Hot recycling of asphalt at a central plant

A general quality control process and long term follow up results
Swedish case studies

Dina K. Kuttah
Preface

It is well known that an effective quality control plan is important to the success of any asphalt recycling project. Therefore, this report has been prepared to assist the international readers in understanding the demands and requirements on the manufacturing of hot recycled asphalt in Sweden which are relatively similar to those used for new hot mix asphalt manufacturing, but with additional demands on the reclaimed asphalt (RA) material and the virgin asphalt binder selected based on RA content. This report is one of many reports prepared to document Re-Road project which has received funding through the European Community’s Seventh Framework Programme (FP7/2007-2013) and directed by Dr. Björn Kalman, VTI.

Correspondingly, it is important to mention that this report is not intended to replace the excellent reports available on the subject and used in this document but it is a translation from Swedish to English of research already done and published in this subject as referred to in the given references.

Linköping October 2013

Dina Kuttah
Quality review

Internal peer review was performed on 14 February 2014) by Björn Kalman. Dina Kuttah has made alterations to the final manuscript of the report 22 May 2014. The research director of the project manager Björn Kalman examined and approved the report for publication on 2 October 2014. The research director of the project manager Björn Kalman examined and approved the report for publication on 2 October 2014. De slutsatser och rekommendationer som uttrycks är författarens/författarnas egna och speglar inte nödvändigtvis myndigheten VTI:s uppfattning.

Kvalitetsgranskning

Intern peer review har genomförts 14 februari 2014 av Björn Kalman. Dina Kuttah har genomfört justeringar av slutligt rapportmanus 22 maj 2014. Projektledarens närmaste chef Björn Kalman har därefter granskat och godkänt publikationen för publicering 2 oktober 2014). The conclusions and recommendations expressed are the author’s/authors’ and do not necessarily reflect VTI’s opinion as an authority.
Contents

Summary .......................................................................................................................... 5
Sammanfattning ............................................................................................................. 7
List of Figures .................................................................................................................. 10
List of Tables .................................................................................................................... 11
1 Introduction .................................................................................................................. 13
2 Hot Recycling at a Central Plant ................................................................................. 14
   2.1 Case Study 1 (Road 40, Delen Rya-Grandalen) ..................................................... 14
   2.2 Case Study 2 (Road 42, Fristad) .......................................................................... 24
3 Follow up of the trial road ......................................................................................... 33
   3.1 Follow up of road Rv 40, Rya – Grandalen at 1997 .............................................. 33
   3.2 Follow up of road Rv 40, Rya – Grandalen at 2007 .............................................. 35
4 Conclusions .................................................................................................................. 37
References ...................................................................................................................... 38
Hot recycling of asphalt at a central plant. A general quality control process for hot asphalt mix recycling – Swedish case studies

by Dina Kuttah
VTI (Swedish National Road and Transport Research Institute)
SE-581 95 Linköping Sweden

Summary

Hot recycling at a central plant is a technique that has increased in popularity over the past years and today there are large numbers of asphalt recycling plants adapted for hot recycling in Sweden.

In case of hot recycling plants, 10–50 percent of asphalt can be recycled depending on the plant type, method of recycling, type of the manufactured mixture, traffic volume and quality of the old asphalt pavement, etc. With respect to hot recycling of asphalt at a central plant, the mixtures can be produced by continuous or batch mixing. Recently, new recycling methods have been developed to enable 90–100 percent reclaimed asphalt (RA) involvement by continuous hot mix recycling.

This report aims to highlight the various demands on hot recycling of asphalt at a plant and to study how the recycled asphalt mixtures differ from the new one and how much asphalt granules that can be mixed without affecting the pavement performance negatively. Nevertheless, this report presents a translation from Swedish to English of already published reports (given in the references list) on hot recycling of asphalt in Sweden.

Correspondingly, the report presents results of tests carried out on the binder layer (ABb) of road 40 and surface course (ABS) of road 42, Västergötland. Research has been carried out on mixes and test sections to cover quality control of RA, stone materials in asphalt, binder content, particle size distribution and voids in asphalt, analysis of recycled binders and mechanical properties of asphalt. In addition, this report presents results obtained from follow–up process on road 40 (Rya–Grandalen part).

In summary, it can be concluded that up to 40 percent of reclaimed asphalt can be added to the asphalt mixes by using hot asphalt recycling and result in asphalt mixture of relatively similar characteristics to the newly manufactured asphalt mixtures.
Varm återvinning av asfalt i verk. En allmän kvalitetskontroll för återvinning av varm asfaltmix – Svenska fallstudier

av Dina Kuttah
VTI, Statens väg- och transportforskningsinstitut
581 95 Linköping

Sammanfattning

Varm återvinning i verk är den teknik som ökat mest på senare år och idag finns ett stort antal verk anpassade för varm återvinning i Sverige.

Vid varm återvinning i verk, kan 10–50 procent asfaltmaterial återvinnas beroende på verk, metod, typ av massa och lager, trafikvolym och kvaliteten hos den gamla asfaltbeläggningen, med mera. Vid varm återvinning i verk, kan massorna tillverkas genom kontinuerlig eller satsvis blandning. Nyligen har nya varma återvinningsmetoder utvecklats som innebär att 90–100 procent asfaltgranulat kan återvinnas varmt genom kontinuerlig blandning.

Syftet med den här rapporten är att kasta ljuset på olika krav angående varm återvinning av asfalt i verk och att studera hur varma återvinningsmassor skiljer sig från nytillverkade massor och hur mycket asfaltgranulat som kan blandas in utan att egenskaperna försämras.

I rapporten redovisas försök med bindlager (ABb) på väg 40 och slitlager (ABS) på väg 42, Västergötland. Kontrollen av asfaltmassorna och provsträckorna omfattar kvalitetskontroll av asfaltgranulat, stenmaterial i asfaltmassan, bindemedelshalt, kornkurva och hålrum på asfaltmassan, analys av återvunnet bindemedel och mekaniska egenskaper hos asfaltmassan vilket redovisas i den här rapporten. Dessutom presenterar denna rapport resultaten från uppföljningsprocessen på väg 40, delen Rya–Grandalen.

Sammanfattningsvis uppvisade återvinningsmassorna med upp till 40 procents inblandning av retrurasfalt i varmblandad massa, motsvarande egenskaper som nytillverkade asfalt massa.
## List of Abbreviations

<table>
<thead>
<tr>
<th>Abb</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>ABb</td>
<td>Asphalt Concrete in Binder Courses</td>
</tr>
<tr>
<td>ABS</td>
<td>SMA, Stone Mastic Asphalt</td>
</tr>
<tr>
<td>ABT</td>
<td>Asphalt Concrete Wearing Courses, Dens-Graded Asphaltic Concrete</td>
</tr>
<tr>
<td>AG</td>
<td>Asphalt Concrete Base Courses (hot-mix base)</td>
</tr>
<tr>
<td>MTS</td>
<td>Material testing system</td>
</tr>
<tr>
<td>RA</td>
<td>Reclaimed asphalt</td>
</tr>
<tr>
<td>RST</td>
<td>Road Surface Tester</td>
</tr>
<tr>
<td>Rv</td>
<td>Riksväg (in Swedish), Highway</td>
</tr>
</tbody>
</table>
List of Figures

Figure 1: The drum mix plant used in recycled mixtures production, (Source: Jacobson and Simonsson, 1998) ................................................................. 14
Figure 2: The particle size distribution of the RA after wet sieving, Rv 40, Rya–Grandalen (Source: Jacobson and Simonsson, 1998) ........................................ 15
Figure 3: The particle size distribution of the extracted RA materials, Rv 40, Rya–Grandalen (Source: Jacobson and Simonsson, 1998) ................................. 16
Figure 4: Particle size distribution of asphaltic samples (one per control section) from road Rv 40, Rya–Grandalen (Source: Jacobson and Simonsson, 1998) .......................................................... 18
Figure 5: Permanent deformation by using the dynamic creep test. Samples from Rv 40, Rya–Grandalen. (according to the VTI's investigation), (Source: Jacobson and Simonsson, 1998) .................................................. 22
Figure 6: Permanent deformation by using the dynamic creep test. Test samples and core samples from Rv 40, Rya–Grandalen. (according to the Swedish Transport Administration Production), (Source: Jacobson and Simonsson, 1998) .......................................................... 23
Figure 7: Indirect tensile strength ratio of 3 and 7 days soaked samples. Asphalt mixes from road Rv 40, Rya–Grandalen (Source: Jacobson and Simonsson, 1998) ........................................................................................................... 24
Figure 8: The Particle size distribution of the original RA (Wash sieving). Rv 42, Fristad (Source: Jacobson and Simonsson, 1998) .................................................. 26
Figure 9: The binder content and the particle size distribution of the extracted materials. Rv 42, Fristad(Source: Jacobson and Simonsson, 1998) ........................................ 26
Figure 10: The particle size distribution of the tested samples (one per section) from road. Rv 42, Fristad. (Source: Jacobson and Simonsson, 1998) .................................................................................. 28
Figure 11: Voids content for the different samples types. Rv 42, Fristad, (Source: Jacobson and Simonsson, 1998) .............................................................................. 28
Figure 12: Stiffness moduli of the tested RA samples. Rv 42, Fristad, (Source: Jacobson and Simonsson, 1998) ................................................................. 29
Figure 13: Indirect tensile strength ratios of dried and soaked RA samples, Rv 42, Fristad, (Source: Jacobson and Simonsson, 1998) .................................................. 30
Figure 14: Permanent deformation results using dynamic creep test. Rv 42, Fristad, (Source: Jacobson and Simonsson, 1998) .................................................. 31
Figure 15: Macro-texture results according to RST measurements, Rv 40, Rya–Grandalen, autumn 1997 (Source: Jacobson and Waldemarson, 2008) ............. 33
Figure 16: Evenness, IRI results according to RST measurements, Rv 40, Rya–Grandalen, autumn 1997 (Source: Jacobson and Waldemarson, 2008) ............. 34
Figure 17: Rut depths results according to RST measurements, Rv 40, Rya–Grandalen, autumn 1997 (Source: Jacobson and Waldemarson, 2008) ............. 34
Figure 18: IRI results according to RST measurements, Rv 40, Rya–Grandalen, autumn 2007 (Source: Jacobson and Waldemarson, 2008) .................... 35
Figure 19: Rut depths results according to RST measurements, Rv 40, Rya–Grandalen, autumn 2007 (Source: Jacobson and Waldemarson, 2008) ............. 36
Figure 20: Visual inspection of Rv 40, Rya–Grandalen, autumn 2007 (Source: Jacobson and Waldemarson, 2008) ................................................................. 36
List of Tables

Table 1: Binder content, voids content, and voids filled with binder (Marshall compaction) of the asphalt mixes from road Rv 40, Rya – Grandalen, (Source: Jacobson and Simonsson, 1998). .......................................................... 17

Table 2: Binder analysis of aged RA samples and RA mixtures. Rv 40, Rya-Grandalen, (Source: Jacobson and Simonsson, 1998 ). ...................................................... 19

Table 3: Stiffness modulus and indirect tensile strength ratio of asphalt samples compacted according to Marshall method, Rv 40, Rya-Grandalen, (Source: Jacobson and Simonsson, 1998 ) .................................................. 20

Table 4: The voids contents for various asphalt samples prepared for creep test, (the average values), (Source: Jacobson and Simonsson, 1998 ). ................................. 21

Table 5: Aggregates analyses of local materials, ABS 11, (Source: Jacobson and Simonsson, 1998). ......................................................................................... 27

Table 6: Binder content, voids contents and voids filled with binder (Marshall) of asphalt samples from road Rv 42, Fristad. (Source: Jacobson and Simonsson, 1998) ........................................................................ 27

Table 7: Stiffness moduli and indirect tensile strength ratios of asphalt samples, Rv 42, Fristad, (Source: Jacobson and Simonsson, 1998). ......................................................... 30

Table 8: Average voids contents of asphalt samples prepared for dynamic creep testing, (Source: Jacobson and Simonsson, 1998). ......................................................... 31

Table 9: Water susceptibilities and water saturation degree of asphalt samples, Rv 42, Fristad, (Source: Jacobson and Simonsson, 1998). ......................................................... 32
1 Introduction

Brown (2000) defined the pavement recycling as a logical and practical way to conserve the decreasing supply of construction materials and to help reduce the cost of preserving the current pavement network. It is important to note that the recycled pavements have been found to perform as well as pavements built with all new materials, in case that the recycled pavements are properly designed and constructed (Brown 2000).

In general, hot mix recycling is the process in which reclaimed asphalt (RA) are mixed with new materials such as asphalt binder and aggregate in a central hot mix plant or in place to produce a recycled mix (Santucci, 2007). According to Santucci (2007), in many cases, the hot mix asphalt plants were modified to handle RA. However, RA can be obtained by milling or ripping and crushing operations of the old existing pavements. Correspondingly, the combination of RA with virgin aggregate and asphalt to produce a hot recycled mix depends largely on the configuration of the hot mix plant (Santucci, 2007).

The most important factors which make pavement recycling having power to arouse interest are cost effectiveness, material conservation, and ecological considerations like limits the amount of waste material going into landfills (Santucci, 2007).
2 Hot Recycling at a Central Plant

Commentary on this chapter: The content of this chapter is a translation from Swedish to English of selected parts of VTI Notat 22-1998 by Torbjörn Jacobson and Bo Simonsson.

The RA and/or macadam are usually warmed up and dried in a drum mixer at a central plant. Mixing of RA, fillers and bitumen take place in the same drum mixer at the same time. This type of plant is usually preferred for large volumes of huge mixes (e.g. during major road construction projects), see Figure 1.

![Figure 1: The drum mix plant used in recycled mixtures production, (Source: Jacobson and Simonsson, 1998).](image_url)

The drum mix plant has been adapted for recycled asphalt, and the most common method is to add the RA in the centre of the drum. This may enable the asphalt mixes to get enough temperature. Note that the cold mixes could lead to overheating of stone materials.

Nevertheless, mixing in the drum mix plant is usually taken a longer time (about 1.5 min) as compared to the mixing time required in the batch-type mixing plant.

According to the plant instructions, mixing of RA up to 40% can be performed in the drum mix plant, but this may require higher warming temperatures for the stone materials. The following paragraphs focus on two Swedish case studies related to the hot recycling of RA at a central plant, the mixing rates of RA and the corresponding follow up process of test roads constructed using hot recycled asphalt materials.

2.1 Case Study 1 (Road 40, Delen Rya-Grandalen)

With respect to this case study, the asphalt mixes have been manufactured at the Swedish Transport Administration Productions Drum Mix Plant (ERMONT plant) in Rya. The RA composed of 10–20 years old ABT and AG materials from road Rv 40.
It is important to mention that an ordinary quality control was carried out by the Swedish Transport Administration Production according to Road 94.

2.1.1 RA tests

The RA materials used in the construction of the control sections were prepared from the upper binder layers of the existing surface course of road 40 as described before. The excavated RA were crushed and sieved (RA materials greater than 18 mm were eliminated) to result in a control sizes of RA materials. The resulting mixtures were mixed later at the plant.

The RA samples were tested at the Swedish National Road and Transport Research Institute (VTI) with respect to:

- Wet sieving, the particle size distribution of the RA materials.
- Binder content and particle size distribution of the extracted materials,
- Petrographic analysis of extracted materials, fractions between 8 and 16 mm.

In addition to the aforementioned analyses, recycled binder samples extracted from the RA were also tested.

The Particle size distribution and the binder content

The particle size analysis of the RA was carried out in accordance with FAS method 221 (corresponding to EN 933-1) using wet sieving and the resulting curve is shown in Figure 2. In addition, the particle size analysis was carried out on extracted asphalt materials according to FAS method 221 and the resulting data is plotted as illustrated in Figure 3.

Figure 2: The particle size distribution of the RA after wet sieving, Rv 40, Rya-Grandalen (Source: Jacobson and Simonsson, 1998).
In regard to Figure 2, the RA materials have more open gradation which is typical for crushed and sorted aggregates suitable for asphalt surfaces. The materials are well graded with a maximum particle size of 22 mm.

Concerning Figure 3, the particle size distribution of the extracted materials is closer to the ABT materials than to the AG materials, and this reflects a denser gradation of the extracted materials.

Petrographic analyses of stone material

In this investigation, petrographic analyses of stone material (fraction between 8 and 16 mm) were carried out by a geologist. The results showed that the aggregates consisted mainly of the following three rock types:

- Gray, fine to medium grained, foliated gneiss (about 56% by weight) with enrichment of mica. The micas sheets were oriented in parallel and uniformly distributed throughout the sample.
- Light reddish, dense, massive quartzite (about 31% by weight).
- Dark, fine to medium grained, massive amphibolite (13% by weight)

Usually, this type of rock material does not have very good properties in terms of wear resistance or brittleness.

Moreover, the binder content test was performed on RA samples according to FAS method 404 (similar to EN 12697-1) and a value of 4.8% was observed. Usually, the excavated materials have lower binder content as compared to the new manufactured mixes. The binder content analysis showed a low penetration value of 32 and a relatively high softening point of 59. It can be concluded from these results that the binder content has become harder over the years.

Nevertheless, analysis of ductility and breaking point tests carried out on binder samples showed that the aged binder had elastic and flexible properties. Many aged asphalt surfaces (and sometimes new asphalt surfaces) exhibited binder of similar properties and therefore the RA material had been considered as a representative. Here, it is important to notice that RA samples with binder of extremely low
penetration or high softening point are not suitable for hot recycling of asphalt. Mixing of softer binder can be a way to compensate the effect of aged and stiffened asphalt. Another way can be to only add a less amount of RA materials (<20%) into the new asphalt mixes.

2.1.2 Stone materials in asphalt mixes

Rock materials involved in the new manufacturing of asphalt mixes were analyzed with respect to the petrographic assessments. The petrographic analysis showed that the rock materials of particle fractions between 16 and 22 mm consisted of pink gray, fine to medium grained, foliated gneiss of mica enrichment. Micas sheets were oriented in parallel and uniformly distributed throughout the sample.

However, based on data from the asphalt plant, low resistance to wear (value of 15), flakiness index of 1.32, brittleness index of 49 and particles density of 2.68 kg/dm³ were obtained for the rock materials adopted in this case study.

2.1.3 Binder content, particle size distribution curve and voids contents of the RA mixes

Control of the binder content and the particle size distribution were carried out in the VTI’s laboratories. In addition, the voids filled with binder and the voids content were assessed. Testing was connected to investigate the mechanical properties and ductility. Consequently, Table 1 and Figure 4 below show the corresponding testing results. The values of voids content presented in Table 1 are the average of 10 manufactured test samples while the values of binder content, the particle size distribution and the voids filled with binder are the results of double testing.

Table 1: Binder content, voids content, and voids filled with binder (Marshall compaction) of the asphalt mixes from road Rv 40, Rya –Grandalen, (Source: Jacobson and Simonsson, 1998).

<table>
<thead>
<tr>
<th>Type of asphalt mix</th>
<th>Binder content (% by weight)</th>
<th>Voids content (% by volume)</th>
<th>Voids filled with binder (% by volume)</th>
</tr>
</thead>
<tbody>
<tr>
<td>B85, reference mix</td>
<td>4.8</td>
<td>4.0</td>
<td>73</td>
</tr>
<tr>
<td>B85 +20% RA</td>
<td>5.4</td>
<td>2.4</td>
<td>84</td>
</tr>
<tr>
<td>B85 +40% RA</td>
<td>5.3</td>
<td>2.2</td>
<td>85</td>
</tr>
<tr>
<td>B180, reference mix</td>
<td>5.3</td>
<td>3.8</td>
<td>77</td>
</tr>
<tr>
<td>B180+20% RA</td>
<td>5.3</td>
<td>3.1</td>
<td>80</td>
</tr>
<tr>
<td>B180 +40% RA</td>
<td>5.0</td>
<td>2.5</td>
<td>83</td>
</tr>
</tbody>
</table>

It appears from Table 1 that the binder content values are within the range of 4.8 to 5.3%. This range satisfies the conditions for ABb22 given by the Swedish Transport Administration technical description for 1998. Also, the voids contents in Marshall compacted asphalt samples, have fallen between 2.2 and 4.0. Correspondingly, the values of voids filled with binder have fallen between 73 and 85. The values of voids contents as well as the voids filled with binder can be considered lower and higher than the corresponding values of new manufactured mixes respectively.
This means that the recycled asphalt mixes of 20% to 40% RA materials are relatively denser than the reference mix. This fact must be taken into account during the determination of the indirect tensile strength ratios.

Moreover, the particle size distribution of the RA samples curve reflects the fact that the mixes are relatively dense, as illustrated in Figure 4.

![Particle size distribution of asphaltic samples (one per control section) from road Rv 40, Rya–Grandalen (Source: Jacobson and Simonsson, 1998).](image)

**Figure 4** Particle size distribution of asphaltic samples (one per control section) from road Rv 40, Rya–Grandalen (Source: Jacobson and Simonsson, 1998).

Analysis of the recovered binder

The binders were recovered from asphaltic materials already extracted from the road according to the FAS method 419 (similar to EN 12697-3).

The residual binder were analysed with regard to:

- Penetration at 25°C according to FAS method 337-91 (corresponding to EN 1426).
- Softening point, ball and ring procedure, according to FAS method 338-95 (corresponding to EN 1427).
- Ductility at 25°C according to ASTM method D113.
- Breaking point according to Fraass IP 80 (corresponding to EN 12593).

The results of the above-mentioned tests are reported in Table 2. These tests were carried out only on recovered binder samples extracted from the RA materials.
Table 2: Binder analysis of aged RA samples and RA mixtures. Rv 40, Rya-Grandalen, (Source: Jacobson and Simonsson, 1998).

<table>
<thead>
<tr>
<th>Type of asphalt mix</th>
<th>Penetration (at 25°C 0.1 mm)</th>
<th>Softening point (°C)</th>
<th>Ductility (at 25°C)</th>
<th>Fraass breaking point (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aged RA samples (granules)</td>
<td>32</td>
<td>59.0</td>
<td>&gt;100</td>
<td>-14</td>
</tr>
<tr>
<td>B85 from the tank</td>
<td>86</td>
<td>47.0</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>B180 from the tank</td>
<td>183</td>
<td>40.0</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>B85, reference mix</td>
<td>64</td>
<td>50.0</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>B85 +20% RA</td>
<td>50</td>
<td>53.0</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>B85 +40% RA</td>
<td>48</td>
<td>54.0</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>B180, reference mix</td>
<td>112</td>
<td>45.0</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>B180 +20% RA</td>
<td>90</td>
<td>47.0</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>B180 +40% RA</td>
<td>70</td>
<td>50.0</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

Complete analysis according to the above mentioned tests was performed only on recovered binder from the aged RA samples as shown in Table 2.

It is well known that the binder content become harder due to the warming up of asphalt mixes during the manufacturing and laying out processes. Therefore, to control the disadvantages of extensively high temperatures, a demand has been introduced regarding the maximum allowable softening point change under the process. For new manufactured asphalt mixes, the allowable increase in softening point from the place where the binder leave the tank at the plant to the laying down of the asphalt mixes on the road, must be less than or equal to 8°C (according to Road 94).

Furthermore, mixing of RA with the new asphalt mixes affect negatively the softening point change even more, considering the fact that the aged binder is harder than the new one.

Usually, during the recycling process, the rocks materials warm up and this may contribute to the hardening of binder content also.

It is important to mention that all the mixtures, except one, have passed the condition of maximum allowable softening point change of 8°C. The ABb22/B180 mixes have acquired about +10°C increase in softening point after mixing with 40% RA materials.

Usually, the penetration value of the binder is also affected by adding RA materials to the virgin asphalt mixes. The penetration values of the binder are usually fall within the range of 48 to 50 for B85 and 70 to 90 for B180.

As expected, softer asphalt mixes (ABb22/B180) have been affected by the addition of RA more than harder asphalt mixes (ABb22/B85).
In order to compensate the extra hardening caused by adding RA materials, softer binder can be added to the mixes and the requirements should be assessed with respect to the aged binder of asphalt mixes.

### 2.1.4 Mechanical properties of asphalt mixes

In the VTI’s laboratories, test samples were manufactured and analyzed with respect to:

- Stiffness modulus test according to FAS method 454-95 (similar to EN 12697-26). The samples were prepared using Marshall compaction.
- Dynamic creep test according to FAS method 468-97 (similar to EN 12697-25). The samples were prepared using gyratory compaction.
- Indirect tensile strength test according to FAS method 449-91 (similar to EN 12697-23). The samples were prepared using Marshall compaction.
- Voids contents.

**Stiffness modulus, indirect tensile strength, and voids contents tests**

Stiffness modulus tests were carried out on different asphalt samples compacted according to Marshall method and the results are reported in Table 3. In addition, for each asphalt type, the indirect tensile strength ratios were determined for five samples and the results are illustrated in Table 3.

It is clear from Table 3 that the stiffness moduli and the indirect tensile strength ratios for ABb22/B85 are higher than the corresponding values for ABb22/B180, as expected. The addition of RA leads to a fair increase in the indirect tensile strength ratios. Nevertheless, incorporation of RA materials with relatively hard binder should result in a stiffer asphalt layer.

*Table 3: Stiffness modulus and indirect tensile strength ratio of asphalt samples compacted according to Marshall method, Rv 40, Rya-Grandalen, (Source: Jacobson and Simonsson, 1998).*

<table>
<thead>
<tr>
<th>Type of asphalt mix</th>
<th>Stiffness modulus (at 10°C, MPa)</th>
<th>Indirect tensile strength ratio (at 10°C, kPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>B85, reference mix</td>
<td>12163</td>
<td>2635</td>
</tr>
<tr>
<td>B85 +20% RA</td>
<td>11452</td>
<td>2781</td>
</tr>
<tr>
<td>B85 +40% RA</td>
<td>12087</td>
<td>2848</td>
</tr>
<tr>
<td>B180, reference mix</td>
<td>7392</td>
<td>1890</td>
</tr>
<tr>
<td>B180 +20% RA</td>
<td>8210</td>
<td>2022</td>
</tr>
<tr>
<td>B180 +40% RA</td>
<td>8623</td>
<td>2028</td>
</tr>
</tbody>
</table>
Dynamic creep test (Investigations at VTI)

In order to get an idea about the deformation properties of the different types of asphalt mixes, the dynamic creep tests were performed on asphalt samples compacted using gyratory compactor. Five samples of each asphalt mix were compacted and tested by MTS unit in the VTI’s road laboratory.

The target of gyratory compaction was to get voids content in consistence with those of samples compacted according to Marshall method. However, the preferred percentage of voids for Marshall compacted samples was between 2 and 4%, but it was difficult to achieve void contents within this range by using the gyratory compaction. Usually, the reason behind such a problem is that the bulk density computed by using the gyratory compaction instrument does not match the bulk density achieved according to FAS 427 method (corresponding to EN 12697-6). However, Table 4 below shows the void contents obtained by gyratory compaction.

Results from dynamic creep test carried out on various asphalt types are shown in Figure 5. It is worth to mention that the values shown in Figure 5 are the average values of five tested samples collected from each asphalt mix.

*Table 4: The voids contents for various asphalt samples prepared for creep test, (the average values), (Source: Jacobson and Simonsson, 1998).*

<table>
<thead>
<tr>
<th>Type of asphalt mix</th>
<th>Average void contents (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ABb 22, reference mix, B85</td>
<td>5.1</td>
</tr>
<tr>
<td>ABb 22 + 20 % RA, B85</td>
<td>3.9</td>
</tr>
<tr>
<td>ABb 22 + 40 % RA, B85</td>
<td>3.3</td>
</tr>
<tr>
<td>ABb 22, reference mix, B180</td>
<td>4.1</td>
</tr>
<tr>
<td>ABb 22 + 20 % RA, B180</td>
<td>2.3</td>
</tr>
<tr>
<td>ABb 22 + 40 % RA, B180</td>
<td>2.7</td>
</tr>
</tbody>
</table>
Figure 5 Permanent deformation by using the dynamic creep test. Samples from Ry 40, Rya – Grandalen. (according to the VTI’s investigation), (Source: Jacobson and Simonsson, 1998).

Dynamic creep test (Investigations at the Swedish Transport Administration Production)

Stabilities of asphalt mixes and core samples were tested in the Swedish Transport Administration Production laboratories in Örebro with regard to creep test. Some of the test samples were prepared by gyratory compaction and the other samples were extracted from the road as core samples. The results of creep tests are shown in Figure 6.
Figure 6 Permanent deformation by using the dynamic creep test. Test samples and core samples from Rv 40, Rya – Grandalen. (according to the Swedish Transport Administration Production), (Source: Jacobson and Simonsson, 1998).

Durability Tests

In order to get a better idea about the durability of the asphalt mixes, water susceptibilities were determined using the indirect tensile test according to FAS method 446 (similar to EN 12697-12). In this investigation, ten asphalt samples were tested. Five samples were tested under dried conditions and the other five were tested under wet conditions. Water susceptibility analysis was carried out for 3 and 7 days soaking in water. Nevertheless, Samples soaked for 3 days in water were tested in the VTI’s road laboratory while those soaked for 7 days were tested at the Swedish Transport Administration Production. Results of water susceptibilities analysis are plotted in Figure 7.
Figure 7 Indirect tensile strength ratio of 3 and 7 days soaked samples. Asphalt mixes from road Rv 40, Rya – Grandalen (Source: Jacobson and Simonsson, 1998).

Referring to Figure 7, the durability of the soaked samples seems to be great. The water susceptibility of 7 days soaked samples are more than 70% and therefore the values have been fallen within the acceptable limit according to the Swedish Transport Administration.

Adding of RA materials increases the tendency towards better durability, which is not really surprising, taking into account that the stones of the RA materials are covered by bitumen and therefore they can be treated in the same manner as bitumen-based stone chips.

Furthermore, ABB22 mixes with B85 shows a better water resistance than that for ABB22 with B180 as shown in Figure 7.

2.2 Case Study 2 (Road 42, Fristad)

As in case study 1, the asphalt mixes were manufactured at the Swedish Transport Administration Productions (Drum Mix, ERMONT plant) in Rya. The RA materials came from an intermediate storage in Gothenburg (Angered) about 400 tons were produced per section. The Paver was a DEMAG DF 130P and during the compaction of the asphalt mixtures in the field, two different compactors (DYNAPAC 3-roll rolling, static and HAMM DV8 2-wire roller, vibratory) were used.

The test road was constructed on 2–3/10 1997 and the weather was relatively cold (+5 to +10 °C) with light rain showers in the implementation of control section 1. However, when the control sections 2 and 3 were laid down, it was sunny but also cold (about +3 °C).

During the manufacturing process, samples of aggregates, RA, binder and the recycled mixes were taken. The mixtures samples were taken only at plant (from truck) and the samples were then divided between VTI and the Swedish Transport Administration Productions. The temperature of the mixtures ranged from 142
to $170^\circ$ C according to the measurements carried out on the bed of the truck (with plug-thermometer) before the overturning of the asphalt mixes in the paver.

The Swedish Transport Administration Productions was responsible for the regular quality control. However, according to recycling studies, the binder was significantly aged (the penetration grade was 20 and the softening point was $69^\circ$ C), therefore probably not suitable for hot recycling, particularly at higher mixing ratios. Correspondingly, the quality control carried out by independent laboratories showed acceptable results.

2.2.1 RA tests

RA materials used to ABS mixtures came from Gothenburg county and included quartzite among other things. The RA materials were tested for:

- Wet wash sieving, RA materials curve,
- Binder content and the particle size distribution of extracted materials,
- Petrographic assessment of the extracted materials,
- Recycling of binders.

The Particle Size Distribution and the Binder Content

The Particle size distribution of the original RA materials can be seen in Figure 8, while Figure 9 shows the particle size distribution and the binder content of the extracted materials.

The particle size distribution broadly complies with the requirements of ABS 11 as given in ROAD 94. Subsequently, the filler percentage is at a somewhat low level according to VTI testing.

Petrographic analyses of stone material (extracted material)

It is worth to mention that the extracted materials greater than 8 mm were consisted of about 90% by weight of light, dense, mass form quartzite. The remaining 10% consisted of equal parts of red, medium-grained granite, fine-grained gray gneiss, and dark fine-grained amphibolite.
Figure 8 The Particle size distribution of the original RA (Wash sieving). Rv 42, Fristad (Source: Jacobson and Simonsson, 1998).

Figure 9 The binder content and the Particle size distribution of the extracted materials. Rv 42, Fristad (Source: Jacobson and Simonsson, 1998).

2.2.2 Stone materials in asphalt mixes

Petrographic assessments were even carried out on new manufactured mixtures by a geologist. Stone materials of particle sizes between 4 and 11 mm consisted of gray-pink, fine medium grained gneiss. Gneiss was foily and relatively rich of mica. However, mica was not accumulated in some layers, but uniformly distributed throughout the rocks. Stone material was analyzed with respect to particle density according to FAS Method 208 (corresponding to EN 1097-6), flakiness index according to FAS Method 209 (an old Swedish specification replaced by EN 933-3) and the resistance to wear by abrasion from studded tires – Nordic test according to
FAS Method 259 (corresponding to EN 1097-9). The results of the aforementioned tests are reported in Table 5.

Table 5: Aggregates analyses of local materials, ABS 11, (Source: Jacobson and Simonsson, 1998).

<table>
<thead>
<tr>
<th>Analyses</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Particle density</td>
<td>2.67</td>
</tr>
<tr>
<td>Flakiness index</td>
<td>1.34</td>
</tr>
<tr>
<td>Resistance to wear by abrasion</td>
<td>11.5</td>
</tr>
</tbody>
</table>

2.2.3 Binder content, particle size distribution curve and voids contents of the RA mixes

A limited control on the binder content and the particle size distribution were carried out at VTI’s laboratories. The tests were connected to asphalt samples (and sampling sections) used to study the mechanical properties and durability of RA mixes. Moreover, the void contents and the percentages of voids filled with binder were determined. The values of void contents refer to the average of 10 manufactured specimens while the binder contents, the particle size distribution curves, and the voids filled with binder values were determined by double testing. The results of these experiments are presented in Table 6 as well as Figures 10 and 11.

Table 6: Binder content, voids contents and voids filled with binder (Marshall) of asphalt samples from road Rv 42, Fristad. (Source: Jacobson and Simonsson, 1998).

<table>
<thead>
<tr>
<th>Type of asphalt mix</th>
<th>Binder content, (% by weight)</th>
<th>Voids content, (% by volume)</th>
<th>Voids filled with binder, (% by volume)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ABS11/B85, reference mix</td>
<td>6.3</td>
<td>1.7</td>
<td>90</td>
</tr>
<tr>
<td>ABS11/B85+ 20 % RA</td>
<td>6.1</td>
<td>2.0</td>
<td>88</td>
</tr>
<tr>
<td>ABS11/B85+ 40 % RA</td>
<td>6.4</td>
<td>2.7</td>
<td>85</td>
</tr>
</tbody>
</table>
2.2.4 Analysis of the recovered binder

The analyses of recovered binder from cores showed relatively high bitumen hardness especially for samples with RA materials. The differences in softening point for these sections were between +10 and +11 °C, while for the reference section was slightly at a lower level, +7 °C. One reason is that the ABS mixes are heated to relatively high temperatures between 142 and 170 °C (in this case, low involvement of RA). To compensate for the additional stiffening of the mixes, slightly softer bitumen can be added to the mixtures. Nevertheless, minimum and maximum values of the softening point and penetration may be suitable criteria for assessment purposes.

Figure 10 The particle size distribution of the tested samples (one per section) from road. Rv 42, Fristad. (Source: Jacobson and Simonsson, 1998).

Figure 11 Voids content for the different samples types. Rv 42, Fristad, (Source: Jacobson and Simonsson, 1998).
2.2.5 Mechanical properties of asphaltic mixtures

The following tests were carried out on laboratory-manufactured specimens of asphalt mixes:

Stiffness Modulus tests (FAS Method 454-95) on samples prepared according to Marshall method.

- Dynamic creep tests (FAS Method 468-97), Gyratory manufactured samples.
- Indirect Tensile strength tests (FAS 449-91), on samples prepared according to Marshall test.
- Voids contents

Stiffness modulus, indirect tensile strength, and voids contents tests

Stiffness modulus and indirect tensile strength were investigated on Marshall specimens for different asphalt mixtures. Stiffness modulus was calculated as the average of four tested specimens for each asphalt mixture, while the indirect tensile strength ratio was calculated as the average of five tested samples for each asphalt mixture. The results of this study are presented in Figures 12, 13 and Table 7.

![Figure 12 Stiffness moduli of the tested RA samples. Rv 42, Fristad. (Source: Jacobson and Simonsson, 1998).](image-url)
**Figur 13** Indirect tensile strength ratios of dried and soaked RA samples, Rv 42, Fristad, (Source: Jacobson and Simonsson, 1998).

**Table 7**: Stiffness moduli and indirect tensile strength ratios of asphalt samples, Rv 42, Fristad, (Source: Jacobson and Simonsson, 1998).

<table>
<thead>
<tr>
<th>Type of asphalt mix</th>
<th>Stiffness modulus (at 10°C, MPa)</th>
<th>Indirect tensile strength (at 10°C, kPa), dried samples</th>
</tr>
</thead>
<tbody>
<tr>
<td>ABS11/B85, reference mix</td>
<td>10793</td>
<td>2697</td>
</tr>
<tr>
<td>ABS11/B85+ 20 % RA</td>
<td>11897</td>
<td>2677</td>
</tr>
<tr>
<td>ABS11/B85+ 40 % RA</td>
<td>12712</td>
<td>3085</td>
</tr>
</tbody>
</table>

It is clear from Figures 12, 13 and Table 7 that the stiffness moduli and the indirect tensile strength ratios are somewhat higher for the RA mixtures as compared to the reference mix.

**Dynamic creep tests (Investigations at the VTI)**

In order to get a better understanding about the dynamic characteristics of the recycled asphalt mixtures, the dynamic creep test were carried out on asphalt samples compacted using gyratory compaction machine. Asphalt samples were first reduced to right size portions and then packed in gyratory compactors. Five specimens of each type of asphalt were tested in the VTI’s laboratories.

It is clear from Table 8 that the average voids contents of asphalt samples compacted by gyratory machine are around 2%.
Table 8: Average voids contents of asphalt samples prepared for dynamic creep testing, (Source: Jacobson and Simonsson, 1998).

<table>
<thead>
<tr>
<th>Type of asphalt mix</th>
<th>Average voids contents (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ABS11/B85, reference mix</td>
<td>2.0</td>
</tr>
<tr>
<td>ABS11/B85+ 20 % RA</td>
<td>2.1</td>
</tr>
<tr>
<td>ABS11/B85+ 40 % RA</td>
<td>1.8</td>
</tr>
</tbody>
</table>

Results related to the creep tests of asphalt samples are presented in Figure 14 and show the average of five tested specimens. It appears from Figure 14 that ABS materials have acquired relatively high resistant to creep and the stability has been considered very good for the all three mixes. The lowest (best) strains have been observed for the mixes containing RA.

![Figure 14 Permanent deformation results using dynamic creep test. Rv 42, Fristad, (Source: Jacobson and Simonsson, 1998).](image)

Durability tests
The durability of the asphalt samples, water susceptibilities were assessed for new and reclaimed asphalt samples compacted with respect to Marshall test. Ten asphalt samples were tested, five of them were dried and the other five were saturated with water. The water susceptibility results of the tested samples are presented in Table 9 below.
Table 9: Water susceptibilities and water saturation degree of asphalt samples, Rv 42, Fristad. (Source: Jacobson and Simonsson, 1998).

<table>
<thead>
<tr>
<th>Type of asphalt mix</th>
<th>Water saturation degree (%)</th>
<th>Water susceptibilities (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ABS11/B85, reference mix</td>
<td>74</td>
<td>81</td>
</tr>
<tr>
<td>ABS11/B85+ 20 % RA</td>
<td>102</td>
<td>90</td>
</tr>
<tr>
<td>ABS11/B85+ 40 % RA</td>
<td>83</td>
<td>82</td>
</tr>
</tbody>
</table>
3 Follow up of the trial road

Commentary on this chapter: The content of this chapter is a translation from Swedish to English of selected parts of VTI Notat 21-2008 by Torbjörn Jacobson and Andreas Waldemarson.

In order to have a better understanding of the performance of constructed trial sections (in which RA have been used) as compared to the control sections (of 0% RA) a follow up process were performed on road Rv 40, Rya – Grandalen at different periods. Part of the follow up process was performed using RST measurements as well as visual inspections as discussed in the following paragraphs.

3.1 Follow up of road Rv 40, Rya – Grandalen at 1997

3.1.1 RST-measurements

The results of RST measurements (using VTI’s Laser-RST, Road Surface Tester) are shown in Figures 15–17 in terms of macro-texture, IRI and rut depths values respectively. Here, it is worth noting that the results refer to the mean values of the measurements carried out on the trial sections.

Figure 15 Macro-texture results according to RST measurements, Rv 40, Rya – Grandalen, autumn 1997 (Source: Jacobson and Waldemarson, 2008).
3.1.2 Visual inspection

Few weeks after opening the road to traffic, a visual inspection was performed on the trial sections. The sections in which RA has been used were looked homogenous and
dense, but the surfaces in lane K2 (160/220) were oilier than those in lane K1 (70/100).

3.2 Follow up of road Rv 40, Rya – Grandalen at 2007

3.2.1 RST-measurements

In the middle of May 2007 further RST-measurements were performed on the test road. The results from the measurements shown in Figures 18 and 19.

Figure 18 IRI results according to RST measurements, Rv 40, Rya – Grandalen, autumn 2007 (Source: Jacobson and Waldemarson, 2008).
Figur 19 Rut depths results according to RST measurements, Rv 40, Rya – Grandalen, autumn 2007 (Source: Jacobson and Waldemarson, 2008).

In lane K1, the rut depths in the wearing course ranged between 8-10 mm. The highest values were observed in the control section (of 0% RA). The rut depths in lane K2 were less than 3 mm for the all sections. IRI values were between 1.0–1.2 mm/m in the test sections.

3.2.2 Visual inspection

The test sections were inspected visually in autumn 2007, and according to the observations no mechanical damages were observed, see Figure 20.

Figure 20 Visual inspection of Rv 40, Rya – Grandalen, autumn 2007 (Source: Jacobson and Waldemarson, 2008).
4 Conclusions

Regarding case study 1, Rv 40–Grandalen, the differences between virgin mixes and those with 20 and 40% RA materials involvement have appeared to be low according to the laboratory testing and even later field measurements (Jacobson and Simonsson, 1998). The stiffness moduli and the indirect tensile strength ratios were slightly higher for mixes containing RA materials and tend to increase with increase in RA involvement. This means that the stiffness (strength) of the asphalt layer will be slightly higher for the recycled mixes but this phenomenon does not need to be a disadvantage for layers of well-designed roads in southern Sweden (Jacobson and Simonsson, 1998). However, materials with good flexibility and low temperature properties are important for pavement layers located on roads of low bearing capacities or on roads of uneven frost heave as in northern Sweden due to the harsh winters (Jacobson and Simonsson, 1998). When durability tests have been carried out, test results have showed that adding of RA materials to the virgin mixes has given a positive effect on the coating’s ability to resist water susceptibilities (Jacobson and Simonsson, 1998). As expected, mixing of RA materials result in greater softening point rise than that achieved from the ordinary mixtures. Therefore it could be difficult to meet ROAD 94’s requirement for a maximum rise of +8 °C in softening point, especially at higher levels of RA materials involvement or if the old coating materials are significantly aged (Jacobson and Simonsson, 1998). The survey has also showed that the binding layers, according to the Swedish Transport Administration’s new guidelines, seem to be of high quality alternative to the AG and therefore suitable for roads construction (replacing the upper AG-layer) that will be exposed to a heavy traffic (Jacobson and Simonsson, 1998).

Pertaining to case study 2, Rv 42–Fristad, reported that the differences between virgin mixes and those with 20 and 40% RA involvement has appeared in this trial to be small according to the laboratory testing as well as later field measurements (Jacobson and Simonsson, 1998). The mixing of RA materials has resulted in slightly stiffer / harder coating than the virgin mixes according to the stiffness modulus and indirect tensile strength tests. The stabilities, for all three sections, were of a very good level according to the tests carried out on laboratory manufactured RA specimens (Jacobson and Simonsson, 1998). Harder extracted bitumen has been observed in case of RA incorporation. Because of this observation, it may be difficult to meet ROAD 94’s requirement for a maximum of +8 °C softening point raise if the standard doesn’t take into account the RA impact (Jacobson and Simonsson, 1998). Generally, most of binder stiffening observed in this case study has been acquired from the manufacturing process and not from the RA materials (conventional mixes meet, the requirements of ROAD 94).

Regarding the results of the follow-up process of Rv 40 (Rya–Grandalen), Jacobson and Waldemarson (2008) reported that after 10 years of the road trafficking, in lane K1, the rut depths in the wearing course ranged between 8-10 mm and the highest values were observed in the control section (of 0% RA). The rut depths in lane K2 were less than 3 mm for the all sections. IRI values were between 1.0-1.2 mm/m in the test sections. Furthermore, no mechanical damages were observed during the visual inspection after 10 years of road trafficking (Jacobson and Waldemarson, 2008).
References


The Swedish National Road and Transport Research Institute (VTI), is an independent and internationally prominent research institute in the transport sector. Its principal task is to conduct research and development related to infrastructure, traffic and transport. The institute holds the quality management systems certificate ISO 9001 and the environmental management systems certificate ISO 14001. Some of its test methods are also certified by Swedac. VTI has about 200 employees and is located in Linköping (head office), Stockholm, Gothenburg, Borlänge and Lund.