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Mechanical Performance and Economic Evaluation of Warm Mix Recycling Asphalt

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Abstract

In Portugal, a low temperature technique for pavement recycling has recently emerged. It consists of the warm mix recycled asphalt (WMRA) with bitumen emulsion. It is considered a very interesting solution in terms of technical, economic and environmental performance. Stiffness and fatigue resistance was evaluated by four point bending test was carried on. Permanent deformation was determined by wheel tracking test. Different asphalt recycled mixtures having different bitumen emulsion content were tested. An economic study for application of such mixtures was also made. It demonstrates the advantages of using WMRA with bitumen emulsion in relation to traditional hot mixes.

Keywords: Warm mixtures, RAP, permanent deformation, resistance to fatigue

1. Introduction

In the construction and rehabilitation of bituminous pavements are used big quantities of non-renewable natural resources, in particular aggregates and binders. The incorporation and reuse of recycled asphalt pavement (RAP) in the production of new bituminous mixtures justify themselves in the environmental benefits and also in the economical benefits. In Europe, each year about 50 million tons of recycled asphalt pavement (RAP) are produced. Although in many countries the reuse and recycling of RAP started more than 30 years ago [1], in Portugal most of these materials are placed in landfill causing a great environmental impact. Research carried out regarding the performance of asphalt containing RAP over the past 30 years shows that the quality of asphalt containing RAP is (at least) as adequate as the quality of asphalt containing virginal materials only [1]. The use of

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RAP allows the obtaining of a good performance pavement, using a small quantity of new materials, contributing to the preservation of the natural resources and reduction of waste materials. The RAP results of the removal of degradated pavements till a certain deepness through a milling machine. After that, they are taken to a central mix followed by a binder addition (cement, bitumen or bitumen emulsion), water (for hydration, pré-mix water and water compaction), aggregates (for gradation correction) and some additive with obtained quantities on a mix design [2]. The bituminous recycling mixtures are obtained through techniques with different production temperatures. In Portugal, the recycling technique most used is based in hot mix recycling.

Inside the different industrial sectors, the production of hot mix asphalt is one activity that is affected by the Kyoto Protocol [3,4]. The industrialized countries look for measures that allow emissions reduction, accomplishing the requested requirements. This way, new bitumen products alternatives are demanded or the improvement of the existing ones, in particular, reducing the production temperature towards the traditional hot mix asphalt [5-7].

In Portugal, an alternative paving process named warm mix recycled asphalt (WMRA) with bitumen emulsion has been studied. These mixtures consists in the incorporation till 100% RAP in temperatures situated between 120 to 130 degrees centigrade, adding, later, a small percentage of bitumen emulsion at the room temperature [8-10]. This technique allows the reduction of CO2 emissions, of the fumes and of the needed fuel to its fabric, improving the safety and comfort conditions when the placement in the work site. Besides that, its lower fabric temperature allows the guarantee of a suitable workability during its application in a way that desired bulk densities can be obtained. It was verified others advantages like the rising of the transport distance, the broadening of the pavement season, allowing its application in lower weather temperatures, reducing the time of construction and decreasing the traffic jams.

The experimental results presented in this paper are concerned with a study developed in Centre of Materials and Building Technologies (C-MADE) at University of Beira Interior (UBI), with the collaboration of the National Civil Engineering Laboratory (LNEC). The main goal of this essay is to contribute to a better knowledge of the WMRA with bitumen emulsion, mainly concerning its mechanical performance. The experimental work carried out in laboratory allowed the characterization of these mixtures establishing some rules to guarantee its good performance and defining some orientation lines to future applications, contributing to this technique implementation and disclosure. Through the economical study done it was intended to determine which the gains, in economical terms, with the application of this recycling technique when compared with the traditional hot mix technique.

2. Case study

The case study presented concerns a rehabilitation work of Portuguese National Road EN 244, between Ponte Sôr and the crossroad with EN 118. This rehabilitation work has a total length of 24,2Km. This road is part of a rural area but with some small urban areas temperature [8,9,11]. The old pavement was removed to a depth of 7cm, corresponding to two different layers carried out in 1987, 6cm from the surface and 1cm from the base. The RAP was carried to a mix plant in truck dumpers (Figure 1). The RAP was homogenized before being introduced into the mix drum (Figure 2).

Fig. 1. Milling the old pavement

Fig. 2. Stock RAP in the plant mix

The WMRA was produced in a hot mix continuous plant. It was necessary to do some adjustments to hot mix plant at level of the burners, since the work was done in lower temperatures than normal in the production of hot mix. Besides that, to control the mixture temperature was necessary to add some temperature sensors, in particular, at the exit of the dryer, in the elevator and at the entry and exit of the mixing drum. The mix composition (in percentage with respect to the aggregate weigh) applied in the National Road was the following [8,9]:

- 100% of RAP
- 0% of added water
- 2% of bitumen emulsion (RECIEMUL 90 - slow setting)

After mix production, it was moved out of the central plant directly to the trucks (Figure 3) being carried to the site work. The mixture temperature at central plant was of 90 ºC, approximately (Figure 4).
The placement and the first compaction of the WMRA were obtained by a conventional asphalt paving machine allowing the obtaining of a uniform and smooth layer. The compaction was carried out at the temperature of 85 ºC approximately, with a steel-wheel vibratory roller followed by a pneumatic-tire roller.

Fig. 3. Exit of the WMRA to the trucks

Fig. 4. Temperature WMRA leaving the central mix.

3. Performance assessment of warm mix recycled asphalt

The mechanical performance assessment of warm mix recycled asphalt (WMRA) with bitumen emulsion was carried out by four-point bending test on prismatic shaped specimen and the wheel tracking test. To the achievement of these tests it was necessary to prepare and characterize laboratory specimens and in situ cored specimens extracted in the base layer of the rehabilitation work of Portuguese national road EN 244 (Case study).

3.1. Characterization of stiffness modulus and resistance to fatigue

The characterization of stiffness modulus and resistance to fatigue was obtained by carrying out the four-point bending test on prismatic shaped specimens (4PB-PR) (EN 12697-26 Annex B and EN12697-24 Annex D, respectively) [12,13]. For that, after the WMRA application in the rehabilitation work of the Portuguese National Road EN244 was extracted slabs of the pavement and later cut into beams with 40x5x5 cm^3. The laboratory tests were carried on after 11 months of cure. At the same time, in laboratory were produced specimens with mixtures with different compositions. Thus, were produced mixtures with 100% RAP (M100) and with 75% RAP + 25% natural aggregates (M75_25). For both mixes were used two different emulsion contents (1,5% and 2,0%). The compaction of the mixture was done at 90 ºC using two different methods, the walk behind vibratory roller and the roller compactor equipment. Table 1 presents the average results obtained to the bulk density of the different mixtures.

Table 1 – Bulk density in prismatic specimens

Mixture	Compaction	Emulsion content	Bulk density (g/cm3)
M100	vibratory roller	2.0 %	2,382
M100	Roller compactor	2.0 %	2,359
M100	Roller compactor	1.5 %	2,333
M75_25	Roller compactor	2.0 %	2,405
M100	In situ	2.0 %	2,349

Comparing the obtained results to the bulk density of the compacted specimen by different methods, it was concluded that for both methods the bulk density values were very similar. However, it was found that the method of the vibratory roller produces specimens with higher bulk densities. It was also verified that in the M100 compacted mixture in laboratory with the roller compactor equipment was obtained a very similar result to the one in situ.

The four-point bending test on prismatic shaped specimen (4PB-PR) to determine the stiffness modulus was carried out with controlled strain. The laboratory tests were done by a set of frequencies (1 Hz, 5 Hz, 8 Hz, 10 Hz, 20 Hz e 30 Hz) in a climatic chamber at 20 ºC and the strain used was 50 μm/m [12].

The Figure 5 shows the evolution of stiffness modulus with the rising of test frequency for the different mixtures produced in laboratory and in situ.

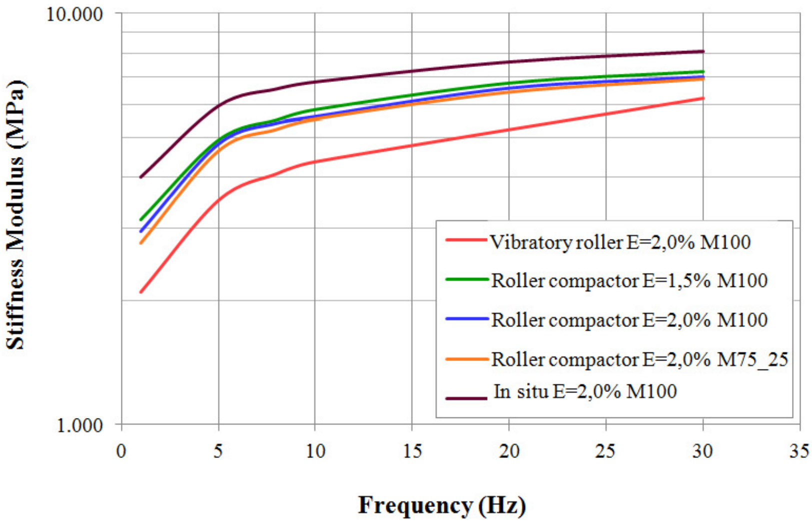

Fig.5. Variation of stiffness modulus with the frequency to the different mixtures

In general, at the same time that the frequency increases which corresponds to a bigger circulation speeds, also increases the stiffness modulus. The compacted mixture in situ presents higher values of stiffness modulus than the rest of the studied mixtures, being the mix M100 with 2% of bitumen emulsion and compacted with a roller compactor, the one with lower stiffness modulus. Comparing the results with results obtained by other authors, can be done to the stiffness modulus obtained at 10 Hz, for example. In the mixture M100 with 2% of bitumen emulsion (compacted with the Roller compactor) it was obtained a stiffness modulus of 5420 MPa, while in the mix M100 with 1,5% of bitumen emulsion it was obtained 6000 MPa. Baptista obtained, to the same frequency, very similar results. For traditional hot mix asphalt mixtures (HMA) obtained values in the order of 5900 MPa, while at hot mix recycling asphalt (HMRA) with 30 and 40% RAP, they obtained values in the order of 5980 MPa e 6055 MPa, respectively [14].

The failure of a bituminous mixture caused by fatigue consists in the presence of cracking under the action of repeated loads. The fatigue life characteristics of asphalt mixtures, often translated by “fatigue laws”, are represented most of the time by relationships between the applied strain and the number of load repetitions to failure (see Equation 1).

$$\varepsilon = A \times N^B \tag{1}$$

Where:

N	is the number of cycle at end of test
ε	extension traction (10^{-6})
A, B	experimentally determined coefficients

There are two important variables to evaluate the fatigue resistance of a bitumen mixture that are used together as fatigue laws to evaluate the performance of the studied mixtures, they are:

N_{100}	is the number of cycle for the extension of $100\text{x}10^{-6}$
ε_6	is the strain at 10^6 cycles

In this study, the assessment tests of fatigue resistance were done at 20 ºC and the frequency used in each case was 10 Hz. The tests were developed by using three controlled strain ($200\text{x}10^{-6}$, $300\text{x}10^{-6}$ e $400\text{x}10^{-6}$). The standard EN 12697-26 recommends that the initial stiffness modulus (taken at the 100th load application) has been taken as a reference to determine the moment of the breakage of the specimen [11]. The fatigue life for a certain level of stress was defined as the number of load pulses leading to a reduction of 50% in the initial stiffness modulus [13]. The results of the resistance to fatigue are presented on the table 2 and in the figure 6.

Table 2 – Obtained coefficients to the Fatigue law

Mixture	A	B	R^2	N100 (cycles)	ε^6 (10^{-6})
M100 (E=2,0%) (2)	3214,6	-0,203	0,8623	2,65E+07	195
M100 (E=2,0%) (1)	3318,9	-0,189	0,7104	1,12E+08	244
M100 (E=1,5%) (1)	2520,4	-0,169	0,9915	1,96E+08	244
M75_25 (E=2,0%) (1)	1746,8	-0,152	0,9792	1,48E+08	214
In situ M100 (E=2,0%) (3)	4370,5	-0,248	0,6905	4,12E+06	142

(1) Compaction with roller compactor; (2) Compaction with vibratory roller; (3) Compaction in situ

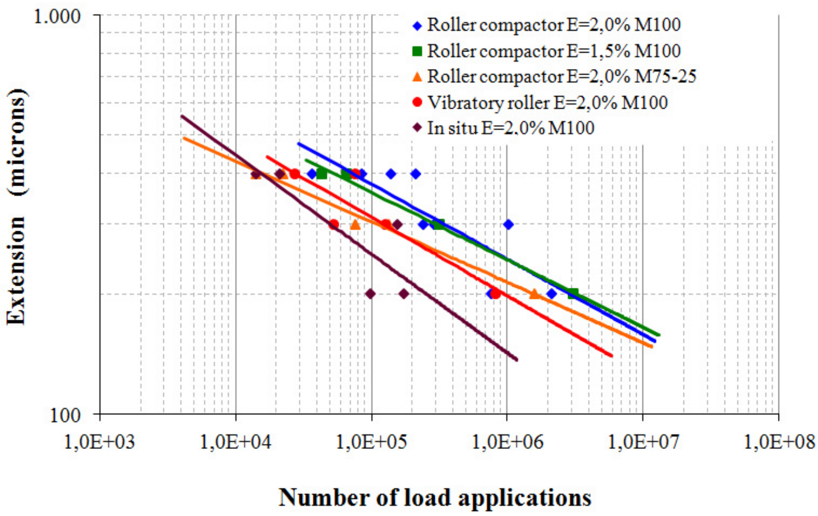

Fig.6. Fatigue life to the different WMRA with bitumen emulsion studied

The test results of the fatigue resistance get us to a conclusion that the mixtures M100 with 1,5% and 2,0% emulsion content present values of higher fatigue resistance than the rest of the mixtures. Comparing the obtained results with the other authors, it was verified that Baptista obtained from the traditional hot mix asphalt (HMA) values of ε6 of 158 µm/m and for hot mix recycling asphalt (HMRA) with 30 % RAP obtained values of 202 µm [14]. This means that one of the studied mixtures present higher values to the obtained to the HMA and to HMRA.

3.2. Characterization of the permanent deformation

The characterization of the permanent deformation was done through the achievement of Wheel tracking test [15]. It was used the small size device model A and B, with temperature conditioning of the specimen made in air. It was extracted the slabs of the base layer of the rehabilitation work of Portuguese national road EN 244 and produced slabs in laboratory with the same compositions used in the previously presented study: M100 with 1,5% and 2,0% emulsion content and M75-25 with 2% emulsion content. The compaction of the mixtures was made in the laboratory at 90 ºC by using the Roller compactor equipment (CRT-RC2S) for all the mixtures. Table 3 presents the results for the bulk density of different mixtures.

Table 3 – Average bulk densities of the slabs

Mixture	Standard	Compaction	Emulsion	Bulk density (g/cm^3)
M100	NLT 173/84	Roller compactor	2.0 %	2,363
M100	EN 12697-22 Proc A	Roller compactor	2.0 %	2,332
M100	EN 12697-22 Proc B	Roller compactor	2.0 %	2,360
M100	EN 12697-22 Proc B	Roller compactor	1.5 %	2,348
M75_25	EN 12697-22 Proc B	Roller compactor	2.0 %	2,400
M100	EN 12697-22 Proc B	Roller compactor	2.0 %	2,361
M100	EN 12697-22 Proc B	In situ	2.0 %	2,374

The wheel tracking test was made at 60 ºC with mixtures M100 with 2,0% emulsion content produced in laboratory following 3 different procedures: according to the Spanish standard NLT 173/84 (Figure 7.a), through the European standard EN 12697-22 by the procedure A (Figure 7.b) and the European standard EN 12697-22 by the procedure B (Figure 7.c). Still by the procedure B, at the temperature of 60 ºC we tested the M100 with 1,5% emulsion content (Figures 7.d) and the mixtures M75-25 with 2% emulsion content (Figure 7.e). In all the tests done, the temperature used was of 60 ºC. However, it has been used also 45 ºC for the mixture M100 with 2,0% emulsion content (Figure 7.f). This choice takes in account the fact of the mixtures WMRA with bitumen emulsion being used in base layers, never reaching the 60 ºC of superficial temperature of the pavement.

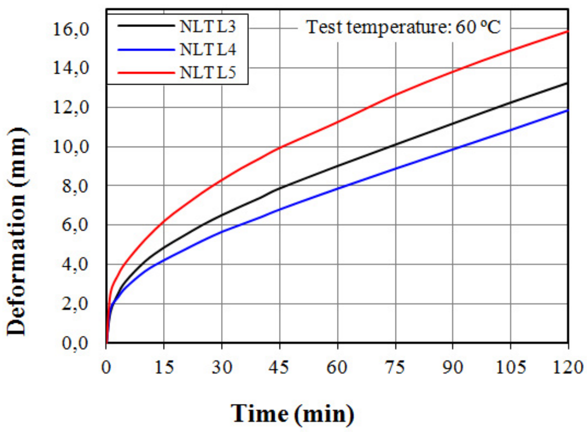

Fig.7. (a) NLT 173/84
Mixtures M100 with 2,0% emulsion content

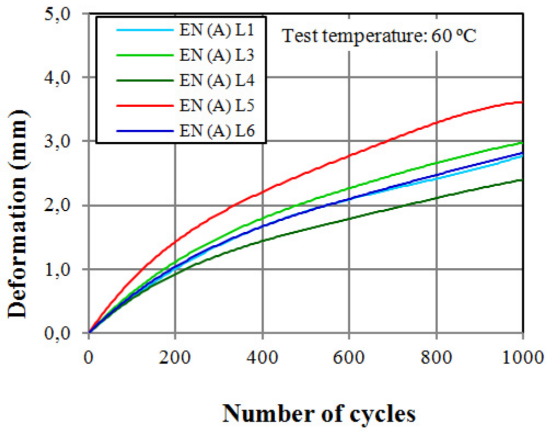

Fig.7. (b) EN 12697-22, procedure A
Mixtures M100 with 2,0% emulsion content

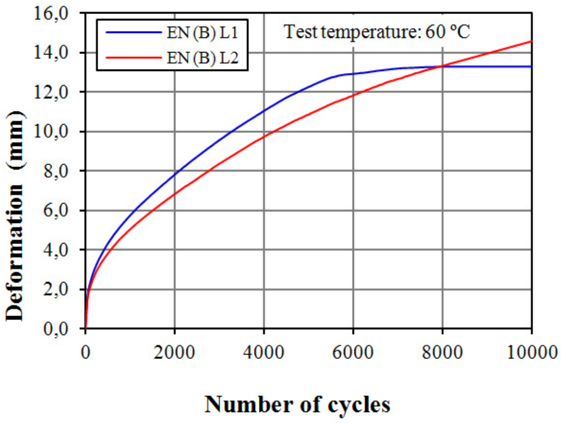

Fig.7. (c) EN 12697-22, procedure B
Mixtures M100 with 2,0% emulsion content

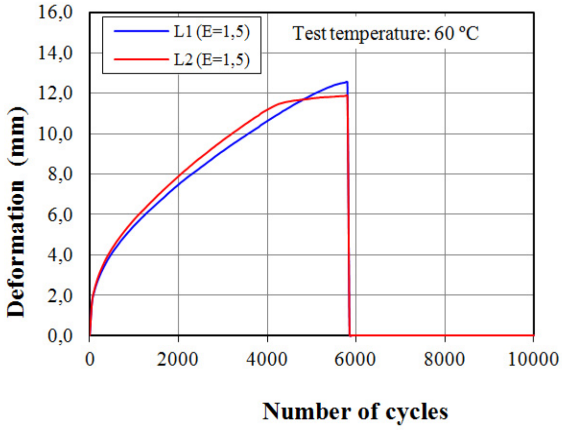

Fig.7. (d) EN 12697-22, procedure B
Mixtures M100 with 1,5% emulsion content

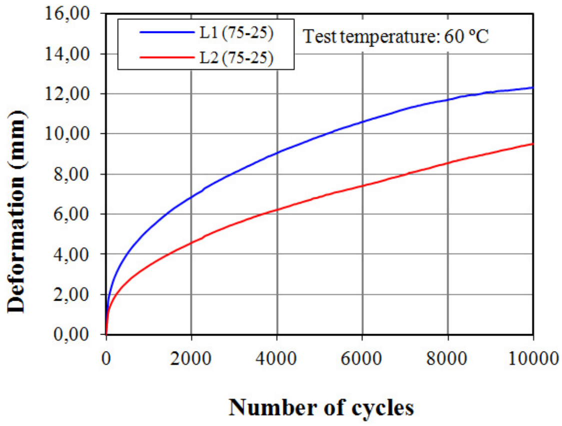

Fig.7. (e) EN 12697-22, procedure B
Mixtures with 2,0% emulsion content

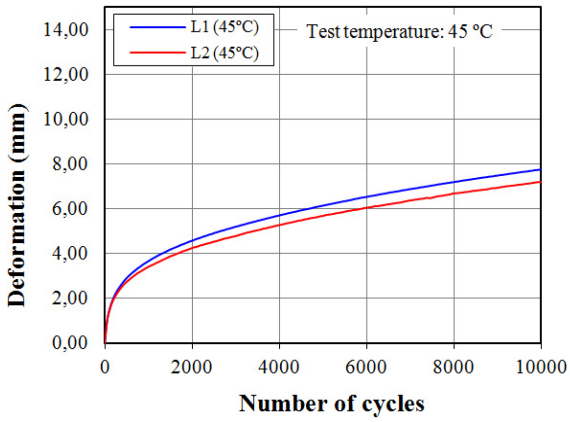

Fig.7. (f) EN 12697-22, procedure B
Mixtures with 2,0% emulsion content

Once there are no reference values for the base layers, it took into account the established values for the surface layers. Thus, all the tests have done show much higher values of permanent deformation of the specified one. The test done at the temperature of 45 ºC revealed a very important decrease of permanent deformation.

4. Economic analysis

The warm recycling with bitumen emulsion, like all the recycling techniques, has consequently a cost reduction comparing to a solution of traditional rehabilitation.

In the case of the WMRA with bitumen emulsion the costs reduction is due to a set of aspects, like, the no use or less use of virgin aggregates, the less use of bitumen and the production of mixture at lower temperatures. Besides that, in a traditional solution there are environmental costs related to a bigger consumption of natural resources (aggregates and crude oil), with the RAP setting in landfills and with a bigger production of CO2 emissions. The advantages, related to environmental factors, of the WMRA with bitumen emulsion are unquestionable. However, they won't be accounted in the economic analysis presented.

The economic analysis compares the traditional hot mix asphalt (HMA) with the WMRA with bitumen emulsion that through this study showed to have a similar performance. Assuming that the value of the initial investment of the pavements construction varies, mostly, due to the manufacturing production cost, there was the determination of cost for one HMA (for base layer) and for two WMRA with bitumen emulsion (without correction gradation and with added virgin aggregates), analysing, comparatively, the obtained results.

4.1. Cost estimate for the finished product

The production of HMA and WMRA is done in the same central plant doing only some changes and adaptations, like it was described. Thus, the construction costs in the application of HMA and WMRA are different mainly in the production costs [16,17].

In the estimate of the cost of the finished product of the different alternatives were considered only the costs directly related to the production and the costs associated with milling the old pavement, transport to the central plant and/or disposal into landfills. These last costs are accepted for the RAP parts put in the landfill or incorporated in the mixtures (transported to the central plant). It was assumed that the landfill cost to the RAP will be the same to the treatment of RAP in the central plant. The average cost used to the RAP was of 15,00 €/ton plus of 0,10 €/ton.Km related to its transport, estimated values by the company JJR & Filhos, S.A., accordingly to what is applied in the rehabilitation work presented in the case study [18].

The manufacturing production cost of a product can be decomposed in cost of raw materials consumed, cost of direct labour, in what concerns the costs with employees that work directly with the manufacture of the product and manufacturing overheads, constituted by all the other product manufacturing costs.

Then, are set out the used assumptions in this economic analysis:

The presented values were estimated by the company JJR & Filhos, S.A.;

RAP is considered cost of raw materials consumed in the WMRA because it is incorporated in the manufacture of the product. In the HMA is considered manufacturing overheads because, even though it is not used as a raw material, it is a production cost in the same way. Table 4 presents the cost of raw materials.

Table 4 – cost of raw materials (€/ton)

Raw materials	Cost / ton
Aggregate 6/15 *	8,35 €
Aggregate 15/25 *	7,30 €
Filler *	6,50 €
RAP *	15,00 €
Reciemul 90 **	457,00 €
Bitumen 35/50 **	624,00 €

* JJR & Filhos, S.A. ** CEPSA Portuguesa Petróleos, S.A.

The percentages allocated to the raw materials in the different manufacturing production cost were calculated on the total weight of the mixture (aggregates and bitumen emulsion);

Production of HMA – 800 tons/day → 16 800 tons/month;

Production of WMRA – 400 tons/day → 8 400 tons/month;

Wages + workers' social contributions

Social costs of workers – 815 €/man.month;

Ten years' constant depreciation rate and nil residual value;

The cost of direct labour (CDL) and other Manufacturing costs (manufacturing overheads) are charged to the industrial cost according to the production.

The comparative analysis of the four mixtures it is resumed in the Table 5. Comparing HMA with WMRA with1,5% emulsion content and with WMRA with virgin aggregate is due to the fact that these last two mixtures had shown that present a similar performance with the first. Comparing HMA with the WMRA with 2,0% emulsion content is due to the fact that was this one, the composition used in the rehabilitation work presented in the case study.

Table 5 – Cost of the finished product (CFP) to the different alternatives studied (€/ton)

CFP		HMA	Warm mix recycled asphalt (WMRA)		
			M100	M100	M75-25
Raw materials		37,51	23,66	21,54	21,78
Direct labour		0,10	0,19	0,19	0,19
Manufacturing overheads	Depreciation	0,74	1,49	1,49	1,49
	Gas, energy and others	3,50	5,00	5,00	5,00
	RAP *	15,00	0,00	0,00	3,75
Total		56,85	30,34	28,22	32,21

*The estimated cost of 15€/ton to the RAP in HMA appears with manufacturing overheads and in the HMRA is incorporated the total cost of raw materials.

The cost of the finished product of WMRA with 2% emulsion content when compared with the HMA reveals a reduction of 46,6% per ton produced. The difference is explained, essentially, by the use of RAP that is done in the case of the WMRA, where it is incorporated in the raw materials. In the HMA are used virgin aggregates in the raw materials, being the RAP an additional cost with no use.

The decreasing of the raw materials cost of the WMRA when compared with the HMA, in about of 37%, it is explained by its different composition. While in the first are used RAP and bitumen emulsion, in the second ones are used virgin aggregates and bitumen.

The values of the direct labour of WMRA are almost the double of the HMA because they were estimated according to the central plant production. They are explained in the same way as the differences verified in the component of depreciation of manufacturing costs. Relating to the fuel component, energy and others, it was verified that even though this cost is smaller than the WMRA, the presented value is superior because, one more time, it was calculated depending on the production.

The noticed differences between the many WMRA studied are explained by the different raw materials used in its composition.

5. Conclusions

This work allowed showing the mechanical and economical advantages of using bitumen emulsion with WMRA in relation to traditional hot mixes. Stiffness modulus and fatigue resistance results for the frequencies of 10 Hz of the WMRA with 100% RAP, 2, 0% and 1, 5% emulsion content are similar to those obtained in HMA. In the wheel tracking tests done at 60 ºC it was concluded that the permanent deformations obtained are much higher than those recommended. However the tests done at 45 ºC the mixtures present important improvements. The economic analysis concluded that taking into account the unavoidable milling of the old pavements and the cost that is associated to it, the benefit in the reuse of the RAP in the bituminous mixtures is clear.

This research work allowed us to conclude that the WMRA with bitumen emulsion presents itself as a valid alternative in the rehabilitation of the road pavements. However, is essential the incentive to use of this type of technique, in particular, through the establishing of appropriate specifications to its application and quality control.

Acknowledgements

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