SYNTHESIS OF THE EUROPEAN NATIONAL REQUIREMENTS AND PRACTICES FOR RECYCLING IN HMA AND WMA (DIRECT_MAT PROJECT)

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ABSTRACT

The purpose of the 2009-2011 European project "DIsmantling and RECycling Techniques for road MATerials" is to contribute to the waste minimization in road maintenance and construction by sharing and disseminating, at a European level, the national know-how and sustainable practices regarding the dismantling of the pavements and the recycling of the reclaimed materials. In the framework of the DIRECT_MAT subproject "Asphalt materials", the present paper gives a broad overview of the European policies, figures and trends concerning pavement recycling in Hot and Warm Mix Asphalts (HMA/WMA). Then, stemming from each country's experience, a survey of the national requirements and practices is conducted to provide reliable information as regard to the different stages of the pavement recycling process: dismantling of the layers, handling of the reclaimed asphalt, mixing equipments, mix design processes, performance evaluation and long term behaviour. This survey is illustrated with a synthesis of typical in-situ case studies. Finally, the experience and the knowledge thus gathered are discussed and summed up in a series of recommendations for an optimal and sustainable use of recycled materials in new road infrastructures in order to combine technical efficiency and environmental protection.

Keywords: Road material, Recycling, Hot Mix Asphalt, Warm Mix Asphalt, European practices

1. INTRODUCTION

The purpose of the 2009-2011 European project "DIsmantling and RECycling Techniques for road MATerials" is to contribute to the waste minimization in road maintenance and construction by sharing and disseminating, at a European level, the national know-how and sustainable practices regarding the dismantling of the pavements and the recycling of the reclaimed materials. In the framework of the subproject "Asphalt materials", a team of 17 experts from 12 European countries followed a three fold approach.
In a fist step dedicated to literature review about 250 articles (national and international scientific papers, national regulations and guidelines) were selected and synthesized to a literature report. Then, to validate the information with regard to the actual practical application, about 45 case studies were gathered indicating specific working sites representing most of the available recycling techniques. Finally, the information thus compiled was discussed and summaries to a best practice guide aiming at indicating the optimum strategies for each recycling technique. This article deals with the main topics of the subproject dedicated to recycling in Hot and Warm Mix Asphalts (HMA/WMA).

2. FIGURES OVERVIEW AND TRENDS

Recycling of reclaimed asphalt (RA) in HMA is a common re-use technique: in Europe approx. 57 % of all RA was recycled in HMA in 2008. Yet, the figures vary widely across Europe according to national policies and circumstances. For example, in 4 countries amounting jointly for three quarters of the total European RA available, the part recycled in HMA ranges from 82% to 20% (Germany 82%, Netherlands 74%, France 41% and Italy 20%). Nevertheless, the trend is generally for low recycling countries to increase the recycling of RA in HMA [1].

WMA [2,3] are new technologies, first experimented in the beginning of the 2000's, that allow a reduction of the temperature at which asphalt mixes are produced; while HMA are produced above 130°C, the WMA production temperatures generally ranges from 80°C to 130°C. The numerous WMA proprietary processes available (>20) can be broadly classified in two types according to the technology used.

- processes using organic or chemical additives acting as binder flow improver or surfactant,
- binder foaming processes by introduction of a small amount of water during the mixing process either through hydrophilic material or a foaming nozzle.

Among the benefits expected from this temperature reduction (environmental, safety, paving), the reduced ageing of the binder during the production is of special interest for recycling as it can compensate for a higher content of RA with aged binder in the final mix. However, despite these promising prospects, the WMA technologies are not yet widely used in Europe. For instance, 2010 estimates for the French WMA production, whether with or without RA, amounted for only 2 or 3% of the total asphalt mix production [4].

Over the last decade, the total European HMA/WMA production ranged between 320 to 350Mt/year while RA made available amounted to 50Mt/year. Thus, a theoretical 100% RA recycling could be achieved assuming an average RA content of approx. 15% in all HMA/WMA produced**.**

3. RECYCLING PROCESS

The recycling of RA in HMA/WMA can be divided in successive stages: characterization and dismantling of the old pavement, characterization of the RA, handling of the RA, mix design processes, mix production, laying and compaction. The first 4 stages are not specific to recycling in HMA/WMA.

3.1 Characterization of the old pavement

The aims of the characterization of a pavement prior to removal and demolition of the structure or parts of it are to:

- detect and analyze distresses to evaluate the need of road rehabilitation and to develop the pavement design of the new structure,
- detect environmental hazardous substances in the structure,
- evaluate homogeneity.

This characterization should involve:

- a review of the existing documents related to the old pavement (construction date, structure, maintenance …)
- a visual distress survey,

- deflection measurements and coring,
- hazardous substance detection (e.g. tar)

While essential, this stage is not specific to the recycling process. In particular, regarding to the design of the structure, in most countries the same mechanical requirements apply to HMA/WMA with or without RA.

3.2 Dismantling of the old pavement

The two options for the demolition are milling and breaking in blocks. The breaking in blocks implies further crushing in the mixing plant. It may be feasible for smaller work sites as well as sites where the road structure is demolished in full depth. Nevertheless, the milling has the following advantages:

- flexible milling depth,
- grain size of reclaimed road material which usually allows the application in new asphalt mixes without further processing (crushing and/or sieving),
- layer by layer milling allowing the reclamation of single-source materials with high homogeneity hence with high potential recycling rates,
- separately milling of layers allows to separate contaminated road layers (e. g. tar) from non-hazardous asphalt layers
- prior thin layer milling of the road marking avoids the contamination of clean RA material.

Milling is actually recommended and usually applied in all represented countries and layer by layer milling is generally recommended. However, it should be noted that the recycling in HMA/WMA is an in-plant process involving RA stockpiles. Thus, unless separate stockpiling requirement, the RA recycled in the new layer is not the material actually reclaimed on site.

3.3 Characterization of the RA and homogeneity requirements

3.3.1 Characterization

The sampling procedure and the specifications of the European standard EN 13108-8 relative to the RA are followed in almost all countries. Five properties shall be compulsorily documented:

- presence, content and type of foreign matter,
- type of binder,
- grading of the aggregate,
- mean binder content,
- maximum RA particule size (U).

Generally, additional properties are also required:

- binder properties (penetration and/or ring and ball),
- aggregate properties (for recycling in surface course),
- homogeneity.

3.3.2 Homogeneity requirements

The homogeneity of the RA is especially important. As a rule of thumb for a given property of a HMA/WMA, the additional scatter due to the added RA depends on the scatter of this property in the RA multiplied by the RA content in the HMA/WMA. As the obtained mix must generally comply given homogeneity requirements, RA with highly scattered properties implies low RA content. For this reason, limit values for recycling or maximum content at which a given RA is allowed to be recycled are generally fixed according to the homogeneity of the stockpile.

In almost all the countries with homogeneity requirements, the span of the same 6 properties are taken into account; 3 regarding to the grading curve of the RA aggregate and 3 regarding to the binder:

- percentage of aggregate < 0,063 mm,
- percentage of aggregate between 0,063 and 2 mm,
- percentage of aggregate > 2 mm,
- binder content,
- binder penetration,

- binder softening point,

In Belgium, Portugal and Spain, RA properties spans are required to be within fixed tolerance limits, without regard to the RA content.

Table 1 : Fixed tolerance limits for spans of RA properties

RA properties		Belgium	Portugal & Spain
Sieving (%)	d>2mm	±10	±5
	0,063 mm < d < 2 mm	-	±3
	d<0,063mm	±3	±1,5
Binder	Content (%)	±1	±0,4
	Penetration (1/10mm)	±10	±4
	Softening point (°C)	±10	-

In France and Germany, the maximum allowed RA content is set according to the homogeneity of the stockpile of RA to recycle. The German method is straightforward: for the 6 properties, the RA weighted span is limited to a given fraction (1/2 for base courses and 1/3 for surface courses) of the allowed span for a HMA. It is readily summed up in a nomogaph; an example is given in Figure 1 supplemented with the French requirements.

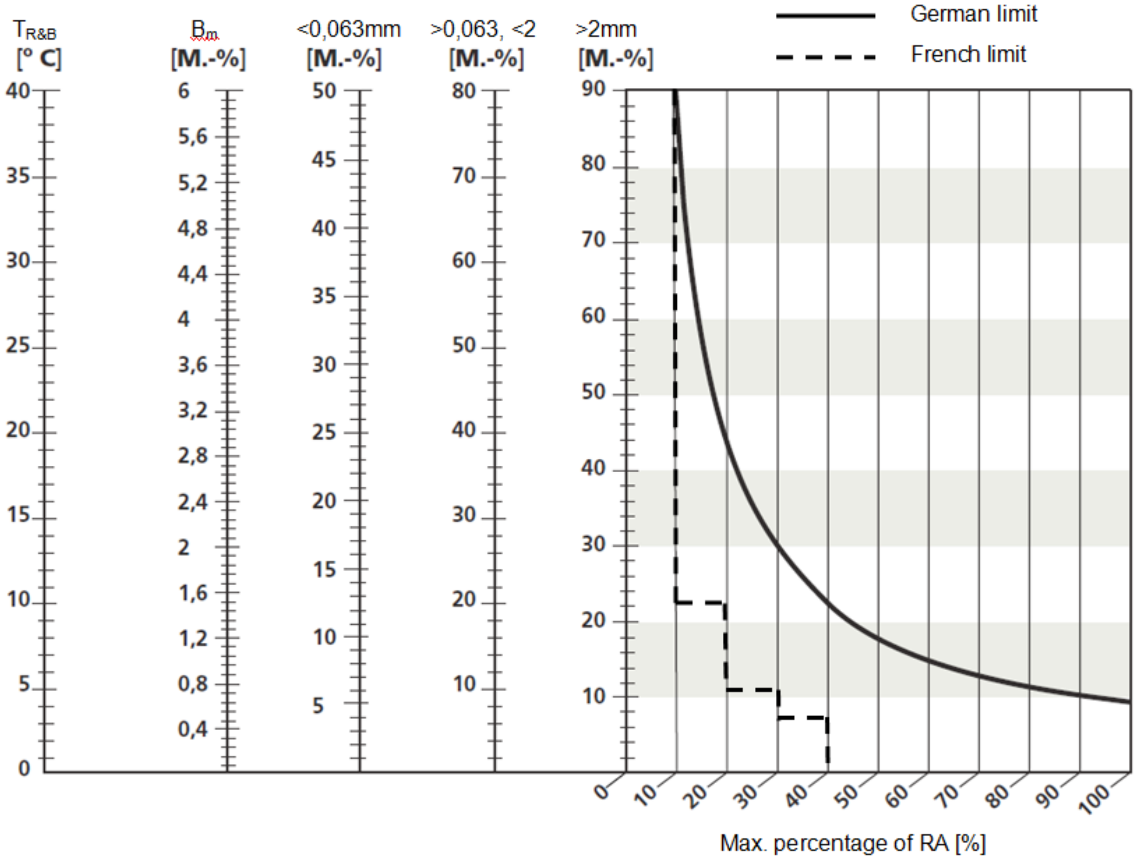

Figure 1 : German nomograph for base course supplemented with the French requirements - the maximum span value plotted on the 5 properties axis (left) is reported on the limit curve (right) to determine the max. percentage of RA allowed

Although the approaches are broadly similar in the 5 countries, the actual allowed percentage can be significantly different from one to another for the same RA stockpile.

Further limits are usually required for the RA binder with a maximum for the softening point and minimum for the penetration (see 3.6.2).

The RA content is generally more strictly limited for uses in surface courses and additional properties of the RA aggregate (PSV, LA coefficient …) are also required.

3.4 Handling of the RA

To improve the RA homogeneity, separate stockpiling according to maximum grain size, grading and type of binder is recommended as well as a regular homogenization for the stockpiles containing RA from several sources. A separated storage of homogeneous RA originating from one single site can be feasible for big worksites. In order to decrease the potential mixing time, RA from milling may be crushed before stockpiling to reduce the largest lumps size U. Roofed stockpiles are recommended since the water content of the RA adversely affects the mixing process because of the extra energy needed for water vaporization.

It should be emphasize that a sound management of the RA is a key point to promote recycling as a routinely applied technique: a secured and regular availability of well identified RA products is an incentive to recycling as it can guaranty returns on investments in recycling equipments and processes.

3.5 Mix design

In most countries, the mix design of mixtures which contain RA refers to the design procedures and requirements of asphalt mixtures containing only virgin materials. The Marshall mix design is still the most used procedure for developing new mix-design.

3.5.1 Grading

The grading curve of a mix containing RA depends on the grading curves of the virgin and RA aggregates, and on the RA content:

Mix grading curve = (virgin aggregate curve) · (1- (RA content)) + (RA aggregate curve) · (RA content)

Also, obviously, the higher the RA content, the less the final mix grading curve can differ from the grading curve of the RA aggregate, hence the interest for a separated RA stockpiling according to the main types of HMA grading (e.g. SMA, AC, PA).

RA can be sieved in separate fractions to improve flexibility for the mix design. However, it should be noted that the larger sieved RA fractions will content more fine particles than a corresponding fraction of sieved virgin aggregate, as some fines are trapped in the binder coating the coarse aggregate. As well, the binder content of the sieved RA will be higher in the finer RA fractions as the coating of the finer aggregate (with higher surface/volume ratio) involves proportionally more binder.

3.5.2 Binder

For a given binder content in a mix containing RA, the amount of new binder to add is generally estimated by deducting the amount of binder in the RA from the amount of binder that would be needed for a mix without RA. As regard to the properties of the final binder, in all countries the calculations of the penetration and the softening point of the binder of the mixture with RA are performed according to the EN 13108-1 annex A:

Penetration:

$$a \lg pen_1 + b \lg pen_2 = (a + b) \lg pen_{mix}$$

where

pen_{mix} is the calculate penetration of the binder in the mixture containing RA
pen_1 is the penetration of the binder recovered from the RA
pen_2 is the penetration of the added binder
a and b are the portion by mass of the binder from RA (a) and from the added binder (b); $a + b = 1$

Softening point:

$$T_{R\&B\ mix} = a \times T_{R\&B\ 1} + b \times T_{R\&B\ 2}$$

where

$T_{R\&B\ mix}$ is the softening point of the binder in the mixture containing RA
$T_{R\&B\ 1}$ is the softening point of the binder recovered from the RA
$T_{R\&B\ 2}$ is the softening point of the added binder
a and b are the portion by mass of the binder from RA (a) and from the added binder (b); $a + b = 1$

Thus, for the final binder content as for the final binder properties, a complete blending is implicitly assumed with the new binder compensating for the ageing of the RA binder. However, numerous studies [e.g. 5, 6] suggested that, practically, it is generally not the case. The actual situation is between complete blending and no blending at all (often termed as “black rock”). In the “black rock” case the new binder is coating the RA particles without interacting with the old binder; the old binder performs as an aggregate. The resulting mix is generally highly sensitive to rutting or cracking. The concern is to be as near as possible of the complete blending.

The harder the RA binder, the more the effective compensation with the virgin binder is to be questioned. Therefore, limit values are generally set to the binder softening point and penetration, for RA to be appropriate for recycling (Table 2)

Table 2 : limit values for the binder for RA to be appropriate for recycling

Properties	Belgium	France	Germany	Ireland	Poland	Portugal	Slovenia	UK
Penetration (1/10mm)	> 10	> 5	> 15	> 15	> 15	> 15	-	> 15
Softening point (°C)	-	< 77	< 70	-	< 70	< 70	< 70	-

For RA with Polymer modified Binder (PmB) the relevance of the above mixing formulae is to be questioned according to the type and properties of the polymer (SBS, EVA,…).

3.5.3 Laboratory study

As far as possible, the laboratory study should mimic the real conditions expected for mix production conditions (e.g. extended mixing time, mixing-plant fittings) and with RA samples from the stockpile that will actually be used for the job.

Most countries allow the use of RA which doesn’t meet the general requirements (e.g. higher recycling rates, special additives) if the resulting mix performance is proven by additional laboratory performance tests. In these cases following HMA characteristics shall be analyzed and compared with properties of conventional mixes:

- resistance against permanent deformation (rutting), e. g. by
  - wheel tracking test (EN 12697-22),
  - cyclic compression test (EN 12697-25),
- resistance against fatigue (EN 12697-24),
- stiffness modulus (EN 12697-26),
- resistance against low-temperature cracking by TSRST (EN 12697-46),
- water sensitivity (EN 12697-12)

Specific concerns arise for WMA on:

- how to realistically mimic the various processes in lab,
- how to take account for the reduced ageing of the new binder in the mix production process,
- the need and the duration of a curing in order to provide adequate mechanical evaluations [7].

In any case, the WMA mixing and compaction temperatures should match the actual expected field conditions.

3.6 Mix production

3.6.1 Mixing equipments

Independently from the RA properties, the maximum possible RA content depends to a large extend on the general design of the mixing plant. For example, in a batch plant, more prevalent than drum plant in Europe, the RA content is generally limited to 30% if cold RA is directly introduced in the mixer or in the dryer drum, while it can be above 60% for plant fitted with an additional parallel drum for a gentle preheating of the RA.

Moreover, some mixing plant features should be taken into account in the mix design step: e.g. RA heating in the same drum as the virgin aggregate may provoke an intensive additional ageing of the RA binder.

As regard to fitting for recycling, the mixing equipments vary widely between the European countries. For example, in the 4 countries above mentioned (comp. section 2), the proportion of the national mixing equipments fitted for HMA recycling range from 35% to 96% (Germany 96%, Netherlands 95%, Italy 46% and France 35%) [1]. Not surprisingly, the link between the proportion of recycling fitted plants and the proportion of available RA actually recycled in HMA/WMA is obvious. Furthermore, the more efficient equipments, allowing the higher recycling rate (e.g. additional parallel drum), tend to concentrate in the more equipped countries [8].

The WMA processes implies further plant modifications whose extend depends on the considered process.

3.6.2 Production

In the recycling process, a prolonged mixing time is generally needed to heat the RA and disintegrate the biggest chunks (usually 5 to 10s). This additional time depends on:

- the amount of RA added,
- the water content of the RA,
- the quality of the RA crushing (ratio of U to the upper sieve of RA aggregate D),
- the mixing temperature,
- the design and efficiency of the mixing equipment.

As a rule of thumb, for a given process, the mixing-plant settings (temperature, mixing time) and the quality of the RA crushing must compensate for the RA amount and its water content.

3.7 Laying and compaction

Regarding laying and compaction, the same requirements and practices apply to HMA/WMA with or without RA. Because of the lower production temperature, the WMA technologies allow, additionally to higher RA content, improved compactibility, longer haul distance and extended paving season. However, it should be emphasized that these benefits are linked: one can not expect all 4 at once.

4. CASE STUDIES

A total of 14 case studies concerning hot mix recycling in plant were included in the DIRECT_MAT database. These case studies originated from 7 different countries and the vast majority reported on specific jobs where hot mix in plant recycling was used for the production of new asphalt mixtures.

The set of case studies includes asphalt mixtures with 10 to 70% Reclaimed Asphalt (RA), originating in most cases from surface layers, sometimes combined with binder layers, with or without modified binders. It covers the use of conventional binders, soft binders and PmB as virgin binders for recycled mixtures applied in wearing, binder and base courses.

The types of asphalt plants used are batch plants or continuous plants, with or without special equipments related to the use of RA. Pre-crushing and sorting of the RA is also applied in some cases.

Some of the case studies include detailed information on the properties of the aggregates and binder included in the RA and on performance testing and quality control of the asphalt mixtures.

The conclusions from the evaluation of case studies on hot mix recycling in plant are listed below:

- RA can be successfully used for the production of HMA in plant. The percentage of RA can be variable depending of the type of equipment used and the type of new asphalt mixture. The main recommendations for using high percentages of RA refer to the need for comprehensive characterisation and homogenisation of RA for incorporation in the new mixture.
- Hot mix recycled asphalt can be applied even when a high performance is needed, like in surface courses and in motorways, for example.
- There were no specific problems reported with relation to the use of reclaimed asphalt with PMB or with asphalt rubber.

5. CONCLUSIONS

The recommendations as regard to the dismantling of old pavements and the recycling in HMA/WMA are comparable throughout Europe. Not surprisingly, they are identical for topics covered by EN standards such as RA characterization (EN 13108-8) and mix binder properties (EN 13108-1), but tend to be more diverse for topics not yet normalized as maximum allowed RA content or RA binder properties limit values.
The actual recycling practices (e.g. average recycling rate, ratio of available RA actually recycled), are more diverse and dependent on national "hard" factors such as reliable RA management units and efficiently fitted mix-plants themselves probably linked to national or local incentive policies.

In the near future, the evolution of the practices as regard to recycling in HMA/WMA will probably depend on the actual diffusion of the WMA processes, not yet widely used in Europe.

6. RESEARCH NEEDS

Although the HMA recycling techniques of road materials in new asphalt layers can be considered as widely used technologies in the majority of European countries there are still a lot of special problems which need to be investigated in the future as regards to:

- characterization of existing pavements in terms of recycling options;
  - development of non-destructive structural evaluation (ground penetrating radar),
  - development of road databases with chronological data ranging from project design to rehabilitation,
- recycling in HMA/WMA;
  - development of energy savings comparators,
  - fatigue resistance evaluation (lab and field long term comparisons),
  - specific WMA concerns (mix design, binder ageing, curing ,..),
  - recycling with PmB,
  - effect of road marking compounds,
- Long term performance;
  - development of a European database on the existing recycling test road and experiments,
  - assessment of long term performance (monitoring of the existing sites throughout Europe),
  - cost efficiency evaluations.

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