Re-Road *End of life strategies of asphalt pavements*

# Processing and Management of Reclaimed Asphalt at the Mixing Plant – Final Report

Erik Nielsen et al.

SEVENTH FRAMEWORK PROGRAMME

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# Re-Road – End of life strategies of asphalt pavements

## Deliverable 4.6

## RA Processing and RA management at the mixing plant

## Final report


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# Executive summary

This report is the final report over the activities which were undertaken by Work Package 4 of the European project Re-Road which is performed under the 7th frame work programme of the EU Commission.

The subject is recycling of reclaimed asphalt into new asphalt.

The main purpose for the activities of WP4 has been to support the main objective of the Re-Road project which can be condensed to:

**Facilitate the highest possible potential of recycling reclaimed asphalt and particular to support recycling in high percentages in surface layers in high trafficked roads in Europe**

The purpose of WP4 can be seen as providing information from the great amount of knowledge and experience in the sector of asphalt producers and asphalt contractors dealing with the subject of recycling reclaimed asphalt. This information has not only been gathered to support WP4, but all the work packages of Re-Road that have the need of input and information. A special need of WP2 concerning laboratory mixing for mix design handling RA will be mentioned later.

In more detail WP4 of Re-Road has had three main tasks or subjects that consist of

**Task 4.1 Production of RA**

- Optimize milling operation for optimal use of RA

**Task 4.2 Handling of RA**

- Impact of crushing, sieving, interim transport, storage etc. on RA

**Task 4.3 Introduction of RA in the mixing process**

- Experiences on utilization of reclaimed asphalt in the mixing process and highlight associated pros and cons of different selected designs of asphalt plants in that respect.

**Conclusions and recommendations:**

Work package 4 has especially been oriented towards the asphalt producers and road contractors to bridge the gap to practise and the great pool of knowledge that exists in the road sector, but which might not have been accessible in a manner that scientists normally search for documentation.

The lessons learned for WP4 during the Re-Road project are:

- The technology is available to recycle also surface layers and not only base layers into new mixes for the same purpose with high percentages of reclaimed asphalt; even close to 100 %.
- It had been recognised that reaching for 100 % recycling can be detrimental for the durability of the new pavement because a lot of constraints (mix design, product standards, functionality, local market

situation, etc. etc.) mean that the optimal solution for reuse of old asphalt is below 100 % reclaimed asphalt addition.

- In order to save our natural resources in the long run sub-optimization must also be avoided because it can drive the development in a direction that is not optimal in a greater perspective.
- Costs of non-renewable resources will be great incentives for an economically driven optimization of the technology to increase the recycling/reuse of reclaimed asphalt. In the deliverables of WP4 details can be found that have identified some of the obstacles or barriers to recycling. This knowledge can also prove to be important for the future of recycling.

Task specific points and recommendations:

**Keeping track records**: Optimising the potential of reclaimed asphalt starts before the asphalt is reclaimed. Information on thicknesses, mix recipes and components of the individual layers in a road construction can be highly beneficial in minimizing analysis prior to milling and for planning the selective milling of individual layers.

**Access to cost-effective machines for selective milling**: The machine parks of the milling companies are dominated by general purpose machines for cold milling with coarse milling drums. These machines are not optimal for selective milling of thin surface layer and this leads often to downgrading by milling several layers in one operation. Increased focus must be given to have access to equipment capable of cost efficient separating the different layers by selective milling with as little degradation of the reclaimed asphalt as possible.

**Separate stock piles**: Management of many separate stockpiles of reclaimed asphalt is eminent for the optimal use of the valuable materials. This can create the need for large storage areas as materials of different kinds may have to accumulate to a certain level before they are cost effective to utilise.

**Constructive dialogue between road industry and authorities**: Storage and pre-processing may cause problems as other types of legislation impose obstacles for this. It is important to have or maintain a good dialog between industry and the authorities (different types and different levels) on how optimize the recycling potential in a cost-effective manner without endangering the environment and durability.

**Optimization of recycling techniques**: Even though the basic recycling techniques are available further development in application/adaptation of the technologies at the asphalt plants to the local market situation can be beneficial. For hot mix application the combination with Warm Mix technology has shown promising potential for utilisation of reclaimed asphalt which must be examined further.

**Global approach – avoid sub-optimization**: In order to drive the recycling potential to a high level to accommodate sustainability in long term perspective all players (road sector, authorities, society) have to work out a transparent system based on documented input for Life Cycle Assessment (LCA). In this manner it will be possible to achieve as global an approach as possible and to avoid the risk of sub-optimization. For this further documented LCA input information is needed.

### Progress of WP4 activities 2009-2012

Quite early in the project Work Package 2 which also embraces laboratory mixing for mix design with reclaimed asphalt had the interest to gather practical experiences from industry on how they handled reclaimed asphalt in the mix design process. Since the partners of WP4 had good contacts to the road sector, WP4 found it beneficial to the project to perform a survey among the national countries of the origin to grasp the essence on how the subject was handled by asphalt producers. With information from B, D, DK, SL, S & UK an overview was reported in Deliverable D4.1. Due to the urgent need – time wise – to have a quick response and report period to facilitate the planning of activities in WP2 it was decided not to broaden the quick to a pan-European survey.

Among the countries are both representatives for tradition of type test being done on laboratory mix and from countries where full scale asphalt plant produced mix is the basis for type testing. From the analysis of the information it was found that the synthesis on a particular point is not very easy to report since it is often influenced among others on the traditional way of performing type test in that area and the level of recycling. For this responses is organized in big tables so the responses can be read horizontal across the answers to one question but then again also vertical to see the background and conditions for these answers. One of the lessons learned was that detailed information could at that point in time be offered but the majority of the responders asked for the information to be reported as “Anonymous”. The detailed information and answers to the questionnaire are reported in Deliverable D4.1.

This quick survey on laboratory mixing provided WP4 with a preliminary input and a good picture on how answers to a questionnaire can be reported back. This knowledge was very valuable for the construction and handling on one of the main activities on processing and management of RA in the mixing plant (Task 4.2 and 4.3). From the acquired knowledge from the first questionnaire WP4 members optimised the questionnaire in that respect which also in linked to how it was issued. It was decided that each partner – apart from covering the country of origin would try to get information from one additional country in order to broaden the feedback. In these additional countries the questionnaire was used as such, but in many case for the partners involved in the particular tasks the questionnaire was combined with a through interview of the industry contacts in order to raise the the quality and quantity of the responses and to iron out any misunderstanding that easily can occur when a general questionnaire is issued to a large group of companies and people whose back ground you are not familiar with. Due to local conditions, typically the levels of recycling in the country and the contact levels (personal or general), the responses vary among the broad range of countries which are not identical for Task 4.2 and 4.3.

In total the countries are: A, B, D, DK, E, FIN, I, IRL, N, NL, PT, S and UK. The findings are reported in Deliverable 4.2.

The production of reclaimed asphalt by optimizing the milling operation (Task 4.1) has been a task for the WP4 partner IFSTTAR from France. Impact of milling operations was studied during several large scale milling jobs on French highways in order to provide information of the influence of the milling operation and its conditions on the quality of the RA compared to the properties of the material before it was "harvested".

The impact of milling on the gradation curve of the reclaimed asphalt (e.g. crushing of the larger aggregates and production of additional fines) was evaluated and compared with control samples from cores taken prior to the milling. The activities revealed also that careful preparations could be needed to obtain a representative reference sample, since the often performed survey prior to milling (coring of the old road) could be biased by the coring operation and influenced by the diameter of the core sample and how you treated the surface of the cut specimen.

The economics of the Re-Road project did not include budget for setting up full scale milling operations with a highly scientific objective, but used already planned maintenance operations for the purpose of Re-Road collection of information. This meant that even through some parameters of the different milling operation could be varied there were limits to variations that could be achieved. Some parameters were also linked or interacted either through some physical conditions or through some regulation design of the milling equipment which could not be altered freely. Through discussion the milling operators the following milling parameters were chosen for the experiments: forward speed, hydraulic pressure and water consumption, but even these parameters had some interdependencies. The detailed report can be found in Deliverable D4.3.

Following the huge effort put in to obtaining the information reported in Deliverable D4.2 – especially for Task 4.2 and 4.3, these tasks continued to activities described as "selected case studies". The principle has been that each partner based on the information in D4.2 would focus additional effort to obtain on or more of the following options in their assigned task:

1. Provide additional information on subjects which D4.2 had revealed that either was lacking or the objective of Re-Road could benefit from acquiring more detailed information
2. Describe job cases where recycling in high percentages of RA has been utilised and reporting on experience gained (pros and cons) for that particular case in order to act as inspiration for others.
3. In recognition that the Life Cycle Assessment part of the Re-Road project in Task 3.1 could use every detailed piece of information on fuel or energy consumption and $CO_2$ emission data that could be gained from full scale normal production or activities WP4 felt a special obligation to provide this kind of information – if possible.

These selected case studies of the individual partners shall not be seen as full covering jigsaw puzzle of a single coordinated plan but a focused activity to provide larger or smaller pieces of the jigsaw puzzle to support the overall objective of the Re-Road project as mentioned in the beginning of this executive summary.

Depending on the main subject of the individual case study the cases are either reported in Deliverable D4.4 if it primarily concerns the production and processing of RA, while the primary focus of the case studies in Deliverable D4.5 has been cases which include production of new asphalt materials with a high percentage of reclaimed asphalt. Some of the last cases can also contain valuable information on processing step needed to introduce the RA in the reported new production.

When the proposal for the Re-Road project was put together the partners had anticipated that WP4 could provide a major contribution to the third option mentioned above (the detailed input of information to the LCA activities on fuel and energy consumption and $CO_2$ emission. The experience gained in the Re-Road which is strongly supported by conclusions from the recent Eurasphalt & Eurobitumen Congress in Istanbul in June 2012 is the "climate" for voluntary information sharing on these subjects is definitely not in 2012 what was expected in Spring 2007. A lot of practical problems are also part of the explanation why the output of Re-Road WP4 on option 3 is meagre. But problems of competitive edge and anxiety among asphalt producers and contractors on how data on energy consumption and $CO_2$ emission can be used as parameters in future tendering documents has certainly played an important part in this. More details on this angle can be found in deliverable D4.5.

**Authors /participants in Re-Road WP4:**

This deliverable summarizes the research work conducted during Re-Road project, Work package 4.

Following authors and research laboratories contributed to the experimental studies and discussions to the results presented (sorted by partner number):

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    - Jean-Baptiste Gobert (task leader) and Thomas Gabet
- Technische Universität Braunschweig (TUBS)
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    - Stefan Vansteenkiste,
- Transport Research Laboratory (TRL)
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## List of explanations and abbreviations

| | |
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| ENxxxxx | European standard where xxxxx is the identification number for either a product statdard or a test method. |
| LCA | Life Cycle Assessment |
| LCI | Life Cycle Inventory |
| PAH | Poly Aromatic Hydrocarbons |
| PmB | Polymer modified bitumen |
| RA | Reclaimed Asphalt (US term: RAP Reclaimed Asphalt Pavement) |

# 1 Introduction

## *1.1 Objectives of WP4*

The main purpose for Work Package 4 in the Re-Road project under the auspices of the 7th frame work program of the EU Commission has been to provide information from road sector in form of milling contractors, asphalt producers and asphalt contractors in general. The team of partners for this work package has been put together in order to draw on their expertise or their connection to the road sector to support the main objective of the Re-Road project which can be condensed to:

> **Facilitate the highest possible potential of recycling reclaimed asphalt and particular to support recycling in high percentages in surface layers in high volume roads in Europe.**

**Figure 1-1 Example of high volume road leading into European capitol**

The subdivision of work into three tasks of WP4 has been:

**Task 4.1:**

- Production of reclaimed asphalt.

The purpose has been to optimize the milling operation for optimal use of reclaimed asphalt and the possible influence of milling on gradation and aggregate properties.

**Task 4.2**

- Handling of reclaimed asphalt

The objective has been to gain insight in the steps at the pre-processing unit or the asphalt plant with regard to initial inspection at delivery, crushing, sieving, storage, interim transport prior to reuse.

**Task 4.3:**

- Introduction of reclaimed asphalt into the mixing process

This part of the work in WP4 has been intended to obtain information and gained experiences with recycling at the asphalt plant and the pros and cons of different asphalt plant design in that respect.

Apart from having its own three subtasks a secondary purposes has also been initially to support some of the other work packages of the Re-Road project with information of different kind to facilitate their contribution to the overall objective. Here two special issues shall be highlighted:

- Practises in laboratory mixing for mix design of new asphalt materials where reclaimed asphalt is introduced as a vital component for the benefit of WP2 Task 2.2.
- Information of various steps or operation where data like energy consumption, $CO_2$ emission or associated economics could facilitate the Life Cycle Assessment (LCA) in WP3 Task 3.2.

The work accomplished in this work package has been documented in several deliverables which holds the detailed information of various subjects and issues. The purpose of this report is to provide the reader with an executive overview on where more detailed information can be found. This document (deliverable D4.6) is together with the other deliverables downloadable from the project website at http://re-road.fehrl.org .

**Figure 1-2 Front page picture of Re-Road deliverables**

## 1.2 Description of WP4 deliverables

In this section a short description will point out the different deliverable of WP4, the main author or editor and the main focus of the document.

### Re-Road Deliverable D4.1

Erik Nielsen: *Laboratory Mixing - State of the Art*

The deliverable describes a survey with input information from Belgium, Denmark, Germany, Slovenia, Sweden and United Kingdom with respect to practises for mix design – especially when reclaimed asphalt is incorporated in the mix. The objective was to provide information to Task 2.2 in WP2 and facilitate the decision of optimal parameters in the experimental design for laboratory mixing incorporating reclaimed asphalt. Other types of information on recycling have been collected as well as a pre-test for activities described in Deliverable D4.2.

**Figure 1-3 German produced laboratory mixer with capacity of approx. 20 kg asphalt mix**

### Re-Road Deliverable D4.2:

Erik Nielsen (editor): *Status Report on Activities and Background for Selection of Case Studies*

The deliverable contains the result of a survey with detailed information from several European countries on handling and pre-processing reclaimed asphalt at the processing site or asphalt mixing plant and its later introduction into the mixing plant in order to produce new asphalt mixes.

**Re-Road Deliverable D4.3:**

Jean-Baptiste Gobert: *Milling Operation: Possible Influence on Gradation and Aggregate Properties*

The deliverable describes after a state of the art on cold milling the influence of milling operation on the aggregate gradation and properties. Several test trials are followed, where important parameters like hydraulic pressure and water consumption varied.

**Figure 1-4 Milling machine on French national road N141**

**Re-Road Deliverable D4.4:**

Dina Kuttah et al.: *Production and Processing of Reclaimed Asphalt - Selected Case Studies*

The deliverable describes several case studies which have been documented to expand the findings from Deliverable D4.2 on special issues like handling and storage of reclaimed asphalt. A special case of a interim storage facility for tar-containing reclaimed asphalt is documented from an environmental point of view.

### Re-Road Deliverable D4.5:

Marjan Tušar et al.: *Optimization of Reclaimed Asphalt in Asphalt Plant Mixing*

The deliverable describes several case studies where the focus is on introduction of reclaimed asphalt in the mixing plant, but the case studies contain also to some extent information on the pre-processing and handling of the materials prior to production of the new materials. A Slovene case study describes the combination of reclaimed asphalt in high percentage and warm mix technology.

**Figure 1-5 Warm mix additive combined with rejuvenator is added manually in the Slovene mix trial**

### Re-Road deliverable D4.6:

Erik Nielsen et al.: *Processing and management of reclaimed asphalt at the mixing plant – Final report*

The present deliverable is a condensed summary report with high lights and conclusions from the other deliverables and activities in Re-Road Work Package 4.

# 2 Mix design with reclaimed asphalt

## 2.1 Laboratory mixing

At the beginning of Re-Road it proved important for WP2 to have some input from the road sector on how reclaimed asphalt was treated in laboratory mix design. A European standard described the principle for mix design but it was not clear what level implementation this standard had reached. According to the objective of Task 2.2 WP2 intended to evaluate the influence of certain mix parameters on mix design with reclaimed asphalt. Input was needed to establish the most appropriate parameters for that exercise.

WP4 put together a short questionnaire which was issued to the road sector in the countries of the partners of WP4 since time was eminent to avoid causing delays in the planning of activities in WP2.

More than 23 responses were collected

Belgium: 1 response (covering a general industry review)

Denmark: 7 responses

Germany: 2 responses

Slovenia: 1 response

Sweden: 7 responses and

United Kingdom: 5 responses

At a first glance the responses seem to be unevenly distributed but a response can represent a national organisation or major asphalt producer in that country or region with several asphalt plants following the same company policy or local tradition. For instance the Belgian response originates from an organisation and the 6 responses from Denmark cover all asphalt producers with in total more than 50 asphalt plants of various configurations.

Several of the responses have asked for the information to be handled anonymously. For this reason all the detailed answers in Deliverable D4.1 are coded and slightly edited in order to strip the company name in some of the answers.

It will be evident from the responses that national traditions in pavement and mix design have a huge impact on some of the information so the national identification is necessary.

The seven groups of information in the questionnaire are

1. Information
2. General company information
3. Background on mix design

4. Asphalt plant data
5. Laboratory mixer equipment
6. Laboratory mixing procedure
7. Full scale asphalt production

## *2.2 Additional comments to the responses*

Some of the following comments and focus points have also been mentioned in the case of gathering the data for laboratory mixing practise as explanations for why a higher percentage of RA was not achieved:

Percentage of RA is the produced asphalt material is often limited by a complex set of constraints which prohibit a high percentage of reuse in a particular mix. Among these factors are:

- binder ageing in the RA
- energy consideration (heat transfer limitation versus plant modification investments)
- gradation of RA in relation to the gradation of the new asphalt
- the demand for control of the gradation of the new asphalt (noise reducing surface layers)
- availability of RA (large enough amount of homogenous RA material)
- area and environmental approval of stock piles
- cost/benefit considerations for
    - virgin materials versus RA
    - upgrading RA for reuse in surface layers
    - demand for laboratory control of RA

**Figure 2-1 Laboratory mixer**

National or regional tradition in road building is reflected in some of the answers to the question-naires. A good example is Type Testing where the Belgian situation is based on laboratory mixed sample and Denmark where full scale production is used. This is of course also influenced by the national selection from the European products standards (the EN 13108-x series)

## 2.3 Discussion & Conclusions

The information is predominantly the result of voluntary responses to a survey of practises in laboratory mixing combining the use of mix design and utilisation of reclaimed asphalt. The objective has been to provide Work Package 2 input on the present situation in different countries and among different companies operating under common conditions. For this reason the contributions in the tables can be seen as initial raw data for a more thorough consideration by the partners in Work Package 2 for determining appropriate parameters for their laboratory mixing study..

All countries covered by this survey are acting under the common set of European asphalt product specifications in the EN 13108-x series where a large range of test methods (predominantly the EN 12697-xx series) are offered as shared background common for type testing and quality control. Nevertheless, large differences are seen in the collected input which may correspond to either country or company tradition or policy. From a CEN and a scientific point of view a few of the answers describing practise can be a little surprising. Regarding the present utilisation of RA national conditions can influence both percentage of RA in the produced mix and which layers in the pavement structure where addition of RA (in practise) are acceptable.

Some items are highlighted below but it must be kept in mind that the population of responses can influenced or biased by their local situation.

1. Generally a cross section on the responses on percentage of RA indicated that 15-20 % often is the maximum unless parallel drum or similar device for preheating the RA is available. Several points are mentioned as reason to stay at this level:
    a. Concern whether or not investment in production equipment for reaching higher percentages with the present and future level of availability of RA will have a reasonable payback period.
    b. European products specification provide more lenient quality control for the RA if the asphalt producer stays below 10 % RA in surface layers and 20 % RA in bituminous base courses.
    c. Technical limitations of the RA (like aggregate gradation and binder properties) enforced restriction in what is possible in normal practise.
2. Marshall mix design is in general still the most used guide for development of new mix recipes.
3. A wide selection of different sizes and manufacturers of lab mixing equipment exists.
4. If technical limitations are mentioned almost all responses point at maximum aggregate size.
5. Dry mixing with aggregate seems to be the predominant cleaning procedure of the mixing equipment.

6. Even though a European standard exists for laboratory mixing (EN 12697-35) it is only used by half of the companies responding.
7. A few responses mention a special sequence of addition of the constituents while the predominant part use an initial dry mixing of "all in" (e.g. all aggregate premixed before addition of binder).
8. Introduction of RA in laboratory mixing is predominantly performed with heated RA irrespectively of the situation at the asphalt plant (cold feed versus preheated by parallel drum or otherwise).

**Figure 2-2 Swedish asphalt plant**

9. Some asphalt producers don't use laboratory mixing at all, but use full scale asphalt production facilities for their development of mix recipes. One response even claims it is cheaper.
10. In general mixing temperature are selected by viscosity of the binder or preselected depending on the grade of binder which may result in comparable temperatures used.
11. Only very few responses claim that their laboratory mixing procedure is linked closely to the conditions of the local asphalt plant.
12. In general the laboratory mixing procedure is used to establish the optimum mix with respect to homogeneity and binder coverage, so mixing times (especially wet-mixing times) are prolonged relative to actual asphalt plant conditions.
13. If special constituents like RA, PMB or cellulose fibres are added some responses mention extended mixing times.

Deliverable D4.1 reveals that a great variety exists in the utilisation of reclaimed asphalt, percentage used and how laboratory mixing is performed (if used at all).

The objective has been to provide the experts of Work Package 2 with some back ground information on the practise in the industry when the Re-Road project started in 2009. Some caution must be taken in the interpretation of the responses as it is a collection of voluntary responses and not a pan-European survey. However the responses from some countries (e.g. Denmark, Sweden and UK) are representative for the general practise in those countries, but yet again from a pan-European perspective these general practises may be influenced by national tradition and circumstances even though common European standards are introduced.

# 3 The three main tasks of WP4

## 3.1 *Work plan of the tasks*

In section 1.1 the tasks of this work package are described with respect to content but they have not all three been designed to follow the same work plan due to different anticipation to sources of information..

Task 4.1 production of reclaimed asphalt used a literature study to surveys the field of milling and to extract important parameters of milling operation. These parameters could be examined through analysis of a number of already planned milling jobs on rehabilitation works on French highways.

For Task 4.2 Handling of reclaimed asphalt and Task 4.3 Introduction of reclaimed asphalt into the mixing process it was envisaged that it would be more advantageous for the information gathering to issue questionnaires aimed at the road sector. The expectation was that the most up to date information on positive and negative experiences for these subjects would not find its way into literature and articles which later could be found it library databases. The two tasks would follow similar work plans consisting of set-up of very thorough questionnaires which later could be analysed. The final stage was a number of selected case studies which could provide even more detailed information on certain subject or supply information on subjects where the responses revealed missing pieces of the puzzle.

## 3.2 *Documentation*

Production of reclaimed asphalt through milling has been reported as an interim report as part of deliverable D4.2, but the final contribution of this subject can be found in the deliverable D4.3, which will referenced in the section 4 of this present final WP4 report.

The results of the questionnaires covering handling and introduction of reclaimed asphalt into the mixing process are reported in the combined deliverable D.4.2. In the present report the two subjects will be handled in section 5.1 and section 6.1 respectively.

The continuation in form of the selected case studies are reported in deliverables D4.4 and D4.5 respectively. In the present report the two subjects will be handled in section 5.3 and section 6.1 respectively.

The selected case studies in deliverable D.4.4 deal almost exclusively with handling of reclaimed asphalt. The selected case studies for introduction of reclaimed asphalt into the mixing process on the other hand can also contain elements of handling in order to provide a full description of the conditions and background for the study.

# 4 Production of reclaimed asphalt (D4.3)

## *4.1 Objectives and limitations*

The present level of technology revealed in the literature review for production of reclaimed asphalt by milling that in practise only cold milling is performed. Hot scarifying of an old pavement surface as part of the remixing process is not considered as production of reclaimed asphalt because the material resource is not obtained to be used in general manner for purposes elsewhere.


**Figure 4-1 Rehabilitation work - milling on French highway N12**

Cold milling works can be performed in order to reach various objectives:

- **Improve the adherence conditions**: fine milling machines can just remove the very first millimetres of the smoothed existing surface in order to regain roughness and adherence;
- **Reshape the road surface**: milling allows restoring the initial road profile by removing some material instead of overlaying where there is a lack of road material (collapsing, stripping, potholes, etc.). In this case, milling also restores drainage flow.

- **Lower the road surface**: milling prevents the road from being elevated too much because of regular overlays that are not consistent with bridge clearances, thresholds for entrance ramps and kerbs, bridge overloads, etc. The defective materials are removed without deconstructing the whole structure.
- **Totally deconstruct the existing road**: in this case, all materials are removed and a new structure is laid.
- **Special purpose (e.g. traffic safety)**: Milling can be used to changes the texture of the surface to introduce acoustical or vibrational impact on the driver as part of traffic safety features. This kind of milling is not considered as production of reclaimed asphalt as the tonnage produced is minimal.

After a review of the history with past and present developments the different elements in the milling technology is described as mentioned in the following list:

- Milling machines
  - Cutting and fragmenting system
  - Cutting tools
  - Water input
  - Evacuation of milled products
  - Driving system
  - Operator panel
- Execution of the milling works
  - Preparation
  - Organisation of the passes
- Milling
  - Sweeping
  - Requirements for the milled surface
  - Requirements for milling products

## *4.2 Possible influence of the milling on aggregates*

The expected changes of the reclaimed asphalt as opposed to the materials in place are mainly changes of the particle sizes (for any fraction) which are supposed to decrease because of possible fragmentation and attrition. In parallel it is possible to expect:

- the flakiness to be modified, but it is quite difficult to anticipate its evolution (increase or decrease of the flakiness index),
- the angularity and roughness to change (creation of new broken faces delimited by sharp angles, attrition),
- the fines content to increase because of the aggregate "crushing" under the cutting tools action. However, the fine content may also decrease because of the loss of fines during milled surface sweeping. Usually it increases of 2 or 3% (order of magnitude).

## 4.3 Milling parameters, field study and laboratory analysis

Several field surveys were performed on rehabilitation milling road works and it was envisaged to vary a number of important parameters – if possible – during each milling operation in order to examine the impact on the characterisation of aggregate gradation and quality. Several candidates for these parameters are mentioned in the next paragraph, but some of them was not free to vary due to contractual constrains of the milling job between road owner and contractor:

- **Milling depth:** the milling depth is set during the preliminary surveys by the road owner in agreement with the milling contractor.
- **Road materials:** Each of the job sites had to be treated individually, since it is almost impossible to find two different road works with exactly the same materials.
- **Machine type and characteristics** (drum diameter, number and tool positioning on the drum, etc.): these parameters could be varied, but in practise the contractors tend to purchase huge general purpose milling machines (capable of high capacity cold milling of thick layers) the variability was virtually non-existing.
- **Drum rotation speed:** on the machines that were used for the field survey, the drum rotation speed is not directly controlled by the driver but it is linked to the hydraulic pressure on the drum. The higher the pressure, the lower the rotation speed.

Finally, two main parameters were selected:

- **the machine forward speed**, which appeared to be linked to the **hydraulic pressure on the cutting drum** (i.e. basically the power needed for milling the pavement). This hydraulic pressure was finally the chosen parameter because it is directly controlled by the driver. Depending on the milling “aggressive-ness”, the aggregates may be subject to various wear.
- **the water flow :** the water being some kind of lubricant as well as a coolant, its flow may have a significant impact on the milling “aggressiveness”. The aggregates may be less damaged if more water is added during the milling.

Whenever it was possible, cores were extracted some days before the milling operation itself because the milling usually starts right after the traffic neutralisation and the intention was not to disturb the milling contractor when working just ahead of them on the same day. The cores were assessed by visual inspection and analysed according to the scheme in Figure 4-2. But an important point must be mentioned that can affect the quality of the reference sample. When coring the old pavement the core diameter has an influence on the amount of cut aggregates on the cylindrical surface of the specimen. The larger the diameter the lesser impact on the gradation curve. This is illustrated by the following experiment shown in Figure 4-3.

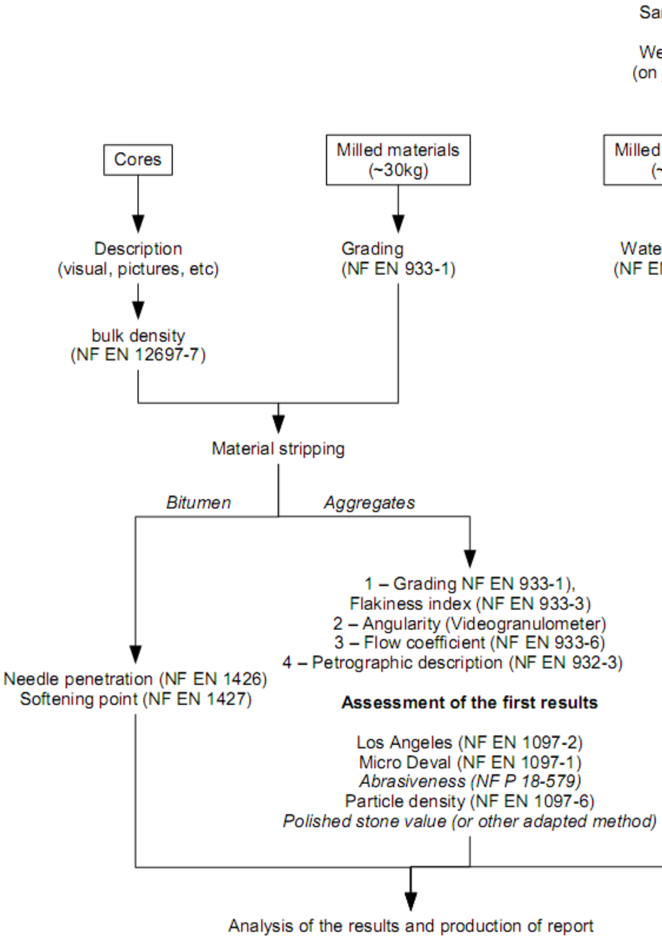


**Figure 4-2 Tests for the field studies**

**Figure 4-3 Impact of core size on reference sample. Elimination of cut surface aggregates on N164 core**

Figure 4-4 displays two curves:

- *DD-M 09-23: MEAN C* represents the grading of the aggregates obtained by removing the binder,
- *DD-M 09-23: cores without surface aggregates* represent the mean grading of two cores after removing the cut aggregates on the cylindrical surface.

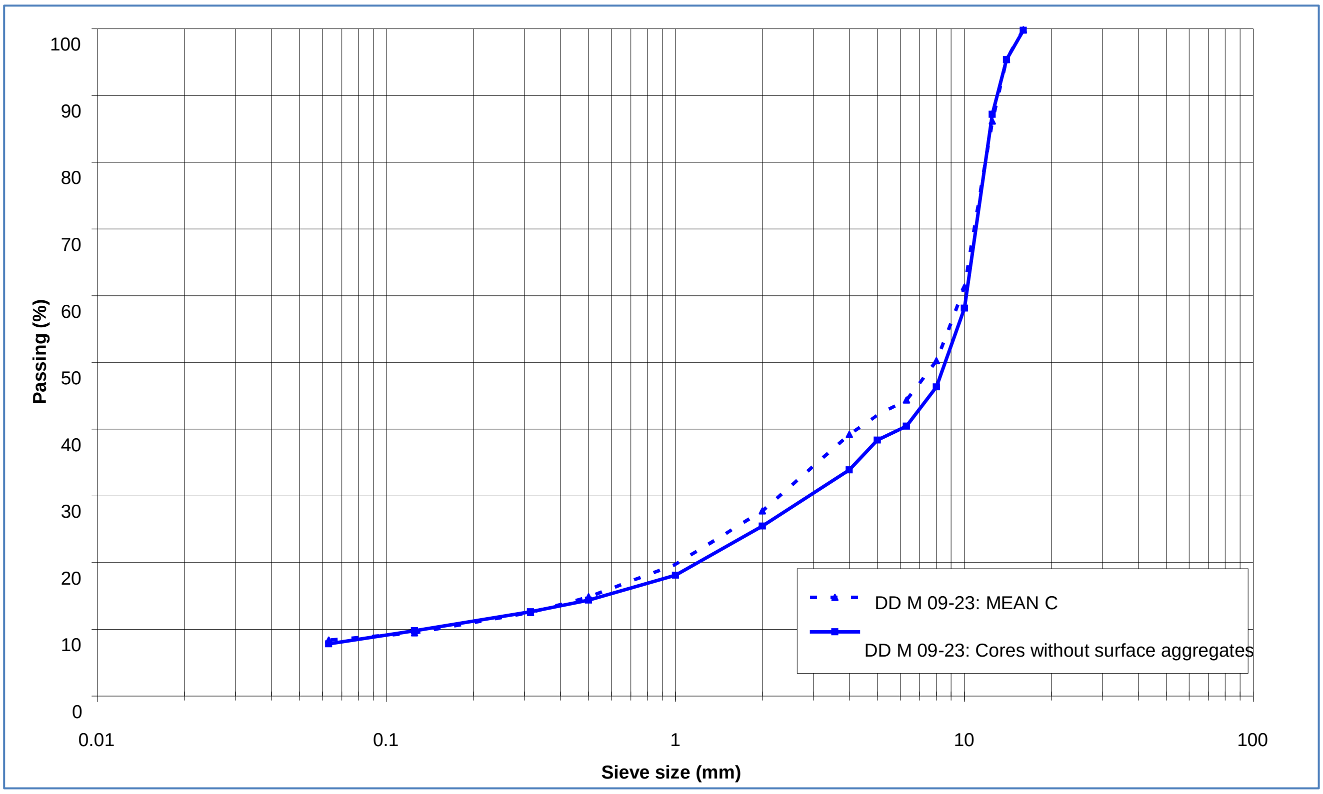


**Figure 4-4 Impact of cut surface aggregate on the reference sample**

The first curve (MEAN C) has less aggregates than the “cores without surface aggregates”, in the 1/10 fraction. It can be interpreted by the fact that cut aggregates are smaller than the ones existing in the pavement. In this study, the effects due to removing cut aggregates from the cores are considered as significant and has been taken into account in the remaining the four of the five case studies whose locations are given in Figure 4-5.

## *4.4 Conclusions of the impact of the parameters*

**<u>Water in RA :</u>** Quantifying the correlation between RA water content and quantity of water added during the milling operation remains difficult, despite the trends observed. The two effects of the speed and the magnitude of the water flow may compensate each other: going slower lead to add more water for a given water flow. This question of RA moisture, which is very important when the RA must be reused straight into a new warm or hot bituminous mixture, was however set aside in all studied cases for this report.

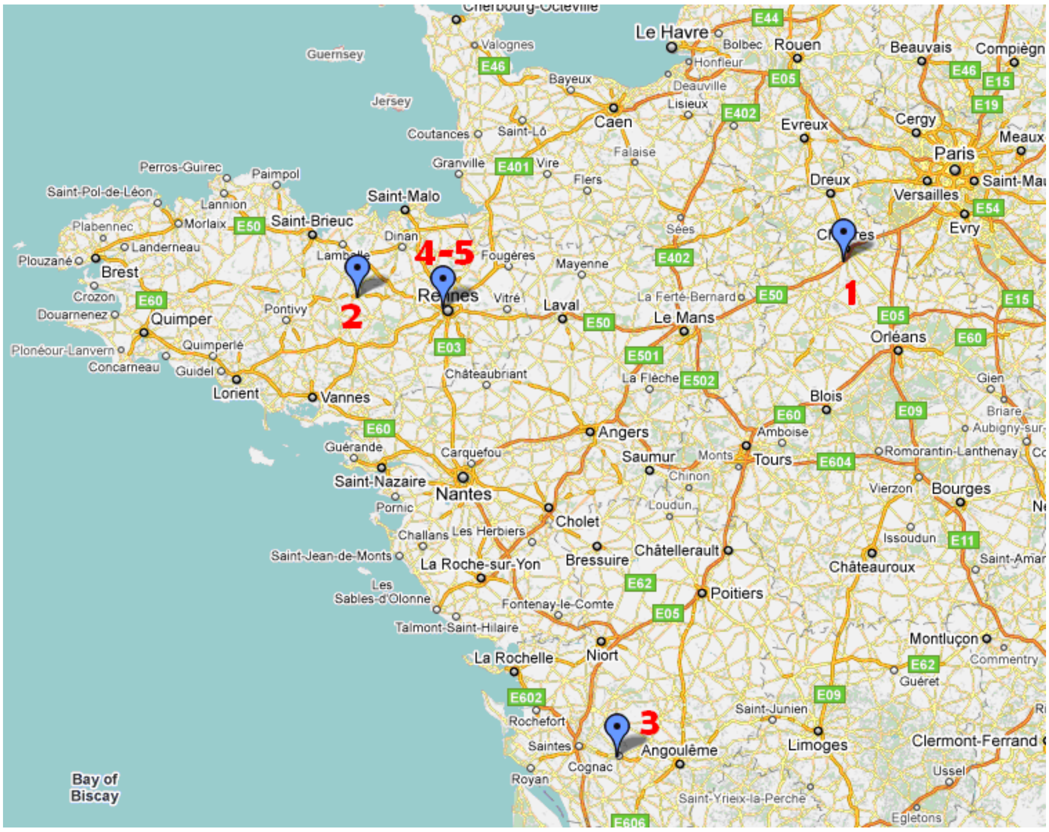


**Figure 4-5 Locations of the five job sites in western France**

It seems that the water flow is mainly adjusted and optimized to prevent cutting tools to wear and to save time, while trying to maintain a reasonable quality of RA. Neither rules nor advises are applicable or applied at this time. This does not help to improve the quality of RA.

<u>**Aggregate deterioration:**</u> From the three sites out of four that have been studied, grading has shown a trend to be modified during the milling process. The aggregates reclaimed from milling seem to be finer that the ones obtained by coring, with a few more fine particles in the milled products. It can be noticed that some fine particles are eliminated by the sweeping and are not recovered. The sweeping was not a subject of this study, although it would have been interesting to analyze it.

Once given this general result, no visible and recurrent effect (from one site to another) of the milling parameters on the grading of the aggregates after extraction of bitumen has been observed. In any case an “optimal” tuning of the machine could be determined to conserve the aggregate grading.

The conclusion is similar for the flakiness index evolution of aggregates after extraction of the bitumen. Several sites showed a decrease of about 2-3 points of the index, one showed no evolution during the milling. Such levels remain in the range of the repeatability of the test, according to the standard EN 933-3. The trend is that milling seems to “round” some flat aggregates as an appropriate crushing can do. However there is no evidence of an effect of the milling parameters on the flakiness index. These results cannot be generalised for other kind of materials, apparatus, or job sites.

**<u>Future variables to examine:</u>** Another key parameter could have been studied: the wear of cutting tools. Indeed, the hypothesis that wear is negligible between two modalities is maybe to strong. It can also be thought that variations in wear have a greater effect than hydraulic pressure or water flow. The quality of interfaces between two layers to be milled seems also to be an important parameter, which would need to be studied. Such study has maybe highlighted the difficulty to perform experimental research on a real job site: owners must agree, shall let us operate while they are working, shall let us study their material and see potential problem, shall let us talk about their know-how, and must allow modifying of some parameters. It is also obvious that a job cannot be done a second time. When something is wrong, it cannot be easily modified. That is why the number of results is less important than expected.

It is clear that the focus is presently set upon organisational questions (as discomfort to the user, machine and cutting tools preservation, etc.) during milling and not on the aggregate preservation. The changes led by the milling to the aggregates have not showed any sufficient magnitude to involve changes in the way the milling works are performed currently (at least for the type of works that were observed for this study). Indeed, other RA “parameters” are obviously more important when aiming at having a RA that can be reused in a new bituminous mixture: quality and knowledge of what is reclaimed, selective milling of each separate bituminous layers – especially with respect to materials that are not bitumen-bound (shoulders, central reserves, hydraulically-bound subbase), and homogeneity of the deconstructed pavement. The RA storage, handling and processing is also of prime importance for the optimal reuse of such materials.

**Figure 4-6 Milling near the central barrier on national road N12**

# 5 Handling of reclaimed asphalt

## 5.1 Result of the questionnaire (D4.2)

The situation at the pre-processing site or at the asphalt plant has been assessed with focus on

- practical aspects of control issues at the gate when reclaimed asphalt is delivered (including sampling and analysis),
- the use of pre-processing of the RA and
- interim storage before reuse.

Through a questionnaire information has been collected from several countries which the partners have been in contact with. The collected information reflects the present state from which recommendations for best practise can be deducted. To a certain extent the responses to the questionnaire also reflects national legislation, contractual relations and tradition that influence the objective of Re-Road with respect to reach very high percentages of RA in surface layers. These restrictions or limitations will also be assessed in the analysis of the responses.

Processing and handling of the RA at the asphalt plant can also be a part of the process to upgrade or ensure utilization at the highest possible level. Pavement slabs need crushing and/or perhaps manual handling to separate, if possible, bituminous base from surface layers to achieve the goal.

Even if the RA arrives at the asphalt plant site as milled material crushing and sieving can be necessary before it can be placed in interim storage.

In order to control the quality of the asphalt in which the RA shall be used, the asphalt contractor needs to identify individual materials in the RA (aggregate properties, amount and age/hardening state of the bituminous binder and dangerous substances like coal tar or asbestos), likewise if beneficial components add to the value or potential of the material like the presence of polymer modified binders or wear resistant aggregate. This can be done as a validation “at the gate” with the use of speed-screen methods or some in-house method.

To collect information on how contractors in different countries handle RA a questionnaire was distributed to members in WP4. Contractors in Denmark, Finland, Sweden, Norway, United Kingdom, Ireland, Slovenia, Austria and Italy were asked to answer the questionnaire. Some difficulties in getting answers occurred, mainly because it was easier to get answers in “our own country” than getting a reply from a company in a foreign country.

Nearly all companies that were approached asked for their contribution to be handled anonymously which means that there will be no reference from a piece of information to the name of the company in question.

## 5.2 Summary of questionnaire

Some differences in validation of RA between countries were expected. Due to the climate in the northern countries, and use of studded tires, surface layers with high quality aggregate are separated for reuse in surface layers. Also the maximum aggregate size is higher (16 mm) due to better wear resistance.

Denmark uses nearly all RA for base layers, since road authorities are reluctant to allow it in surface layers to avoid the risk of frost sensitive aggregate particle from old base courses. Therefore all RA goes into the same pile.

All countries document their RA according to EN 13108-8.

The value of the RA varies, it can be positive, zero or negative depending on local situation. In some cases RA is the property of the road owner.

Beside contamination of earth or gravel, coal tar is the only real contaminant to consider. The only speed screen method used is for coal tar.

Size and type of interim storage depends on local legislations. Some companies have paved foundations and sewer systems with oil separators to take care of run-off water from RA piles in one plant, while the other plant has its stock piles on gravel. In order to minimize water content and save fuel tents or some cover is used, at least for finer fractions.


**Figure 5-1 Front loader – a commonly used vehicle for interim transport**

Interim transport of RA is handled as virgin material. RA is normally crushed in batches and the amount varies from “not very big” to 10,000 - 15,000 t. Roof shaped piles are common and actions to prevent segregation are taken.

Crushing and sieving is performed in one operation, with a feedback loop for oversized material.

The question about environmental survey shows differences between legislation in different countries.

The amount of RA reclaimed varies between companies and even in companies depending on location (From 5,000 t up to 350,000 t).

This was a summary of the information gathered from the questionnaires, but many more details can be found in the deliverable D4.2 Annex 7.1 from the individual countries mentioned in Table 5-1 as documented results of the questionnaire from Task 4.2..

**Table 5-1 Countries that were targeted with the questionnaire from Task 4.2 Handling of reclaimed asphalt.**

| Partner | National country | Second country |
|---|---|---|
| DRI | Denmark | Finland |
| PEAB / VTI | Sweden | Norway |
| TRL | United kingdom | Ireland |
| ZAG | Slovenia | Contacts in Austria/Italy |

## 5.3 Selected case studies (D4.4)

Based on the responses from the questionnaires each partner allocated to this task in work package 4 has tried to develop selected case studies as supplements and to support the objectives of the Re-Road project. This has resulted in five different cases that are documented in deliverable D4.4.

### 5.3.1 Production of reclaimed asphalt from Danish motorways and associated conditions for milling and maintenance.

The first case concerns how selective milling of old surface layers on Danish motorways for maintenance works has created new insight in risks that can occur when the noise reducing thin surfacings are applied as replacement. The experience gained in Denmark results from a multifactorial failure pattern with impact of parameters like:

- Selective milling of old surface layers (milling depth and quality of layer beneath)
- Coarse versus fine milling (texture of substrate)
- Impact of period of traffic on milled surface under wet conditions
- Harsh winter conditions
- Maintenance work at night to ease traffic congestion at rush hours
- Durability of new surface layer

**Figure 5-2 Milled surface on M20 motorway on Zealand, Denmark**

A Task force was created to assess the cause of the decrease in durability and the case study concludes with recommendations to solve or avoid the problem in the future. Time will tell whether the recommendations have been sufficient to restore the durability.

### 5.3.2 Removal, storage and processing of reclaimed asphalt in Sweden

From Sweden two case studies describe the situation for handling reclaimed asphalt. The first one is a general documentation of the conditions for removal, storage and processing of asphalt materials for recycling which can be in form of

- Hot recycling
- Half-warm recycling
- Cold recycling or
- Recycling into unbound layers (down grading)

Practical experiences gained in stock pile management and steps to avoid unnecessary caking are mentioned

**Figure 5-3 Sorted RA materials for hot recycling. The heaps on the left consist of fine and coarse-grained asphalt concrete mixes respectively, while the heap on the right consists of stone mastic asphalt mixes.**

### 5.3.3 Environmental impact of handling tar-containing reclaimed asphalt at an interim storage and processing site in Sweden

The second Swedish case has special focus on the environmental impact of an interim storage and processing site before, during and after handling of tar-containing reclaimed asphalt which was recycled through a half-warm process.

In connection with the rebuilding and strengthening of Highway Road 348 on a stretch from Bredbyn to Solberg (approx. 570 km north of Stockholm, Sweden) reclaimed asphalt (RA) was utilized for the construction. The road from which the RA was produced was known to contain tar which meant that the produced RA would be tar contaminated. In order to examine the environmental impact a special temporary storage area was established with determination of the PAH level at the site before the storage was built, during the storage period and after dismantling the storage site.

**Figure 5-4 Sampling in the buried tank (tank 2).**

A paved site was established with collection systems for surface water and water samples were taken to follow the PAHs and a potential risk of contamination of the surroundings.

### 5.3.4 Demolition subcontractors for processing reclaimed asphalt.

In the initial questionnaire results from Denmark it was found that reclaimed asphalt from various smaller sources (both slabs and milled pavements) went into an inhomogeneous stock pile which once or twice a year was crushed and sieved by a demolition subcontractor. For this reason only a few details about these processing steps were found. To improve the knowledge on this point a special questionnaire was put together and issued to the demolition contractors that operate on reclaimed asphalt in Denmark. From the information gathered it seems that the role as subcontractors for the asphalt companies is a minor activity with respect to reclaimed asphalt, as the materials they receive themselves goes into unbound use (down grading).

**Figure 5-5 The challenge for the demolition contractors - Reclaimed asphalt ready to be processed**

# 6 Introduction of reclaimed asphalt into the mixing process

## 6.1 Results of questionnaire (D4.2)

The partners of Task 4.3 have gathered information from their own national references given in Table 6-1 and tried to gather information from one additional country. Due to difficulties to get the questionnaires to the right people the information from this work has not been as successful as for the national country where also personal contacts could be utilized.

**Table 6-1 Countries that were targeted with the questionnaire from Task 4.3 Introduction of reclaimed asphalt into the mixing process.**

| Partner | National country | Second country |
|---|---|---|
| BRRC | Belgium | The Netherlands |
| DRI | Denmark | Finland |
| PEAB / VTI | Sweden | Norway |
| TUBS / LCPC | Germany | France |
| TRL | United kingdom | Ireland |
| ZAG | Slovenia | Contacts in Austria/Italy |
| LNEC | Portugal | Spain |

The aim of this project deliverable is to present knowledge obtained on the inclusion of RA and the method of addition of RA into asphalt mixtures across Europe. A questionnaire was developed and sent to suppliers to gain an understanding of current practice.

**Figure 6-1: Stockpile of slabs of reclaimed asphalt (CMC - Slovenia)**

The questionnaire on introduction of RA in the mixing process was used to find the benefits and problems of different designs of asphalt plants. Representatives from several European countries (Belgium, Germany, Denmark, Finland, Ireland, Netherland, Portugal, Slovenia, Spain, Sweden and UK) answered the questionnaire . In the questionnaire a list of different designs of asphalt plants was included. Design of the asphalt plants was not the only consideration of questionnaire. From answers we also wanted to find experience on different ways of addition of the RA. The main goal was finding all possible scenarios enabling us to achieve high levels of RA into the mix.

## *6.2 Responses on questionnaire on introduction of RA in the mixing process*

### 6.2.1 "In situ" recycling

First part of the questionnaire deals with "In situ" recycling. Several countries responded that they use REMIX technology right for the replacement of the wearing course. Also foamed bitumen (and emulsion) technology is frequently used. Base asphalt layer is commonly produced with foamed bitumen (and emulsion) technology.

### 6.2.2 "Mix in plant" recycling

Second part of the questionnaire deals with "Mix in plant" recycling. Roughly 95% of asphalt plants are batch plants with charge production. In Europe there are several manufacturer's of asphalt plants: Benninghoven, AMMANN, Marini, Wibau, Vianova, KVM, Astec, Ermount, Braham Miller, Bristow, KVM, Marini Parker, Standard Havens, Titan, Teltomat, Alfelder, Uniplant, Gibat, Vögele IMA, Huther, and Linnhof.

The maximum capacity of asphalt plants varies significantly from 50 t/h to 600 t/h

Optimum content of reclaimed asphalt in asphalt mixture varies in different countries from 7 % to 50 % (m/m). 50 % (m/m) means that new asphalt mixture consists half from reclaimed asphalt and half from virgin material. In Netherland in wearing course optimum content of reclaimed asphalt is 30 % (m/m) and in base course 50 % (m/m).

Capacity of asphalt plant when reclaimed asphalt is used can increase 30 % when parallel drum is used, but in cases, when cold reclaimed asphalt is introduced in the mixer, the capacity can even decrease down to 20 %.

Prolongation of the mixing time varies from 0 s up to 15 s when reclaimed asphalt is introduced.

Softer bitumen is the most common virgin material added to the mixture. Some producers use additives like rejuvenator oils as a lubricant in a parallel drum. Other additives include hydrated lime, PFA, and Sasobit.

Heating reclaimed asphalt indirectly with hot mix of stone fractions is, in the majority of countries, the most common way to introduce lower quantity of reclaimed asphalt. Only in Belgium and Netherland separate heating of reclaimed asphalt and hot mix of stone fractions is the mainly practise.

For recycling using continuous plants, heating reclaimed asphalt together with stone fractions is more common than heating reclaimed asphalt in a separate device ("black drum").

There is a method used for mixing cold and warm RA method in Denmark (Figure 4-2), and this technology has the potential to replace parallel drum technology.

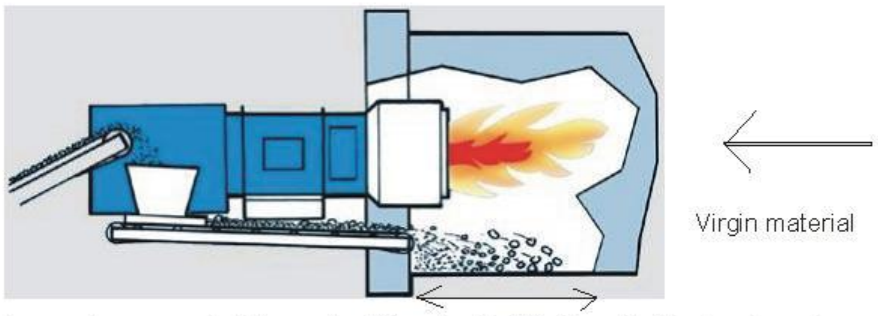


**Figure 6-2: Mixed design of cold and warm RA method**

### 6.2.3 Evolution of problems connected with moisture content and PmB in RA

In Germany, the water content of the RA is considered. The German guidelines give a table containing the same figures as the table in the questionnaire with an additional line for 40 % RA content (Table 4-1).

**Table 6-1 Elevation of temperature (OC) in dependence of content of moisture in asphalt granulate**

| Percentage of asphalt granulate | Content of moisture in asphalt granulate | | | | | |
|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 |
| | Elevation of temperature (°C) | | | | | |
| 10 | 4 | 8 | 12 | 16 | 20 | 24 |
| 15 | 6 | 12 | 18 | 24 | 30 | 36 |
| 20 | 8 | 16 | 24 | 32 | 40 | 48 |
| 25 | 10 | 20 | 30 | 40 | 50 | 60 |
| 30 | 12 | 24 | - | - | - | - |

In other countries contractors try to keep the introduced RA as dry as possible, and the burner control is used to drive off any small variations in moisture. Reuse in short period after removing RA can be critical due to high moisture content. Large exposed stockpiles were stated to shed any water remarkably well and typically the moisture content is about 3-5 %. If needed, adaptations or corrections are made and these generally rely on the practical experience of the plant operator.

**Figure 6-3: Asphalt Recycling Crusher (Benninghoven - Germany)**

A common problem is that it is time consuming to measure moisture content and sometimes software on plants does not allow increases in temperature. Some contractors avoid feeding RA directly into the mixer due to "steam explosions" if RA with high water content occurs. Moisture content in RA should be as low as possible or at least constant.

In Belgium, experience with PmB is common. If used RA containing PmB (mostly SBS polymer) is to be used in combination with 'normal' unmodified RA in order to avoid sticking problems (ratio: 1/3 PmB + 2/3 normal binder). In some cases it has been mixed prior to adding the material to the mixer. Sometimes two cold feed bins are utilized for RA.

In other countries PmB containing RA is seldom occurring (as the PmB pavements are young and not up for recycling yet). Perhaps less that 2 % of the RA is PmB containing and therefore not kept separate. All materials are crushed and processed together. Generally, no special precautions are taken for RA with PmB. Though, many producers report about sticking of PmB at handover devices in the plant (e.g. exit of parallel drum). Cold addition can solve problem.

**Figure 6-4: Stockpile of milled reclaimed asphalt (CMC - Slovenia)**

For economic reasons PmB containing RA should be used for new PmB containing asphalt. In the UK there are trials with PmB RA with new PmB from alternative sources.

More practical solution can be 1/3 PmB + 2/3 normal binder are mixed.


**Figure 6-5: Batch plant with two routes for recycling the reclaimed asphalt: a vertical system for adding RA directly in the mixer, and a horizontal conveyor belt for preheating RA in the virgin drum dryer (Denmark)**

### 6.2.4 Evolution of common problems

All material transport shall either be vertical (cup elevators) or horizontal (conveyor belts) but not any angle in between unless electrically heated. Non-stick materials must be used in order to avoid material build-up.

It is only worthwhile to start up the parallel drum plant for heating RA if the order exceeds 100 t as there will be some fouling deposits at each cold start-up. When this fouling shall be removed it is an unpleasant operation that must be performed manually and takes 14 days (due to market situation parallel drums are skipped).

Problems may occur for if the RA is contaminated, of an incompatible grading to the material being produced, or if the residual binder in the RA is severely aged. RA from Mastic Asphalt (MA) containing high viscosity binder and high contents of fines (MA RA should be used only in new MA).

There were some issues with foamix (fine and coarse added to solve problem). Stockpiles are generally limited to 3 – 4 m high to prevent over consolidation of the RA.

A particular problem is encountered when using RA with PmB (e.g. originating from SMA surface courses). Latter RA has to be mixed with ‘normal’ without PmB RA before adding. Cold addition can solve problem.

Environmentally problematic is the presence of coal tar (PAK marker can be used for its detection) in old pavement layers (see Figures 3-2 and 3-3). In most European counties it is strictly forbidden to recycle coal tar containing RA in either hot or cold process. But in UK recycling of coal tar bound layers is permitted and often the best solution and more sustainable than the alternative of disposal. In Denmark due to the low occurrence a dispensation can be applied provided protective measures are taken.

Low penetration grade of RA can be problematic when dealing with porous asphalt.

The discontinuous grading of RA originating from SMA limits to some extent its reuse. The most proper solution can be to make from such RA similar materials, i.e. a new SMA.

The rounded aggregate shape of gravel (frequently used in the past but for environmental reasons its exploitation is nowadays restricted) limits its reuse to base courses.

The presence of thermoplastic road marking, and joint seal materials should be kept separate from the RA to avoid problems.

Common to all countries is that there is no change in specifications due to RA mixed in asphalt.

**Figure 6-6: Cold RA method (cold feed into the batch mixer) (CMC - Slovenia)**

### 6.2.5 Asphalt plant modifications

In Denmark all plants are equipped for some type of recycling and it is an on-going optimization process. There is perhaps a small trend in discarding asphalt plant configurations with parallel drum for RA (originating from virgin drum dryers from old asphalt plants) and converting the asphalt plant configuration with some means of using a part of the virgin drum for heated RA. This is market situation driven.

In Germany all contacted producers changed their plant equipment in the last 10 years to improve recycling capacity. The answers on what was done are given below:

- The charge addition was added or renewed to allow more precise addition especially for RA into surface asphalt mixes.
- Parallel drums were added in some plants according regional specialties.
- One producer states that the rising binder price encourages the increase of RA content. The company’s goal is a mean recycling rate of 40 % (over the whole asphalt production).

In UK improvements to asphalt plants to increase recycling rates have been made by some or ‘upgrades’ done where new plants are commissioned.

[Note: the drivers in the UK are increasing and clients have demanded certain levels of recycling on specific surface course schemes].

The procedure for mix in plant recycling at batch plants and continuous drum plants was plant specific with a different procedure adopted depending upon plant type.

In Belgium modifications to asphalt plants in order to facilitate recycling were generally made in the mid ’90’s. Further optimisations have been implemented more recently. These include:

- Installation of a sieve of 63 mm on cold feed bins to avoid large particles RA in production
- Some kind of hammer in order to avoid sticking of RA in cold feed bins and warm feed bin (other option or system includes vibrations)
- Adaptation of the warm RA storage bin shape in order to facilitate the ‘gliding’ of RA from the bin into the mixer.

**Figure 6-7: Recycling Parallel Drum installation. (Benninghoven - Germany)**

In Netherlands generally, modifications to asphalt plants in order to facilitate recycling were made in the nineties. Further optimizations were implemented more recently. Latter include:

- Optimization of the material flow in the parallel drum by adapting its length and/or the position of the paddles.
- Pre-heating of RA using hot air in a separate chamber in order to avoid the “burning” of the bitumen and reduce emissions.
- The covered storage of RA in order to minimize moisture content
- The separate storage of different types and qualities of RA (e.g. porous asphalt, PmB, gravel containing RA…).

In Portugal introduction of a unit for RA particles dimension reduction before entering in the batch plant mixer. This allowed overcoming some previous difficulties of getting a homogeneous mixture. Installation of a weighting unit to control % of RA in the mixture is common.

In Slovenia new belt conveyor and silo were installed.

### 6.2.6 Asphalt plant data with respect to parameters like energy, $CO_2$ etc

In UK asphalt plant data is generally available and includes KWh/t, btu/t, recycle% RA% etc.

Note: asPECT (asphalt Pavement Embodied Carbon Tool) was launched in October 2009 in the UK which enables producers (and clients) to establish their carbon footprint. This was developed by TRL under the collaborative research programme funded by HA/MPA/RBA and currently covers sourcing of all materials to production of asphalt. Ongoing research is looking at maintenance and "end of life" and will be completed by end of 2010. asPECT is available as a free download from www.sustainabilityofhighways.org.uk .

In Netherlands it is reported that the use of RA results in an increased need for fuel at the plant level (estimated to be approx. 10–15 %). However, considering the entire LCA of the use of RA, less $CO_2$ is produced since far less new materials are needed. Moreover, this is particular the case in the Netherlands where natural resources with regards to aggregates is very scarce. In this context, the road administration is taken initiatives to stimulate the sustainable development in the future by working (in collaboration with the sector) on appropriate frameworks (e.g. for a given project or production site).

In other countries some contractors have some data of energy consumption (heating and electricity) but it is thought to be difficult to link this to a specific production as it will be influenced by several factors with virtually no possibility of control. Other contractors state that this kind of information is seen as their internal know-how and a possibility to be in front in a competitive market situation and will not be given away freely. This obstacle can be a problem for data to the LCA part of Re-Road in WP3.2.

**Figure 6-8: Conveyor belt for adding reclaimed asphalt in the back end of the virgin drum dryer in a batch plant (Denmark)**

**Figure 6-9: RA middle ring adding system approx. 30% at 4 % humidity. (Benninghoven - Germany)**

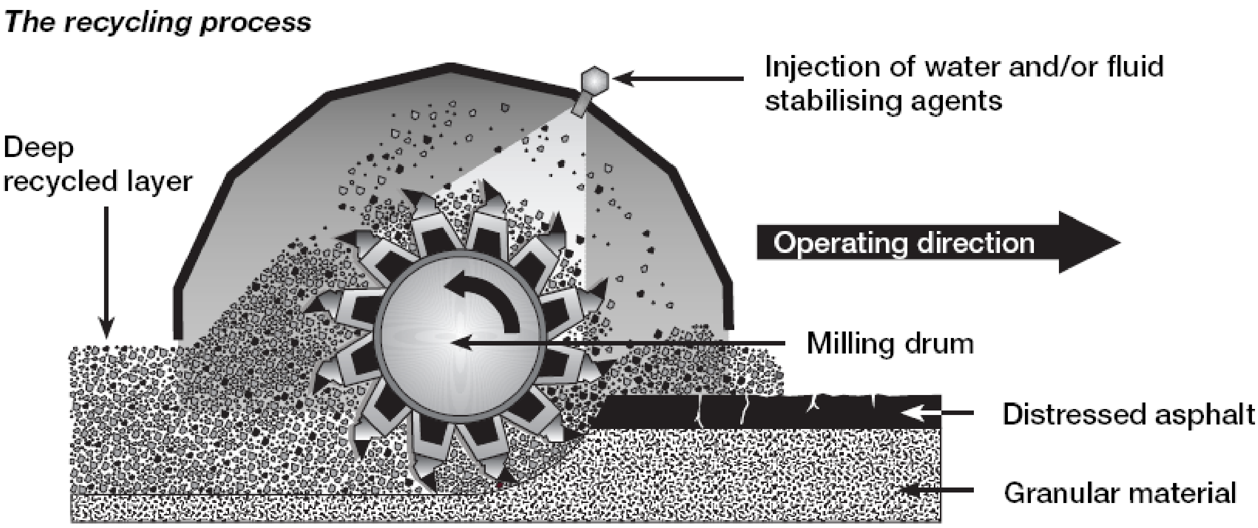


**Figure 6-10: The recycling process of "in-situ" method: Cold in place recycling with foamed bitumen**

**Figure 6-11: Recycling train for cold in place recycling with foamed bitumen (Primorje – Slovenia)**

## 6.3 Selected case studies (D4.5)

Selected case studies on the subject of introduction of the reclaimed asphalt into the mixing plant have been examined in Belgium, Denmark, Germany, The Netherlands, Portugal, Slovenia, Sweden and United Kingdom. The outcome is reported in Deliverable 4.5. Some of the case studies contain also elements of handling of reclaimed asphalt, as this item was difficult to split from the rest of the case without losing the overview.

### 6.3.1 Description of common practise in Belgium

A single case study has not been followed in Belgium but a description is given on experience and common practise on recycling. A special focus is given to recycling of reclaimed asphalt containing polymer modified asphalt because the stickiness of the materials has caused problem in the asphalt plants which almost all are capable of recycling. A present practise to avoid the problem is to “dilute” the PMB containing reclaimed asphalt with ordinary reclaimed asphalt in the ratio 1:2. A practical solution but since the polymer is “diluted” the benefit of this high valued component in the RA can be lost in the new asphalt mix.

### 6.3.2 Obstacles in acquiring data on energy and $CO_2$ emissions

From Denmark an explanation is given on the difficulties in obtaining the information that the project had hoped to gain in order to support the Life Cycle Assessment study in work package 3. The issues can be described in a combination of the following practical points:

- Varying moisture content in raw materials which is not monitored
- Frequent mix shifts and variations through a normal production day

- Lack of available measuring possibilities to link energy consumption to a specific mix type
- Competitive edge and confidentiality/secrecy

The last point on competitive edge and confidentiality/secrecy has had some impact information gathering. Presently (year 2012) the asphalt contractors are reluctant give share information on energy consumption and $CO_2$ emissions because they are starting to investigate and collect the information themselves and they are not certain how premature data taken out of its context can influence the market situation like the tendering process for public works. This situation was also mentioned on the Eurasphalt & Eurobitumen Congress in Istanbul June 2012.

### 6.3.3 Case study from Germany

The German case study describes the common practices for RA management and restricting factors of an asphalt contractor that operates eight asphalt plants of various configurations with respect to introduction of reclaimed asphalt into the mixing plant. Besides two plants equipped with parallel RA heating drums, the other plants are equipped with cold feeding equipment. The plants are located approx. 50 km apart of each other.

The report documents that even though some of the plant designs allow in theory up to 100 % reclaimed asphalt in the new mix the maximum level is often set 50 % due to mix composition restrictions and capacity of the virgin aggregates drum dryer.

The overall economic goal of the asphalt contractor in management of reclaimed asphalt is to reduce the amount of virgin binder in new asphalt mixes. This will be reached by high RA contents. This creates automatically an incentive to support the objective of the Re-Road project for as high level of recycling that is economical feasible.

### 6.3.4 Description of common practise in the Netherlands

Like in Belgium no specific case is documented but an overview on the recycling issues, among others the problems that have been encountered. The Netherlands was in front with recycling when the first generation of asphalt plant adaption took place in the nineties. Further developments in recycling technology have recently been introduced for further optimization. A few point can be mentioned:

- Optimization of the material flux in the parallel drum by adapting its length and/or the position of the paddles.
- Pre-heating of RA using hot air in a separate chamber in order to avoid the “burning” of the bitumen and reduce emissions.
- The covered storage of RA in order to minimize moisture content
- The separate storage of different types and qualities of RA (e.g. porous asphalt, PmB, gravel containing RA…).

### 6.3.5 Case studies from Portugal

The selected case studies refer specifically to the production of hot mix asphalt mixtures incorporating up to 40% of RA for application as regulating/binder courses.

One of the applications was made in the frame of rehabilitation works of a stretch of a motorway (A1) located in the centre of Portugal, where 15 % to 25 % of RA milled from the motorway was used for the production of the new asphalt binder mixture.

The other case study concerns the production of hot mix asphalt applied in a binder course on a National road (EN 105) in the North of Portugal, using 40 % of RA, which had been milled from another rehabilitation work in the region.

The comprehensive documentation gives in sight in handling of the reclaimed asphalt and the associated mix design by the Marshall method. On both rehabilitation jobs drum mixer plants were used. From the results presented above, it can be concluded that hot asphalt mixtures with up to 40 % of RA can be successfully produced using continuous drum mix plants with minor adaptations.

**Figure 6-12 Introduction of RA material in the continuous drum mix plant – Motorway A1**

### 6.3.6 Combination of warm mix/rejuvenator and reclaimed asphalt in Slovenia

The Slovene case study is particular interesting as it combines the warm mix additive and rejuvenator, Storbit, with the reclaimed asphalt in a high percentage, where the common practise I Slovenia had been a range from 10 – 30 % RA in the mix. New mix of dense graded asphalt concrete containing approx. 50 % RA was produced in December 2011 with a mix temperature of approx. 100 °C while the reference mix without reclaimed asphalt and the warm mix additive was produced at approx. 170 °C

The test sections were paved under not optimal condition, but the test mix accommodated even handwork down to 70 °C and the low temperature of the test mix reduced to a great extent the exposure of the workers to fumes.

Tests on asphalt cores taken from the test filed confirmed appropriate compaction degree and void content of asphalt layers. Wheel tracking test performed on cores performed for both types asphalt layers showed a slightly lower resistance to the formation of ruts for asphalt layer containing RAP. All asphalt properties are within acceptable limits.


**Figure 6-13 Temperature of asphalt mixture containing RAP on the test field**

### 6.3.7 Hot, half-warm and cold recycling in Sweden

Sweden gives a comprehensive overview of experiences gained with recycling at a central plant by three different technologies:

- Hot mix recycling
- Half-warm recycling and
- Cold recycling

**Figure 6-14 Manufacturing of half-warm mixtures in a batch mixer with steam heating**

### 6.3.8 Case studies in United Kingdom

From United Kingdom case studies give reference to activities in another part of Re-Road (Task 2.3) where road trials with surface layers having reclaimed asphalt in the new mix ranging from 23 – 40 % are being monitored for their performance. Some are still very new (3 years), but other have been around for more than a decade and have shown to provide comparable service to virgin mixes for the medium to long term.

# 7 Conclusions

It is difficult to sum up the conclusions for all the activities that have taken place over the four years from 2009 – 2012 in the EU co-funded research program under the 7th frame work program of the EU Commission on the subject of End-of-life strategies.

The objective of Re-Road can be interpreted as improving and spreading the knowledge on recycling of reclaimed asphalt to facilitate the reuse of the materials (both binder and aggregate) at the highest possible level. A secondary objective has been likewise to focus on situations where downgrading can be avoided, both in order to save natural resources and to utilize the potential that is in stored in these materials.

Work package 4 has especially been oriented towards the asphalt producers and road contractors to bridge the gap to practise and the great pool of knowledge that exists in the road sector, but which might not have been accessible in a manner that scientist normally search for documentation.

The lessons learned for WP4 during the Re-Road project are:

- The technology is available to recycle also surface layers and not only base layers into new mixes for the same purpose with high percentages of reclaimed asphalt; even close to 100 %.
- It had been recognised that reaching for 100 % recycling can be detrimental for the durability of the new pavement because a lot of constraints (mix design, product standards, functionality, local market situation, etc. etc.) mean that the optimal solution for reuse of old asphalt is below 100 % reclaimed asphalt addition.
- In order to save our natural resources in the long run sub-optimization must also be avoided because it can drive the development in a direction that is not optimal in a greater perspective.
- Costs of non-renewable resources will be great incentives for an economically driven optimization of the technology to increase the recycling/reuse of reclaimed asphalt. In the deliverables of WP4 details can be found that have identified some of the obstacles or barriers to recycling. This knowledge can also prove to be important for the future of recycling.

# 8 References

References to WP4 deliverables which are downloadable from http://re-road.fehrl.org .

**Re-Road Deliverable D4.1:**

Laboratory Mixing - State of the Art

Erik Nielsen

The deliverable describes a survey with input information from Belgium, Denmark, Germany, Slovenia, Sweden and United Kingdom with respect to practises for mix design – especially when reclaimed asphalt is incorporated in the mix. Other information on recycling is collected as well.

**Re-Road Deliverable D4.2:**

Status Report on Activities and Background for Selection of Case Studies

Erik Nielsen (editor).

The deliverable contains the result of a survey with detailed information from several European countries on handling and pre-processing reclaimed asphalt at the processing site or asphalt mixing plant and its later introduction into the mixing plant in order to produce new asphalt mixes.

**Re-Road Deliverable D4.3:**

Milling Operation: Possible Influence on Gradation and Aggregate Properties

Jean-Baptiste Gobert

The deliverable describes after a state of the art on cold milling the influence of milling operation on the aggregate gradation and properties. Several test trials are followed, where important parameters like hydraulic pressure and water consumption varied.

**Re-Road Deliverable D4.4:**

Production and Processing of Reclaimed Asphalt - Selected Case Studies

Dina Kuttah et al.

The deliverable describes several case studies which have been documented to expand the findings from Deliverable D4.2 on special issues like handling and storage of reclaimed asphalt. A special case of

a interim storage facility for tar-containing reclaimed asphalt is documented from an environmental point of view.

**Re-Road deliverable D4.5:**

Optimization of Reclaimed Asphalt in Asphalt Plant Mixing

Marjan Tušar et al.

The deliverable describes several case studies where the focus is on introduction of reclaimed asphalt in the mixing plant, but the case studies contain also to some extent information on the pre-processing and handling of the materials prior to production of the new materials. A Slovene case study describes the combination of reclaimed asphalt in high percentage and warm mix technology.

**Re-Road deliverable D4.6:**

Processing and management of reclaimed asphalt at the mixing plant – Final report

Erik Nielsen et al.

The deliverable is a condensed summary report with high lights and conclusions from the other deliverables and activities in Re-Road Work Package 4.

Re-Road

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**THE RE-ROAD PROJECT** aims to develop knowledge and innovative technologies for enhanced end of life strategies for asphalt road infrastructures. Such a strategy has an important impact on the energy efficiency and the environmental footprint of the European transport system and fits within the life-cycle thinking which is being introduced in waste policy at European level. It leads to reduction of the need for new raw materials, prevents the creation of waste and the occupation of landfills and consequently minimizes the need to transport these materials to and from the work site and hence reducing energy, pollution including $CO_2$-emissions.

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A FP7 Collaborative Project
**WORK PROGRAMME** Sustainable Surface Transport
SST.2007.1.2.2 End of life strategies for vehicles/vessels and infrastructures

**WORK PACKAGES**

**WP 1** Sampling and Characterization of RA
*Virginie Mouillet*

**WP 2** Impact of RA quality and characteristics on mix design and performance of asphalt containing RA
*Konrad Mollenhauer*

**WP 3** Environmental performance of RA
*Anja Enell*

**WP 4** RA processing and RA management at the mixing plant
*Erik Nielsen*

**WP 5** Performance modelling of RA
*Sabine Werkmeister*

*RA = Reclaimed asphalt*

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