SYNTHESIS OF EUROPEAN KNOWLEDGE ON ASPHALT RECYCLING: OPTIONS, BEST PRACTICES AND RESEARCH NEEDS

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ABSTRACT

From 2009 to 2011, the various technologies for the demolition of flexible pavements as well for recycling of reclaimed road materials in new bituminous bound layers were collected and synthesized during the EC 7th RTD Framework Project DIRECT-MAT. Starting from the current status of regulations, recommendations and guidelines in the countries participating in the project, the differences between recycling strategies for asphalt pavements were highlighted. This knowledge was supplemented by relevant research results available in international and national literature and by a high number of case studies indicating the actual procedures applied on site. Using these data, various recycling options for the re-use of reclaimed road materials in new bituminous bound pavement layers were elaborated. For each of these recycling options, best practices for in-situ characterization of old pavements, demolition procedures, handling and manufacturing of reclaimed material in plant, characterization of and requirements on the reclaimed material as well as in-plant and in-place recycling techniques were defined. For various items addressed in the research work lacking knowledge and research needs were also identified.
The paper summarises research results of the project on asphalt pavement demolition and material characterisation. By adding the findings on warm and hot-mix recycling applied in several European countries (as presented in accomanying paper no. 442 as well as cold-mix techniques presented in paper no. 460) knowledge gaps are summarized proposing several future research works on asphalt recycling.

Keywords: Road material, Asphalt demolition, Recycling, European recycling practice

1. INTRODUCTION

Pavement maintenance is needed when its surface and structural characteristics do not meet the requirements due to deterioration caused by traffic loading, climatic influence and/or bad material quality. Maintenance works usually involve one or more layers of the flexible or semi rigid pavement and sometimes demolition (or removal) of the complete bound structure. Another reason for pavement demolition may be the demolition of an entire pavement if it is not needed any more.

An additional source for reclaimed asphalt is the asphalt plant itself. For large pavement works, material in excess may be produced. In the beginning of the asphalt production or when changing the mix production from one mix design to another, the produced asphalt mix often does not meet the quality requirements. This material can be added to new mixtures again as reclaimed asphalt.

According to European waste legislation, material resulting from demolition works shall be considered as construction waste if transported from the site of demolition. Options for the handling of waste in order of priority are:

- reuse: use of the waste material in the same application as before,
- recycling: use of the material in a new application,
- disposal: deposition of material with best safety for health and environment.

During the European research project DIRECT-MAT the available technologies applied in Europe were analysed. Differences in applied procedures for characterization, mix design and mix production were analysed in detail in order to compare the various recycling approaches and to draft best practice guides for the proven recycling procedures. Hence, today reclaimed road material can be referred to as “recourses” allowing the production of new high-quality road material and the construction of new pavements.

This paper reflects on the various approaches for asphalt road recycling. Based on the findings presented in this paper as well as in the associated contributions of this conference proceedings emphasizing cold recycling (paper no. 442) and warm/hot recycling (paper no. 442) techniques, new research issues are presented which shall be solved in future projects in order to improve the quality of new research works.

2. RECYCLING STREATEGIES APPLIED IN EUROPEAN COUNTRIES

For demolition of flexible pavements and recycling of road materials, several options have been developed in the past in order to produce new pavement materials (compare figure 1).

In order to identify optimum recycling strategies the detailed characterization of the existing pavement is of high importance. According to the reason for demolition of the old pavement as well as o the required properties of the structure and paved material, the feasible recycling technique can be selected. The old asphalt pavement is demolished either by block crushing or milling in order to enable its reuse in new hot-mix asphalt or its recycling in cold-mixes. cold mixes. For both options, in-place and in-plant techniques are available.

As indicated in figure 2, each European country found adequate strategies to reuse, recycle or dispose reclaimed asphalt. According to the analysed statistics of European Asphalt Pavement Association (EAPA), these techniques differ considerably from one country to another. Whereas some countries focus on the recycling of reclaimed asphalt as unbound material in road base layers, others specialised in the reuse of the old bituminous bound material in new hot mixed asphalt or in cold bitumen and/or cement stabilised materials. In both cases, the material from roads having reached the end of their service life is recycled in new road structures, and high recycling rates are reached.

The causes of these differences can be found in differences of the general infrastructure in the various countries. Some countries have a high number of stationary mixing plants which enables the plant-recycling by avoiding long-distance transportation of material. In these, the percentage of plant-recycling is comparably high. Other countries apply In-Situ recycling more often because of longer transport distances to mixing plants. Another reason for diverting recycling solutions may be the availability of natural aggregates. Other reasons for one or the other technology are the available construction time for road maintenance works, the need for CO_2-reduction and the resulting lifetime and recyclability of the new structure.

3. CHARACTERISATION OF EXISTING PAVEMENTS IN ORDER TO SELECT SUITABLE RECYCLING STRATEGIES

Careful characterisation of the pavement subject to demolition will give important information regarding economy and environmental considerations for assessment of different recycling options. To ensure a prolonged service life of the rehabilitated road structure, badly deteriorated or inferior layers shall be removed or improved. For example, the construction of a new wearing course for crack covering is not feasible if the bearing capacity of the structure is not adequate. The aims of the characterisation of a pavement prior to removal and demolition of the structure or parts of it are:

- detect deteriorated road layers 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.

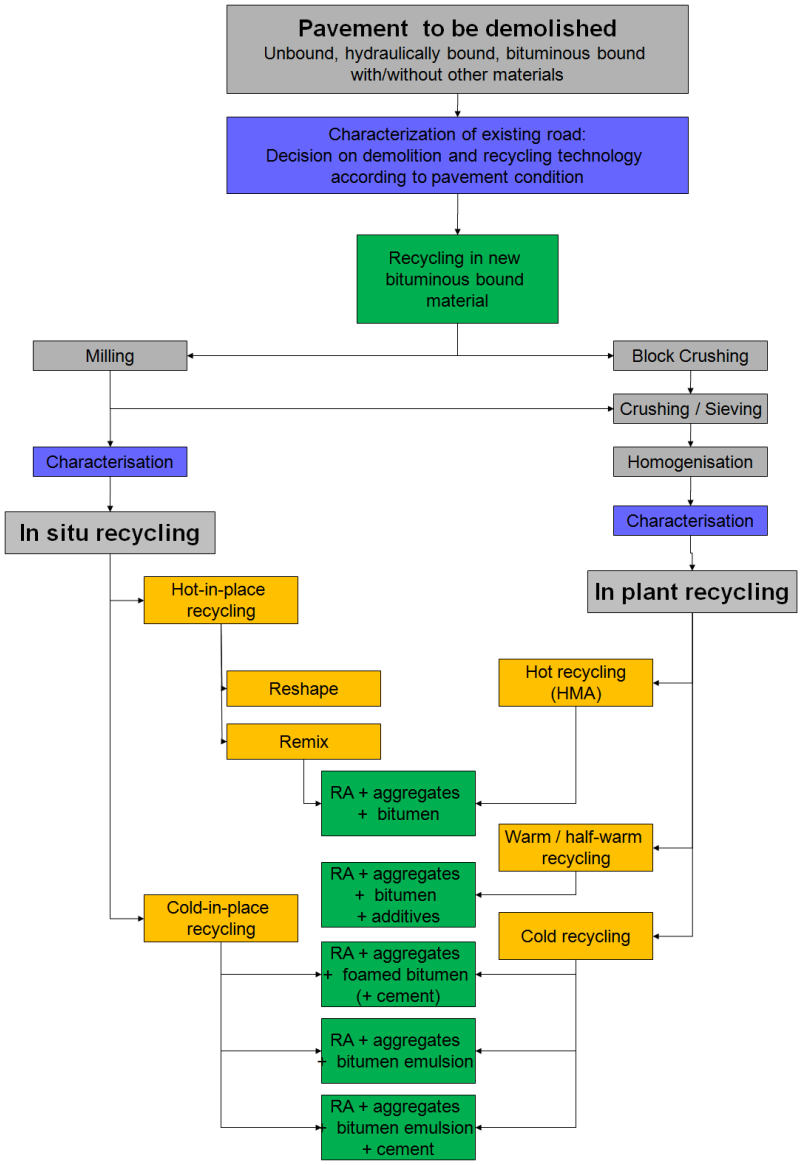

Figure 1: Flowchart of techniques for demolition of flexible pavements, handling and recycling of reclaimed asphalt [1]

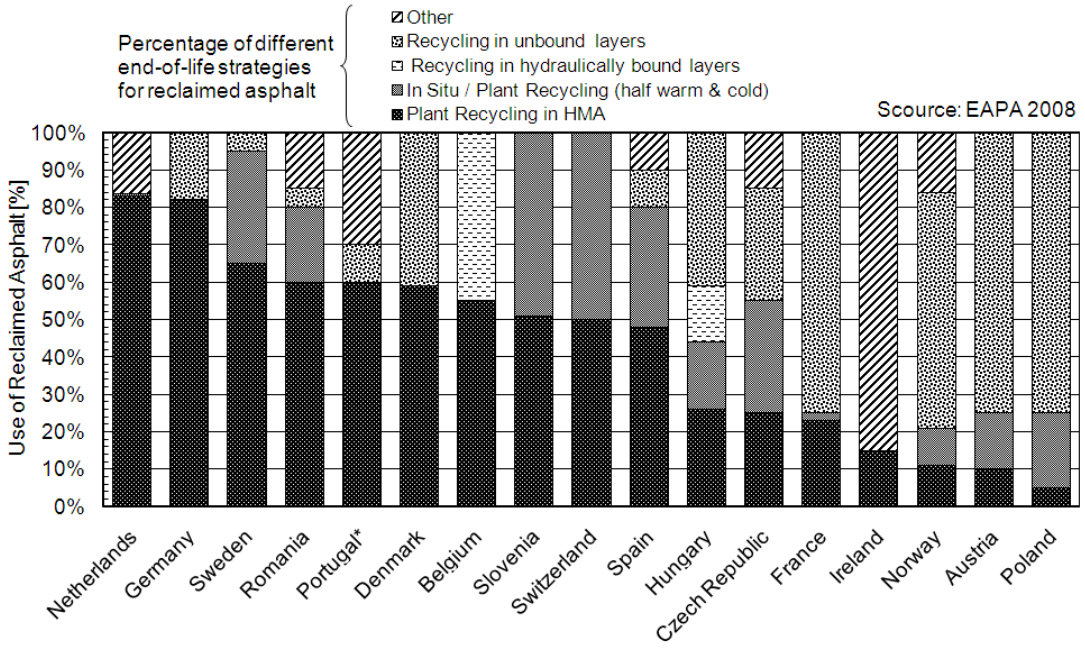

Figure 2: Use of reclaimed asphalt material in road recycling (EAPA, 2008/*2007) [2,3]

The means for characterising the existing pavement before demolition are:

- assess existing documents on road structure (e.g. road data base) regarding the following information:
  - date of construction:
    - some hazardous materials (e.g. tar or asbestos) may be excluded immediately as from a specific date their use was prohibited,
    - status of service lifetime of structure,
  - structural information:
    - (design) thickness of road layers,
    - mix design of used material,
  - peculiar structural information, e.g.
    - existence of structural improvements such as steel or plastic reinforcement (e. g. geotextile),
    - ground water level,
    - subground conditions,
    - drainage problems,
    - pipes, cables for communal infrastructure,
- assess the surface characteristics of the pavement to be demolished:
  - patches of prior repairs and seams can be used for indicating the (in)homogeneity of the structure,
  - surface deterioration (cracks, rutting) will give information on the structural properties and feasibility of material re-use, e.g.
    - rutted surface may indicate low deformation-resistance of surface course material prohibiting the application of repaving or remixing,
    - type of cracking will indicate failure type: e.g. alligator cracking indicates low bearing capacity involving the need for structural rehabilitation, whereas single cracks may indicate low resistance of surface material against low-temperatures or reflective cracking,
- non-destructive pavement evaluation:
  - assessment of structural parameters (number and thickness of road layers) by Ground Penetration Radar to indicate the heterogeneity of large road sections to be rehabilitated in order to indicate homogene pavement areas suitable for one recycling option,
  - bearing capacity tests to indicate needs for strengthening the road structure and to avoid the construction of surface wearing courses on deteriorated structures,
  - destructive pavement evaluation by testing cores will give important information on:
    - existence of hazardous substances (e.g. tar, asbestos),
    - number and thickness of existing road layers,
    - material properties of existing road layers.

Regarding the asphalt pavement condition, recommended recycling options are indicated in Table 1. As can be seen for most recycling options, in-plant recycling options as well as in-place technology is available. The only exceptions are pavements which are heavily patched where properties are very heterogeneous. For the structural maintenance of the layers below the wearing course (asphalt binder and base course, hydraulically bound or unbound road base) there is the option to reuse / recycle them as hot-mix asphalt or to recycle them in cold-mixed bituminous bound material. For all recycling options which result in new base or binder courses, the wearing course shall always be paved as hot-mixed asphalt.

4. DEMOLITION TECHNIQUES OF EXISTING PAVEMENTS

The demolition of the existing pavement is the first production step of reclaimed asphalt. In order to reach material properties resulting in high quality reclaimed asphalt which will enable high recycling rates in the new road material, some recommendations on the demolition process can be drawn.

Existing pavements can be demolished by block crushing or milling. For block crushing the entire bound pavement structure is demolished, whereas the depth of milling can be varied between some millimetres and more than 30 centimetres, depending on the milling equipment.

Whereas the reclaimed material after milling can be recycled directly without any additional processing, block crushed material needs further crushing in mixing plant or by mobile crushers. Therefore, if the material will be recycled in-place, the only option is milling.

But also for in-plant recycling techniques, milling is the preferable demolition option because this technology enables the separately demolition of the single layers. This plays an important role for the recycling of the milled material in new hot-mix asphalt, because the properties of the reclaimed material as well as their homogeneity play an important role for the mix design of the new mix. The properties of the reclaimed asphalt must fit to the requirements for the new mix. Therefore, if RA shall be added to wearing course mix, the RA must originate from wearing courses with the same of or smaller maximum grain size. By considering the actual grading of RA, it is even possible to use high percentages of RA in new SMA or MA mixes. In this way, separate milling in combination with a suitable RA management based on separated stockpiles, additional crushing, screening and homogenisation and detailed control of the RA characteristics on the plant site will help to reach high recycling rates in all kinds of asphalt mix types. Furthermore, the separated milling allows the removal of road material for recycling which is paved on top of layers containing

hazardous substances (e. g. tar). Therefore, the contamination of clean material is avoided. Because of these advantages, in 12 among 14 countries, the milling layer by layer is applied regularly or recommended by national guidelines.
For high quality asphalt mixes (usually hot-in-plant), the requirements on composition ask for homogeneous reclaimed materials, in which grading and binder content as well as aggregate and binder properties meet the requirements for virgin materials. In hot-in-plant recycling, for example, the binder of reclaimed materials is melted during the mixing process, and therefore acts as a part of the total binder of the new mix. This may require separate milling of single layers, which is of importance especially if RA is reused in surface asphalt mixes.

Table 1: Recommended recycling options for flexible pavement [2]

Pavement condition (from visual inspection)	Reuse / recycling technology									
	wearing course rehabilitation		rehabilitation of asphalt layers				rehabilitation of asphalt and hydr. bound / unbound base			
	Hot-In-Plant	Hot-In-Place	In-Place		In-Plant		In-Place		In -Plant	
			Hot	Cold	Hot	Cold	Hot	Cold	Hot	Cold
unevenness (rutting)	x	x[2)]	o[4)]	o[4)]	o[4)]	o[4)]	-	-	-	-
unevenness (bearing capacity)	-	-	x	x	x	x	x	x	x	x
skid resistance (macrotexture)	x	x[3)]	-	-	-	-	-	-	-	-
alligator cracks	-	-	x	x	x	x	x	x	x	x
ravelling	x	x	-	-	-	-	-	-	-	-
patches	-	-	-	-	x	x	-	-	x	x
longitudinal cracks	o[1)]	o[1)]	x	x	x	x	x	x	x	x
transversal cracks	o[1)]	o[1)]	x	x	x	x	x	x	x	x

x feasible, o feasible with explanations, - not feasible / not economic
[1)] if cracking originates from the pavement surface (top-down cracking)
[2)] reshaping if deterioration originates from low compaction, remixing or repaving if it originates from improper stability
[3)] repaving
[4)] if rutting originates in asphalt binder course

On the other hand, some recycling techniques are less dependent on the characteristics of the reclaimed road material than others. Cold-mix techniques only need homogeneous conditions whereas the actual composition of the reclaimed material in details (e. g. grading of aggregates, binder content, binder properties) can be neglected. In cold recycling technology, the grading of the reclaimed material is of importance but the actual composition of reclaimed asphalt, cement bound layers or unbound material is of less importance. If cold recycling technique is applied on the material produced during road demolition, the entire structure can be demolished in one working step.

5. RECYCLING OPTIONS

As indicated in figure 1, recycling options for reclaimed road materials in bituminous bound material are hot-mix asphalt and warm-mix asphalt. The other option is recycling in cold-mixed materials.
Both recycling options result in pavement materials with specific properties and shall not be confounded.
The recycling of reclaimed asphalt in new hot- or warm-mix asphalt demands for high quality RA with detailed characteristics important for the design of the new mix. Therefore, requirements are defined according to EN 13108-8 which enables the CE marking of reclaimed asphalt as a high-quality constituent material for new hot-mix asphalt. Nevertheless as indicated in table 2, the level of detail in which RA is specified as well as threshold values for important RA properties vary considerably throughout Europe.
Ideally for hot-mix recycling, the binder of the reclaimed asphalt is melted during the hot-mix asphalt production and is therefore reactivated to play its technical role in the new hot mix. This results in new asphalt mixes which have similar properties as hot-mix asphalt composed of virgin materials. The procedure on mix design, homogeneity requirements as well as experience from research works and practical application is further discussed in associating paper no. 0442.
The recycling of reclaimed asphalt pavements in cold mixes calls needs less strict requirements on the material characteristics. For the mix design of the new mixture, the grain size distribution of the reclaimed material is of importance whereas its actual composition (binder content, viscosity, grading) does not influence the resulting material performance. Cold-mixes result in material properties which differ significantly from those of hot-mix asphalt. These issues are further discussed in paper no. 0446.

Table 2: Requirements on RA for the use in HMA

Property		*Country*														
		EN 13108-8	*Austria*	*Belgium*	*Denmark*	*France*	*Germany*	*Hungary*	*Ireland*	*Poland*	*Portugal*	*Serbia*	*Slovenia*	*Spain*	*Sweden*	*UK*
Reclaimed asphalt	Type of mix	IR	x	-	specification on the resulting mix[3]	IR	-	-	-	-	-	Not specified: RA is not recycled in HMA	-	-	specification on the resulting mix[3]	-
	Max. grain size U [mm]	C	x	x		x	x	x[8]	28	40	32		32	25		32
	Binder content [%]	C	x	x		x	x	x	x	-	x		x	x		-
	Max. Ddensity ρ_m	x	-	-		-	x	-	-	-	-		x	-		-
	Content of foreign matter	C	x	-		x	x	x	x	x	x		-	-		x
	Homogeneity	C[7]	x	-		x[9]	x	x	-		-		-	-		-
Aggregates	Type of aggregate	IR	x	x		IR	x	-	-	-	-		-	x		-
	Grading	C	x	x		x	x	x	x	x[10]	-		x	x		x
	Shape index	-	-	x		-	x	-	-	x[10]	-		x	x		-
	Flakiness index	-	-	-		-	x	-	-	x[10]	-		-	x		-
	Crushed surfaces	-	-	-		x	x	-	-	x[10]	-		x	-		-
	LA Coefficient	-	-	-		x	x	-	-	x[10]	-		-	x		-
	Polished stone value	-	-	-		x	x[2]	-	-	x[10]	-		-	-		-
	Water absorption	-	-	-		-	x	-	-	x[10]	-		-	-		-
	rResistance to freezing and thawing	-	-	-		-	x	-	-	x[10]	-		-	-		-
	rResistance to freezing and thawing (NaCl)	-	-	-		-	x[2]	-	-	x[10]	-		-	-		-
Binder	Type of binder	C	x	-		x	x	x	-	-	x		x	-		-
	$T_{R\&B}$ [°C]	70	x	x		77[9]	70	x	-	70[2]	70		70	x[5]		-
	Pen [1/10 mm]	15[6]	-	10[1]		5[9]	15	x	15[4]	15[2]	15		-	x		15
	Viscosity @ 135°C	IR	-	x		-		-	-	-	-		-			-
Reference document		[4]	[5]	-	-	[6]	[7]	[8]	[9]	[10]	[11]		[12]	[13]	-	[14]

C: compulsory for CE-marking
IR (if required): National specification may specify the property
-: not specified
x: Sspecification needed for the characterisation of RA
[1] or 50 % of initial value
[2] for the recycling in surface courses
[3] specifications either as on virgin materials or on performance
[4] for RA content of > 10 %
[5] for surface working sites > 70.000 m²
[6] for soft asphalt
[7] EN 13108 specified at least 5 samples per stockpile or at least 1 sample for each 500 t. If RA is added with a smaller percentage to the HMA, 1 sample can be used.
[8] since plant hot recycling rate cannot exceed 10-20%, the only requirement is that the D_{max} of reclaimed asphalt cannot be higher than that of new asphalt mixture
[9] penetration average > 5 1/10 mm and range < 15 1/10 mm; $T_{R\&B}$ average < 77°C and range <8°C
[10] as for virgin aggregates, according to technical specification

6. RESEARCH NEEDS

The demolition of asphalt pavements and the various recycling techniques of road materials in new asphalt layers can be considered as widely used technologies in the majority of European countries. Based on the results on demolition and characterising summarised in this paper as well as the experiences made in several European countries with cold recycling and hot recycling which are presented in the accompanying papers no. 442 and 460 following research needs can be raised in order to improve the recycling technology for reclaimed asphalt.

- Characterisation of existing pavements in terms of recycling options
  - Application of ground penetrating radar (GPR) for identifying local structural defects and heterogeneities (the success of these research activities can provide an information source with practically continuous quality data about pavement layers to be demolished allowing rather reliable design of their demolition and recycling techniques).

- The development of road databases which contain the mix design data as well the rehabilitation history of the existing road network would help the choices for maintenance and rehabilitation techniques in early planning stage and reduce costs for thorough pavement characterisation.

- Cold-recycling techniques
  - Compared to hot-mix asphalt, the mix design procedures applied for cold-mixed asphalt vary considerably throughout Europe (compare paper no. 460). Pre-normative research is needed to indicate common procedures for
    - laboratory compaction methods,
    - curing procedures,
    - performance test methods and
    - mix design requirements.
  - Investigation of the effect of multiple binders in reclaimed material, on the quality of recycling (some asphalt recycling techniques are performed using bitumen emulsion or foamed bitumen and cement as binders, the medium-and long-term performance of these recycled layers should be evaluated and utilised in future research; besides, reclaimed asphalt can be contaminated during demolition by hydraulically bound materials, as for example lean concrete base material which can influence the required quality of the new asphalt layers using this crushed material.).
- Recycling in hot-mixed asphalt
  Despite this recycling procedure is widely used in Europe, some questions (as addressed in paper no. 442) shall still be addressed in future research:
  - For mix design of HMA it is assumed, that the virgin binder added mixes thoroughly with the aged RA binder. Though, experience in research and practice indicates that the mixing results rather in a double coating. Therefore, the equation for calculating the resulting binder viscosity will not be valid. This is especially of importance for HMA and RA containing modified binders.
  - Evaluation of energy need for various mixing procedures for the addition of RA in mixing plant compared to hot-in-place recycling in order to identify "carbon footprint" of various technologies.
  - Comparison of the fatigue characteristics of "traditional" and recycled asphalt layers (there is a danger that the fatigue performance of the asphalt layers with relatively high percentage of RA can be – due to various physical and/or mechanical reasons – worse than that of the layers with natural aggregates).
- Recycling techniques (execution)
  - Development of effective methodologies for reducing the workers' health risk during hot-in-place asphalt recycling (the vapours of hot bitumen and other components of the layers to be demolished and recycled in hot condition can be dangerous for the health of persons being continuously in the work places).
  - Further development of warm and half-warm mix asphalt design and construction techniques related to recycling (connected to these relatively new, energy efficient and environmental-friendly construction methodologies, there are still various open questions especially when also recycled road materials are applied).
  - Identification and solution of problems related to recycled asphalt materials with polymer modified binder or rubber bitumen (a lot of heavily trafficked road pavement structures have been built using PmB and rarely rubber bitumen; their recycling can cause environmental and/or technical problems during demolition and application in new mixes that need to be solved.)
  - Evaluation of the effect of road marking material on the quality of reclaimed asphalt and the new asphalt layers using this material (when demolishing asphalt wearing course, road marking material can contaminate the reclaimed material; there is a danger that a relatively high percentage of this plastic material can deteriorate the recycled layers.)
- Evaluation of long-term performance
  - Data collection and analysis: As the case studies gathered indicate, the level of details is very inhomogeneous. One reason for this is that the information on existing road structure (e. g. pavement construction, layer thickness, layer properties, construction techniques applied,...) were often not available even for former test roads. Therefore, creating a comprehensive data base for European asphalt recycling test roads (or even a common database on all roads) where detailed information with data considering the pavement structure, material properties, traffic loads, weather conditions, etc. in various countries will help to analyse the long-term performance of specific road materials, pavement techniques as well as innovative construction approaches.
  - Assessment of the long-term performance of former asphalt recycling test roads in various countries (if the pavement structures, the actual recycling techniques, traffic loads and weather conditions during road operation are relatively reliably known for the asphalt recycling test sections, their monitoring can provide data about the actual long-term performance of these experimental sections, and the information can be utilized in the future practice of various European countries.)
  - Long-term performance and future maintenance needs will also benefit to the assessment of cost efficiency and environmental impacts, which is another area with lack of knowledge.

The presented list of research needs is based on some aspects on pavement demolition and characterisation experiences allocated in several European countries. Aspects on cold recycling and hot recycling techniques are discussed in detail in the accompanying pares no. 442 and 460. For further inquiry the reader is advice to check the detailed literature synthesis and best practice guides as well as numerous case studies collected in the open-source web database presented on ***www.direct-mat.eu***.

ACKNOWLEDGEMENTS

The research leading to these results has received funding from the Europeans Community's Seventh Research and Technology Development Framework Program (FP7/2007-2013) under grant agreement no. 218656. The presented results are based on the project-internal national reports of all beneficiaries participating in DIRECT-MAT project..

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