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DISMANTLING OF ASPHALT AND RECYCLING ROAD MATERIALS IN ASPHALT LAYERS

LITERATURE REVIEW - PORTUGAL

1 Introduction

The interest of recycling of asphalt and other road materials for pavement construction and rehabilitation has been generally growing in Portugal, for the last 15 years. After some occasional demonstration projects dealing with hot and cold in situ recycling of asphalt layers, the first significant experiences with cold in situ recycling and hot mix plant recycling of asphalt applied in full scale rehabilitation projects, took place in the late 1990's.


At that time, the standard specifications for road construction works of the Portuguese Road Administration ("*Caderno de Encargos Tipo de Obras*", JAE 1998 did not include any provisions for using recycled materials in plant or for in situ recycling. The specifications for the first road works with recycled materials were produced case by case, primarily based on experiences from abroad. The follow-up of these construction works and the evaluation of the pavement's performance allowed for the adjustment of these specifications. The specifications for road construction works issued by the Road Administration (presently EP) issued in 2009 [EP, 2009] include provisions for use of recycled materials in unbound and bound pavement layers and also for in situ recycling.

In 2008, a new Decree-Law (Decreto Lei Nº 46/2008), addressing the management of Construction and Demolition Waste (C&DW), was issued. One of the main objectives of DL Nº 46/2008, which replaced the former DL 178/2006, was to establish technical rules for C&DW management from the design phase to construction and to promote the use of recycled C&DW through the reduction of taxes when these materials are used on site. LNEC's technical guides for use of recycled aggregates and reclaimed asphalt were developed in 2006 as a support to the application of this Decree. These technical guides were re-edited in 2009 [LNEC, 2009].

2 Dismantling techniques

In Portugal there are no official guidelines concerning dismantling techniques for road materials, in view of their re-use and recycling on paving works.

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3 Recycling of road materials in plant mixed asphalt

3.1 Recycling techniques

Until now, the main techniques used in Portugal for recycling of road materials in plant mixed asphalt, have been the production of hot mix asphalt, in one of the following alternatives:

- Heating reclaimed asphalt indirectly through the hot aggregates.
- Heating reclaimed asphalt (RA) together with the aggregates when using continuous plants. In this case, the RA is generally introduced via a special device in the middle of the drum dryer.

More recently, half-warm plant recycled asphalt was applied in a rehabilitation work in Portugal, using emulsion. The RA was heated up to 90°C – 120°C and mixed with the (cold) emulsion.


3.2 Recycling unbound materials in plant mix asphalt

In Portugal, there is no experience with recycling of unbound materials in plant mix asphalt.

3.3 Recycling of formerly hydraulically bound materials in plant mix asphalt

In Portugal, there is no experience with recycling of formerly hydraulic bound materials in plant mix asphalt.

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3.4 Recycling of reclaimed asphalt in plant mix asphalt

3.4.1 National specifications and regulations

LNEC specification E 472 [LNEC, 2009] provides recommendations concerning recycling of reclaimed asphalt for the production of hot mix asphalt. This specification is not mandatory.

LNEC E 472 classifies RA into 3 categories, depending on the amount of foreign mater and the characteristics of the recovered binder, as indicated in Table 1, and presents recommendations concerning the maximum amount of RA in the final mixture, depending on RA class and on the type of application (Table 2). LNEC E 472 highlights the possibility of using higher percentages of RA, provided that the performance of the recycled mixture is demonstrated through a specific study.

The aggregates included in the RA are supposed to comply with the specifications for new aggregates for asphalt mixtures.

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Table 1 – Properties of RA for use in hot mix asphalt [LNEC, 2009b]

Requirements (EN 13108-8)		Classification of Reclaimed Asphalt			
Property	Test Method	MBR1	MBR2	MBR3	
Amount of foreign matter	EN 12697-42	F1	F5	F5	
Recovered binder in the RA	Type ⁽¹⁾	-	Paving grade or polymer modified bitumen	Paving grade or polymer modified bitumen	Paving grade or polymer modified or hard grade bitumen
	Characteristics of recovered binder	EN 12697-3 or EN 12697-4 EN 1426 or EN 1427	P15 or S70 ⁽²⁾ or P ≥ 15x10 ⁻¹ mm or S ≤ 70°C ⁽³⁾	P15 or S70 ⁽²⁾ or P ≥ 15x10 ⁻¹ mm or S ≤ 70°C ⁽³⁾	Pdec or Sdec ⁽²⁾ or Declare type of binder and characteristics ⁽³⁾
Maximum size of RA particles	NP EN 933-1	32 mm	32 mm	32 mm	
RA aggregates	Average grading	NP EN 933-1	Declared values	Declared values	Declared values
	Maximum particle size, D	NP EN 933-1	Declared value	Declared value	Declared value
Average binder content in the RA	EN 12697-1	Declared value	Declared value	Declared value	
Maximum water content in the RA	EN 12697-14	5 %	5 %	5 %	

(1) See EN 12597

(2) If the RA binder is a paving grade bitumen

(3) If the RA binder is a modified bitumen

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Table 2 – Recommendations for maximum amount of RA in hot mix asphalt when no performance tests are available [LNEC, 2009b]

Classification of RA	Type of application	Maximum amount of RA ⁽¹⁾
MBR1	Wearing courses	10% ⁽²⁾
	Binder courses and Base courses	50% ⁽²⁾
MBR2	Binder courses and Base courses	25% ⁽²⁾
MBR3	Binder courses and Base courses	10% ⁽²⁾

(1) The maximum amount of RA can be higher depending on the results of a specific study of the final mixture performance.


(2) The maximum amount of RA can be limited due to the type of plant used.

Recycling of reclaimed asphalt in plant hot mix asphalt is considered in the specifications for road works issued by the Portuguese Road Administration (EP) in February 2009 [EP, 2009]. These specifications refer to LNEC E 472, and specify tolerances for the RA variability, which are indicated in Table 3.

Table 3 – Tolerances for Reclaimed Asphalt variability

Characteristics		Unit	Tolerance
Grading of the aggregates % passing on sieves	> 2 mm	% of total mass	± 5
	≤ 2 mm and >0,063 mm		± 3
	0,063 mm		± 1,5
Binder content		% of total mass	± 0,4
Binder penetration		0,1 mm	± 4

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3.4.2 Research results

Plant hot mix recycled asphalt

The research performed in Portugal concerning the use of recycled plant hot mix mixtures has been addressing the following main topics [Antunes, M.L., et al, 2009; Batista, 2006]

- Methodologies for mix design;
- Performance characteristics of the recycled mixtures and their relation to the amount of RA and its properties.

Two specific research projects in the field of asphalt hot mix plant recycling are highlighted. The first one was developed at the University of Coimbra [Batista, A. 2006], focused on the use of different mix design methods for hot mix recycled for application in binder courses, and on the performance of recycled asphalt mixtures with different amounts of RA (0 to 40%). The second project was developed jointly by LNEC and by the Universities of Coimbra and Minho, in the sequence of this first one, and addressed the mix design and performance of recycled mixture with higher percentages of RA (up to 70%) [Antunes, M.L., et al, 2009].

The results of these projects have shown that the performance properties (stiffness, resistance to permanent deformation and to fatigue) of the recycled mixtures are at least as good as the properties of asphalt mixtures with 100% fresh materials.


When high percentages of RA are used (70%) it will be difficult to comply with the normal specifications for asphalt mixtures, especially grading requirements. Furthermore, it is very difficult to derive an optimum binder content directly from conventional mix design procedures (for example, Marshall), since the variations of the Marshall characteristics with binder content do not follow the normal path as for conventional mixtures.

At present there is a research project undergoing at LNEC concerning the effect of rejuvenators in the hot mix plant recycled asphalt mixtures. This project is particularly focused on the binder properties.

Warm / Half-warm mix recycled asphalt

Another project is being developed jointly by the University of “Beira Interior” and LNEC, concerning half-warm mix asphalt plant recycling using bituminous emulsion. This project is focusing on the mix design methods and the performance of the final mixture. The mixtures under study consist of 100% RA, heated to moderate temperatures and mixed with emulsion. In other words, there are no added virgin aggregates.

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This research study is linked to an application on a National Road, where this type of asphalt mixture was applied in a binder course. The practical experience with this specific construction work is briefly described in the next section.

One of the main alleged advantages of this technique, when compared to cold recycling, is the much smaller curing time for the final mixture. The obvious advantages of the technique with respect to hot mix asphalt are the reduced energy consumption and lower emissions. One of the focus of the research is the verification of the mix properties with age.

3.4.3 Practical experience

Plant hot mix recycled asphalt

The first known applications plant hot mix asphalt using RA in Portugal took place in the late 1990's. The first applications where reasonably high percentages of RA were used (up to 40%) were performed in the context of rehabilitation works where the RA had been milled as part of the project and therefore, there was a reasonable consistency of the characteristics of the RA introduced in the mixture. A continuous drum mixer was used in this project (Figure 1).

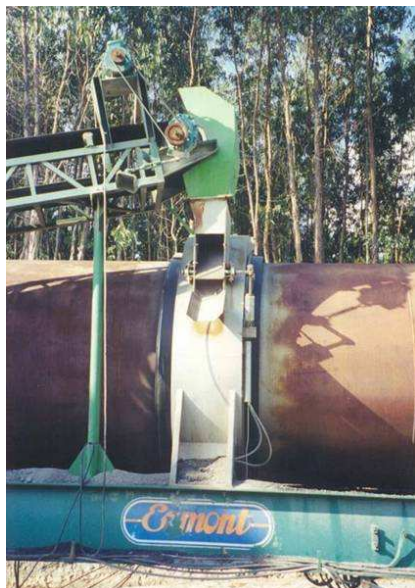



Figure 1 - Introduction of the RA in the continuous drum mixer (Monte & Monte, SA, 1998)

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The use of parallel drums for the production of recycled hot mix asphalt is not yet common in Portugal. The most common processes and associated maximum amount of RA are:

- Mixing cold RA with overheated aggregates in batch-plants: up to 20 % of RA in the mixture
- Introducing RA half way through the drum mixer, though a special device introduced in the drum, for continuous asphalt plants.

In some cases, a special unit for reduction of the RA maximum particle size is also introduced at entrance of the asphalt mixer.

The type of binder most commonly used for the production of fresh asphalt mixture is paving grade pen 35/50. This type of binder has also been used in recycled mixtures, although in some cases softer binders (pen 50/70) are used to compensate for the aged binder in the RA. There are not many known experiences with rejuvenators.


The mix design procedure used for recycled hot mix asphalt is the same as the one used for new asphalt. In Portugal, the Marshal method, complemented with the verification of specific characteristics such as water sensitivity is the standard mix design procedure. Other characteristics, such as fatigue resistance or permanent deformation resistance (determined on wheel tracking tests) have been only used in special projects, for example for motorways. Nowadays, these tests are becoming more common.

Half-warm / warm mix recycled asphalt

The first experience in Portugal with half-warm plant recycled (100%) asphalt mixtures took place in 2008 /2009, with the application of a mix consisting of RA with 2 % slow setting modified cationic emulsion. The grading curve adopted for the aggregates in the mixture had a maximum particle size of 20mm and the upper limit for the RA particles was set to 25mm.

Initially, this mixture was supposed to be produced by warming the RA up to 90°C, and compacted at a minimum temperature of 60°C, therefore it would fall into the category of half-warm mixtures. However, a good homogeneity of the mixture was not achieved with this procedure; therefore the RA temperature was increased to 120°C.

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4 In-situ recycling

4.1 In-situ recycling techniques

In-situ recycling of asphalt pavements can be performed either by hot or cold processes, using dedicated paving equipment that disaggregate the existing pavement layers (by heating or milling), mix with new materials and lay it back on the pavement.

In Portugal in situ hot recycling has been applied only in occasional demonstration projects in the late 1980's. Therefore, this technique will not be subsequently referred in this report.

Cold in situ recycling, where the existing pavement layers are milled, remixed with new binder and possibly some new aggregates or corrective materials, may be performed using the following binders:

- Bitumen emulsion
- Foam bitumen
- Portland cement
- Bitumen emulsion + Portland cement.

Most of the experience gathered in Portugal concerning cold in-situ recycling has been using bitumen emulsion, Portland cement or bitumen emulsion + cement. This type of techniques has been used on rehabilitation projects in Portugal since 1993.


4.2 National specifications and regulations

The Portuguese Road Administration (EP) specifications for road works, issued in February 2009 [EP, 2009], include requirements for in-situ recycling of asphalt pavements.

The main requirements for cold in situ recycled asphalt refer to the unconfined compressive strength (dry) of cured specimens (3 days @ 50°C) and their retained strength after immersion in water (wet). These requirements are summarized in Table 4.

Table 4 – Requirements for in-situ cold recycled mixtures (emulsion or emulsion + cement)

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Characteristic	Unit	High traffic volume (T0 / T1)	Low traffic volume
Unconfined compressive strength, dry	MPa	≥ 3,0	≥2,5
Unconfined compressive strength, wet	MPa	≥ 2,5	≥ 2,0
Retained strength (wet/dry)	%	≥ 75	≥ 70

The above specifications refer to in-situ recycled asphalt using bituminous emulsion as binder or using emulsion plus Portland cement. In the later case, the cement content is relatively low (around 2%). The recycled materials consist of 100% asphalt layers or a mix of asphalt and unbound granular layers. This situation is more common in older pavements where the thickness of asphalt layers is relatively low. In these cases, it often happens that corrective materials such as virgin aggregates, lime or cement need to be added.

4.3 Research results


Research studies concerning cold in-situ recycled mixtures have been going on since the 1990's, in many cases, supported by the Road Administration (Junta Autónoma de Estradas, JAE, later designated as Estradas de Portugal, EP) [Antunes, et al 1999; 2004; Batista, F. 2004]. These research studies addressed the following topics:

- Mechanical characteristics of the recycled mixtures and their evolution with curing;
- In situ curing of the mixtures;
- Laboratory compaction procedures for simulation of in situ compaction;
- Accelerated laboratory curing (for mix design studies);
- Development of mix design procedures.

In general, it was concluded that, when the cold recycled asphalt mixtures are properly designed and applied, their final mechanical characteristics of the (after complete curing) are similar to the ones obtained for hot mix asphalt, in terms of stiffness, fatigue resistance and permanent deformation.

It was also concluded that, although the water content of the mixtures stabilizes after 2 weeks, on good weather conditions, the curing process will still go on with a total duration of around 2 month. When a small amount of cement is added to the recycled mixture (recycling with emulsion + cement) the stabilization of the mixture is faster.

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4.4 Practical experience

The first experiences with in-situ cold recycling in Portugal started in 1993. The rehabilitation works using asphalt cold mix in situ recycling performed in Portugal since then, were of the following types (Nunes, M.G., 2008):


- In situ recycling of a combination of asphalt and unbound granular layers using emulsion (3 to 5%);
- In situ recycling of a combination of asphalt and unbound granular layers using emulsion (3 to 5%) and cement (1,5 to 2%);
- In situ recycling of asphalt layers using emulsion (around 3%);
- In situ recycling of asphalt layers using emulsion (around 3%) and a small amount of cement (0,5%).

The recycling depth was 10 to 20 cm. In most cases the target depth was 12 to 15 cm.

Although in-situ cold recycling has proved to be an excellent rehabilitation solution for deteriorated asphalt pavements, not all the experiences made in Portugal with in-situ cold recycling were fully successful. The practical experience gathered with these paving works leads to the following recommendations:

- In situ recycling of very heterogeneous pavement structures is not recommended, since the mix design formula depends on the composition of the recycled layers.
- The mix design should be preceded by a careful characterization of the existing pavement and the materials used for testing must be representative of the section to be recycled. These materials should be milled with the recycling machine, in order to achieve a representative grading for mix design.
- Recycling to depths in excess of 15 cm leads in many cases to non-homogeneous layers. Sometimes, a pre-milling operation prior to the passage of the recycling equipment, will improve the homogeneity of the recycled layer.
- The compaction equipment should be as heavy as possible, in order to be able to achieve a good compaction with minimum amount of added water and to expel the water from the recycled mixture, as much as possible during compaction.
- It is very difficult to achieve an even surface for a in situ recycled layer. Therefore, for a good evenness, this type of solution must be used with subsequent levelling course, before the surface course is applied.

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5 References

Antunes, M.L.; Batista, F. A.; Barros, R.; Fonseca, E. (1999) – “*Acompanhamento da obra de eabilitação do pavimento da EN 260 (IP8) entre Serpa e Vila Verde de Ficalho*” (Technical report regarding the rehabilitation of the pavement of EN 260, between Serpa and Vila Verde de Ficalho). LNEC/JAE Report, 1999.

Antunes, M.L.; Batista, F.A. (2004) – “*Reabilitação do Pavimento do IP2, entre a Barragem do Fratel e a EN 118, utilizando reciclagem “in situ” a frio, com emulsão betuminosa*” (Rehabilitation of the IP2 pavement section between the Fratel dam and EN 118, by in-situ cold recycling using a bitumen emulsion). LNEC Report, 2004.

Antunes, M.L.; Batista, F.; Picado-Santos, L.; Batista, A.; Pereira, P.A.; Pais, J. – “*Reabilitação de Pavimentos através de Reciclagem a Quente*” (Pavement rehabilitation using hot mix recycling) LNEC, 2009.

Batista, A. (2006) - “*Misturas Recicladas a Quente em Central. Contribuição para o seu Estudo e Aplicação*” (Hot mix recycled asphalt mixtures. Contribution for its study and application) PhD Dissertation, Univ. of Coimbra, 2006.

Batista, F.A. – “*Novas técnicas de reabilitação de pavimentos – Misturas betuminosas densas a frio*” (Innovative pavement rehabilitation techniques – dense asphalt cold mixtures), PhD Dissertation, LNEC/FEUP, 2004.

Estradas de Portugal, SA – “*Caderno de Encargos Tipo Obra*” (Type Specifications for Construction), Estradas de Portugal (EP), S.A., February 2009.

LNEC E 472 (2009b) – “*Guia para a reciclagem de misturas recicladas a quente em central*” (Guide for the production of recycled hot mix asphalt), 2nd ed, LNEC, 2009.

Nunes, M.G. – “*Reciclagem de Pavimentos “in situ” a frio com emulsão betuminosa – a experiência Portuguesa*” (In situ pavement recycling using bitumen emulsion – the Portuguese experience). Master Dissertation, ISEL, 2008.

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