CHAPTER V
RECYCLING
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## Chapter V – Recycling

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Chapter V - Recycling of Pavement Materials in a European perspective

1. Introduction
Road infrastructure is a major user of virgin aggregates and binders. Due to maintenance and reconstruction of asphalt pavements, large amounts of used materials are released each year. The reasons to recycle materials coming from the road infrastructure can differ strongly per country and even per area inside a country. Depending on the geological nature, a strong economically based incentive not to recycle can be the availability of sufficient fresh aggregates at a reasonable cost. In countries where nearly all the aggregates have to be imported, for example the Netherlands, a strong need exists to optimise the use of recycled materials as much as technically feasible. In the past decennium, an additional incentive came up in favour of recycling, based on long term environmental concerns. Politicians adapted this trend for sustainable development and it resulted in some governmental decisions that favour the use of recycled materials. Nevertheless, under free market conditions, the actual level of recycling is determined by the economics based on the local circumstances.

In general it can be stated that recycling road materials was stimulated in the last decades by lacking suitable aggregate sources, not enough landfill areas, economical benefits and environmental concerns.

However, when reconstruction becomes necessary, the reclaimed materials should be reused in the same layers with identical properties to those of the original pavement [1]. Recycling of bituminous materials corresponds very well with this principle.

This paper deals with the most recent state of the art of recycling of materials coming from the asphalt road infrastructure and related sources in general. It focuses in particular on the recycling of bituminous materials in hot- and cold-recycling techniques for the end application in road infrastructure.

2. Abbreviations and definitions
Used abbreviations [2]:

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>RA</td>
<td>Reclaimed Asphalt (according to European standard prEN 13108-8 Bituminous mixtures - Draft version).</td>
</tr>
<tr>
<td>ARA</td>
<td>Hot Mix Asphalt, manufactured with the use of RA.</td>
</tr>
<tr>
<td>NA</td>
<td>Hot mix Asphalt made with New virgin aggregates, so without the use of RA.</td>
</tr>
<tr>
<td>Hot Mix</td>
<td>Hot mix asphalt recycling in plant in this paper is defined as the technique to produce hot mix asphalt in a mixing plant which uses reclaimed asphalt granulate (RA) to a certain percentage as feed material. This percentage can vary between 0% and almost 100% depending on the type of plant and the type of mix to be produced. When recycling is performed in situ, special heating equipment is used to raise the temperature of the pavement to facilitate its milling and mixing.</td>
</tr>
</tbody>
</table>
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Cold Mix Cold mix recycling, without heating the existing materials of the old pavement, is generally carried out in situ.

RA granulate It is a product obtained by crushing RA broken out from a road construction or obtained by in place milling of bituminous layers from an asphalt pavement.

In situ It is the recycling of the material without moving it in horizontal direction. Example: milling, adding a binder and compacting at the same square meter.

In place The old material is taken out of the road, moved to a nearby mobile plant, processed and laid back and compacted at the same site or RA is laid in a new road and processed with the in-situ technique.

In plant The old material is taken out of the road, moved to a fixed plant and becoming part of a pool of recycled material. This stockpile is processed and brought on a road were needed but not necessary the road from which it was extracted.

3. Recycling techniques

The recycling techniques can be classified according to:

- The place where the mixing process is carried out
  - in-situ, in-place, in-plant

- The temperature used during the mixing process
  - hot, cold, warm

- The characteristics of the material being recycled
  - RA granulate, Cement granulate

- The type of binder used.
  - Bituminous, Cement, etc.

4. Historical development of hot mix asphalt recycling (Batch Plants)

In most countries, the development of hot mix asphalt recycling started after the energy crisis in 1973. Recycling was limited to a maximum of 15 to 20% RA. In this partial recycling process the RA was added cold, into the batch plant mixer, filled with overheated virgin materials. The existing hot mix batch plants needed only small changes to be suitable for this process. The maximum percentage was set by the ability to dry and heat up the wet and cold RA.

In the beginning of the 1980’s in several countries many existing batch plants were equipped with an additional, separate heating drum for the drying and heating of the cold and wet RA granulates. In this way it was possible to raise the percentage of the RA granulates from roughly 20% (cold addition) to a maximum of approximately 50%, depending on the RA properties and final mix performance level needed.
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5. **Asphalt: the highest level of recycling in our society**

RA granulate recycling in hot mix asphalt represents the highest level of recycling in our society. The performance of the end product is at the same level as when fresh materials are used. The use of RA and ARA in the total tonnage produced asphalt per country is still increasing. Many examples exist where asphalt pavement have been recycled for the 4th time. The percentage of RA varies in general between a minimum of about 15% (Sweden) and a maximum of 55% (Japan).

The reasons for using high percentages of RA are:

- Regulations set by governments to charge for dumping waste (for instance of RA) to landfill or even a prohibition on dumping recyclable waste, for instance in the Netherlands, resulting in lower prices for ARA compared with NA.
- The requirement in tender-documents that the use of a minimum percentage of ARA is obligatory.
- Better technical possibilities of modern hot mix asphalt plants, equipped for high rates of recycling of RA to produce ARA

6. **Philosophy of designing and producing ARA**

In all European countries, the starting point in the consideration of ARA is that the quality (performance) has to be at the same level as the quality of NA.

Accordingly, if the requirements for the mix composition and the components are fulfilled, including demands of production, laying and compaction, asphalt mixes with specific functional properties (fatigue, durability, stiffness, resistance against deformation, cracking resistance, etc) are manufactured.

For ARA, in many countries a lot of research was executed on pavement requirements. This was not only for the demands and properties of the layers itself but also for the demands for the production of the ARA for these layers. For instance, some countries did a lot of quality-control in plant and made test-sections to measure the resistance against rutting and fatigue by cutting out asphalt slabs and making beams to test. The actual behaviour of test-sections during longer periods has been studied as well to validate the new materials and models. The experience in this field over a period of 10 years is reported available [2].

The result of this research was the conclusion that the performance of ARA was at least as good as the performance of NA. That is why in many countries specifications are made for the requirements for ARA, similar to those existing for NA.

7. **Mixture requirements**

As pointed out above, hot mix asphalt (whether NA or ARA) is of good quality if it meets certain requirements for the mixture and the components.

These demands relate to the mixture as well as to the production, laying and compaction of the asphalt.

The demands in relation with the mixture in many countries concern:

- Composition of the mixture: grading of minerals, sand- filler- and binder content, nature of the binder.
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- Volumetric properties as voids: voids of minerals aggregates, voids filled with bitumen, etc.

In ARA-mixtures, RA is one of the constituents (raw materials) and therefore the following properties of RA have to be known in addition:

- Grading of all mineral components in RA
- Amount of binder in RA
- Penetration, softening point ring & ball and viscosity of binder in RA
- Amount and grade of round stones and of crushed stones in RA
- Amount of modified binder and kind of modifications (polymers)

With these data, it is possible to blend an ARA asphalt mix containing RA.

Based on this approach, several countries (e.g. Belgium, the Netherlands) use the penetration of the bitumen recovered from the RA as an indicator to calculate the quantity and properties (grade) of the bitumen to be added. This is carried out in order to meet the specifications of the properties and the amount of binder in the ARA mix.

Other countries like Germany use the temperature of softening point Ring and Ball as an indicator, still other countries (e.g. Sweden) use the viscosity of the binder as an indicator.

It is also assumed that other properties of the ARA mix can be predicted in the same way as for mixtures made with virgin components. The demands concern mainly binder content, Marshall-strength, -flow, -quotient, porosity, bulk factor (filler ratio) and volumetric properties. The assumption is, based on long term experience in some countries, that ARA has the same functional properties as new asphalt. This should enable countries to use their normal quality system for the production of ARA. Of course, one should not forget that empirically based conclusions are only valid within the window of experience.

8. Different techniques to recycle asphalt pavements

As pointed out in §1.2., different techniques to recycle asphalt are available. Without going into detail, a brief description of the different techniques, with their advantages and disadvantages will be given below.

To illustrate the potential recyclability of asphalt aggregates, Table 1 shows the suitability for recycling in various mixtures [1].

Table 1 - Recyclability of various mixtures

<table>
<thead>
<tr>
<th>Course</th>
<th>Reuse in Aggregate of</th>
<th>SMA</th>
<th>PA</th>
<th>DA</th>
<th>OA</th>
<th>CSA</th>
<th>GA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surface</td>
<td>SMA</td>
<td>-</td>
<td>-</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>&quot;</td>
<td>PA</td>
<td>-</td>
<td>0</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>&quot;</td>
<td>DA</td>
<td>-</td>
<td>-</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Binder</td>
<td>OA</td>
<td>-</td>
<td>-</td>
<td>0</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Base</td>
<td>CSA</td>
<td>-</td>
<td>-</td>
<td>0</td>
<td>0</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>&quot;</td>
<td>GA</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>0</td>
<td>+</td>
</tr>
</tbody>
</table>

SMA = Stone Mastic Asphalt  OA = Open Asphalt  + = suitable
PA = Porous Asphalt         CSA = Crushed Stone Asphalt - = not suitable
DA = Dense Asphalt          GA = Gravel Asphalt    0 = possibly suitable

The main features of warm and cold recycling techniques are presented in the table 2 below.
<table>
<thead>
<tr>
<th><strong>Table 2 – Warm &amp; cold recycling techniques</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>WARM RECYCLING</strong></td>
</tr>
<tr>
<td><strong>REFORM</strong></td>
</tr>
<tr>
<td><strong>Process</strong></td>
</tr>
<tr>
<td><strong>Purpose</strong></td>
</tr>
<tr>
<td><strong>REPAVE</strong></td>
</tr>
<tr>
<td><strong>Process</strong></td>
</tr>
<tr>
<td><strong>Purpose</strong></td>
</tr>
<tr>
<td><strong>REMIX</strong></td>
</tr>
<tr>
<td><strong>Process</strong></td>
</tr>
<tr>
<td><strong>Purpose</strong></td>
</tr>
<tr>
<td><strong>Advantages</strong></td>
</tr>
<tr>
<td><strong>Disadvantages</strong></td>
</tr>
</tbody>
</table>
9. Recycling contaminated asphalt mix

In the past, in some countries binders being based on a mix of bitumen and coal tar were popular for use in asphalt layers and as surface dressings binders. The recycling of such contaminated RA in a hot mix recycling process should be avoided. According to the draft European standard of Reclaimed Asphalt (prEN 13108-8 § 3.1.8.), reclaimed asphalt may not contain tar. In some countries it is allowed to relay on cold techniques with or without binders (emulsion, foamed bitumen and or hydraulic binders). In this case cold mix recycling with a bitumen emulsion or with foamed bitumen can be used as alternatives; in some applications cement or a similarly fine graded material is also used in order to further reduce the leaching by water. Techniques combining bitumen and cement have big advantages over pure cement based techniques in this application. The bitumen bound materials keep their elastic/viscous nature; this results in a lower tendency to crack. The resistance against leaching by rain water is comparable to that of conventional dense asphalt concrete. In the case of a Portland cement bound binder, the percentage of binder required for a sufficient leaching resistance level becomes extremely high. This results of course in an even greater tendency to form cracks and thus a need for thicker asphalt overlay to limit reflective cracking. In the Netherlands, since January 1, 2000, the use of RA containing more than 75mg/kg PAH (Polycyclic Aromatic Hydrocarbons) is legally forbidden. Such materials are not allowed in a cold mix process. In the Netherlands a "full-scale-pilot-plant" was erected by a group of Dutch contractors. In this plant, the tar components in RA are destroyed thermally, the cleaned aggregate is re-used to produce new ARA (with a maximum of 10-15%) [2], the heat generated in the process is used to heat the connected asphalt mix plant. This TORBED process (see figure) [3] uses bitumen at the end of its life cycle for its heat value and saves high quality fuel like natural gas which is normally used for heating the plant.

10. Recycling of polymer modified asphalt

In general, the recycling of most polymer modified mixtures causes no problems in the hot mix plant. Problems however, could be that the recycling specifications set up for conventional binder containing RA do not apply to PMB mixtures. SBS modified RA do normally have significantly increased R&B temperatures. EVA modified binders hardly have increased R&B temperatures, but they can significantly increase the stiffness of the asphalt. Depending on the specification methodology in use in a certain country, problems can arise how to evaluate these RA materials.

As an example, in the Netherlands the advice was given by a working group to limit the use of polymer containing RA to maximum 20% in ARA [4]. This was proposed because it was assumed that in this case, the penetration rule could still be used for the evaluation of the final mixture. This maximum of 20% for base courses and 10% for surface courses will also be prescribed in future in the new European Standards.

In general, new asphalt with PMB does not contain RA in most countries, although the recycling of a specific PMB in a new asphalt mixture with the same binder might become more interesting in the future.
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For larger jobs it will be advantageous to carry out full mixture testing on such materials. In this case the remaining performance increase caused by the polymer becomes "visible" and will help to reach the desired performance level.

11. Recycling of concrete pavements and cement bound materials
Cement bounded materials cannot be recycled at the same high performance level as asphalt pavement. Recycling of broken aggregate from cementious pavement is normally limited to the re-use in the road base layer of a new road [11].

12. Conclusions

12.1. Bituminous asphalt pavements with intrinsic visco-elastic properties
➢ Can several times be re-used at the highest performance level, even in new asphalt roads having the same performance level.
➢ The risk of failure of re-using asphalt granulates is, based on long term experience, low.
➢ Lacking healing properties can cause a high risk of failure of recycled asphalt. It is recommended to limit the amount of recycled material in the bottom layer of the asphalt pavement to avoid fatigue problems at this depth (due to the over estimation of the assumed healing properties).

Another possibility to reduce the risk of failure in the bottom layer is to increase the virgin binder content in such a layer by approximately 0.3%.

12.2. Concrete pavements and cement bound materials
➢ Cannot be re-used at the same level of performance, but have to be downgraded to be road base or sub-base material.

13. References
1. Recycling of Existing Flexible Pavements, PIARC Technical Committee on Flexible Roads, July 1999
5. Modified bitumen, CROW - publication nr. 104, 1996, the Netherlands