisbon
Lisbon, Portugal
E-mail: picado.santos@civil.ist.utl.pt

ABSTRACT

We are developing warm asphalt mixtures, at a temperature not exceeding 120°C, because we believe that they will have an increasing demand in the short term, not only in terms of the construction of new road pavements, but also in the rehabilitation of the existing ones. To maximize, simultaneously, energy and natural raw materials savings in the manufacturing of warm mixes, we included by-products from three of the most important industrial activities established throughout Portugal. This construction strategy is now of major importance from the economic recession´s point of view which affects most of the European countries.

Starting with a laboratory characterization of some by-products, such as steel slag, construction and demolition waste, reclaimed asphalt pavements, as well as the appropriate bituminous binder and additives, we have studied the compositions of several mixtures, selecting those with a better mechanical performance. One of the main objectives of this research project is to establish conditions of use for the tested by-products, aiming to produce warm asphalt mixtures that may be able to be applied instead of traditional asphalt mixtures, maintaining the level of performance.

In this paper some of the results of raw materials characterization are shown, together with the preliminary studies concerning the mixtures design. For several blends of by-products and binder additives used to produce warm mixtures, preliminary performance testing results are presented. This allows to propose some of the basic rules to follow throughout the process of selecting the raw materials and the design of warm mixtures incorporating the by-products studied in this research project.

1 INTRODUCTION

Environmental concerns, along with technical reasons, are the driving force behind the reuse of "waste" produced by different industries. Among the most representatives, there are the construction industry, the manufacture of steel and the road construction industry. In any of these industries many by-products are produced, which may serve other purposes although they have no commercial value in that row. Therefore, one should encourage the aspects that can be improved within real projects to develop the incorporation of alternative materials that contribute to a "better environment". In fact, the production of waste and industrial by-products is increasing and the elimination of many of them can cause disturbing problems and handling costs are sometimes very high. Therefore a study was initiated aiming to evaluate the asphalt mixtures' behaviour when they incorporate some by-products. It must be emphasised that this does not require reinvestment in the adaptation of production plants and that the final cost is lower than that of traditional asphalt mixtures.

In order to maximise savings in this asphalt mixture production, the process is being developed at temperatures lower than those applied for traditional hot-mix asphalt.

We believe that in the future this project can be seen as a contribution to achieve a more innovative design and maintenance techniques for pavements.

2 THE WARM ASPHALT MIXTURES (***WMA***)

The production and application of asphalt mixtures have been improved greatly during the past two decades, having as main objectives the economy in the process and a greater respect for the environment. More recently, we have sought to reduce the maximum energy consumption during the whole process, especially the consumption of fossil fuels, without changing the in-service mechanical performances of these asphalt mixtures.

On the other hand, there is a growing international pressure to reduce the emissions of the GreenHouse effect Gases (GHG), such as Carbon Dioxide (CO_2). The gain for the environment and for the society might be important, because it can achieve a significant decrease in the temperature of production of asphalt mixtures, maintaining, or even improving its workability and mechanical performance, those obtained in the HMA.

The PIARC (Olard & Noan, 2008) and EAPA (EAPA, 2010), among others, state that WMA are generally produced in a temperature range from 100 to 140°C, whereas the half-warm mix asphalt (H-WMA) are manufactured from 70 to 100°C. The temperature reduction is thus about 30°C for the first case and can reach 80°C for the second case.

Currently, there are already several technologies available to produce WMA and some others under development. WMA technologies promise several benefits compared with HMA, which can be grouped into three categories: environmental, production and application of the mixtures, and costs. However, some disadvantages are also pointed out to these mixtures.

2.1 Benefits and disadvantages of *WMA*

The emissions declared in the literature have some variation, depending on the WMA technology used, but all of them have a significant reduction on the emissions observed in the WMA production process. The evaluations carried out in a number of European countries (EAPA, 2010), show very well the decreasing of various emissions throughout the production process in the asphalt plants: 30 to 40% for Carbon Dioxide (CO_2) and Sulphur Dioxide (SO_2), 50% for Volatile Organic Compounds (VOC), 10 to 30% for Carbon Monoxide (CO), 60 to 70% for Nitrous Oxides (NO_x) and 25 to 55% for dust.

Reductions in asphalt aerosols/fumes and Polycyclic Aromatic Hydrocarbons (PAHs) were reported with values from 30 to 50%. The exposure to these products has a substantial negative influence on workers and on the surrounding area of construction sites.

When applying WMA techniques with hard bitumen, such as higher asphalt recycling rates or high modulus asphalt, especially during cold weather, the mix workability is better as the viscosity of the stiff binder decreases and the drop of temperature with time is less important. This also allows higher haulage distances, reduces the risk of compaction troubles and the laid material requires less time to cool before opening it to traffic or to apply the next layer.

Depending on the WMA process applied and on how much the temperature is reduced, the production temperature allows reducing the energy consumption up to 35%, or more (D´Angelo *et al.*, 2008) and the associated cost will decrease accordingly.

In the current scenario of energy price rising the cost saving can be far more interesting, depending on the amount of temperature reduction achieved, but some WMA processes require initial investment to modify the layout of the plant and others require permanent purchase of additives.

When the WMA technology is compared with Cold Asphalt Mixtures (CAM), there are also benefits, because it doesn’t need curing time before opening up to traffic and also doesn't require a sealing layer as for some of the CAM applications. In addition, the laying and compaction operations, and the coating of aggregates by the binder are better than for CAM, leading to a better in-service material (Button *et al.*, 2007).

As some of the technologies available for WMA could increase the initial production cost, there are some concerns related to WMA cost in its whole life-cycle. This fact can be connected to the additional equipment needed for plants, allowing the use of specific technologies or additives. On the other hand, the use of additives brings some supplementary cost, which could be only partially compensated by lowering the operating temperature.

The technologies widespread can face some struggle because there is not enough experience yet on the long-term performance of WMA, unless the governments establish more severe environmental regulations or WMA ensure clear construction and characteristics benefits (Kristjansdottir *et al.*, 2007).

When some kinds of mixtures with low binder content are used, there are some concerns related to in-service moisture susceptibility of WMA. Moreover, the generally good workability of some WMA products, resulting in a lowered voids content compared to conventional HMA, together with a less oxidative hardening of the binder throughout the production process, can increase the in-service rutting potential of some WMA products, despite that it can also conduct to an increased durability.

2.2 Methods to achieve mixing temperature reduction

Temporary or permanent adjustments of various bitumen properties take place in some of the WMA technologies, as it happens for the viscosity, for instance. The adhesion between binder and aggregate particles, in some technologies, is chemically manipulated to improve the way mineral aggregates are covered by bitumen. If surfactants are included in the process they will act at the microscopic interface of aggregates and bitumen, reducing friction at that interface, allowing inferior mixing and compaction temperatures. Other techniques launch water into the process, improving temporarily the workability of the asphalt mixture.

Most part of the processes involved in WMA allows lowering fabrication and handling temperatures of the mixture, as well as achieving the same, or even better, in-service performance compared to HMA. The number of known WMA technologies is high but they can be classified in three main groups: organic additives, chemical additives and foaming technologies.

Organic waxes are added to bitumen and blending with it to produce asphalt concrete mixtures, reducing the viscosity of the binder. When the temperature decreases, the additive crystallises, forming a lattice structure of microscopic particles, which ensures higher stiffness of the binder and improves its resistance to deformation (EAPA, 2010). This type of additives is formed by a long chain of hydrocarbon atoms, which is solid at ambient temperature and melts generally around 100°C (Gandhi, 2008). It can be expected that using organic additives the mixing temperature of asphalt can be reduced about 20 to 30°C (Zaumanis, 2010), although a small variation can also be found in the literature (Gandhi, 2008).

Sasobit® is a commercial product belonging to the group of organic waxes, produced by the so-called Fisher-Tropsch (FT) process (Sasol, 2012). There are also references to other organic additives, such as the following examples: Asphaltan-B, which is a blend of wax obtained by solvent extraction from lignite or brown coal (Montana wax) and fatty-acid amides (Button, 2007); Thiopave™, which is a technology that uses a sulphur-enhanced additive patented by Shell.

Chemical additives are also applied within the WMA technology. They can be formed by a group of products such as surfactants, emulsification agents, aggregate coating promoters and anti-stripping additives. Chemical additives are usually added to the binder during the production process, although in some cases the package of the products is introduced by means of a bituminous emulsion (Button, 2007) (Zaumanis, 2010). These additives may reduce the mix and compaction temperatures about 30°C (EAPA, 2010).

Examples of chemical additives are Rediset™ WMX and Cecabase® RT, which are product packages formed by surfactant and adhesion agents, among other components. Those types of products chemically improve active adhesion as well as the wetting of aggregates by bitumen without changing considerably the binder performance.

Evotherm™ is a typical technology used in the USA wherein a group of additives is added to the process in the form of emulsion. The aggregates are heated before mixing, so the water contained by the emulsion vaporizes during the production process and the bitumen covers the aggregate particles. This technology has evolved aiming at incorporating much less water than with emulsion. The third generation of this process available (Evotherm 3G) is a water-free technique. In this case, the additive is incorporated into the bitumen before its deliver to asphalt plants.

The number of techniques used to produce foaming bitumen is large (EAPA, 2010) and most of them are proprietary. Bitumen foam is usually obtained by adding a small amount of cold pulverised water into preheated bitumen. The water vaporises and the released steam is encapsulated within the bitumen, resulting in a temporary expansion of its volume together with a reduction of its viscosity (Zaumanis, 2010).

3 BY-PRODUCTS REUSED IN *WMA*

Production of waste is rising to worrying levels and the deposition of waste in landfills is becoming increasingly difficult and expensive. Since the principle of prevalence of the waste recovery is well established in the Portuguese law it was decided to investigate the feasibility of its introduction in the manufacture of asphalt mixtures.

For this reason some of the by-products produced by two of the biggest industries in Portugal were considered in the study. Moreover, three of them have already been used before in real HMA projects (Martinho *et al.*, 2009): construction industry (Reclaimed Asphalt Pavements - RAP and Construction and Demolition Waste - CDW) and the production of steel (steel Slag Aggregates processed for use in Construction - SAC).

These concerns will satisfy the current public interest in having a greater incorporation of recycled materials in public works, among other measures, in order to improve the sustainable management of materials and waste.

3.1 Reclaimed Asphalt Pavements (***RAP***) – grade 0/20 mm

The use of reclaimed asphalt pavement has several advantages, especially economic and environmental, particularly associated to the lowering consumption of aggregates and binders (which have lately suffered significant price increases) and the reduction of haul-distances, thus producing less environmental impacts. The characterization of the recovered asphalt used in this project was made according to the recommendations in (Baptista & Picado-Santos, 2007) by determining: the percentage of residual binder (≈4.2%), its penetration

(≈35x0.1mm) and ring and ball softening point temperature (≈52°C), as well as the aggregate grading of the blend, before and after bitumen extraction. The properties of the samples collected vary with the origin of the materials recovered. Therefore, it is essential to identify and separate them according to the source to obtain homogeneous materials, which can be more suitable for future reuse.

3.2 Steel Slag Aggregates for use in Construction (***SAC***) – grade 0/16 mm

Slag coming from the production process of steel and laminates can be retrieved from one of the following sources: *Blast Furnace* (basic oxygen furnace) – slag granulating liquid that solidifies is released by sudden cooling in a water tank, by slow cooling in air or by a process that uses a mixture of air and water, thereby giving rise to a cluster of slag; *Electric Oven* (electric arc furnace) – slag resulting from the merger (caused by electric arc produced between two graphite electrodes) of scrap metal of any kind and can be used after demetallization; *Converter* – slag consisting essentially of oxides resulting from the injection of pure oxygen into liquid iron from the first smelting that comes from the furnace.

Although the chemical composition of any type of slag depends on the technology used in the manufacturing of steel, this by-product contains essentially oxides (calcium, magnesium and aluminium - which represent over 90% of the total weight) and iron. The water absorption of slag is high, which shows a high porosity and a very rough surface. Because of that the adhesion to any type of asphalt binder is generally good. In mineralogical terms, several substances can be found in steel slag aggregates, such as slag *Wusite* [$Fe_{0,965}O$], Calcium *Silicate* [Ca_2SiO_4] and *Ghelenite* [$Ca_2Al\ (AlSiO_7)$] (Martinho *et al.*, 2007).

On average, it is estimated that for each tonne of liquid steel produced, 110 to 150 kg of black slag will be generated (which is potentially usable in road infrastructure and geotechnical works). The 20 to 30 kg of white slag also produced is not reusable in the road infrastructure since this by-product has very high levels of lime.

The two steel mills in operation in Portugal (Seixal and Maia) produced more than 1,400,000 ton of steel slag, processed between 2007 and 2011 (around 300 thousand ton/year).

3.3 Construction and Demolition Waste (***CDW***) – grade 0/20 mm

Over the years, more than 200 million tonnes of CDW have been produced in Europe, being potentially recycled only 30 to 40% (Martinho *et al.*, 2011).

Although the average composition of the construction waste and demolition varies from one country to another, it shows more potential of use and importance of screening at the origin

Many countries have now their own laws regarding management of CDW (for example, in Portugal it is regulated by "*Dec. Lei nº 46/2008, of 12th of March*"). These rules ensure the implementation of policies to reduce, reuse and recycling of the waste and covered all the operators, as well as the producers and holders.

Thus, it is essential to implement the recovery of reusable waste, decreasing the quantities of new materials to incorporate in works and reducing the impact on sewers.

In addition, there are already some laws encouraging and giving an impulse to a more efficient reduction in energy consumption and emissions of gases into the atmosphere (in Portugal is in force the "*Dec.-Lei nº 183/2009, of 10th of August*").

The crushing of these products (old concrete) can be made at a central site, on a fixed crushing plant, where all waste will be collected and subsequently forwarded to the asphalt plant. Alternatively, a mobile crushing and screening equipment can be used placed near the origin of the CDW. Then the material will be transported to the asphalt plant without need of further transportation. This fact can reduce the cost of moving the original and the resulting crushed materials.

4 BITUMEN

All the asphalt mixtures studied were produced with a 35/50 paving grade bitumen. The binder used was supplied by CEPSA, with the specifications referred to in *Table 1*. This type of bitumen is at present the most commonly used in Portugal regarding asphalt pavement construction, maintenance and rehabilitation.

Table 1: Characteristics of the bitumen used.

Ref.	Tests	Norms	Units	Bit. 35/50
Pen_{25}	Penetration, 25°C, 100g, 5s	EN 1426 / ASTM D5	0.1mm	45
R&B	Softening Point	EN 1427 / ASTM D36	°C	56

5 ADDITIVES USED

In this study three additives were used to allow an adequate mixing of the components at lower temperatures: one organic (Sasobit®), one chemical (Rediset™) and a chemical with cellulosic fibres (Viatop® with Rediset™). All of these additives are supplied in a solid way, as pellets. *Figure 1* shows a general view of the aforementioned additives.

Sasobit® is a solid organic additive. It's a wax of a fine crystalline long-chain aliphatic hydrocarbons synthesised from natural gas using the Fischer-Tropsch process. The manufacturer claims that adding just 3% of the weight of a 50/70 paving grade bitumen results in a large increase in R&B softening point, reaching a level similar to a 10/20 bitumen. Sasobit® melts at about 100ºC and significantly reduces the viscosity of the base bitumen at mixing and compaction temperatures (Sasol, 2012).

Rediset™ is solid and it combines organic and chemical additives. It is designed to improve the adhesion between the aggregate and the bitumen. The manufacturer claims that it can reduce viscosity of the binder within hot mixes, even if the dosage is about 2% of the weight of the bitumen. The hydrocarbon chain becomes part of the asphalt, so there is a water resistant bridge holding the aggregate and the asphalt together (Akzonobel, 2012).

Viatop® is a granulate derived from modified cellulosic fibres. This bitumen-coated cellulose fibre pellets are used as a stabiliser in asphalt mixes, avoiding the "output" of bitumen and therefore the loss of efficacy of the mastic (JRS, 2012). These fibres can also contribute to prevent the binder from draining-off the mineral aggregates and minimize the permanent deformation if there is too much binder in the mixtures with RAP.

Sasobit® *Rediset™* *Viatop®*

Figure 1: Additives used in this study.

6 WARM MIXTURES STUDIED

Based on the different characteristics of the by-products and taking their costs into account, various preliminary compositions were tested to evaluate some volumetric and empirical properties. This type of WMA can be called "eco-mixes" as they contribute to the reduction of some by-products, preventing some complex environmental problems.

The study has begun with fifteen WMA incorporating the aforementioned by-products, one traditional hot mixture and three warm mixtures produced with new aggregates used as a reference, numbered from M*01* to M*19*. The WMA components were heated at 120°C prior to mixing, while the HMA raw materials were heated at 160°C. The compaction temperature was about 100°C for all of the WMA compositions studied and 140°C for the HMA. When RAP was used as a by-product, the virgin limestone aggregate was heated at 160°C because RAP was introduced in the mixing bowl at an ambient temperature and, thus, heated by conduction. The volumetric and Marshall properties determined for all the nineteen mixtures were compared with each other. All the aggregate blends respect the gradation defined for a typical *AC 20 base/reg/bin 35/50* hot mix asphalt. *Table 2* summarises the numbers of the mixtures and the composition of each one.

Table 2: Asphalt mixtures studied, **Mxy** (*HMA*=**M*01***; *WMA*=**M*02*/*04***; *eco-WMA*=**M*05*/*19***).

MATERIALS		REFERENCES				eco-WARM MIX ASPHALT														
		01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19
BITUMEN	35/50	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
NATURAL AGGREGATES	Gravel 2: L = Limestone	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
	Gravel 1: L = Limestone	●	●	●	●	●	●	●	●	●										
	Powder: L = Limestone	●	●	●	●	●	●	●	●	●	●	●								
BY-PRODUCTS (%) "EWL" (European Waste List)	10 02 01: S = Steel Slag Aggregate for Constr.	HOT MIX ASPHALT	WARM MIX ASPHALT								30	30				35	35	40	40	40
	17 01 07: C = Constr. and Demolition Waste								60	60			35	35	35	40	40			
	17 03 02: R = Reclaimed Asphalt Pavements					30	30	35					35	35	40			35	35	40
ADDITIVES (% of binder)	Organic: S = Sasobit®		4			4			4		4		4			4		4		
	Chemical: R = Rediset™			2			2			2		2		2			2		2	
	Mix: V + R — R = Rediset™				1.5			1.5							1.5					1.5
	Mix: V + R — V = Viatop®				5			5							5					5
AGGREGATES TYPES		L	L			L + R			L + C		L + S		L + C + R			L+S+C		L + S + R		

By-products: the values in the table are in percentage of the total weight of aggregates;
Additives: amounts added according to the ranges recommended by the suppliers.

This stage of the study was carried out after a preliminary evaluation of several alternative combinations of aggregates and by-products, trying to reduce harmful impacts as much as possible. Thus, the choice of the by-products for each one of the fifteen alternatives followed the criteria considered essential for the viability of a future practical implementation: cost, availability of raw materials in the vicinity of the manufacturing plant and no need of reinvestment to adapt the available production equipment.

7 VOLUMETRIC PROPERTIES AND MARSHALL TESTS

7.1 Mix properties

At this stage of the study, the evaluation of all the compositions was based on the production of twenty cylindrical specimens per mixture. The bitumen content varied from 3.5 to 5.5%, with steps of 0.5%. Volumetric properties and Marshall tests' parameters were evaluated on all the specimens. The laboratory study carried out until now allowed an evaluation of the following properties: bulk density, maximum density, air voids content, voids in the mineral aggregate, voids filled with binder, stability, flow and the Marshall Quotient (stability/flow). The results are shown from *Figure 2* to *9*.

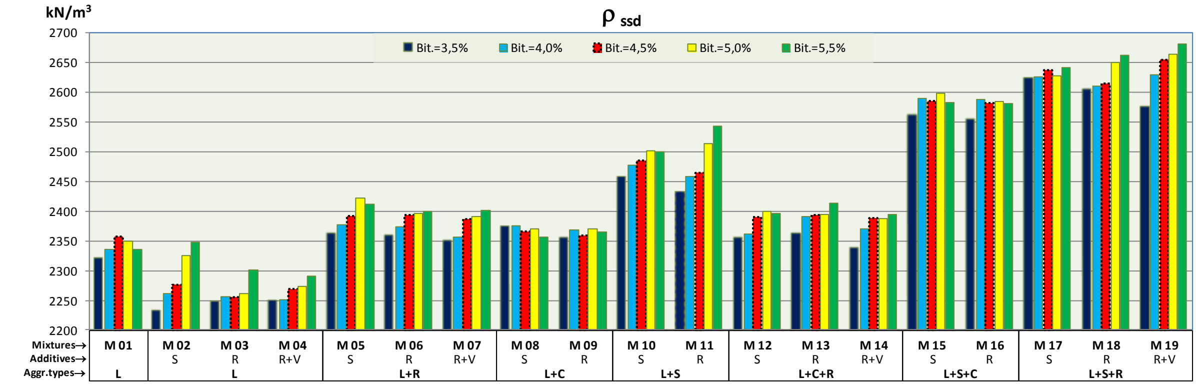

Figure 2: Results obtained for the bulk density (saturated surface dry), ρ_{ssd} (kN m^{-3}).

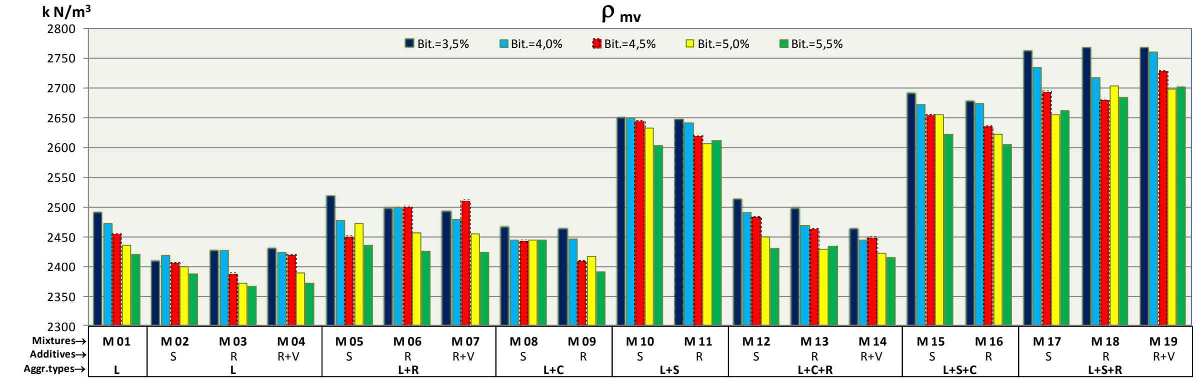

Figure 3: Results obtained for the maximum density, ρ_{mv} (kN m^{-3}).

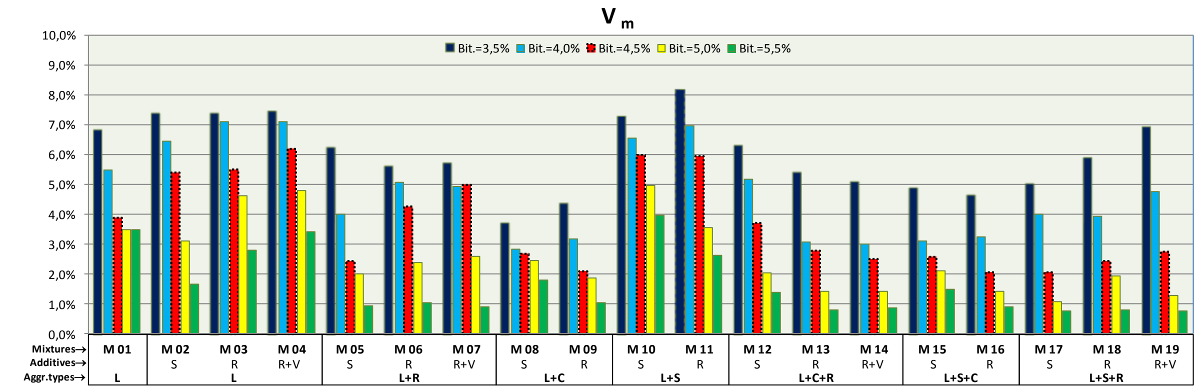

Figure 4: Results obtained for the air voids content, $\mathbf{V_m}$ (%).

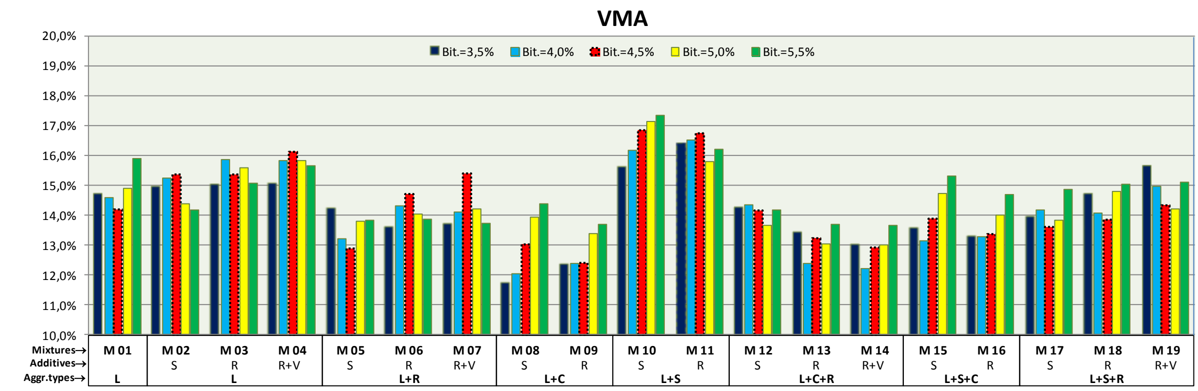

Figure 5: Results obtained for voids in the mineral aggregate, **VMA** (%).

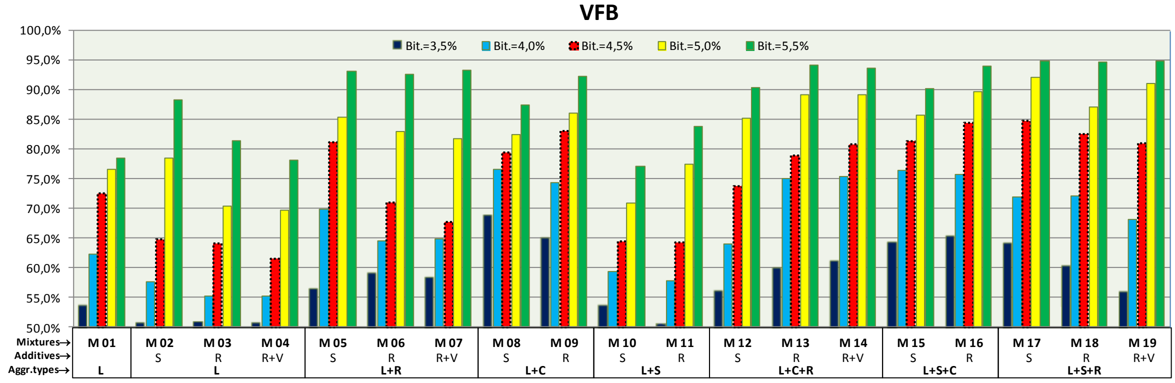

Figure 6: Results obtained for voids filled with binder, **VFB** (%).

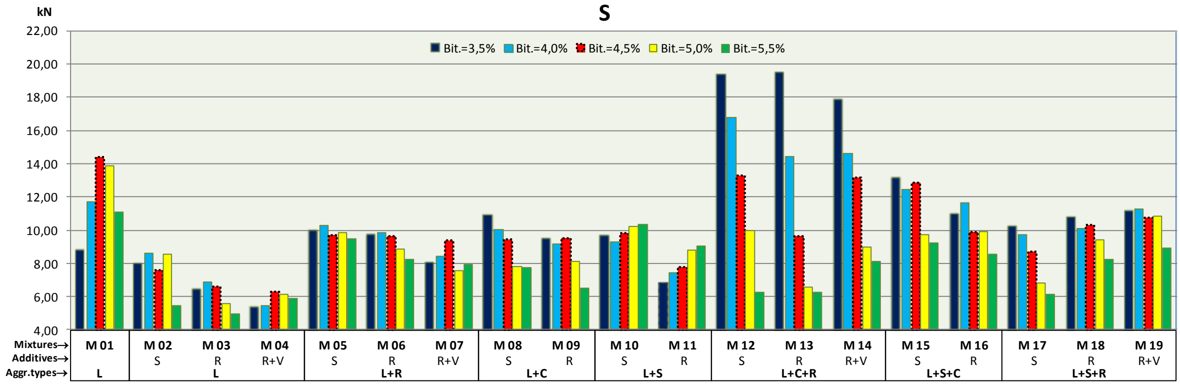

Figure 7: Results obtained for stability, **S** (kN).

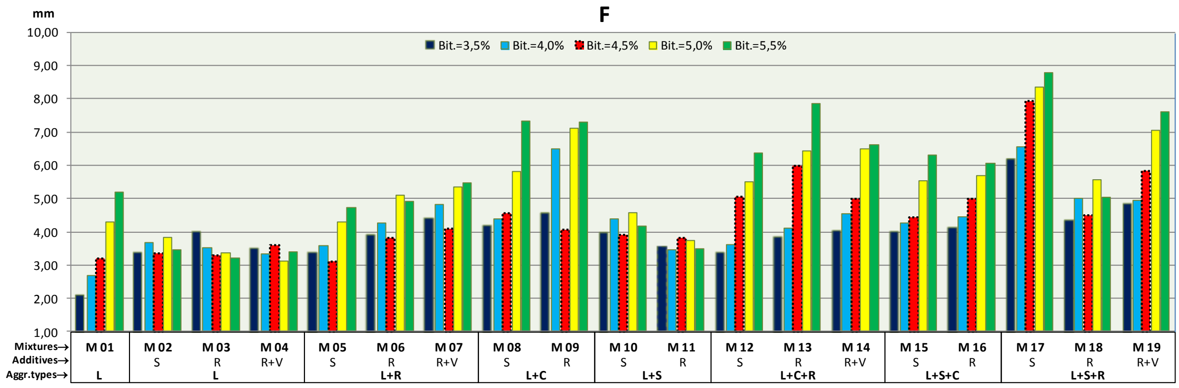

Figure 8: Results obtained for flow, **F** (mm).

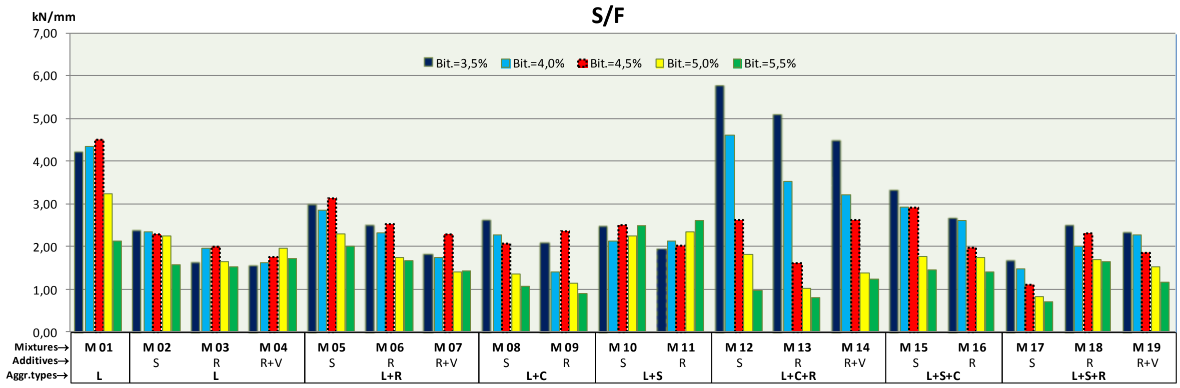

Figure 9: Results obtained for Marshall quotient, S/F (kN mm^{-1}).

7.2 Properties for the Optimum Bitumen Content of the HMA Used as a Reference

The optimum binder content derived from the Marshall method for the HMA was 4.5%. For the same bitumen content, *Table 4* summarises the results obtained.

Table 4: Comparison of the results obtained for all the tested compositions (bitumen = **4.5%**).

Properties	HMA[1]	M01	M02	M03	M04	M05	M06	M07	M08	M09	M10	M11	M12	M13	M14	M15	M16	M17	M18	M19
Bulk Dens. (kN m^{-3})	-	2357	2276	2256	2270	2391	2393	2386	2366	2359	2485	2464	2390	2394	2388	2586	2581	2637	2615	2654
Air Voids Cont. (%)	3 / 6	3,9	5,4	5,5	6,2	2,4	4,3	5,0	2,7	2,1	6,0	6,0	3,7	2,8	2,5	2,6	2,1	2,1	2,4	2,7
VMA (%)	>14	14,2	15,4	15,4	16,1	12,9	14,7	15,4	13,0	12,4	16,8	16,7	14,2	13,2	12,9	13,9	13,4	13,6	13,9	14,3
Stability (kN)	7,5 / 15	14,4	7,6	6,6	6,3	9,7	9,6	9,4	9,5	9,5	9,8	7,8	13,3	9,6	13,1	12,9	9,9	8,7	10,3	10,7
Flow (mm)	2 / 4	3,2	3,3	3,3	3,6	3,1	3,8	4,1	4,6	4,1	3,9	3,8	5,1	6,0	5,0	4,4	5,0	7,9	4,5	5,8
Stab./Flow(kN mm^{-1})	>2	4,5	2,3	2,0	1,8	3,1	2,5	2,3	2,1	2,3	2,5	2,0	2,6	1,6	2,6	2,9	2,0	1,1	2,3	1,8
Additives used	**-**	**-**	**S**	**R**	**V+R**	**S**	**R**	**V+R**	**S**	**R**	**S**	**R**	**S**	**R**	**V+R**	**S**	**R**	**S**	**R**	**V+R**
Aggregates types	**-**	**L**	**L**			**L + R**			**L + C**		**L + S**		**L + C + R**			**L + S + C**		**L + S + R**		

[1] Typical specification limits used for HMA.

8 DISCUSSION

The results indicated in Table 4 show that, generally, the WMA mixtures used as a reference (M02, M03 and M04) produced lower stability values than those obtained for the HMA (M01). This is apparently related with the lowering of the compaction temperature, as the air voids content is higher for the WMA control mixes. These results show that the additives used were not able to completely compensate the effect of the temperature reduction.

The mixtures M12 and M15, which incorporate [35% of CDW+35% of RAP] and [35% of steel slag+40% of CDW], respectively, and Sasobit as additive, seem to be promising based on the results obtained for the Marshall stability and flow.

Analysing the measured flow values, they show that the flow is generally high for “eco-mixes”. This is particularly clear for the mixtures M13, M17 and M19, which also have low stability/flow ratios. Looking at the overall results, this tendency seems to depend more on the additive used in these cases than on the by-products.

The total amount of by-products included in the different eco-mixes, vary from 30% (M05/06/10/11) to 80% (M19). Despite this, these results must be confirmed during the following project steps, the results obtained with this variation show that it is possible to produce WMA incorporating a very small quantity of virgin aggregates.

When the mixes included CDW (obtained from crushed concrete) and RAP the results found were generally better. This fact is probably related with the amount of cement existing in CDW added as filer, which can act as an adhesion promoter.

9 FUTURE WORKS

Future works will include the completion of the laboratory mix design for the best compositions achieved and, in sequence, the evaluation of some trial sections with the final most promising mixtures. The next steps will comprise the mechanical evaluation of these WMA compositions, allowing to compare the observed mechanical performance with that of the mixtures used as a reference. The laboratory work plan includes the evaluation of the following properties (these activities are being carried out at the moment, *Figure 10*).

Water sensitivity assessed by the procedures described in EN 12697-12 using the tensile strength ratio (TSR) as the control parameter; stiffness modulus (stress/strain ratio) evaluated according to EN 12697-26; resistance to cracking by means of the procedure proposed in EN 12697-24. Resistance to permanent deformation evaluated in the laboratory by various testing methods, such as the wheel-tracking test, according to EN 12697-22, or the cyclic compression test, according to EN 12697-25, for instance, which use a variety of parameters to rank mixtures (Capitão & Picado-Santos, 2005 & 2006).

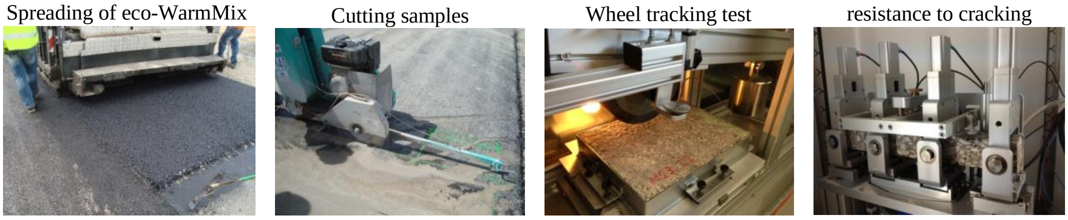

Figure 10: Execution of trial sections, collecting and testing samples.

After those evaluations the authors hope to be able to answer some of the common issues related with the WMA. The most mentioned questions are linked with the mix design process, including the selection of binder grades and the potential problems regarding moisture sensitivity and permanent deformation of WMA. The construction of the trial sections will allow some insight regarding *cost- benefits* (the reduction in fuel consumption and emissions need to be quantified), *plant operations* (the suitability of WMA for high production rates), *control of mixing process* (since WMA has a mixing process that is different from conventional HMA, new guidelines need to be developed for proper QC/QA of the mix), *workability at the paving site* (WMA should remain workable at the paving site), *verify if WMA pavements can be quickly opened to traffic after construction* (in a time frame similar to or lower than that achieved for conventional HMA pavements) (NCHRP, 2012).

10 CONCLUSIONS

WMA comprise a great number of asphalt mixtures, as a large amount of different mixes (dense and gap graded, SMA, asphalt rubber, RAP, etc.). They can be fabricated with natural or recycled aggregates, laid and compacted by using traditional technologies. The required temperature reduction can be achieved through the use of additives (wax and chemical additives) or foaming techniques.

With some eco-WMA the achieved performance can be identical to that of traditional asphalt mixtures. The use of by-products in the WMA can lead to a number of benefits: reduction in the consumption and cost of natural raw materials; big reduction in volumes of waste transported to deposit; reduction in the energy used in the production and heating of aggregates; reduction of pollution and environmental liabilities (mainly fumes).

Moreover, more collateral benefits are expected, such as, an ease of mixing and compaction, paving in non-attainment areas, cool weather paving, early site opening, extend paving season, increased plant production, longer storage and increases haul time, corresponding to longer haul distances.

In this first stage of the project it was possible to show equivalent results when a percentage above 35% of RAP are used with limestone. The same conclusion seems correct for a percentage above 60 % of CDW. A combination of two different by-products is possible and it’s clear that some mixtures have a good potential, for example, mixes with RAP and CDW in a proportion of approximately fifty percent for each (M12/14).

The most recent results obtained in the performance evaluation for some of the mixtures indicate very interesting values (but still under review), especially in the mixtures which incorporate SAC. However, the grading of the mixtures has to be checked due to a high density of the fine particles (which leads to some segregation in stockpiles).

REFERENCES

Akzonobel Website: *http://www.akzonobel.com/...* (Rediset) [Accessed in *June 2012*].

Baptista, A. and Picado-Santos, L. (2007). Method of Preparation of Hot Recycled Asphalt Mixtures. *Proceedings of the XIV Ibero-Latin American Asphalt Congress*, La Habana, Cuba, 18 - 23 November, CD-Rom edition.

Button, J.; Estakhri, C. and Wimsatt, A. (2007). A Synthesis of Warm-Mix Asphalt, Report FHWA/TX-07/0-5597-1, Texas Transportation Institute, Texas.

Capitão, S.; Picado-Santos, L. (2006), Assessing Permanent Deformation Parameters in High Modulus Bituminous Mixtures, ASCE - Journal of Transp. Eng., 132(5), pp. 394-401.

Capitão, S.; Picado-Santos, L. (2005), Laboratory Fatigue Performance Assessment of High Modulus Bituminous Mixtures. *Proceedings of the 4th International Symposium on Maintenance and Rehabilitation of Pavements and Technological Control*, Ulster University, Belfast (CD-ROM).

D'Angelo, J.; Harm, E.; Bartoszek, J.; Baumgardner, G.; Corrigan, M.; Cowsert, J. et al. (2008). Warm-mix Asphalt: European Practice. FHWA, AASHTO, NCHRP. *Report no. FHWA PL-08-007*, Alexandria.

EAPA (2010). The use of warm mix asphalt. Position Paper. *European Asphalt Pavement Association*, Brussels, 13 pages.

Gandhi, T. (2008). Effects of Warm Asphalt Additives on Asphalt Binder and Mixture Properties. *A Dissertation Presented to the Graduate School of Clemson University in Partial Fulfilment of the Requirements for the Degree Doctor of Philosophy in Civil Engineering*, Clemson, 144 pages.

JRS Website: *http://www.jrs.de/SMAviatop_engl/index.shtml* [Accessed in *June 2012*].

Kristjansdottir, O.; Michael, L.; Muench, S. and Burke, G. (2007). Assessing the Potential for Warm Mix Asphalt Technology Adoption. Proceedings (CD), *86th Annual Meeting of the Transportation Research Board*, National Academy of Sciences, Washington, D.C.

Martinho, F.; Martinho, A. and Gomes, J. (2011). The Reuse of CDW (Construction and Demolition Waste) in Urban Operations - The Case of Troiaresort (peninsula of Tróia – Portugal). *Proceedings of the National Conference "Sustainability in Urban Regeneration - the New Paradigm of the Construction Market"*, Lisbon, Portugal, 29 - 30 September. Vol 1, p. 135-142 (ISBN 978-989-96543-2-7).

Martinho, F.; Baptista, A. and Picado-Santos, L. (2009). Ecological Bituminous Mixtures - Greater Contribution to Sustainability. *Proceedings of the XV Ibero-Latin American Asphalt Congress*, Lisbon, Portugal, 22 - 27 November. Vol. 1, p. 427-437 (ISBN 978-972-8692-43-6).

Martinho, F.; Mira Fernandes, E. and Korczak, P. (2007). The Use of Steel Slag in the Construction of Infrastructures. *Proceedings of the XIV Ibero-Latin American Asphalt Congress*, La Habana, Cuba, 18 - 23 November, CD-Rom edition.

NCHRP (2012). Guidelines for Project Selection and Materials Sampling, Conditioning, and Testing in WMA Research Studies. *Research Results Digest 370*. Transportation Research Board. Washington, 35 pages.

Olard, F.; Noan, C. (2008). Low Energy Asphalts. *PIARC Prize for Sustainable development, Routes Roads 336/337*. PIARC (World Road Association). p. 131–45.

Sasol Wax Website: *http://www.sasolwax.us.com/sasobit.html* [Accessed in *June 2012*].

Zaumanis, M. (2010). Warm Mix Asphalt Investigation. *Master of Science Thesis (revised after presentation)*. Project conducted at Technical University of Denmark in cooperation with the Danish Road Institute, Department of Civil Engineering, Kgs. Lyngby, 111 pages.