Svenska erfarenheter av rivning samt återvinning av vägmaterial i nya vägar

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Förord

VTI och SGI deltar i EU-projektet Direct-Mat ”Dismantling and Recycling Techniques for road Materials – Sharing knowledge and practices”. En del av projektet har varit att sammanställa svensk kunskap avseende olika återvinningstekniker för vägmaterial. Denna rapport består av en sammanlagning av de svenska bidragen till den gemensamma europeiska rapporten. Rapporten inleds med en kort svensk inledning som ger en översikt över projektet, följt av de svenska bidragen avseende obundet material, hydrauliskt bundet, asfalt och övriga material. Dessa bidrag har inkluderats i original version, det vill säga på engelska.

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Svenska erfarenheter av rivning samt återvinning av vägmaterial i nya vägar

av Fredrik Hellman, Robert Karlsson, Maria Arm*, Ebba Wadstein*, Leif Viman, Ola Wiik*, Helen Åhnberg*) och Gunilla Franzén

VTI

Sammanfattning


Avsikten med projektet är att ur ett europeiskt perspektiv sprida kunskap och erfarenheter om återvinning av vägmaterial. Resultaten kommer att presenteras i en webbaserad databas där handböcker, vägledningar, nationella dokument, referenser och litteraturstudier är enkelt åtkomliga. Även fallstudier som exemplifierar praktiskt användande av metoderna från de deltagande länderna kommer att finnas tillgängliga.

Projektet är indelat i fyra delområden som studerar återvinning av olika typer av vägmaterial. Dessa delar är:

- obundna vägmaterial
- hydrauliskt bundna vägmaterial
- asfaltbaserade material
- övriga material (t.ex. askor, slagg, gummidäck, förorenade sediment och vegetation från diken).

Den här VTI-rapporten summerar de svenska erfarenheterna av rivning samt återvinning av vägmaterial för användning i nya vägar.

*) SGI, Linköping
Swedish experience of demolition and recycling of road materials for use in new roads
by Fredrik Hellman, Robert Karlsson, Maria Arm*, Ebba Wadstein*, Leif Viman, Ola Wiik*, Helen Åhnelg* and Gunilla Franzén
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Summary
DIRECT-MAT (Dismantling and Recycling Techniques for Road Materials – Sharing knowledge and practices) is a European project in the Seventh Framework Programme (http://cordis.europa.eu/fp7/home_en.html project no. 218 656). The project consists of 20 partners in 15 countries.

The purpose of this project is, in a European perspective, share knowledge and experiences about recycling of road materials into new roads. The results will be presented in a web-based database where manuals, guides, national documents, references and literature studies are easily accessible. Case studies that exemplify the practical use of methods from the participating countries will also be available.

The project is divided into four groups that concentrate on recycling of different types of road materials. They are:

- unbound road materials
- hydraulically-bound road materials
- asphalt-based materials
- other materials (e.g. ash, slag, rubber tires, contaminated sediment and vegetation from ditches).

This VTI report summarizes the Swedish experience of demolition, and recycling of road materials for use in new roads.

*) SGI, Linköping
1 Inledning

DIRECT-MAT (Dismantling and recycling techniques for road materials – sharing knowledge and practices) är ett europeiskt projekt i 7:e ramprogrammet (projekt nr. 218656). Projektet består av 20 partners, uppdela på 15 länder.

Avsikten med projektet är att ur ett europeiskt perspektiv sprida kunskap och erfarenheter om återvinning av vägmaterial. Detta är viktigt för att snabbare implementera metoder för miljömässigt och hållbart användande av naturresurser vid byggande av vägar och infrastruktur. Tidigare har återvinning av vägmaterial studerats i olika europeiska och nationella projekt men resultaten och kunskapen har ofta stannat och implementerats inom de enskilda länderna. Det här projektet syftar till att göra denna information tillgänglig internationellt. Slutresultatet kommer att presenteras i en webbaserad databas där handböcker, vägledningar, nationella dokument, referenser och litteraturstudier är enkelt åtkomliga. Även fallstudier som exemplifierar praktiskt användande av metoderna från de deltagande länderna kommer att finnas tillgänglig.

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- hydrauliskt bundna vägmaterial
- asfaltbaserade material
- övriga material (t.ex. askor, slagg, gummidäck, förorenade sediment och vegetation från diken).

Den här VTI rapporten summerar resultaten från de svenska erfarenheterna av rivning och återvinning av vägmaterial för användning i nya vägar (figur 1). Nedan ges en summering på svenska av resultatet från de 4 olika arbetsgrupperna. Därefter följer en mer detaljerad beskrivning på engelska av de svenska erfarenheterna.

**Figur 1 Vägens kretslopp.**
1.1 Obundet material

Studien beskriver rivning av obundna väglager och återvinning av vägmaterial som nya obundna lager i vägar och vägkonstruktioner i Sverige. Den litteratur som studerats är nationella regler (t.ex. trafikverksdokument), nationella forskningsrapporter och praktisk erfarenhet från projekt där återvunna material använts.

Studien behandlar:

- rivning av obundna lager för vägöverbyggnad
- återvinning av obundna vägmaterial till nya obundna lager
- återvinning av hydrauliskt bundna vägmaterial till obundna lager
- återvinning av asfaltbundna vägmaterial till obundna lager.


1.2 Hydrauliskt bundet material

Studien beskriver rivning och återvinning av hydrauliskt bundet vägmaterial (betong) som nya hydrauliskt bundna lager i vägar och vägkonstruktioner i Sverige. Den litteratur som studerats är nationella regler (t.ex. trafikverksdokument), nationella forskningsrapporter och praktisk erfarenhet från projekt där återvunna material använts.


1.3 Asfalt

Studien beskriver rivning och återvinning av bitumenbundet vägmaterial (asfalt) i Sverige. Den litteratur som studerats är nationella regler (t.ex. trafikverksdokument), nationella forskningsrapporter och praktisk erfarenhet från projekt där återvunna material använts.

Asfaltlager kan återvinnas i ett asfaltverk alternativt återvinning på plats. Lagren fräsas eller grävs upp. Svensk asfalt är ofta lämplig att återvinna då användning av tillsats-
medel som försvårar återvinningen är begränsad. Ofta krossas och siktas asfalten för att säkerställa kvalitén.

Om återvinning i asfaltverk ska göras används asfaltgranulat med tillsats av nytt bindemedel. Vilken typ som används är beroende av vilken återvinningsmetod som används.

Tre olika återvinningsmetoder i asfaltverk är:

- varm återvinning
- halvvarm återvinning
- kall återvinning.

Forskning visar att låg andel (20–30 %) återvunnen asfalt granulat inte påverkar asfalt-egenskaperna i någon större omfattning. En liten förstyvning kan iaktas och hållbarheten förbättras. Vid högre inblandning (30–50 %) finns risk att de mekaniska egenskaperna påverkas negativt. Egenskaperna hos det återvunna materialet är en viktig faktor. År materialet åldrat eller uppvisar tendenser till dålig beständighet eller bristande funktionell prestanda kan detta inverka menligt. Är det återvunna materialet inte åldrat och av god kvalité är det möjligt att öka inblandningen återvunnet material. Vid för stor inblandning ökar risken för sprickbildning då beläggningen blir för styv.

Flera tekniker för återvinning på plats finns (se 4.4.1). Trafikvolymen är en viktig faktor att ta hänsyn vid val av teknik. Även avståndet till närmaste asfaltverk är en viktig faktor. Tabell 5 (4.4.3) ger en sammanfattning av val av återvinningsmetod.

1.4 Övriga material

Studien beskriver erfarenheter av rivning och återvinning av material som inte så ofta används i vägkonstruktioner i Sverige. Den litteratur som studerats är nationella regler (t.ex. trafikverksdokument), nationella forskningsrapporter och praktisk erfarenhet från projekt där återvunna material använts.

Materialen i denna grupp delas in i:

- material som försvårar återvinning (vägmarkeringar)
- farliga och oönskade material (tjärasfalt, asbest)
- sekundära ballastmaterial (slagg, askor)
- gummidäck
- förorena jordar och sediment (dikesmassor, grus)
- vegetationsavfall (dikesklipp).

De svenska erfarenheterna rör främst återvinning av asfalt som innehåller tjära, användning av askor från förbränningsanläggningar och metallurgiskt avfall som används i vägkonstruktioner. Generellt är avfallsprodukter som konstruktionsmaterial i vägkonstruktioner relativt ovanliga i Sverige. Undantaget är metallurgiskt avfall från metall- och gruvindustrin som är vanligt förekommande i kommunala vägar i närheten av produktionsanläggningarna.

Material som försvårar återvinning är material som vägmarkeringsfärg, stälarmering och geosyntetiska material. Vid varje rivningsprojekt bör en plan för hantering av dessa material göras upp.
Farliga och oönskade material i vägar är oftast förknippade med tjärasfalt i Sverige. Vid varje rivnings- och återvinningsarbete ska förekomst av tjära och eventuellt andra farliga ämnen identifieras. Strategin är sedan att konsultera miljömyndigheter och arbeta fram en plan för återvinning och återanvändning. Förorenade material bör inte blandas med nya material. Normalt bör tjärasfalt återanvändas på samma plats som obundet eller bundet material.

Under de senaste 30–35 åren har forskning undersökt tekniska och miljömässiga egenskaper vid användning av sekundära ballastmaterial som stålslag, bottenaskor från avfallsförbränning (även kallade slagg) och flygaskor i vägkonstruktioner. De tekniska erfarenheterna är ofta positiva. De miljömässiga egenskaperna ska kontrolleras i varje enskilt fall då dessa material har mycket olika egenskaper beroende på ursprung.

Årligen genereras ca 70 000 ton utslitna gummidäck i Sverige. Hälften används i förbränningsanläggningar och den andra hälften går till olika former av materialåtervinning. Nerklippta gummidäck (gummichip) används som lättviktsfyllning i ljuddämpningsbarriärer, frostisoleringslager, dränerade lager, elastiska lager på rid- och travbanor. Miljömässigt är det främst lakning av metaller som järn och zink som man måste ta hänsyn till. I Sverige har det även byggts några teststräckor där återvunnet gummi använts för att modifiera bitumen i asfaltbeläggningar. Asfalten får då egenskaper som förbättrar livslängd, ljuddämpande och minskad sprickbildning.

I Sverige gäller generellt att jord och material från rivningsarbeten ska återanvändas i närheten. Jord från högtrafikerade vägar (>10 000 ÅDT) ska provtas och analyseras innan återanvändning i vägområdet. Grus från halkbekämpning sopas upp efter vintern och återanvänds.

Vegetationsavfall och gräsklipp från rensning av diken och vägrenar samlas sällan upp utan lämnas kvar på plats.
2 General tendencies and political developments in Sweden concerning environmental-friendly technology

Every year, about 95 million tonnes of aggregate material are used in Sweden. The road construction industry is responsible for about half of this. Natural gravel and rock material of good quality is in nature easily accessible in Sweden and therefore there is a long tradition of road construction with unbound material, especially natural gravel. Besides, unbound layers are less sensitive to settlements and frost heave than bound layers and are therefore used to neutralize frost heave in pavement design.

However, as in other sectors, sustainable management of resources has commenced in Swedish road construction. This has resulted in the introduction of alternative aggregate materials, such as recycled aggregates or industrial residues of different kinds. The background to this is a number of political objectives and control instruments together with administrative and technical measures. The overall idea is that it should be a matter of course to use alternatives when possible and thus decrease landfill and reduce extraction from gravel pits and rock quarries. In this way, the use of alternative materials prolongs the life of existing landfills and reduces the need for new pits and quarries.

2.1 Environmental regulations

The Swedish Environmental Code contains 33 chapters comprising almost 500 sections. More detailed provisions are laid down in ordinances made by the Government. The fundamental backbone of the environmental code are the eight general rules of consideration which concerns any activity or measure that may have environmentally impact: The reverse burden of proof principle; The knowledge requirement; The precautionary principle; The polluter pays principle; The BAT principle; The appropriate location principle; The resource management and ecocycle principle and The product choice principle.

Any recycling that is regarded as a waste handling activity requires either notification to local authorities or licensing by court or county authority. This is also relevant in the production of new road materials (e.g. asphalt plants, gravel pits or rock quarries). Reuse of waste in constructions requires notification in case of a minor risk of pollution of land or water and licensing in the case of more than a minor risk. The administrative burden of notification and licensing often counteracts the recycling of road materials classified as waste. Consequently, criteria for “minor risk” and “end of waste” have been discussed extensively.

The Swedish EPA has developed “end of waste” guidelines with values on content and leaching for reuse of waste in constructions (criteria for “ less than low risk”) (DRF2.72). The guideline values are very strict (90% of natural background values for some substances) and when the draft was circulated for consideration, it was overall favourably received by environmental authorities but negatively received by research organisations and the industry e.g. the Swedish Road Administration (SRA). The SRA has published its own guidelines for promoting the recycling of road materials like asphalt and excavated materials.
2.2 Policies and environmental objectives

Sweden has set goals for the future state of its environment – Swedish Environmental Objectives (DRF2.71). The Swedish Parliament (Riksdag) has adopted 16 environmental quality objectives, describing the state of the Swedish environment that would be necessary to achieve sustainable development within our generation. For guidance, interim targets for each objective have been adopted, indicating the directions and timescale of the actions to be taken (Figure 2). Implementation of the objectives is reviewed every year and new and revised targets and measures are evaluated every fourth year.

![Figure 2: Implementation, monitoring, evaluation and decision procedure of the environmental objective of Swedish parliament.](image)

Three action strategies have been drawn up to cover the activities in society that give rise to the majority of today’s environmental problems:

- more Efficient Energy Use and Transport
- non-Toxic, Resource-Saving Environmental Life Cycles
- management of Land, Water and the Built Environment.

Within the transport sector the SRA has been given a special responsibility for five of the Environmental objectives: Reduced Climate impact; Clean Air (nitrogen dioxide and particles); Good-Quality Groundwater (good-quality drinking water); Good Built Environment (noise) and A Rich Diversity of Plant and Animal Life. Its environmental policy includes promoting the use of environmentally-friendly materials and methods in road construction and maintenance.

2.3 Ordinance of Waste, Waste Tax and Ban on landfill of certain wastes

The European waste frame directive thematic strategy on the prevention and recycling of waste is implemented in the Swedish Ordinance of Waste. Political control instruments contributing to this trend are the Waste Tax and the Ban on landfill using sorted combustible waste. The tax of waste deposited on landfill sites was introduced in
the year 2000. Since then it has gradually been increased, to ca € 46 per tonne as from January 2006. For deposited material that is reused in some way, in road construction for example, the waste tax is repaid. Some waste categories are exempted, such as waste at landfill sites for excavated inert waste, mining waste, steel slag and blast furnace slag. On the other hand, incinerator ash, reclaimed asphalt as well as construction and demolition waste are affected by the tax.

Furthermore, one of the environmental objectives’ interim targets reads: “The total quantity of waste generated will not increase and maximum use will be made of its resource potential while minimizing health and environmental effects and associated risk…” This target is judged to be achievable if further vigorous measures are taken. So far, the disposal of industrial and construction waste has decreased substantially, partially due to the Waste Tax and the Ban on landfill using sorted combustible waste.

2.4 Tax on gravel from natural deposits

Swedish deposits of natural gravel that are of great value for the drinking water supply and the natural and cultural landscape will be conserved. In 1996 a tax on natural gravel was introduced. Since 2006 the tax is ca € 1.4 per tonne of gravel extracted. It is the gravel producer that pays the tax. Over the years, natural gravel has more and more been replaced by crushed rock in aggregate production. The reason is mainly increased requirements on road aggregates and restrictions in new licenses for gravel pits. Further reduction of the extraction of natural gravel is required and one of the environmental objectives’ interim targets states “By 2010 the extraction of natural gravel in the country will not exceed 12 million tonnes per year”. However, in 2007 the corresponding figure was 20 million tonnes (SGU, 2008) and the 2010 target is still not reached.
3 Unbound material

3.1 Introduction

This report describes Swedish experiences regarding dismantling of unbound road materials and recycling of different road materials into new unbound road layers. The description is based on relevant Swedish literature.

3.2 Dismantling Techniques

Swedish roads are not often demolished in the meaning that unbound layers are excavated. Usually old roads are kept and used by the local traffic, only the maintenance responsibility is transferred to another organisation.

3.2.1 National Regulations

Requirements for road constructions and dismantling are described in SRA (DRF2.77). There are no specific requirements for dismantling unbound road layers except that waste materials harmful to the environment shall be collected environmental friendly. However, the Swedish Road Administration and the Swedish Railway Administration have jointly written recommendations for handling excavated materials (DRF2.75). The report contains answers to questions like When should excavated material be regarded as “waste”? (Figure 3), What are the regulations for handling material classified as waste? And if not classified as waste? It is noted that the handling itself plays a crucial part in the classification process.

![Figure 3](image.png)

*Figure 3  Administrative handling of excavated materials from Swedish roads. After (DRF2.75).*

3.2.2 Research results

No research reports dealing with dismantling of unbound layers have been found, but it can be previewed that research is needed. It is for instance difficult, but important, to properly assess the materials in an old road in advance to enable suitable recycling actions. There is therefore a need for classification system and better methods for not harmful and harmful testing.
3.2.3 Practical experiences

Techniques for dismantling unbound layers are partly described in (DRF2.74) published by Swedish Road Administration. Normally, milling or excavation is performed layer by layer, in order to separate different kinds of material.

The material can either be used directly on site or be temporary stored waiting for a suitable application. It is important to keep in mind that the dismantling and later processes can affect the grain shape and grain size distribution of the material and influence the mechanical properties of the material.

Good knowledge of the pavement structure is a prerequisite for successful recycling. It is necessary with accurate investigations in advance since detailed documentation is rare, especially for old roads not built according to any standard.

3.2.3.1 Investigation methods

Measuring with falling weight deflectometer, FWD, is routine in Sweden for non-destructive testing, give information about the bearing capacity and stability. In addition to FWD, and maybe complementary georadar measurement (mostly for asphalt thickness), test pits and sampling is needed (Figure 4). The Swedish equipment “Underlätten” (Facilitator in English) is developed for sampling unbound road layers in asphalt paved roads (Figure 5). The vehicle has remote-controlled equipment for drilling, digging, filling and compaction. Normally, the sampling width is 0.35 m and the maximum depth is 1.2 m. Alternative equipment is a cylinder that is pressed through the unbound layers by means of hydraulic power (for example by an excavator). Afterwards, the cylinder can be split up lengthwise and thus show the whole road structure (Figure 5).

![FWD](image1)
![Georadar](image2)

Figure 4 Equipment for non harmful testing (SRA, 2008).
3.3 Recycling of road materials in new unbound layers

When recycling road material in new unbound layers it is possible to use both unbound rock material and asphalt layer. It is possible to recycle both so called virgin material (rock material and bitumen separated) and asphalt. The dismantled asphalt is called asphalt granulate. Dismantled concrete roads can also be recycled as new unbound road layers.

Both temporary and stationary recycling plants are used in Sweden, in both cases temporary storage is necessary. Stationary plants also handle demolishing waste from other construction activities.

3.3.1 Recycled unbound materials in new unbound layers

Unbound material from an old road can be recycled in a new road if its virgin properties have been measured. This is normally done according to specifications and methods published by the Swedish Road Administration. Sometimes, the excavated road material can be used directly on site as road base in cycle paths and footpaths along the new road.

3.3.1.1 National Regulations

When unbound materials are recycled in new unbound layers they must fulfil the same requirements as new unbound materials. These requirements are described in VVTBT Unbound layers (DRF2.76) which is valid together with VV AMA Construction (DRF2.77). The first document contains the Swedish Road Administration’s requirements on properties of delivered unbound pavement materials as well as on test of materials, levels and bearing capacity of final unbound road layers. The second document is a reference document for preparation of tendering invitations for civil engineering works.
Property requirements on unbound materials delivered for road construction purposes exist on the amount of crushed and broken surfaces, the resistance to wear and fragmentation, the quality of fines, the petrography and the content of organic material (Table 1). These requirements should also be fulfilled in the final pavement layers.

Table 1 Requirements on unbound materials for Swedish road construction. After (DRF2.76) and (DRF2.77).

<table>
<thead>
<tr>
<th>Property</th>
<th>Asphalt paved roads</th>
<th>Gravel roads</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Standard</td>
<td>Road base</td>
</tr>
<tr>
<td>Crushed &amp; broken surfaces of aggregates</td>
<td>EN 933-5</td>
<td>&gt;50%\text{crushed} ≤30%\text{rounded}</td>
</tr>
<tr>
<td>Resistance to wear (micro-Deval)</td>
<td>EN 1097-1</td>
<td>1^M_{DE}&gt;20</td>
</tr>
<tr>
<td>Resistance to fragmentation (Los Angeles)</td>
<td>EN 1097-2</td>
<td>LA40</td>
</tr>
<tr>
<td>Quality of fines (Sand equivalent)</td>
<td>EN 933-8</td>
<td>&gt;35</td>
</tr>
<tr>
<td>Compaction properties</td>
<td>EN 13286-2</td>
<td>Yes, shall be done</td>
</tr>
<tr>
<td>Petrography (mica content)</td>
<td>EN 932-3</td>
<td>1^&lt;30%</td>
</tr>
<tr>
<td>Organic content</td>
<td>EN 1744-1 SS 027102</td>
<td>4^&lt;2%_{org}</td>
</tr>
<tr>
<td>Grading</td>
<td>EN 933-1 EN 13242 EN 13285</td>
<td>Curve GO 0/31,5</td>
</tr>
</tbody>
</table>

1. Can be used for traffic during construction
2. No traffic allowed during construction
3. Recommended values
4. On fraction >2 mm

If ADT_{total} ≥ 2,000 or if the construction site area exceeds 5,000 m² the bearing capacity of the final pavement layers should be tested and fulfil the requirements in Tables 2 and 3.
Table 2  Requirements on bearing capacity of Swedish road bases or top unbound layers. Interval for acceptance of flexible construction, static tests according to DIN 18134. After (DRF2.76) and (DRF2.77).

<table>
<thead>
<tr>
<th>Number of tested points</th>
<th>New construction</th>
<th>Reconstruction for bearing capacity improvements</th>
</tr>
</thead>
<tbody>
<tr>
<td>n=8</td>
<td>$X_{Ev2} \geq 140 + 0,96 \cdot s$ MPa</td>
<td></td>
</tr>
<tr>
<td>n=5</td>
<td>$X_{Ev2} \geq 140 + 0,83 \cdot s$ MPa</td>
<td>$X_{Ev2} \geq 120 + 0,68 \cdot s$ MPa</td>
</tr>
</tbody>
</table>

- In all tested points
- If $E_{v2} \leq 140$ MPa; $E_{v2}/E_{v1} \leq 2,8$
- If $E_{v2} \geq 140$ MPa; $E_{v2}/E_{v1} \leq 1 + 0,013 \cdot E_{v2}$
- At least 7 of 8 tested points or 4 of 5 points must be approved
- $G_{f}$ if $x < 125$ MPa

Table 3  Requirements on bearing capacity of Swedish road bases or top unbound layers. Interval for acceptance of flexible construction, surface compaction meter tests. After (DRF2.76) and (DRF2.77).

<table>
<thead>
<tr>
<th>New construction</th>
<th>Reconstruction for bearing capacity improvements</th>
</tr>
</thead>
<tbody>
<tr>
<td>$E_{v2} \geq 125$ MPa</td>
<td>$E_{v2} \geq 105$ MPa</td>
</tr>
<tr>
<td>$E_{v2}/E_{v1} \leq 1,5 + 0,019 \cdot E_{v2}$</td>
<td>$E_{v2}/E_{v1} \leq 1 + 0,015 \cdot E_{v2}$</td>
</tr>
<tr>
<td>All test points must be approved</td>
<td>At least 4 of 5 tested points must be approved</td>
</tr>
</tbody>
</table>

3.3.1.2  Research results

There are no real research reports dealing with recycling of unbound road materials in unbound road layers, but there is a lot of experience that is referred to in section 3.1.3. In the middle of the nineties it was stated that further research on deep stabilisation and also on simple reproducible performance laboratory tests was needed (DRF2.67) and this is still valid.

3.3.1.3  Practical experiences

The term recycling also includes measures for strengthening and thereby prolongation of the design period of an existing road, for example by deep stabilisation of unbound layers with binders or macadam. These measures are primarily used for low traffic volume roads and at long transportation distances to the pit. They are suitable for unbound materials that are unstable due to surplus of sand. In low traffic volume roads also thin asphalt surface layers are mixed with the unbound base course by milling on site.
A recycled material can sometimes be used further down in a new pavement, but sometimes a more high-quality material can be produced by crushing/sorting.

Where one or several materials from an old pavement are combined with new material it is recommended to perform preparatory laboratory tests to achieve an end product that is mechanical stable enough.

Performance testing of the recycled material in the laboratory by means of cyclic load triaxial tests is an alternative, but note that as in the case with FWD, only stiffness is not enough as performance measure. This is due to the fact that materials with very different grading and/or grain shape could show similar stiffness moduli, but their resistance to permanent deformation can differ a lot. Furthermore, water sensitivity has to be investigated since it is crucial for stiffness and permanent deformation behaviour of unbound materials containing fines.

Count on deterioration

Reusing unbound road materials will always result in a loss of material due to deterioration during handling and at the same time wear of sharp particle edges, but also due to difficulties in excavating and separating material from different layers. This means that new material has to be added, fines to be separated or binder to be added. The recycled unbound material can have been mixed by penetrating fine grained material (subgrade material) into the sub-base due to missing filter layer or by fine grained sub-base entering into the base course. It is common with high sand content and rounded particles in Swedish sub-bases – in old roads even in the base course. Scraping during previous road strengthening work can have resulted in a degraded base course.

Wrong design leads to deterioration due to traffic, for example degrading of weak rock material that produces plastic fines. Unbound materials are exposed to the largest stress (and degrading) during construction, in connection with spreading and especially by construction vehicles. In the final road no degrading of unbound layers occurs if the road is properly designed.

To think of in the new road

- In addition to traffic, water has an impact on the unbound materials performance, this means that very poor unbound materials can perform well in a dry location. Damages arise first when water enters through a cracked asphalt surface layer.
- Rounded material is sensitive for permanent deformation, i.e. it is rutting during loading.
- If the excavated material is weak it should be used in a well-graded form to allow some degrading/crushing at mechanical stress in the new road.
- Drainage of the new road is always important for good performance.

Repeated recycling results in decreasing homogeneity of the material.

3.3.2 Recycled hydraulically bound materials in new unbound layers

There are very few concrete roads in Sweden. It is therefore not common that they are dismantled. However, concrete for recycling can have other sources e.g. waste from concrete plants and plants for pre-fabricated concrete elements and concrete from dismantled constructions. The use of this type of concrete waste in road constructions
has been studied for several years in Sweden and research results and practical experiences have been implemented in national regulations and handbooks.

### 3.3.2.1 National Regulations

The Swedish requirements for use of crushed concrete in new unbound road layers are published by the Swedish Road Administration in (DRF2.73). An English summary is also available and published as a report within the European project SPENS. In the specifications, crushed concrete is classified into quality classes depending on concrete quality and amount of impurities and to these classes are assigned different design moduli (Table 4). If stiffness increase properties can be proved, an even higher modulus value may be used. The quality of the concrete should be determined either by compressive strength or by micro-Deval. Methods to be used are EN 12390-3\(^1\) and EN 1097-1\(^2\).

<table>
<thead>
<tr>
<th>Constituent</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Design modulus</td>
<td>450 MP</td>
<td>450 MP</td>
<td>250 MP</td>
<td>150 MP</td>
</tr>
<tr>
<td>Concrete</td>
<td>100</td>
<td>≥ 95</td>
<td>≥ 80</td>
<td>≥ 50</td>
</tr>
<tr>
<td>Masonry</td>
<td>≤ 5</td>
<td>≤ 20</td>
<td>≤ 50</td>
<td></td>
</tr>
<tr>
<td>Lightweight</td>
<td>≤ 1</td>
<td>≤ 5</td>
<td>≤ 50</td>
<td></td>
</tr>
<tr>
<td>Bituminous mixes</td>
<td>≤ 0.5</td>
<td>≤ 2</td>
<td>≤ 10</td>
<td></td>
</tr>
<tr>
<td>Other foreign</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>materials</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Quality classes 1 and 2 meet the requirements of unbound base and sub-base of roads. The lower quality class 3 can be used as sub-base in cycle ways and foot paths. Class 4 is usually only used in simpler tasks as filling. These quality classes are mainly based on research described in (DRF2.80).

### 3.3.2.2 Research results

In the nineties, several research projects were performed in Sweden regarding the use of crushed demolition concrete in road constructions. They included both laboratory tests and field tests. In the laboratory, the following properties were determined: Grain size distribution, optimal water content, maximum dry density, Los Angeles and micro-Deval values as well as stiffness and stability according to cyclic load triaxial tests. In the field, strength was monitored by means of falling weight deflectometer measurements. The results from this research are published in many reports, but summarised and referred to in (DRF2.80) and (DRF2.66) and they have served as bases for the present national requirements described in (DRF2.73).

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\(^1\) EN 12390-3: Testing hardened concrete - Part 3: Compressive strength of test specimens.
\(^2\) EN 1097-1: Tests for mechanical and physical properties of aggregates - Part 1: Determination of the resistance to wear (micro-Deval).
The origin and handling of the concrete influence the mechanical properties of the crushed material. Porous cement as well as foreign weak particles, such as lightweight concrete and brick, but also wood, plaster and reinforcement, reduces quality. Particle size distribution with a large maximum particle size as well as a well-graded curve is positive, as is the case for natural aggregates. According to cyclic load triaxial tests and FWD measurements, crushed concrete initially has the same resilient modulus as crushed rock (granite, gneiss and limestone). The $M_r$ is less stress-dependent than is the case for crushed rock.

**Stiffness increase in unbound layers of crushed concrete**

Both laboratory and field results have shown an increase in stiffness for unbound layers with crushed concrete, which is not present for unbound layers with natural aggregates. This increase is considerably larger in the field tests than in the laboratory test. The increase is greatest during the first months and then diminishes. This means that the layer modulus two years after construction can be about twice as high as the level after one month.

A low degree of carbonation in the original concrete yields faster carbonation and subsequent stiffness increase in the final compacted layer of crushed concrete. A lot of masonry and natural aggregate is limiting, since these materials are not subject to carbonation themselves. It is favourable for the stiffness of the construction to have a long contact period between water and concrete particles. A dense grading, rich in fines, gives a large particle surface area and speeds up the carbonation process.

Crushed concrete has lower resistance than gravel and crushed granite when tested with standardised mechanical laboratory methods like LA. The concrete material produces greater proportion of fines and is subject to greater disintegration. The resistance to mechanical impact depends on particle shape and indirectly on the way of crushing – the flakier, the lower resistance. The resistance is also affected by the amount of foreign material, for example a lot of masonry and lightweight concrete decreases the resistance. High strength in the original concrete yields better resistance to wear. If the concrete material is clean, the fines produced are not plastic as in natural aggregates, but contribute to the stiffness increase due to carbonation as mentioned above.

**3.3.2.3 Practical experiences**

Recycled crushed concrete is mainly used as base or sub-base in roads or parking spaces or as fillings in other construction purposes. Test sections with unbound layers of crushed concrete in road base and sub-base show good durability compared to reference sections with unbound rock materials (DRF2.80); (DRF2.66). Experience from crushing is described in (DRF2.79).

**3.3.3 Recycled reclaimed asphalt in new unbound layers**

The information in this section is summarized from (DRF2.68), (DRF2.69), (DRF2.70), (DRF2.74) and (DRF2.78). Asphalt granulate that cannot be recycled in a new asphalt layer can be recycled in an unbound road base or sub-base. It can also be used as surface on gravel roads, as material in road shoulders, in temporary repair work and as surface layer at construction sites.
3.3.3.1 National Regulations

The Swedish Road Administration’s requirements on reclaimed asphalt are collected in (DRF2.74). They are based on several years of research that is referred to here below.

3.3.3.2 Research results

Important Swedish research reports dealing with reclaimed asphalt are (DRF2.68), (DRF2.69) and (DRF2.70).

Regardless of the dismantling method it is recommended that the asphalt material is crushed and sorted in different size fractions before use in new unbound layers. The quality of the asphalt granulate is improved by addition of new binder. However, sometimes it can be favourable to use it without addition of new binder. This has to be decided from case to case depending on how the material will be used and on the quality of the asphalt granulate. A specific investigation should always be done. Quality parameters, durability and material properties are still not fully understood even though this material has been used for many years. More research is needed in this field of application.

3.3.3.3 Practical experiences

Crushed asphalt granulate can be suitable in unbound base and sub-base layers, especially when the granulate comprises a high portion of rock material. Practical experience shows that this type of material can obtain a load bearing capacity that is as good as or even better than that of crushed rock in a base or sub-base layer. Stability can be problematic if bitumen content is too high or if the material is poorly compacted. It is not recommended to use asphalt granulates were high static loads are expected, because it increases the risk for deformation.

The size fraction, the grading curve and other material properties of the asphalt granulate will affect the final quality of the construction. Another critical factor for a good result is the construction workmanship, and particularly the compaction. Compaction of asphalt granulate can be difficult. Best results are obtained if the material is laid in thin layers of 8–15 cm thickness and then carefully compacted while watering in warm weather conditions (Swedish summer). The compactor should be heavy (15 ton). Compaction should be done at low frequencies and high amplitude to obtain good compaction at depth. Traffic on these layers before the final asphalt layer is laid will decrease later surface rutting. The traffic load will improve the compaction with time and it is not uncommon that the material sticks together and creates a compact asphalt layer on roads with high traffic intensity.

Asphalt granulates can be used as surface layer on low traffic volume gravel roads. Granulates of sieve fraction 0–11 or 0–18 mm are used for this purpose. To obtain the best result, the granulates are mixed with ordinary gravel for surfacing of gravel roads. The mix is then levelled with a road grader. This procedure can be repeated when the road surface is rutted after it has been subject to traffic for some time. Normally the layer thickness is about 50 mm. One problem that can occur is that the asphalt granulates lump together and create a brittle layer. This layer is sensitive to cracks and potholes can develop. The problem can be solved by adding more gravel on the surface. The use of asphalt granulates can reduce the amount of dust emitted from the road surface.
Another use of asphalt granulate is as road shoulder material. It is then crushed and sieved to fraction 0–18 mm. Compaction can be done with the wheels of a truck. Asphalt granulate has sticky behaviour and will therefore decrease the risk for erosion when the ditch and road shoulders are subject to large water flows. A drawback is that the roadside has similar colour to the road.

Asphalt granulate can also be used for temporary repair of potholes, water damages and other damages on the asphalt surface. The advantage compared to gravel is that it sticks better on place.

It is also possible to use asphalt granulate as a surface layer for heavy traffic at construction sites. The advantage is that it emits little dust. It gives not a smooth surface but can work temporary. After use the material can be removed and reused elsewhere.

3.4 International literature review results

The present report is based on relevant Swedish literature. Literature from international conferences, seminars, meetings, results of European projects, and literature from other countries which are not represented by WP2 members are not reviewed in this phase. A synthesis of this important knowledge will be added in the next phase of finalizing the Deliverable D3 Synthesis of national and international documents on existing knowledge regarding unbound materials.

3.5 Conclusions

Swedish roads are seldom demolished, but kept and used by the local traffic when a new road, a ring road or similar, is constructed. The term recycling also includes measures for strengthening and thereby prolongation of the design period of an existing road, for example by deep stabilisation of unbound layers with binders or macadam. However, when roads are excavated there are national recommendations for handling the excavated materials published by the Swedish Road Administration (SRA).

Recycling in Swedish road construction industry is promoted by the Waste Tax, the Tax on natural Gravel, the ban on landfill of certain wastes and the national Environmental Objectives with interim targets whose implementation are reviewed every year.

Recycled unbound road materials are mostly strengthened by addition of coarse crushed material but reclaimed asphalt in granulated form is being used more and more. Crushed concrete from roads is seldom used in new unbound layers due to the scarceness of concrete roads. On the other hand, crushed concrete from other demolished constructions, mainly buildings, are more and more utilised.

Technical guidelines for recycling of asphalt, crushed concrete and unbound industrial by-products into new roads have been published by the Swedish Road Administration. These guidelines are based on several years of laboratory and field research, documented in a row of research reports. The use of “old” unbound road materials in new unbound layers is not regulated specifically, but the material should fulfil the same requirements as new unbound materials.

Environmental guidelines are at the moment given on site specific bases, but general guidelines from the Swedish Environmental Protection Agency has been circulated and will be published next year.
It is recommended to investigate the road carefully and then excavate layer by layer in order to separate different kinds of material. The handling of excavated material has to be planned, because of the classification as waste or not. Recycled unbound material is often deteriorated during handling and construction.

Crushed concrete for use in unbound road layers is classified into quality classes (with different design moduli) depending on concrete quality and amount of impurities. If stiffness increase properties can be proved, an even higher modulus value may be used.

It is not recommended to use asphalt granulates were high static loads are expected, because it increases the risk for deformation. Compaction of asphalt granulate is very important and should be performed in thin layers at low frequencies and high amplitude with a heavy compactor.

More research is needed on the classification of recycled unbound materials, on not harmful and harmful testing, on deep stabilisation of unbound road layers, on simple reproducible performance laboratory tests as well as on quality parameters, durability and material properties of asphalt granulate.

3.6 Definition of reviewed documents

National regulations:
– standards; standardised technical & environmental terms of contract
– governmental guidelines
– governmental recommendations

Research results
– published project reports
– national and international papers

Practical experiences
– Nationally and internationally published state-of-the-art reports
– National common practice – not published, found in other papers like tender specifications, articles in technical journals etc.

3.7 References

(DRF2.66)

(DRF2.67)


(DRF2.77)

(DRF2.78)

(DRF2.79)

(DRF2.80)
4 Hydraulically bound road materials

4.1 Introduction

This report describes Swedish experiences regarding dismantling of hydraulically bound road layers and recycling of various road materials into new hydraulically bound layers. Since no relevant literature has been found, the description is based on interviews.

In Sweden, few concrete roads have been built since the seventies. The total length of all Swedish concrete roads is currently 87 km (Table 5).

<table>
<thead>
<tr>
<th>Road number</th>
<th>Built year</th>
<th>Length (km)</th>
<th>Maintenance and Repair</th>
</tr>
</thead>
<tbody>
<tr>
<td>E4 Helsingborg</td>
<td>1978</td>
<td>7</td>
<td>Diamond grinded in 1992</td>
</tr>
<tr>
<td>E4, E65 Arlanda</td>
<td>1990</td>
<td>1.6</td>
<td>No maintenance</td>
</tr>
<tr>
<td>E6/E20 Falkenberg    (phase 1)</td>
<td>1993</td>
<td>15</td>
<td>No maintenance</td>
</tr>
<tr>
<td>E6/E20 Falkenberg    (phase 2)</td>
<td>1996</td>
<td>13</td>
<td>No maintenance</td>
</tr>
<tr>
<td>E20 Eskilstuna</td>
<td>1999</td>
<td>14</td>
<td>Diamond grinded in 2000</td>
</tr>
<tr>
<td>E4 Uppsala</td>
<td>2006</td>
<td>23</td>
<td>No maintenance</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td><strong>87</strong></td>
<td></td>
</tr>
</tbody>
</table>

Most of the roads constructed before 1970 have been overlaid with an asphalt surface layer and only a few have been dismantled. Information about dismantling techniques is therefore limited. In fact, this study has not found any research reports or regulations dealing with dismantling and recycling of concrete roads. Some practical experience and knowledge exists among contractors and within the Swedish Road Administration (SRA).

4.2 Dismantling Techniques

A worn out concrete pavement can be repaired through an overlay with a new concrete layer or, more commonly in Sweden, overlaid with asphalt. If the concrete layer is removed it is done by crushing the concrete with a falling weight (guillotine). After crushing it is possible to excavate the material. The crushed concrete is then transported to a storing place for further treatment. Normally it is crushed and used as an unbound material.
4.2.1 National Regulations

No specific regulations for dismantling concrete roads are available in Sweden. However, the Swedish Road Administration and the Swedish Railway Administration have jointly written recommendations for handling excavated materials (SRA, 2007). The recommendations are relevant also for hydraulically bound materials and contain answers to questions like When should excavated material be regarded as “waste”? (Figure 6) What are the regulations for handling material classified as waste? And if not classified as waste? It is noted that the handling itself plays a crucial part in the classification process.

![Diagram](Excavated_material)

*Figure 6 Administrative handling of excavated materials. After (SRA, 2007).*

4.2.2 Research results

No research in this field.

4.2.3 Practical experiences

Practical experience about dismantling techniques can to some extent be found among contractors and within the Swedish Road Administration.

4.3 Recycling of road materials in new hydraulically bound layers

4.3.1 Recycled unbound materials in new hydraulically bound layers

Reclaimed unbound road materials have not been used as aggregate in new concrete layers. They are usually re-used in unbound layers.

4.3.1.1 National Regulations

No regulations.

4.3.1.2 Research results

No research in this field.

4.3.1.3 Practical experiences

No information.
4.3.2 Recycled hydraulically bound materials in new hydraulically bound layers

Reclaimed concrete is not used as aggregate in new concrete layers for roads. It is possible to use the concrete waste from a dismantled concrete road as unbound layer in a new road. To be able to use the material its properties needs to be measured. This is described more in detail in the Swedish WP2 report of DIRECT-MAT. Sometimes the concrete layer is re-used as base layer under an asphalt surface layer (see section 3.2.3).

4.3.2.1 National Regulations

No specific regulations.

4.3.2.2 Research results

No research in this field.

4.3.2.3 Practical experiences

Swedish concrete roads are usually not dismantled. Normally, when a concrete road is worn out the top layer is covered by a flexible asphalt layer. Thus, the concrete surface layer is reused as a new base layer. Recently it has been popular to use rubber asphalt surface layer which is claimed to better conceal the joints in the concrete.

A number of old concrete roads built in the 1940s are still in use. They have a reinforced concrete layer of 150 mm. About ten years after they were built, they were overlaid with approximately 50–100 mm asphalt. During the years this action has resulted in reflexion cracks in the asphalt surface layer due to shrinkage in the concrete. In recent years a new maintenance technique has been tested to prevent the occurrence of such reflexion cracks. The concrete has been crushed by the use of a special falling weight/ guillotine at every metre of the road in connection with ordinary maintenance of the asphalt layer. The method has worked out well giving a substantial decrease in cracks caused by shrinkage. It has been used on the following roads in Östergötland county: Väg 796 Beatelund–Linghem–Gistad, Väg 636 Sjögestad motel–Vikingstad, Väg 1037 Vikingstad–Hasselbacken.

4.3.3 Recycled reclaimed asphalt in new hydraulically bound layers

Asphalt granulate is not used as aggregate in new concrete layers.

4.3.3.1 National Regulations

No specific regulation.

4.3.3.2 Research results

No research in this field.

4.3.3.3 Practical experiences

No information.
4.4 International literature review results

This report is based on interviews. Literature from international conferences, seminars, meetings, results of European projects, and literature from other countries which are not represented by WP3 members are not reviewed in this phase. A synthesis of this important knowledge will be added in the next phase.

4.5 Conclusions

Swedish information about dismantling techniques for hydraulically bound layers is limited. No research reports or regulations dealing with dismantling and recycling of concrete roads have been found. Some practical experience and knowledge exists among contractors and within the Swedish Road Administration.

Only a few concrete roads have been dismantled. It has been done by crushing the concrete with a falling weight (guillotine) and then excavating. Worn out concrete pavements are most commonly overlaid with an asphalt surface layer, which actually means that it is reused as a concrete base layer.

Reclaimed unbound road materials have not been used as aggregate in new concrete layers. Reclaimed concrete has not been used as aggregate in new concrete layers for roads. It is, however, possible to use the concrete waste as an unbound material in new roads. Asphalt granulate is not used as aggregate in new concrete layers.

4.6 Definition of reviewed documents

National regulations:
- standards; standardised technical & environmental terms of contract
- governmental guidelines
- governmental recommendations

Research results:
- published project reports
- national and international papers

Practical experiences:
- Nationally and internationally published state-of-the-art reports
- National common practice – not published, found in other papers like tender specifications, articles in technical journals etc.

4.7 References

Personal communication 2009 with:
- Mr Christer Hagert, Swedish Road Administration
- Mr Bengt-Ake Hultqvist, VTI
- Mr Torbjörn Jakobson, Swedish Road Administration
- Mr Krister Ydrevik, Swedish Road Administration.


5 Asphalt

5.1 Introduction

This report describes Swedish experiences regarding dismantling and recycling of asphalt pavements. The description is based on relevant Swedish literature. Most of the issues are already covered in a handbook for asphalt recycling comprising 184 pages of the current state of the practice in Sweden (DRF4.217). Therefore chapters 2 to 4 are mainly based on the handbook where meta-analysis is done based on a large number of references, but in the case of other original sources, these are referenced instead.

5.2 Dismantling Techniques

5.2.1 Dismantling Techniques

Main reasons for reclamation of asphalt concrete are:

- complete removal of pavement or road works such as pipe works
- removal of asphalt layers, i.e. deep milling in wheel paths or removal of inferior materials
- planning and levelling before new layers are placed, either to get an even foundation for subsequent layer or to adjust levels for adjacent pavement, curbs, manhole covers etc.

In the process of removal, either planning/milling or in the case of complete removal or road works excavation is used. Excavated material is cleaned from non-asphalt materials or sources of contamination in a general context. It is recommended that road markings are removed by milling prior to removal of asphalt layers. Recycling of tar asphalt is described separately in WP 5.

Handling of RA after the reclamation stage is considered as being important. RA should be sorted separate groups according to different quality aspects:

- surface layers from different pavement types
- mixed layers
- mixed pavements types
- contaminated pavements.

Milled pavements can exceptionally be reused without further treatment but normally crushing and sieving is performed to ensure quality and homogenization requirements. It is recommended that a delicate crushing is performed and that oversized aggregates are crushed separately (DRF4.214).

Dug up RA can be stored without restrictions of the height but after milling or crushing the height should be kept less than 3 m. Binding can occur during summer time but is usually constrained to the surface and easy to handle.

5.2.2 National Specifications/Regulation

Storage facilities are either temporary (on site) or permanent and are regulated by Ordinance on waste and Tax on waste. Notification (local authorities) is obligatory and
if the stored amount exceeds 30 000 tonnes licensing (regional authorities) required. Storage for longer periods than 3 years are prohibited.

Guidelines on sampling has been published by SRA (DRF4.220). Pavements or stored RA:s should be delineated in homogenous populations (areas or quantities) based on available documentation or inspection. Sampling of dug up uncrushed material should be avoided. Pavements are sampled by boring and stored RA by the aid of an excavator in order to get representative and homogenous samples. Stratified random sampling is recommended. Some guidance is given on how to calculate the required number of samples as a function of acceptable error and estimated variance. Generic recommended sampling frequency based on practical experience is given in the table below.

Table 6  Sampling frequency for extracting samples from pavements and RA.

<table>
<thead>
<tr>
<th>Object at ≤ 20,000 m²</th>
<th>Increments per composite sample</th>
<th>Composite samples for small populations</th>
<th>Composite samples for larger populations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pavements &lt; 40 mm</td>
<td>4</td>
<td>2</td>
<td>1+n</td>
</tr>
<tr>
<td>Pavements ≥ 40 mm</td>
<td>4</td>
<td>3</td>
<td>2+n</td>
</tr>
<tr>
<td>Stored RA</td>
<td>4</td>
<td>3</td>
<td>2+n</td>
</tr>
<tr>
<td>Stored uncrushed dug up RA</td>
<td>4</td>
<td>4</td>
<td>3+n</td>
</tr>
</tbody>
</table>

Tabulated guideline values for identification of outliers and acceptable coefficient of variation are given. If these values are not met further sampling and a modified delineation of homogenous areas are recommended.

5.2.3  Research results

No research

5.2.4  Practical experiences

The dismantling and storage of uncontaminated asphalt pavement are not associated with significant environmental or health issues except those associated with transport or noise. Prolonged storage initiates biological processes that can be a cause of annoying odours and smell during recycling.

Adding virgin aggregates to RA during crushing gives a material that is easier to handle. The amount and quality of added aggregates should correspond with the requirements in subsequent recycling.

5.3  Recycling of road materials in plant mixed asphalt

Traditionally Swedish asphalt pavements have been suitable for low temperature (warm or cold) recycling. The use of additives like anti-stripping agents and PMB has been limited. Swedish experiences on additives from working environment perspective have been summarized in (DRF4.20504). Blue smoke and associated emissions to air can be an important working environment issue. From a general point of view the use of additives that requires hot recycling or additives that may increase the release of blue
smoke (rubber or plastics) requires attention. The use of amine based anti-stripping agents has been causing irritating adverse effects on sensitive individuals even well below occupational guideline values. Modern more environmentally friendly release agents based on vegetable oils or refined petroleum oils have been introduced as alternatives to diesel.

5.3.1 Recycling Techniques

The reclaimed asphalt in granular form is mixed with new material. An overview of used techniques can be seen in the table below.

Table 7 In-plant asphalt recycling methods.

<table>
<thead>
<tr>
<th>Method</th>
<th>Application</th>
<th>Added binder</th>
<th>Normal amount of reclaimed asphalt</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hot Recycling</td>
<td>For wear-, bind- and base layer for all traffic volumes and road categories</td>
<td>Bitumen</td>
<td>Between 5 and 30% depending on reclaimed asphalt, the process, kind of plant and kind of layer</td>
</tr>
<tr>
<td>Warm recycling</td>
<td>For wear- and base layer, mostly for lower volumes of traffic</td>
<td>Soft bitumen or foamed bitumen</td>
<td>More than 80%</td>
</tr>
<tr>
<td>Cold recycling</td>
<td>For wear- and base layer, mostly for lower volumes of traffic</td>
<td>Bitumen emulsion, soft bitumen or foamed bitumen</td>
<td>More than 80%</td>
</tr>
</tbody>
</table>

Guidance schemes on how to perform simplified environmental and cost assessment in a life cycle perspective are available. Input (generic) data are not supported but should be audited on case by case premises.

5.3.2 Recycling of reclaimed asphalt in plant mixed asphalt

- **Hot recycling**

Hot recycling can be carried out in two kind of plants, batch plants or continuous plants. In continuous plant the asphalt is cold mixed and the amount of reclaimed asphalt that can be added varies between 5 and 80 % depending of the used equipment. In batch plants the amount of reclaimed asphalt often is lower. Batch plants with separate warming up possibility give the highest amount of added reclaimed asphalt. The possible amount to be added is also depended of the properties of the reclaimed asphalt and the requirements on the end product.

In **batch** plants the reclaimed asphalt are added in the following different ways:

1. Directly in the mixer (the reclaimed asphalt are heated by the mix).
2. Added to dry and warm aggregate.
3. Added to the main drier barrel
4. Added to a separate drier barrel parallel to the main drier barrel.
When using method 1–3 the amount of reclaimed asphalt can be up to 20%. Method 4 makes it possibly to increase the amount of reclaimed asphalt.

In continuous plants drying, warming and mixing are all together carried out in a rotating barrel. The reclaimed asphalt is normally added after drying and warming of the new aggregate. It is most common to add the reclaimed asphalt directly to the barrel but sometimes some pre-warming takes place by using a “double barrel”.

- **Warm recycling**
  
  Typical for warm recycling is a temperature between 50°C and 120°C (most common 50–80°C) and soft bitumen as binder. The granular reclaimed asphalt is added in the same way as new material and the warming is done mostly by steam at high pressure.

  The plants are relatively easy to move which means that they can be used to low volumes of material. Soft binders are used which makes the method suitable on roads where flexibility properties are desirable. The method is recommended in colder climate and low heavy traffic volumes.

- **Cold recycling**
  
  Cold recycling is a rather simple procedure mostly performed in continuous plants with capacities up to 120 metric ton/h. The plants are easy to move and are suitable for low volumes of reclaimed asphalt. This method is used on roads with low volume of heavy traffic (<AADT 1,500). Aggregates and/or granular reclaimed asphalt are mixed without warming and at natural water content in continuous plants where the binder is added. Batch plants are also used to produce cold mixes. In this case only the binder are warmed up (emulsion, soft bitumen or foamed bitumen). There are different ways to add binder, granular reclaimed asphalt and new aggregate with respect to where it is inserted, temperature etc.

  From an energy saving point of view, this technique is considered favourable since transport distances are kept at a minimum and heating is unnecessary. Especially transport distance is a problem in less populated areas of Sweden, but is also a major cost issue.

5.3.2.1 **National Specifications/Regulation**

In brief, the most important requirements for cold and warm recycled mixes are grain size distributions and the requirements presented in the table below (DRF4.216).
Table 8  Requirements in brief for cold recycled mixes in Sweden.

<table>
<thead>
<tr>
<th>Requirement</th>
<th>Wearing course</th>
<th>Base course</th>
</tr>
</thead>
<tbody>
<tr>
<td>Added bitumen emulsion (target) [%-weight]</td>
<td>2,2–4,2 (3,6)</td>
<td>1,2–2,7 (2,4)</td>
</tr>
<tr>
<td>Water ratio in granules [%-weight]</td>
<td>2,0–4,0</td>
<td>3,0–5,0</td>
</tr>
<tr>
<td>Air voids [%-vol]</td>
<td>4–12</td>
<td>6–14</td>
</tr>
<tr>
<td>Marshall stability @ 25°C [kN]</td>
<td>&gt; 5</td>
<td>&gt; 7</td>
</tr>
<tr>
<td>Stiffness modulus [MPa]</td>
<td>-</td>
<td>&gt; 2,000</td>
</tr>
<tr>
<td>Indirect tensile strength [kPa]</td>
<td>&gt; 300</td>
<td>–</td>
</tr>
<tr>
<td>ITSR, mean 3 samples</td>
<td>&gt; 60</td>
<td>&gt; 50</td>
</tr>
</tbody>
</table>

Table 9  Requirements in brief for warm recycled mixes in Sweden.

<table>
<thead>
<tr>
<th>Requirement</th>
<th>Wearing course</th>
<th>Base course</th>
</tr>
</thead>
<tbody>
<tr>
<td>Added soft bitumen (target) [%-weight]</td>
<td>1,2–3,0 (2,3)</td>
<td>0,6–2,4 (1,6)</td>
</tr>
<tr>
<td>Water ratio in granules [%-weight]</td>
<td>2,0–4,0</td>
<td>3,0–5,0</td>
</tr>
<tr>
<td>Air voids [%-vol]</td>
<td>3–8</td>
<td>5–10</td>
</tr>
<tr>
<td>Marshall stability @ 25°C [kN]</td>
<td>&gt; 8</td>
<td>&gt; 10</td>
</tr>
<tr>
<td>Stiffness modulus [MPa]</td>
<td>–</td>
<td>2,000–5,000</td>
</tr>
<tr>
<td>Indirect tensile strength [kPa]</td>
<td>&gt; 500</td>
<td>–</td>
</tr>
<tr>
<td>ITSR, mean 3 samples</td>
<td>&gt; 70</td>
<td>&gt; 60</td>
</tr>
</tbody>
</table>

Addition of reclaimed asphalt in hot mixes is limited to 20%-weight to wearing courses and 30 %-weight to binder and base layers. For polymer modified layers, the corresponding figures are 10 and 15%-weight, respectively. For asphalt layers with entirely new material, the current limit for increase in softening point R&B after laying is 6 degrees, while this limit is raised to 8 degrees for layers containing reclaimed asphalt. All hot recycled asphalt layers must be tested with regard to abrasive resistance according to EN 12697-16 (Prall) and fulfil the same requirements as for asphalt without RA. Softer binders are not allowed to account for aged binders in additions of 10%-w RA in wearing courses and 20%-w RA in binder and base courses. In these cases, the specified grade must be used, in order to avoid excessive permanent deformations.

It should be noted that a considerable share of procurements in Sweden are based on performance and no requirements on material composition is made in these contracts.

5.3.2.2  Research results and practical experiences

- Hot recycling

Investigations show that a moderate adding of granular reclaimed asphalt (20–30%) does not influence the composition or properties of the mixes too much. The granular reclaimed asphalt can have some stiffening effect and the durability seems to increase a bit. This increase in durability can be explained by the fact that the surfaces of the granular particles are covered with bitumen.
At higher amount of added reclaimed asphalt (30–50%) the mechanical properties can be influenced and it can be hard to fulfil the requirements in the Swedish specifications (DRF4.216) related to particle size distribution and increase of softening point (DRF4.206). The degree of ageing of the binder in the reclaimed asphalt is an important factor. Moderate ageing makes it possible to increase the amount of reclaimed asphalt.

Increased stiffness may increase the sensitivity to cracking especially at low temperatures or if the pavement bearing capacity is low. Ways to neutralize the stiffening effect is to use softer binder or increase the amount of new binder which improves the fatigue properties.

- **Warm recycling**

Based on the results and experiences from test roads, control sections and investigations of damaged sections the following remarks have been made with respect to type of damage:

<table>
<thead>
<tr>
<th>Type of damage</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plastic deformation</td>
<td>Can be the case if the relation between binder content and binder viscosity is too high</td>
</tr>
<tr>
<td>Traffic compaction</td>
<td>Some mm/layer (layer thickness 50 mm)</td>
</tr>
<tr>
<td>Rutting</td>
<td>Moderate in most cases</td>
</tr>
<tr>
<td>Eveness</td>
<td>Sometimes uneven surfaces, normal IRI-values are 1,5–2,0 mm/m. Maybe related to stiffer mixes. Milling prior to laying result in more even surfaces.</td>
</tr>
<tr>
<td>Bleeding</td>
<td>At high binder content bleedings can occur after periods of high temperature (higher binder content sometimes needed to fulfil mix design criteria).</td>
</tr>
<tr>
<td>Friction</td>
<td>Generally not affected, with some rare exceptions related to excess of binder.</td>
</tr>
<tr>
<td>Macro texture</td>
<td>Generally not affected</td>
</tr>
<tr>
<td>Separation</td>
<td>Sometimes large, especially when the content of coarse aggregate is high.</td>
</tr>
<tr>
<td>Bearing capacity</td>
<td>Moderately better or the same as new cold or warm mixes.</td>
</tr>
<tr>
<td>Flexibility</td>
<td>Depends on the binder used and the degree of ageing of the reclaimed asphalt. Often better when soft bitumen is used.</td>
</tr>
<tr>
<td>Ravelling</td>
<td>Can be a problem at areas with separation</td>
</tr>
<tr>
<td>Pot hole</td>
<td>No problem in normal case</td>
</tr>
<tr>
<td>Surface properties</td>
<td>Softer when new, gets harder after initial traffic compaction</td>
</tr>
<tr>
<td>Surface appearance</td>
<td>Same as with new mix</td>
</tr>
<tr>
<td>Joints</td>
<td>Careful work is recommended (spraying)</td>
</tr>
</tbody>
</table>

- **Cold recycling**

Based on the results and experiences from test roads, control sections and investigations of damaged sections the following remarks have been made with respect to type of damage:
<table>
<thead>
<tr>
<th>Property</th>
<th>Explanation/comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plastic deformation</td>
<td>Can be the case if the binder content is too high</td>
</tr>
<tr>
<td>Traffic compaction</td>
<td>Some mm/layer (layer thickness 50 mm)</td>
</tr>
<tr>
<td>Rutting</td>
<td>Moderate in most cases</td>
</tr>
<tr>
<td>Eveness</td>
<td>Sometimes uneven surfaces, normal IRI-values are 1.5–2.0 mm/m</td>
</tr>
<tr>
<td>Bleeding</td>
<td>No problem in normal case</td>
</tr>
<tr>
<td>Friction</td>
<td>Mostly good</td>
</tr>
<tr>
<td>Macro texture</td>
<td>As for dense asphalt (ABT).</td>
</tr>
<tr>
<td>Separation</td>
<td>Sometimes large, especially when the content of course aggregate is high.</td>
</tr>
<tr>
<td>Bearing capacity</td>
<td>The same as new cold or warm mixes or better.</td>
</tr>
<tr>
<td>Flexibility</td>
<td>Not as good as new cold and warm mixes</td>
</tr>
<tr>
<td>Ravelling</td>
<td>Can be a problem at areas with separation especially when salt is used as de-icing agent</td>
</tr>
<tr>
<td>Pot hole</td>
<td>No problem in normal case</td>
</tr>
<tr>
<td>Surface properties</td>
<td>Soft when new, gets harder due to traffic compaction and water evaporation,</td>
</tr>
<tr>
<td>Joints</td>
<td>Careful work is recommended (spraying)</td>
</tr>
</tbody>
</table>

For cold recycled pavements the compaction and initial maturation of the recycled layer is important for its performance. Both steel wheel rollers and rubber tyre rollers should be used. After compaction it is desirable that the layer can dry out for a few days in preferably warm and dry weather in order to gain in strength. The total curing period extends for several weeks up to half a year, if the treatment is performed during the autumn. Traffic and temperature is of importance to the curing process.

Tar containing asphalt is often recycled cold in Sweden. From an investigation on a layer recycled using foamed bitumen in a movable plant, it was concluded that the recycled layer contributed significantly to the structural strength so that the thickness of the bound base layer could be reduced (DRF4.207). Investigations have also been performed to evaluate the use of reclaimed asphalt as base course, without added binder and only water to make the material compactable. The results indicate that reclaimed asphalt cure and develop structural strength and stability, sometimes reaching properties close to ordinary new bound base course asphalt concrete (DRF4.209). Allowing traffic on the recycled base layer for some shorter period of time is favourable since much of the initial rutting (compaction by traffic) can be taken out when a new overlay is placed.

Research and practical tests have been performed during many years to develop rape seed oil derivatives as alternative binders in cold recycling (DRF4.221).
5.4 In-Situ Recycling

5.4.1 In-Situ Recycling techniques

The most frequently used techniques for in-situ recycling in Sweden are as follows:

- **Repaving** means warming up, scarifying and levelling of the existing asphalt and applying new asphalt mix layer (normally 40–50 kg/m²). This new mix is applied at the end of the repaving machine. New binder can be added to the existing mix. The method of repaving was established during the seventies in Sweden and is a further development of the Heating method as it is spreading out the existing mix before overlaying.

- **Hot remixing** means warming up and scarifying of the existing asphalt and mixing with new asphalt mix (about 15–30 kg/m²). After mixing the asphalt is spread out with a screed in one layer (thickness about 30–40 mm). This is done in an integrated process with the same machine or two machines milling in two steps with intermediate heating. The old mix need to have a temperature that gives correct temperature to the final mix. The remixer machines are usually preceded by an ordinary heater. New binder and softening agent can be added. The amount of new material typically corresponds to the ruts in the existing pavement and allows adjacent levels to be maintained, for example adjacent lanes, shoulders and connecting roads.

- **Remixing Plus** is a combination of remixing and repaving. The existing asphalt is heated, scarified, mixed with new material and placed on the pavement again. On this recycled layer a new asphalt layer is applied (>30 kg/m²). All is done in an integrated process with the same machine which means that the machine needs to have two screeds.

- **Warm remixing** is when the pavement is moderately heated with a heater and then a machine is milling and adding new mix or soft bitumen before laying.

- **Stabilisation** is when old asphalt bound layers are milled and incorporated in the lower base and subbase layers and new binder is added in the form of bitumen emulsion or foamed bitumen. Down to 20 cm depth.

- **Cold Remixing** is when one or more asphalt layers are milled and mixed with bitumen emulsion, aggregate or mixture before laying. Down to 10 cm depth.

- **Deep milling** means that asphalt layers are milled down to 0.5 meter into the unbound layers and no extra binder is added.

5.4.2 National Specifications/Regulation

The aim is that in-situ recycled materials should fulfil the same requirements in-plant recycled or new materials, but one exception is found in the Swedish regulations. The tolerance for air voids is larger, between 1.5 and 6.0% (DRF4.216).

5.4.3 Research results and practical experiences

In the treatment selection phase, in-situ recycling techniques are assessed relative to other maintenance treatments. As previously mentioned, traffic flow are one important factor when selecting between hot, warm or cold techniques. In-situ techniques are favoured by long distances to nearest stationary plant. In table 10 some figures are given on when to select different in-situ techniques or to use movable asphalt plants with regard to object size. Quality and homogeneity of existing pavement and material is also an important factor. Type of damage on existing pavement is often used as a basis for
judging quality of existing materials. Pavements which exhibit plastic deformations in the asphalt layers or water sensitivity should not be subject to remixing or repaving since the problem is likely re-occurring.

Table 10 Selection guide for in-situ techniques or movable plants with regard to object size.

<table>
<thead>
<tr>
<th>Method</th>
<th>Hot</th>
<th>Warm</th>
<th>Cold</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Plant</td>
<td>Remix m²</td>
<td>Remix m²</td>
</tr>
<tr>
<td>Tonnes of mix</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&lt; 500</td>
<td>&lt; 5,000</td>
<td>&lt; 5,000</td>
<td>&lt; 5,000</td>
</tr>
<tr>
<td>500–1,500</td>
<td>&lt; 15,000</td>
<td>&lt; 15,000</td>
<td>&lt; 15,000</td>
</tr>
<tr>
<td>1500–2,500</td>
<td>&gt; 15,000</td>
<td>&lt; 25,000</td>
<td>&gt; 15,000</td>
</tr>
<tr>
<td>2500–5,000</td>
<td></td>
<td>&gt; 25,000</td>
<td></td>
</tr>
<tr>
<td>5000–10,000</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&gt; 10,000</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Green = Suitable
Yellow = To investigate
Red = Not suitable

- Repaving (hot) has been used as wearing course treatment since the middle of the seventies. Large areas have been executed, mostly on the national road network and in cities. The wear and texture properties after repaving is believed to be as good as paving with new material if the composition and execution fulfils the requirements in the national specifications.

- Remixing (hot) has been used as wearing course treatment since the eighties. The method has been used mostly on the national road network and in cities but also on airfields. During the period 1993 to 1995 investigations were carried out at nine test sites on the road network. A summary of the results are given below (DRF4.205):
  - The quality was generally good and uniform. Requires fairly good and homogeneous existing material as well as acceptable weather conditions.
  - The environment for the workers was satisfying if catalytic converter where used.
  - It was not possible to change the composition in a radical way on the existing asphalt with additions normally in the range of 10 to 25% new material.
  - The effect of added binder is not clarified. Recycled layers appear softer than expected if complete mixing is anticipated.
  - The binder gets harder, 3–5 °C in softening point (first instance of recycling).
  - The milling of the warm asphalt does not lead to more crushing.
  - Existing asphalt gets more homogeneous.
Following the above study, Karlsson (DRF4.212) investigated the process of mixing old and new binders during asphalt recycling. It was concluded that complete mixing is possible but the degree of mixing is a result of the intensity and time of mechanical mixing, degree of ageing (viscosity of old binder), temperature (viscosity of old and new binders, rate of diffusion), and geometries in mixture on scales from binder layer thickness to aggregate size allowing for diffusion of binder components. These factors occur at a rate that may explain occurrence of incomplete mixing during hot remixing, and certainly in colder applications or if the difference in viscosities between old and new binders are very large. Consequently, it was concluded that the old binder may act partly as “Black rock” but always mix to some extent with the new binder.

From investigations on airfields during 1996 to 1998 it was concluded that remixing has a high potential to be an integrated part of the maintenance treatments at airfields.

- **Remixing Plus** has been used as wearing course treatment since the middle of the nineties. The method has been used mostly on the national road network and in cities but in last years also on airfields.
- **Warm remixing** has mainly been used in the northern part of Sweden where comparably softer mixtures are used, especially on stretches with lower AADT. These layers are relatively easy to remove and mix when heated to moderate temperatures.
- **Stabilisation** was tested and evaluated by VTI on a number of stretches during eight years of service (DRF4.208). These stretches experienced serious damages. The roads had AADT:s of 500-2000 and the depth of treatment was 10 cm, which meant that some unbound material was also included. A wearing course was placed on top of the recycled layer. The treatment was considered a success and especially useful if it is important to maintain road surface levels. The initially developed rutting was substantial but the subsequent rut development was relatively low. During the first year it was difficult to extract cores to test in the laboratory due to the low added binder content, down to 1,0 %-weight. After eight years the layer had cured and samples could be removed in one piece.
- **Cold Remixing** was evaluated by VTI during construction in 2000 and the following year (DRF4.211). Nominally 11 cm was treated and a new asphalt layer was subsequently placed on top. No damages were observed and the structural strength measured using FWD/surface curvature was 50% larger compared to stretches with unbound base layers.
### 5.5 References

<table>
<thead>
<tr>
<th>Document Review Form (DRF)</th>
<th>file name</th>
<th>title</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>DRF4.218</td>
<td>SEPA. 2010. Återvinning av avfall i anläggningsarbeten. Swedish Environmental Protection Agency</td>
</tr>
<tr>
<td></td>
<td>DRF4.219</td>
<td>SEPA. 2009. MILJÖMÅL. Swedish Environmental Protection Agency</td>
</tr>
</tbody>
</table>
6 Other material

6.1 Introduction
This report describes Swedish experiences regarding dismantling and recycling of not commonly recycled road materials. The description is based on relevant Swedish literature.

Swedish experience exists primarily within the management of tar contaminated asphalt layers and the recycling of different types of incinerator ash and metallurgical slag in unbound road layers. However, waste is still not commonly used in Swedish road construction, except for metallurgical residues that are frequently used in municipalities where metal producing plants are located.

6.2 Handling of excavated materials
The Swedish Road Administration and the Swedish Railway Administration have jointly written recommendations for handling excavated materials (SRA, 2007a). The report contains answers to questions like When should excavated material be regarded as “waste”? (Figure 7), What are the regulations for handling material classified as waste? And if not classified as waste? It is noted that the handling itself plays a crucial part in the classification process.

The main criteria for classifying are the cleanliness of materials and the probability that they will be utilised. If not classified as waste generally no further notification or licence is required for the use. However, the place for use can require certain precautions, e.g. for filling in water.

If the materials are classified as waste they should not be transferred to any private person even if there is a need for the materials. However, if the materials are clean and will be used by the private person, the transfer can be done before the excavation (they are then not classified as waste).

The recommendations also contain contract forms to be used when transferring materials from the SRA to a contractor or other company.

Figure 7 Administrative handling of excavated materials. After (SRA, 2007a).
6.3 Materials that complicate the dismantling and recycling

Materials that can complicate the dismantling and recycling of roads are road markings, steel reinforcement materials and geosynthetics.

Road markings have to be removed separately if the recovered asphalt material shall be recycled in new hot mixes (SRA, 2009).

A Swedish experience when using steel net in asphalt layers to prevent crack propagation is that the vertical position of the steel net in reinforced flexible structures is important. A position below a thin wearing course (40 mm) cannot be recommended according to this study (Wiman et al., 2009).

Steel material from culverts and road barriers is reused. Geosynthetics have only been used in road construction in recent years and therefore there is no experience in dismantling such materials. In each road demolition project, a control programme should be drawn up, where complicating materials are alerted in order to obtain a management that is economically and environmentally successful (Andersson, 2009).

6.4 Unwanted materials, hazardous waste

Examples of hazardous waste and other materials that are unwanted in road recycling activities are tar and asbestos. Here is described how tar asphalt is handled in Sweden.

6.4.1 Tar

Old Swedish asphalt pavements, from 1940 to the middle of the seventies, often contain coal tar (Figure 8). It is estimated that about 0.7–1.1 million tonnes of asphalt from these pavements are excavated every year. Supposing that 25% of these materials contain tar, about 170,000–250,000 tonnes of tar containing recovered asphalt arise every year (Wik et al., 2005).

Figure 8 Examples of road constructions containing tar in the lower layers.

6.4.1.1 Legal regulations (national implications)

Dismantled and excavated asphalt pavements containing tar asphalt are considered hazardous waste according to the Swedish waste regulation and European Waste Code. Generally, waste is regarded as hazardous if the content of carcinogenic compounds is
larger than 0.1%. However, the Swedish Road Administration does not regard tar containing asphalt that is recycled on-site (in the same road) as waste.

If the road area will be used for other purposes after the dismantling, the soil has to be cleaned from tar containing asphalt to an acceptable extent. The Swedish Environmental Protection Agency has set up general target values for the residual content of various types of PAHs, depending on their molecule weight. For example, the target value for cleaned areas for future housing estates is 1 mg/kg TS for PAHs with high molecule weight, while the corresponding value for cleaned areas for future industrial estates is 10 mg/kg TS.

6.4.1.2 Identification techniques

There are various techniques to identify tar in an asphalt layers. A relatively simple method, which also can be used in field, is to use spray paint and UV lamp on cored specimens or excavated samples (Figures 9–11). The result indicates if the sample contains tar and in which layer, but the amount cannot be calculated. Odour is also a good indicator of tar.

Figure 9  Equipment for the spray test (UV lamp and spray paint).

Figure 10  Sprayed samples in daylight with visible colour changes.

Figure 11  Specimens illuminated in the dark with UV light. The left specimen contains tar, the right specimen does not.

Recommendations for sampling and analyse of tar containing asphalt material are given in (SRA, 2004).
Sampling
Sampling is carried out after a positive result of field analysis. Methodology for sampling of asphalt material from roads or from heaps for asphalt recycling is described in (SRA, 2000). This methodology can also be used for tar containing asphalt, but then it is very important that cored samples from the tar containing road include all layers to be removed. Frequency of sampling (number of samples per tonne) etc. is described in the SRA report but can also be determined in dialogue with the road owner.

Sample preparation
If tar presence has been confirmed, the sample (cored from the road or sampled from intermediate storage) has to be crushed down to a maximum grain size of 20 mm. The sample weight should be 3–5 kg crushed reclaimed asphalt material. Sampling and sample preparation should follow SS-EN 932-1\(^3\). The granules are extracted thereafter according to SS-EN 12697-1\(^4\). The extract is stored in glass bottles supplied by an analytical laboratory. Unless otherwise stated, a simple test can be performed. The extraction can be made by an asphalt laboratory.

Analysis
The extract is usually analyzed by gas chromatographic mass spectrometry, GC-MS, with respect of 16 PAHs. PAH content converted from the entire mass of the sample is expressed in mg/kg dw (dry weight). The unit mg/kg is the same as ppm (parts per million).

There is no analysis showing how much coal tar a material contains. However, it is known that coal tar contains high levels of polycyclic aromatic hydrocarbons, PAHs, and PAH content is therefore used as an indicator of tar. Some individual PAHs are classified as carcinogens. The group of “16-PAHs” has been identified by the Swedish Environmental Protection Agency and includes seven PAHs classified as carcinogenic (Table 11).

Table 11  The group “16-PAHs”. After (SEPA, 1996).

<table>
<thead>
<tr>
<th>Carcinogenic PAH</th>
<th>Other PAH</th>
</tr>
</thead>
<tbody>
<tr>
<td>Benso(a)antracen</td>
<td>Naftalen</td>
</tr>
<tr>
<td>Chrysen</td>
<td>Acenaftalen</td>
</tr>
<tr>
<td>Benso(b)fluoranten</td>
<td>Acenaften</td>
</tr>
<tr>
<td>Benso(k)fluoranten</td>
<td>Fluoren</td>
</tr>
<tr>
<td>Benso(a)pyren</td>
<td>Fenantren</td>
</tr>
<tr>
<td>Indeno(l,2,3-cd)pyren</td>
<td>Antracen</td>
</tr>
<tr>
<td>Dibenso(a,h)antracen</td>
<td>Fluoranten</td>
</tr>
<tr>
<td></td>
<td>Pyren</td>
</tr>
<tr>
<td></td>
<td>Benso(g,h,i)perylene</td>
</tr>
</tbody>
</table>

\(^3\) Tests for general properties of aggregates – Methods for sampling.

6.4.1.3 Separation techniques

If it is possible, pure asphalt layer should be separated from tar contaminated asphalt by cold milling. On older streets and roads it can be difficult in practice to effectively separate the asphalt, unless control is very accurate, because the layer thickness can vary greatly. However, wearing course should in most cases be possible to separate from other asphalt layers. For milling, a margin of safety compliance due to tar may have penetrated a few cm of the adjacent (above and below) asphalt layer. At excavation of asphalt, it is difficult to separate tar contaminated layers from pure asphalt layers but the amount of unbound material in the masses should be limited. Left-over layers of tar asphalt should be excavated and removed not be milled. It is for example difficult to mill in grouted macadam (IM) and milling gives a stronger odour than excavation. The material is also significantly more granulated when milling instead of excavating, which can complicate the retention of the masses.

Recommendations for the dismantling of old asphalt layers:
- determine whether the asphalt pavement contains tar
- consult responsible environmental authorities if tar containing materials will be reused
- try to keep contaminated materials separated from pure bituminous mixtures
- inform the staff about the tar content in the asphalt material.

6.4.1.4 Recycling solution

According to SRA, excavated asphalt pavements containing less than 70 mg/kg of 16-PAH” are regarded free from tar and can be reused without restrictions as surface layer or base course. Asphalt pavements containing tar, i.e. containing at least 70 mg/kg 16-PAH, must be handled as follows:

For all tar containing asphalt materials:
- The asphalt material is primarily reused within the same site.
- The asphalt material is used as bound or unbound road base.
- Cold or semi-hot recovery method used.
- Base layer is covered with dense wearing course.
- The asphalt material can be used in such sound barriers if they are covered by plastic sheet or other water diversion protection layer.
- The asphalt material must be above the groundwater table.
- Staff dealing with the material should be informed.

At concentrations between 300 and 1,000 mg/kg of 16-PAH:
- Intermediate storage is done only if the asphalt material cannot be used directly. The storage should be limited in time.
- Stored material has to be covered to prevent leaching.
- Storage of uncovered material should be performed at close support and combined with device for disposing of leachate water.
- Storage should not be made at sensitive sites, such as water protection area.
- Reuse is not made within sensitive land areas.

At concentrations above 1,000 mg/kg of 16-PAH: See section 6.4.1.5.
6.4.1.5 Non-road end-of-life treatments (incineration or disposal)
A special investigation has to be made on how to handle the material in the best environmental and technical way (recycling, destruction or disposal).

6.4.2 Asbestos
Asbestos is normally not used in Swedish road construction. However, there are special rules in the occupational safety and health act for handling of asbestos.

6.5 Secondary aggregates
During the last 30–35 years, much research has been performed in Sweden on the mechanical and environmental properties of various secondary aggregates. Several laboratory studies have been reported and a number of test roads and test areas with secondary aggregates like steel slag, incinerator bottom ash and fly ash have been built. Some of the roads have been monitored, for example with respect to long-term strength and environmental impact and a few has been excavated within research projects in order to study the long-term properties of the aggregates used.

Since the late 90ies, Swedish waste producers and industry associations, such as Värmeforsk (combustion residues), Avfall Sverige and Jernkontoret (metallurgical residues), have funded research and development projects with the purpose to increase the possibility of using waste, for example in road construction.

Furthermore, in recent years the Swedish Road Administration, SRA, and the Swedish Rail Administration have developed guidelines for use of alternative materials in construction (SRA, 2007c). The guidelines describe the legal, technical and environmental considerations to be made in the use of alternative materials. They also give examples of materials currently used or tested as construction materials: processed MSWI bottom ashes and other bottom ashes, Fly ashes (from coal and solid biofuel), Foam glass, Blast furnace slag, Crushed concrete, Ferrochrome slag, Shredded tyres and Iron sand (Table 12). The report also presents examples of technical properties of these materials (Table 13). The publication is based on many years of research.

Table 12 Alternative materials in a road construction – examples of use, properties and reference to technical quality. After (SRA 2007c).

<table>
<thead>
<tr>
<th>Part of the road structure</th>
<th>Function</th>
<th>Alternative materials (examples)</th>
<th>Useful properties*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bound base course</td>
<td>Base course</td>
<td>Blast furnace slag, fly ash with or without crushed rock materials</td>
<td>Stiffness increase (hardening) with time frost heave</td>
</tr>
<tr>
<td>Unbound base course</td>
<td>Base course</td>
<td>Fly ash, crushed asphalt, crushed concrete</td>
<td>Stiffness increase (hardening) with time</td>
</tr>
<tr>
<td>Sub-base</td>
<td>Base course</td>
<td>Fly ash, iron sand, ferrochrome slag crushed asphalt, blast furnace slag, crushed concrete or MSWI bottom ash with or</td>
<td>Frost heave, capillary break, draining,</td>
</tr>
</tbody>
</table>
without crushed rock materials

Lower sub-base | Frost insulation, material separation | Ash materials, some slag types, iron sand, foam glass, tyre shreds | Frost heave, draining, low density

Subgrade | Fill | Ash materials, metallurgical slag, foam glass, tyre shreds | Frost heave, low density

Subgrade | Light-weight fill | Some ash materials and slag types, foam glass, tyre shreds | Frost heave, low density

Stabilization of all unbound layers | Base course | Metallurgical slag, ash material | Stiffness increase (hardening) with time.

*Valid for all structural components, but not always relevant in pavement design and use of the components.

Table 13 Example of technical properties for some secondary material. After (SRA 2007c).

<table>
<thead>
<tr>
<th>Material</th>
<th>Maximum dry density (t/m³)</th>
<th>Bulk density (t/m³)</th>
<th>Density for design purposes (t/m³)</th>
<th>Optimum water content (%)</th>
<th>Permeability (m/s)</th>
<th>Friction angle (°)</th>
<th>Stiffness modulus (MPa)</th>
<th>Water suction height (m)</th>
<th>Thermal conductivity (W/(m·°C))</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crushed concrete</td>
<td>1,8–2,0</td>
<td>8-12</td>
<td>10⁻⁵-10⁻⁶</td>
<td>200-480</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Blast furnace slag</td>
<td>1,8–2,1</td>
<td>1,5-2,0</td>
<td>5-7</td>
<td>200-600</td>
<td>0,3-0,7</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Iron sand</td>
<td>loose compaction is necessary</td>
<td>2,0-2,3 (loose compaction)</td>
<td>2,0 loose (compaction)</td>
<td>2,10⁻⁵-5*10⁻⁵</td>
<td>34-43</td>
<td>100-200</td>
<td>0,1-0,15</td>
<td>0,26-0,47</td>
<td></td>
</tr>
<tr>
<td>Ferrochrome slag</td>
<td>2,4–2,6</td>
<td>1,75-2,55</td>
<td>2,4</td>
<td>2,5-3,0</td>
<td>7,10⁻⁵-1,10⁻³</td>
<td>200-230</td>
<td>0,12-0,18</td>
<td>0,36-1,8</td>
<td></td>
</tr>
<tr>
<td>Fly ash</td>
<td>0,8–1,7</td>
<td>0,7-2,0</td>
<td>30-60</td>
<td>10⁻⁶-10⁻⁷</td>
<td>50-150</td>
<td>0,5-0,9</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MSWI bottom ash</td>
<td>1,4–1,8</td>
<td>1,2–1,8</td>
<td>14-20</td>
<td>10⁻⁷-10⁻⁵</td>
<td>35-38</td>
<td>45-140</td>
<td>0,2-0,5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bottom ash apart from MSWI</td>
<td>0,8–1,7</td>
<td>0,7–1,7</td>
<td>13-33</td>
<td>10⁻⁶-10⁻⁹</td>
<td>15-30</td>
<td>0,3–&gt;0,8</td>
<td>0,1–0,6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Foam glass</td>
<td>0,2–0,3</td>
<td>0,18–0,35</td>
<td>0,35–0,40</td>
<td>10⁻¹-10⁻¹</td>
<td>36-45</td>
<td>75–150</td>
<td>&lt;0,12-0,17</td>
<td>0,10–0,15</td>
<td></td>
</tr>
<tr>
<td>Tyre shreds</td>
<td>0,67</td>
<td>0,5–0,7</td>
<td>Does not matter</td>
<td>&gt; 10²</td>
<td>21–38</td>
<td>0,2–0,5</td>
<td>Capillarity breaking layer</td>
<td>0,2</td>
<td></td>
</tr>
<tr>
<td>Natural gravel</td>
<td>1,7–1,9</td>
<td>6–10</td>
<td>&gt; 10²</td>
<td>30–37</td>
<td></td>
<td></td>
<td>0,6–01,8 (one sample)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

In parallel with the SRA guidelines, the industry funded a broad project in order to produce manuals for the use of “their” alternative materials in road and construction works. The manuals have been developed by the Swedish Geotechnical Institute in collaboration with Luleå Technology University and industry representatives. So far, the series of manual includes: Fly ash (Munde et al., 2006), MSWI bottom ash (Arm, 2006), Foam glass (Eriksson & Hägglund, 2008) and Tyre shreds (Edeskär, 2008).
6.5.1 Metallurgical slag

The mechanical and environmental properties of steel slag from electric arc furnace (EAF), blast furnace slag (both air-cooled and granulated), ferrochrome slag and “iron sand” (granulated slag from copper production) have been studied in several Swedish research projects. The SRA has published guidelines for using air-cooled blast-furnace slag in road construction (SRA, 2005).

A ten year old road with EAF steel slag in the subbase was excavated and sampled in order to study the ageing reactions occurred since the construction (Figure 12). Among the conclusions were mentioned that fresh EAF steel slag age with time due to carbonation and other processes leading to pH decrease and subsequent change in leaching properties (Figure 13). Road edges with uncovered shoulders allow exposure to these processes. If fresh material has been used in an old road, excavation will show that the road edge material has aged much more than the road centre material, which means that leaching characteristics for the material differs across the road section (Arm et al., 2008b).

Figure 12  Sampling of EAF steel slag subbase in Smedjebacken Sweden in 2006. After (Arm et al., 2008b).
Figure 13 Results from laboratory and field study of an old excavated road with EAF steel slag in the subbase. Percolation tests, SEM photo of particle surface and pH profile of the road. Smedjebacken, Sweden in 2006. After (Arm et al., 2008b).

Within the European ALT-MAT project a Swedish road with blast furnace slag in the subbase was excavated and the results reported (ALT-MAT, 2000).

EAF slag has also been tested as aggregate in asphalt wearing courses, especially in roundabouts. Good resistance to wear by abrasion from studded tyres and good durability properties made it also interesting in porous asphalt, a bituminous mix type commonly used for better drainage and to reduce noise. (SALAR, 2008).

6.5.2 Incinerator ash

The properties of various incinerator ash materials have been studied in several Swedish research projects. Since the end of the 90ties, the research program “Environmentally correct utilisation of non-coal ashes”, funded by Värme forsk Sweden AB, has produced much knowledge. All research reports have an English summary and can be downloaded from www.varmeforsk.se. Examples of reports in this programme are (Arm et al., 2008a) and (Arm et al., 2008b). Furthermore, all laboratory and field data arising within the research program is collected in a free access database called ALLASKA (= “all ash” in Swedish). The database can be reached at http://www.askprogrammet.com/BakgrundALLASKA.shtm.

Test sections with processed municipal solid waste incinerator (MSWI) bottom ash in the sub-base retain its strength after several years, about 70% of that of reference sections with crushed rock in the sub-base (Figure 14 and 15). Comparison between the leachates from the whole test section and results from previous laboratory leaching of the MSWI bottom ash alone showed significantly different patterns. This should be taken into account in the assessment of potential use. (Arm et al., 2008a).
Figure 14  Törringevägen test road, stiffness change of the test structure. Layer moduli for the combined layer of base of crushed granite and sub-base of MSWI bottom ash, evaluated from FWD measurements. Mean value of ten points. The test structure is designed according to Figure 9b. (Arm et al., 2008a).

A nine year old test section with processed municipal solid waste incinerator (MSWI) bottom ash in the sub-base was excavated and sampled in order to study the ageing reactions occurred since the construction (Figure 16). Among the conclusions were mentioned that the bottom ash from the pavement edge was more aged than the bottom ash from the road centre, which could be seen in the leaching properties. However, no difference in pH was found, instead the differences were said to be caused by differences in water exposure (Figure 17). Road edges with uncovered shoulders allow this to happen which means that when excavating an old road with bottom ash, various leaching characteristics for the material across the road section can be expected (Arm et al., 2008b).

Figure 15  Törringevägen test road, reference structure (left) and test structure (right). Test structure from top to bottom: surface course + asphalt bound base course, unbound base course of crushed rock, MSWI bottom ash and clay moraine. (Arm et al., 2008a).
A 16 year old road partly constructed with MSWI bottom ash in the subbase was excavated in the year 2003. Before excavation FWD measurements were performed. All layers were sampled and from the ash layer specimens for cyclic load triaxial tests were cored. Comprehensive environmental tests were performed. It was concluded that it was easy to excavate the different layers in the road construction separately which is favourable for future reuse (Bendz et al., 2006).
6.5.3 Recycling in unbound road layers

According to the present manuals for various secondary aggregates, the materials can be excavated and reused again in a similar design or stored for later use. However, there is only little experience of putting this into practice.

6.5.4 Recycling in hydraulically bound road layers

There is only little knowledge in Sweden about how to recycle secondary aggregates in hydraulically bound road layers.

6.5.5 Recycling in bituminous bound road layers

There is only little knowledge in Sweden about how to recycle secondary aggregates in bituminous bound road layers. Test sections with steel slag as aggregate in asphalt surface layer are currently monitored, but no research reports are available so far.

6.6 Vehicle tyres

Every year, approximately 70,000 tonnes of used tyres are generated in Sweden. All returned tyres are reused or recycled in one way or another, either as a material or in energy recovery. Today, half of all collected tyres go to energy recovery in heating plants and to the cement industry and half to material reuse or recycling. Examples on reuse are in retreads and in blasting mats. An example of recycling is when the rubber raw materials is utilized or replace other materials in constructions. The trend is towards increased material reuse and reduced energy recovery. This has taken place thanks to research and practice providing a more profound knowledge of utilisation and the environmental impact.

6.6.1 Identification

Tyre shreds are fragmented end-of-life tyres, mainly from passenger cars but also from heavy vehicles. The size of the individual shreds is controlled by sieving and re-shredding of coarse shreds. The first pass results in 100–300 mm large tyre shreds, the second pass results in 100–150 mm and finer tyre shreds are re-processed until the material passes the desired sieve size. The result is disc shaped tyre shreds with protruding steel cord. Smaller tyre shreds have relatively more protruding steel cord compared to coarser fractions (Figure 18). (Edeskär, 2006).
In USA there is an established standard\(^5\) for nomenclature and determination of some of the technical properties, and in Europe the work with establishing a common standard\(^6\) is now in progress. These two standards will to some extent differ in nomenclature and procedures to determine properties. (Edeskär, 2006)

6.6.2 Handling and preparation

6.6.2.1 Collection and transport

The recycling of tyres follows the Swedish regulation\(^7\) on producer responsibility for tyres. This liability means that whichever company places tyres on the market must also accept liability for how they are dealt with at the end of their service lives. Regulator is the Swedish Environmental Protection Agency (SEPA) in cooperation with local environmental agencies.

Tyre importing companies can join the tyre industry’s recycling system (Figure 19), which is organized by the Swedish Tyre Recycling Ltd, (SDAB). SDAB is a trade association owned by Tyre, Rims & Accessories suppliers Association (DFTF) and Tyre Specialist Association (DRF) and it is responsible for members’ obligations under the Regulation including the reporting to SEPA. SDAB has in turn hired a contractor for all tyre collection and recycling throughout Sweden.

Recycling is funded by the consumers that pay a recycling fee when purchasing new tyres.

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\(^6\) prEN 14243:2004 Post-consumer tyre. Materials and applications.

\(^7\) SFS 1994:1236.
Tyres are collected in local garages and tyre companies and transported to a depot where they are fragmented. Private persons can leave their tires without rims to the tire shop free of charge. Only clean tyres are accepted.

### 6.6.2.2 Technologies for product preparation

The tyres are fragmented by a shredder, normally in mobile processes. The fragmentation is mainly due to transportation reasons in order to reduce the volume and takes place regardless of the future use. The shredding is executed on hard surfaces to avoid mixing soil into the material. The tyre shreds are stored at the shredding plant separate from other materials and it is delivered free from foreign objects and pollutants. The size of the shreds depends on how many times the tyres have been fragmented and whether the material has been sieved.

Presently, there is no production of tyre shreds in Sweden and all shreds have to be bought abroad. However, a factory will be built in the south western part of Sweden. The plan is to produce two fractions, 1–4 mm and powder, from about 30,000 tonnes of tyres (SDAB, 2009).

### 6.6.3 Recycling whole tyres as lightweight / massive material in embankments

No Swedish experience.
6.6.4 Recycling as aggregate in rubber-based pavements (sport fields,..)

The tyres can be recycled in the form of tyre shreds as lightweight filling material in noise barriers, as frost insulating material in roads, as drainage in landfills and as elastic bed in riding and trotting tracks. The Swedish Geotechnical Institute (SGI) has published a handbook that describes both technological and environmental perspectives (Edeskär, 2008).

Lightweight fills are used to reduce stress on the underlying soil in order to reduce consolidation settlements or to increase global stability of constructions by reducing load. The low bulk density of tyre shreds, compared to soil materials, makes the material suitable as lightweight fill material. The high porosity and drainage capability limits the presence of water in the fill and the low maximum water content in individual tyre shreds preserves the low bulk density over time.

In design, the initial compression, creep, maximum in-situ density and thickness must be considered. The initial compression depends on the stress from overlaying layers. If the fill is subjected to load, creep will occur under a long period. The creep in a Swedish test road was at average 5% during two years. It will result in slightly increased density and should be encountered for in design of lightweight fill applications.

To limit the potential leaching effects, the fills should be placed above the ground- or surface water table and ensure the surface run-off beneath the tyre shred fill (Figure 20). In large fills the fire risks should be considered. ASTM\(^8\) recommends a maximum height of tyre shreds fills of 3 m. (Edeskär, 2006).

![Figure 20 Tyre shreds used as lightweight fill in a noise barrier (Edeskär, 2006).](image)

Frost penetration combined with accessibility of water causes frost heave, especially in fine grained soils. Thawing and corresponding bearing capacity loss due to low draining capacity in the partly frozen soils is also common. Thermal insulation materials are used to reduce frost penetration. The low thermal conductivity in tyre shreds makes the material suitable for thermal insulation material (Figure 21). Combined with the high permeability, the material could decrease the frost heave by acting as a capillarity breaking layer and increase bearing capacity at thawing by drainage of excessive water (Edeskär, 2006).

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\(^8\) ASTM D 6270-98
In landfill construction, tyre shreds can be used as drainage layers in the bottom construction and in the top cover to protect the sealing layers to have water pressures being built up (Figure 22). The bottom drainage layer is a part of the leachate collection system used for transportation of leachate for treatment or release. Normally a gas drainage system is installed in landfills. The gas drainage system collects landfill gas, which has a high greenhouse effect potential due the high content of methane. The gas also increases the risk for landfill fires (Edeskär, 2006).

**Figure 21** Tyre shreds used as thermal insulation in road construction (Edeskär, 2006).

**Figure 22** Tyre shreds used as drainage layer in top cover, as gas drainage layer and as bottom drainage layer (Edeskär, 2006).

### 6.6.4.1 Environmental properties

Among the metals it is primarily iron and zinc that is of concern due to the high concentrations found in leaching studies. Iron hydroxides could be an aesthetic problem if precipitated outside a construction and will affect the release of other charged ions which may be accumulated absorbed on iron hydroxides or released if the hydroxides are dissolved. For zinc to be toxic, high concentrations are needed. If the recipient is sensitive to additional zinc sources the use of tyre shreds from large constructions to small recipients should be considered. In most cases the zinc release are acceptable in
terms of ecological effect levels in a potential recipient. Leaching of PAH compounds is insignificant. This is supported by the conclusions of for example Scientific committee on toxicity, ecotoxicity and the environment (CSTEE)\(^9\). Tyre shreds leaches phenols. In evaluation of the effects, natural sources and sinks, i.e. biological degradation, must be considered. Aerobic conditions in the recipient should be sufficient to biodegrade the obtained phenol concentrations in the leachate. The other studied elements are not considered to be of environmental concern (Edeskär, 2006).

6.6.5 Recycling as modified binder in asphalt pavements

Since 2007 the Swedish Road Administration has built some test roads with rubber bitumen in the asphalt surface layer. The technical aim for this mix type is primary to increase the layer’s service life, reduce noise level or prevent crack propagation.

A dense mix has been used with good results regarding the crack propagation prevention. However, the increased temperature of the mix increases the smoke generation during laying. The smoke is not dangerous to health but it might be troublesome to the workers. To reduce the smoke generation, tests with blower equipped asphalters will be made (SDAB, 2009).

The rubber bitumen consists of rubber crumbs with particles less than 50 mm mixed with bitumen and the roads are constructed according to experience and specifications from Arizona Department of Transportation (ADOT).

6.6.6 Non-road end-of-life treatments (incineration or co-processing)

In 2008, just over 50% of the collected tyres were used as fuel, either in the cement industry or in municipal district heating plants.

6.7 Polluted soils and sediments

In general, SRA promotes recycling as much as possible in road demolition projects. In each project, a control programme should be drawn up, where complicating materials are alerted in order to obtain a management that is economically and environmentally successful (Andersson, 2009). In the first place, excavated soils are recovered in construction of new roads in the neighbourhood.

SRA has written an administrative guide in cooperation with legal expertise (SRA, 2007a) which describes how to categorize excavated soil, when it should be regarded as waste and when it should be considered hazardous waste, see section 1.2 in this report. SRA has also developed a manual for handling sediment and soil from road ditches, which describes among others when and how the soil should be sampled and also environmental criteria for different uses (SRA, 2007b). Soils and sediments from roads with high traffic volume (> 10,000 vehicles/day) must be sampled and analysed before use in the “road area”. If not classified as waste, generally no further notification or license is required for the use. However, the place for use can require certain precautions, e.g. for use in water protection area, national park and cultural reserves.

\(^9\) Questions to the CSTEE relating to scientific evidence of risk to health and the environment from polycyclic aromatic hydrocarbons in extender oils and tyres, Document C7/Gf/csteeop/PAHs/12-131103 D(03), European Commission, Brussels.
The coming Swedish regulations for use of waste in construction, mentioned in section 1.1.1, will imply some changes in the management of recycled soil.

6.7.1 Excess soil from excavation works

In some cases, excess soil from road works is transferred to landowners in the vicinity. Only non-contaminated soil may be transferred. SRA will then contract with the landowner, which means that the landowner takes over operations responsibility over the masses. If the soil is contaminated or of poor quality, it must be deposited at a municipal landfill for non-hazardous waste. If the soil contains high concentrations of pollutants it must be disposed of at a landfill for hazardous waste. For disposed soil there are special testing requirements, including leaching tests.

6.7.1.1 In-situ recycling and soil improvement technologies

SRA tries to recover all soil of sufficient quality in each road project. Primarily soils are used as embankment filling. They can also be used for construction of road side area to improve the road environment. This means, for example, use for filling around culverts and crossings, to cover the slopes of hills or large rocks for facilitated vegetation mowing or in order to stabilize steep road side area to improve road safety. Many low quality materials, eg vegetation layers or soil containing silt and clay, can be used for construction of noise barriers.

6.7.2 Sediment from road ditches and rainwater basins

There is a Swedish manual for handling sediment and soil from road ditches (SRA, 2007b). It gives guidance for sampling and analysis of sediment quality as well as environmental criteria with benchmarks for assessing whether the sediment is suitable for reuse. The environmental criterion is outlined in Table 4. The manual also describes current environmental legislation relating to natural and cultural environment. Furthermore, the manual contains analytical data for sediment samples taken from the ditches of roads with different traffic volume (Figures 23 and 24).

<table>
<thead>
<tr>
<th>Table 14 Environmental criterion for reuse of sediment from road ditches (SRA, 2007b).</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Element</strong></td>
</tr>
<tr>
<td>Pb</td>
</tr>
<tr>
<td>Cu</td>
</tr>
<tr>
<td>Zn</td>
</tr>
<tr>
<td>Cd</td>
</tr>
<tr>
<td>Canc PAH</td>
</tr>
<tr>
<td>Other PAH</td>
</tr>
<tr>
<td>Oil</td>
</tr>
<tr>
<td>Electric conductivity at L/S 2</td>
</tr>
</tbody>
</table>
About 400 wet ponds and similar treatment facilities for removal of pollutants from highway runoff have been constructed in Sweden since the nineties. They prevent the pollutants to be discharged to ground or receiving watercourses and they also provide environmental protection in case of road accidents. In most ponds removing of accumulated sediment will be needed to prevent clogging or remobilisation of polluted sediment. The frequency of removing depends on traffic volume and the performance of sediment chambers upstream of the treatment facility as well as on the vegetation and the size and design of the ponds.

SRA has published a maintenance manual for runoff treatment facilities (SRA, 2008). In addition to maintenance schedules and inspection checklist it includes advice and techniques for sediment sampling, analysis, removal, disposal or reuse at the site. The manual states that it is important to sample and analyse the sediment before removing it. The reason is that the degree of pollution determines which sediment handling is suitable. Preferably the sediment should be reused within the treatment facility area. If this is not possible, it should be treated at an approved treatment plant or landfilled. In all cases dewatering could be necessary. The manual also reports results from previous studies of sediment composition which give information on how the content of pollutants and the leaching characteristics of sediment may vary.

6.7.3 Road cleaning waste

6.7.3.1 Anti-skid materials (gravel and sand)

Each year, nearly 750,000 tonnes of anti-skid material is swept up from Swedish roads, streets and squares. The material can often be reused or recycled, but the solutions and techniques vary among municipalities. To help, the Swedish Association of Local Authorities and Regions has published a guide that presents solutions meeting high standards for health and environment (Johansson, 2008). Possible solutions are: reuse as anti-skid material, recycling as fill material, recycling in asphalt production or final disposal. The report also takes up environmental risks and the national regulations for handling the material. Several examples of how Swedish municipalities handle the material are also provided.
6.8 Green waste

6.8.1 From road shoulder maintenance

6.8.1.1 Grass

Haymaking on road shoulders is common in Sweden (Figure 25). However, the vegetation is seldom collected and recycled by means of composting or anaerobic digestion (Eriksson, 2009) During the early 2000s, there was a lot of advanced experimental studies (SRA, 2000). Various haymaking techniques, logistics, costs and possible contents of pollutants in the vegetation were investigated. One of the conclusions was that collection of vegetation is optimal from biological point of view, yet this is not performed in practice.

Figure 25 Haymaking on Swedish road shoulders.

6.8.1.2 Trees and bushes

Cutting of trees and bushes from the road shoulder is made regularly in Sweden. Chipping of the cut vegetation occurs, but often the vegetation is left on the road shoulder.

6.8.1.3 Natural vegetation layer

The design of roadside and vegetation is important for the road alignment in the landscape. By taking advantage of the natural surface soil at the excavation work, you can maintain a sustainable, climate-friendly and natural flora on the roadside. The SRA has performed experiments with the return of surface soil, both in the forest environment and the re-establishment of roadside with species-rich meadows environment. The experience is very good and has resulted in general recommendations in a pamphlet which is also available in English (SRA, 1999).

6.8.2 On-site treatment

Not common in Sweden.
6.8.3 Off-site treatment
Composting of grass and chipping for energy recovery in heating plants are common in the management of municipal parks in Sweden but is rare in the maintenance of roads.

6.8.4 Biomass utilization

6.8.4.1 Compost
See section 7.3.

6.8.4.2 Biogas to energy
Wood chips from forest and park management is used as energy recovery in heating plants in Sweden, not for biogas production. However, it is unusual in the maintenance of roads.

6.9 References

Andersson, G. 2009-09-29, Swedish Road Administration, Region Mälardalen in Eskilstuna, Road construction, verbal reference.


Eriksson, O. 2009-09-29, Swedish Road Administration, Borlänge, verbal reference.


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