
Rejuvenating RAP with light oil products and a new mixing method for hot in-plant recycling

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1 Introduction

1.1 Background

Reclaimed asphalt pavement (RAP) is used as a raw material in recycled hot mix asphalts. The old binder in the RAP (RAP-binder) is typically hard and brittle due to the aging of the bitumen. Conventionally softer bitumen grades have been used to compensate the hardness of the RAP-binder. When the amount of RAP in the recycled asphalt mixture is large, the properties of the RAP-binder have a significant effect on the quality of the pavement and soft bitumen cannot compensate the hardness of the RAP-binder without exceeding the target binder content of the mixture. Rejuvenators are low-viscosity products designed to restore the properties of the RAP-binder and to improve the properties of the asphalt mixture containing RAP. Ideal rejuvenator not only restores the mechanical properties of the bitumen, but also corrects the chemical composition of the aged bitumen.

A rejuvenator should meet a number of partially overlapping requirements. Rejuvenators should be easy to blend with bitumen and have low viscosity to make RAP-binder sufficiently soft to coat the aggregates. The chemical composition of a rejuvenator has to be adequate with the RAP-binder to achieve a stable blend. The blend of the rejuvenator and binder should provide sufficient binder properties to achieve the desired mix design. Further, rejuvenators should be safe to use: high flash point and no smoke or fumes. (Chaffin et al. 1997, Karlsson et al. 2009)

The popularity of recycled pavements is continuously increasing as the environmental aspects of road construction are gaining more value. By using environmentally friendly rejuvenators the non-renewable natural resources can be saved and the emissions of volatile organic compounds and polycyclic aromatic hydrocarbons (PAHs) reduced. Based on a literature search executed for the master's thesis, there is ongoing research concerning environmentally friendly rejuvenators, but there are only few publications available. The research has been concentrating on the binder testing instead of actual mixture testing or field experiments.

The technology of the asphalt plants has been problematic when using light rejuvenators. Conventionally the rejuvenator has been blended with the bitumen before spraying the binder into the batch mixer. The blending time of rejuvenator and bitumen is short because of technical reasons. The short duration of blending for two materials with totally different viscosities can lead to inhomogeneous binder and, further, to poor quality of the pavement (Dunn et al. 2001, Sanders 2000). To solve this problem, a new mixing method has been developed for asphalt plants. Light rejuvenator can be sprayed straight on to the surface of the RAP before it is transferred to batch mixer. The method has been tested in Sweden with encouraging results (Tyllgren 2010). The new method would make the handling of bitumen and rejuvenators easier in asphalt plants and possibly improve the quality of the recycled pavement by promoting the diffusion of the rejuvenator.

1.2 Objective

The primary goal of this study was to evaluate the use of light high procession rate oil products as rejuvenators in in-plant asphalt recycling. The products were bioflux, Nytex 810, Nytex 820 and V1500. Bioflux is an oil manufactured of renewable resources by NExBTL -process patented by Neste Oil Oy. Nytex 810 and Nytex 820 are high processed oils that are cleaned of polycyclic aromatic hydrocarbons by hydration. Nytex 820 has been previously studied as rejuvenator by Tyllgren (2010). V1500 is the softest bitumen product classified in the Finnish asphalt specifications, but there is no experience of V1500 as a rejuvenator. As a bituminous material V1500 gave a point of comparison for the lighter oil products. All four products are available on the market. The effectiveness of

the rejuvenators was evaluated by their influence on the rheological properties of the extracted RAP-binder and the mechanical properties of the mixture fabricated using RAP.

To improve the quality of the rejuvenated asphalt mixture the new method of mixing was tested: The secondary goal of this study was to investigate the possible benefits of adding the rejuvenator straight into the RAP instead of using the conventional method of mixing the rejuvenator with the binder. The effect of fluxing time on the properties of recycled asphalt mixture was also investigated.

2 Experimental section

2.1 Materials

2.1.1 Rejuvenators and bitumen

The basic properties of the products are shown in Table 1. The aim was to rejuvenate the RAP-binder to the average level of 70/100 Pen bitumen which was the reference bitumen of the research. For bitumen testing the products were blended with binder extracted from RAP so that the penetration (at 25 °C) of the blend would be 85 1/10 mm. The amount of the rejuvenator needed for rejuvenating the RAP-binder was calculated by kinematic viscosities according to the following equation:

$$(a + b) * \lg(\lg(\text{visc}_{mix})) = a * \lg(\lg(\text{visc}_1)) + b * \lg(\lg(\text{visc}_2)) \quad (1)$$

where visc_{mix} is the viscosity of the mixed binder, visc_1 is the viscosity of the RAP-binder, visc_2 is the viscosity of the rejuvenator or softer bitumen, and a and b are the proportions of RAP binder (a) and rejuvenator or softer bitumen (b) so that in the final mixture $a + b = 1$.

In the laboratory the bitumen was extracted from the RAP and the binder was mixed with the rejuvenator in a penetration cup. The proportions of rejuvenator and RAP-bitumen used in mixtures are also presented in Table 1 with the sample identifications. The test results of the rejuvenated RAP-binders were compared to virgin 70/100 bitumen.

Table 1. The basic properties of the products and the suitable proportions of rejuvenator and RAP.

| Property | Unit | Bioflux | Nytex 810 | Nytex 820 | V1500 |
|---------------------------|--------------------|------------|------------|--------------|----------|
| Kinematic viscosity 60 °C | mm ² /s | 2 | 10 | 36 | 1500 |
| Density 15 ° C | kg/m ³ | 777 | 903 | 920 | 985 |
| Flash point | °C | > 60 | 174 | 212 | > 200 |
| Cloud point | °C | | -45 | -30 | |
| Chemical nature | | Paraffinic | Naphthenic | Naphthenic | Aromatic |
| Color | | Clear | Clear | Light yellow | Black |
| Sample identification | | RAP+BIO | RAP+N81 | RAP+N82 | RAP+V15 |
| Proportions | w -% | 93 / 7 | 89 / 11 | 86 / 14 | 60 / 30 |

2.1.2 Asphalt mixtures

The virgin aggregates and the 0/16 mm crushed RAP were delivered from the same asphalt plant that manufactured the asphalt mixtures for the field tests. The basic properties of the RAP and the virgin aggregates were studied and the materials were verified to be applicable. The binder content of the RAP was 4 % with penetration of 26 1/10 mm. To study the effectiveness of the rejuvenators and difference between the conventional and new mixing method, rejuvenated AC16 RC40 mixtures were manufactured with three different mixing methods according to Table 2. The short fluxing time of (30 seconds) presents the pre-fluxing time achieved in asphalt plant when spraying the rejuvenator straight on RAP before transferring it to the batch mixer. Extended fluxing time (1 month) would require stockpiling. As a reference, a conventional mixture without rejuvenator was manufactured; softer

grade binder was used to compensate the hardness of RAP-binder. The mix design was chosen according to the Finnish asphalt specifications. The mixtures contained 40 mass -% RAP (abbreviated RC40) and rejuvenators were used with the same proportions as in the binder tests. 70/100 Pen bitumen was added to the mixtures to meet the bitumen content target of the mix design. Asphalt samples of the recycled asphalt mixtures were manufactured using gyratory compactor.

Table 2. The mixing methods and sample identifications used for AC16 RC40 -mixtures

| Method no. | Method of mixing | Mixture identification |
|------------|--|------------------------|
| 1 | Conventional method: The rejuvenator was blended with the 70/100 bitumen just before mixing the asphalt. | Rejuvenator + “C” |
| 2 | The rejuvenator was added to RAP 30 seconds before mixing the asphalt (adding 70/100 bitumen and virgin aggregate) | Rejuvenator + “S” |
| 3 | The rejuvenator was added to RAP and stored for 1 month before mixing the asphalt | Rejuvenator + “M” |

2.1.2.1 Asphalt mixtures of the field tests

Field tests were performed to achieve experience of the new mixing method and the mixture properties in field. The target level of rejuvenating (penetration 85 1/10 mm), mixture design and gradation were the same as in the laboratory. Also a higher concentration of rejuvenator was tested with calculated penetration of binder 120 1/10 mm. Asphalt slabs were compacted with laboratory size vibrating roller of both of the mixtures. The test field paved with the mixtures was low-traffic volume residential street.

2.2 Methods

2.2.1 Tests for binders

The test methods and temperatures are presented in Table 3. The viscoelastic properties and their dependency on the time of loading and temperature were tested with Dynamic Shear Rheometer (DSR) in oscillation mode. The resistance against deformation was examined by softening point (ring & ball –method), Multiple Stress Creep and Recovery (MSCR) test and by calculating the “rutting factor” $|G^*|/\sin\delta$ from DSR -results. The resistance against low temperature cracking was examined by Fraass Breaking point and Bending Beam Rheometer (BBR) test. Also, the effect of rejuvenators to the chemical composition (SARA –fractions) of the RAP-binder was evaluated by thin-layer chromatographic method.

The rutting factor, MSCR- and BBR-results were evaluated by the Superpave Performance Grade Asphalt Binder Specification. Critical temperature is the temperature at which the studied property of the binder crosses the boundary value given by the specification. The behavior of the materials was roughly assumed to be linear between the testing temperatures.

Table 3. Test methods used for binder testing.

| Test | Standard / Method | Test temperature | SUPERPAVE |
|--|-------------------|---------------------------|--|
| Softening point (ring & ball) | SFS-EN 1427 | | |
| Complex shear modulus $ G^* $ and phase angle δ | SFS-EN 14770 | 10-100 °C (0.01-10 Hz) | $ G^* /\sin\delta > 1.0 \text{ kPa (1,59 Hz)}$ |
| Multiple Stress Creep and Compliance | AASHTO TP 70-11 | 50 and 64 °C | $J_{nr3200} < 4 \text{ kPa}^{-1}$ |
| Bending Beam Rheometer | EN 14771 | -16, -24 and -36 °C | $S_t < 300 \text{ MPa,}$ |
| Fraass Breaking point | SFS-EN 12593 | | |
| SARA -fractions | IATROSCAN MK-6s | | |

2.2.2 Tests for compacted asphalt

The effects of the rejuvenators and mixing methods on the mechanical properties of the recycled asphalt mixture were examined according to Table 4. All tests were performed with Universal Testing Machine (UTM) -25. The possible changes in the pavement properties were monitored with follow-up testing during the curing time.

Table 4. Testing matrix for recycled asphalt mixture samples compacted with gyratory.

| Mixture | Rejuvenator | Tensile strength (ID) | Stiffness (ID) | Permanent deformation | |
|----------------------------|-----------------|-----------------------|------------------|--------------------------|---------|
| | | SFS-EN 12697-23 | SFS-EN 12697-26 | SFS-EN 12697-25 method A | |
| | | 10 °C | 10 °C | 40 °C | |
| | | 1, 7 and 28 days | 1, 7 and 28 days | 4 and 32 days | 70 days |
| AC16 RC40 in laboratory | Bioflux | X | X | | |
| | Nytex 810 | X | X | | |
| | Nytex 820 | X | X | X | |
| | V1500 | X | X | | |
| | REF | X | X | X | |
| AC16 RC40 in plant | Bioflux 85 Pen | X | | | X* |
| | Bioflux 120 Pen | X | | | X* |

*compacted with vibrating roller

ID = indirect method

3 Results and discussion

3.1 Bitumen test results

The results of the rejuvenated binders were compared to the results of unrejuvenated RAP-binder and virgin 70/100 Pen binder. The penetration, softening point and Fraass breaking point results and the critical temperatures determined from rutting factor, MSCR and BBR results are given in Table 5. An example of determination of critical temperature is given in Figure 1. The penetrations of rejuvenated binder blends were slightly higher than expected. This may have been caused by inaccuracy in calculations and/or measurements. However, the penetration of the binder samples was within acceptable range and the samples can be considered as comparable.

The rutting factor $|G^*|/\sin\delta$ results show that the samples rejuvenated with light products have as good viscoelastic behavior at high temperatures as virgin 70/100 Pen bitumen. With bioflux and Nytex 810 the samples achieved 1-3 °C higher rutting factors indicating improved resistance against rutting. Also, the MSCR test results indicated better resistance against permanent deformation to samples rejuvenated with light products. The critical temperatures of bioflux and Nytex 810 were 1-2 °C higher. Both $|G^*|/\sin\delta$ and the critical temperature of MSCR-testing point that pure RAP-binder is highly stiff and resistant to deformation. The results of softening point, MSCR-tests and rutting factor correlated with each other. As the different test results support each other, the results can be considered as reliable.

The results of BBR and Fraass breaking point tests revealed that rejuvenated binders are significantly more resistant to low temperature cracking than the virgin 70/100 Pen bitumen: According to BBR –test results binder samples rejuvenated with light rejuvenators tolerate about 10 °C lower temperatures. The Fraass breaking point test gave more moderate results, but the results showed that using light rejuvenators improve the low temperature properties. The sample rejuvenated with bioflux did not crack in the testing range, so the Fraass breaking point of the sample is marked to be lower than -35 °C. Performance of the sample rejuvenated with V1500 in BBR-test was weaker than samples with light rejuvenators, and the Fraass breaking point of the sample was 2 °C higher than reference bitumen. The light rejuvenators with low cloud points keep up the viscous properties of the binder in low temperatures and prevent cracking.

Table 5. The results of penetration, softening point and Fraass breaking point tests and the critical temperatures of the binders according to rutting factor, MSCR and BBR results.

| Property | Unit | 70/100 | RAP | RAP+BIO | RAP+V15 | RAP+N81 | RAP+N82 |
|--|---------|--------|-------|--------------------|---------|---------|---------|
| Penetration | 1/10 mm | 82 | 26 | 89 | 97 | 99 | 103 |
| Softening point | °C | 46.6 | 61.4 | 46.8 | 44.6 | 44.8 | 44.8 |
| Rutting factor, critical temp. | °C | 64.4 | 77.9 | 68.0 | 62.0 | 65.5 | 64.4 |
| MSCR, critical temp.(J_{nr3200}) | °C | 51.4 | - | 53.0 | 51.0 | 52.2 | 51.7 |
| Fraass breaking point | °C | -20 | -7 | < -35 ^a | -18 | -22 | -25 |
| BBR, critical temp.(stiff.) ^b | °C | -20.2 | -17.5 | -35.8 | -26.5 | -32.8 | -32.8 |
| BBR, c.temp. (m-value) ^b | °C | -22.5 | -16.4 | -30.9 | -27.5 | -31.7 | -33.2 |

^a The sample did not break at the lowest temperature achieved with the device

^b BBR testing was performed for one beam only

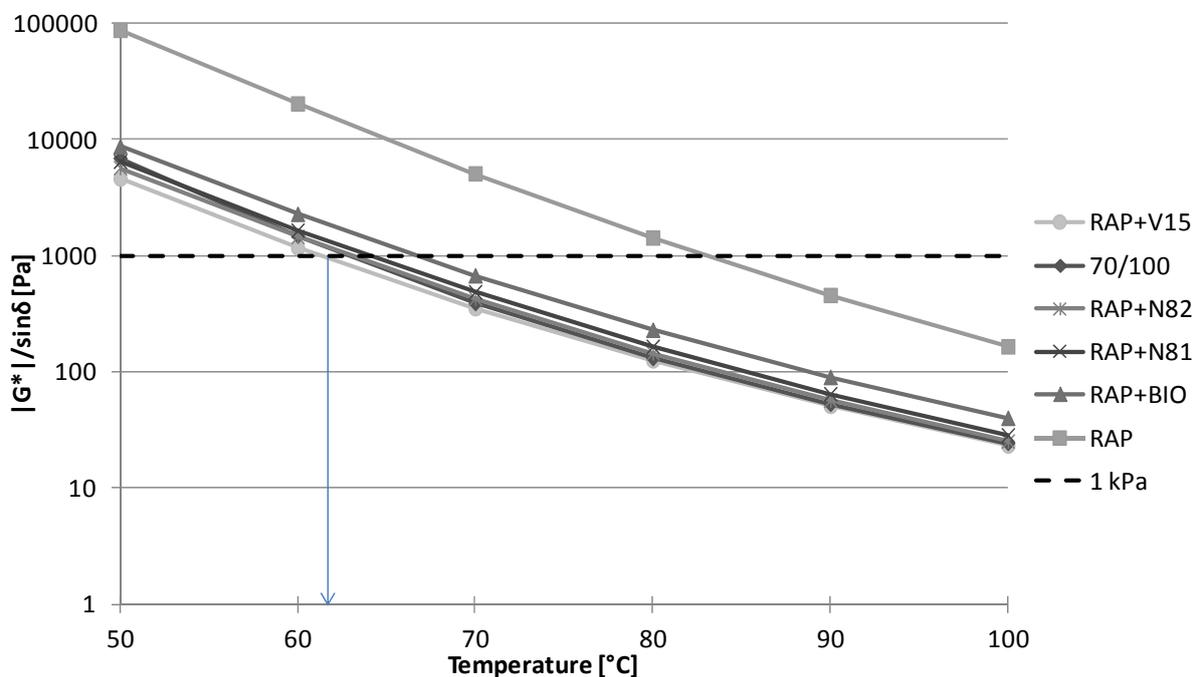


Figure 1. Determining the critical temperature ($|G^*|/\sin\delta = 1 \text{ kPa}$) of the calculated rutting factor results.

Master curves of the complex shear modulus $|G^*|$ were drawn (Figure 2) by parallel shifting according to time-temperature superposition principle. The results of DSR-testing showed that the rejuvenators restored the rheological properties of the RAP-binder to the same level with virgin 70/100 Pen bitumen. At low frequencies the curve there was a difference between light rejuvenators (RAP+BIO and Nytex -oils) and the bitumen products: the bitumen products (RAP+V15 and virgin 70/100) were stiffer at high frequencies and/or low temperatures.

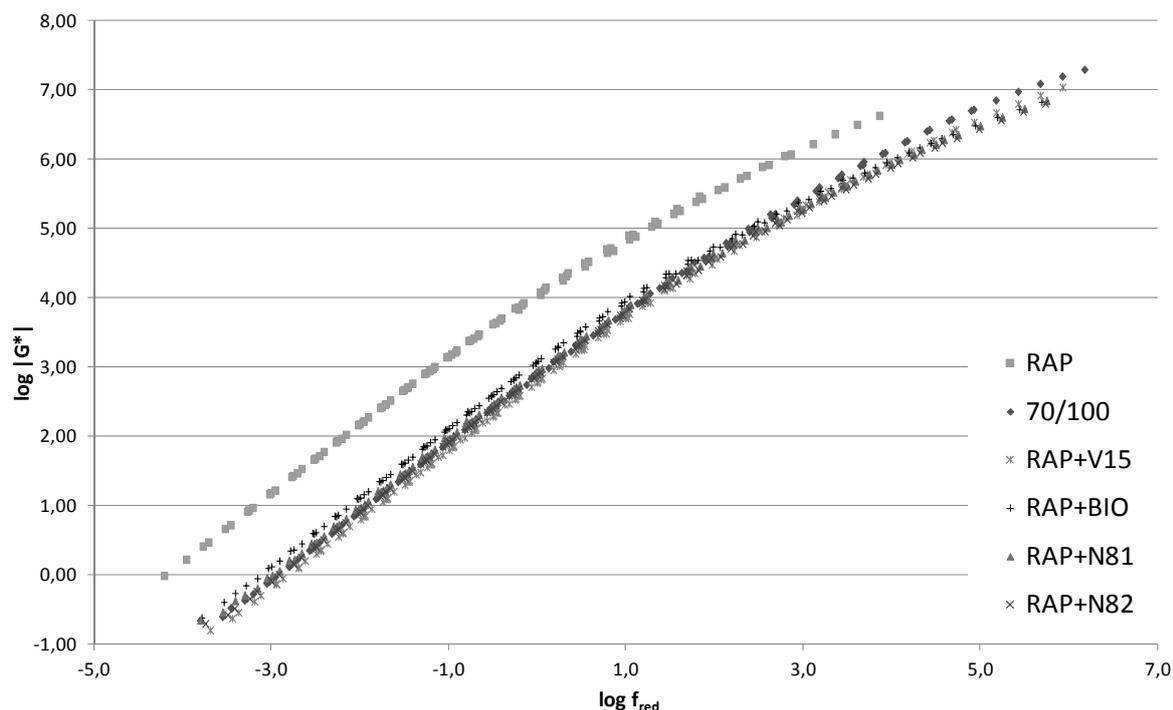


Figure 2. The master curves of the binder samples.

The results of determining the SARA-fractions were expected. Mixing the rejuvenators with RAP-binder raises the proportions of the lighter components. The composition of light products is mainly paraffinic or naphthenic so the products raised the proportion of saturates. V1500 is soft bitumen and the results indicated a lift in the proportion of aromatics. The results confirmed that these light products are not able to restore the chemical composition of the RAP-binder. Although, there have been discussion whether the thin-layer chromatographic method is suitable for light rejuvenators or fluxing agents.

3.1.1 Mixture test results

The results of the indirect tensile strength test are shown in Figure 3. The results were relatively smooth. The IDTS of the mixtures rejuvenated with bioflux were slightly higher than the other mixtures. The low IDT-strength of mixtures V15M and N82S was explained by higher bitumen content. The strength of the samples of reference mixture was lower than expected. The strength of the samples increased approximately 10-20 % during the curing time of 28 days. Adding the rejuvenator straight into the RAP (mixtures marked with S) decreased the average strength of the samples with 4-13 %. Extending the curing time from 30 seconds to 1 month did not have a statistically significant effect on the strength of the samples. The indirect stiffness modulus test was performed to three parallel samples from each mixture after curing time of 1, 7 and 28 days. The results were smooth during the period of the follow-up.

The cyclic compression test results in 40 °C are shown in Figure 4 as average of 3 parallel samples. Both mixtures achieved deformation class I ($\epsilon_n < 2,0$ %) according to Finnish asphalt specifications. The possible separation of the rejuvenator and weakening of the stability of the structure was controlled by repeating the test after one month to three more parallel samples but the strain values indicated no change. However, gyratory compaction grinds the aggregates to a firm structure that is more resistant to deformation than the compaction achieved with a vibrating roller or in field conditions. Because of the uncertainty of the results, the cyclic compression test was also performed to the mixtures of field test compacted by vibrating roller.

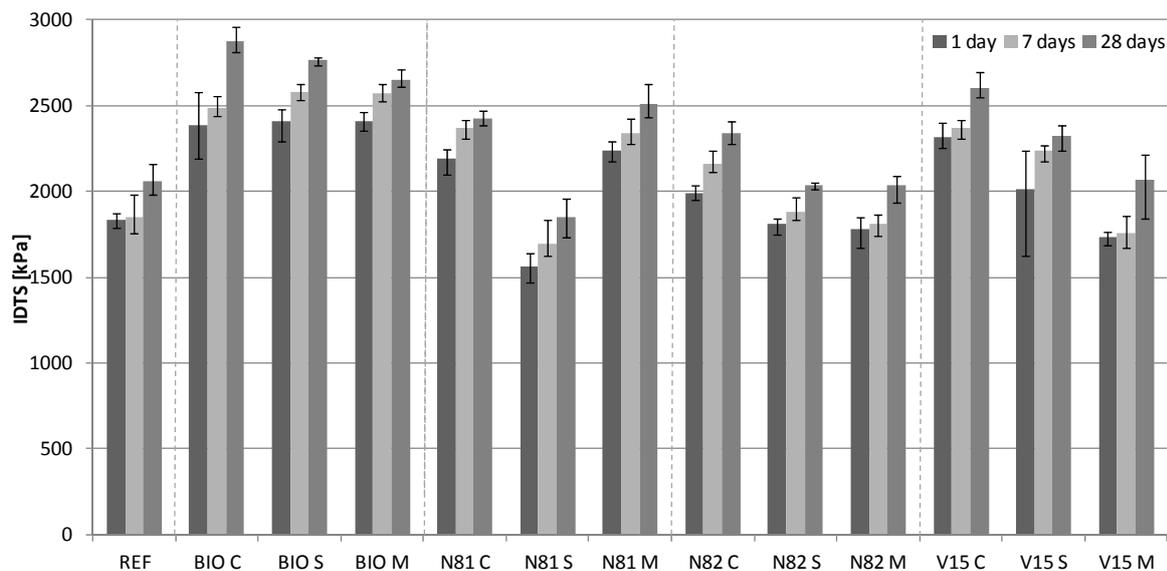


Figure 3. The average IDT-strength of the mixtures in 10 °C.

3.1.2 Field tests

The paving of the test site was performed in June 2011. The process of adding the rejuvenator straight into the heated RAP was successful. The two mixtures with different concentration of bioflux were laid at adjacent lanes. The workability of the rejuvenated mixtures was evaluated to be better than conventional recycled asphalt mixtures. Slight fuming was observed during the paving process. The condition of the pavement was inspected 5 weeks after the paving and the condition was excellent with no bleeding or sweating of oil.

Asphalt slabs were compacted with vibrating roller of the two mixtures containing bioflux. Asphalt samples with diameter of 150 mm were drilled of the slabs 10 weeks after the compaction and sawed to height of 60 mm. The results of cyclic compression test at 40 °C are presented in Figure 4. Both mixtures achieved deformation class II ($\epsilon_n < 3.5\%$) according to Finnish asphalt specifications.

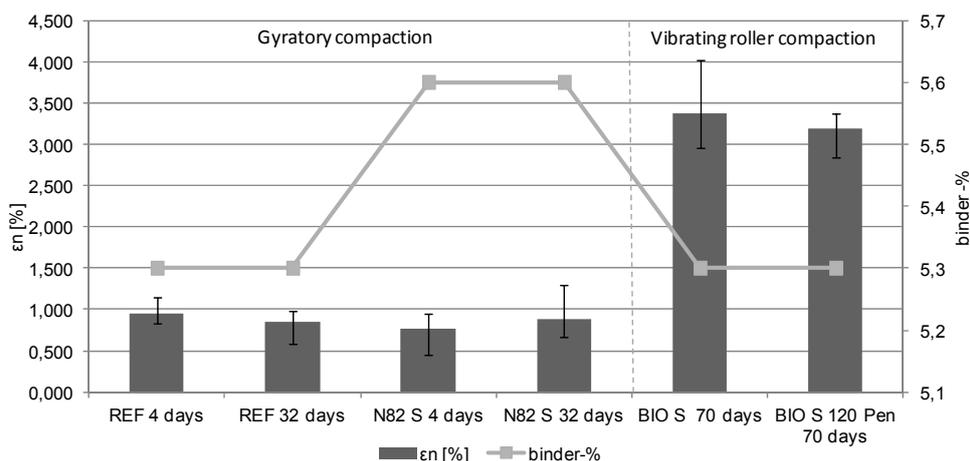


Figure 4. The average results of cyclic compression test in 40 °C.

4 Conclusions and recommendations

Based on the results, the products tested in this study are suitable as rejuvenators for reclaimed asphalt pavement. The products restored the rheological properties of RAP-binder but they were not able to correct the chemical composition. The binder samples rejuvenated with light products indicated clearly improved resistance against low

temperature cracking compared to the virgin 70/100 Pen bitumen. Furthermore, the light rejuvenators suggested slightly better resistance against permanent deformation.

The results of IDTS and stiffness modulus tests indicated that the rejuvenated asphalt mixtures have the same development of strength as the reference mixture. The resistance against deformation of the rejuvenated mixtures was sufficient according to the results gained from field test mixtures. Adding the rejuvenator straight into the RAP improved the workability of the recycled asphalt mixture and slightly decreased the indirect tensile strength of the asphalt samples. The pre-rejuvenation seemed to assist the diffusion of rejuvenator into the RAP-binder and made the mixture more homogenous. Extending the duration of the fluxing time did not have a significant effect on the properties of the pavement: The fluxing time achieved in the asphalt plant (less than 30 seconds) is adequate. The new mixing method has great potential to promote the use of light rejuvenators in hot in-plant recycling. In the asphalt plant pre-rejuvenation simplifies the handling of the bitumen and rejuvenators. The improved workability of the mixtures enables lower compaction temperatures.

This study concentrated on short term mechanical testing of the samples. Based on the results the high processed light oil products suggested great potential as rejuvenators. The research should be continued by studying the long term properties of the pavement and chemical investigations of the rejuvenated binder: there is a lack of knowledge in understanding of the chemical effects of rejuvenation. Particularly the aging properties of the rejuvenated binder should be studied. Field testing should also be continued, and it is recommended to execute a test site with higher traffic volume.

About the research

The text is based on writer's master's thesis implemented in Aalto University School of Engineering, Laboratory of Highway Engineering in co-operation with the research laboratory of Neste Oil Oy in Porvoo, Finland. The instructors of the thesis were Prof. Terhi Pellinen and M.Sc. (Tech.) Timo Blomberg. The supervisor of the thesis was Prof. Terhi Pellinen. The financiers of this project were Nynas Oy and NCC Roads Oy.

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