The Impact of a Bio-based Polymer Modified Binder on the Performance and Sustainability of High-RAP Asphalt Mixtures

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Abstract. The asphalt industry is under pressure to reduce its environmental impact, particularly CO_2 emissions linked to the use of fossil-based bitumen. Conventional hot mix asphalt (HMA) generates between 78 and 100 kg CO_2-eq per ton, with bitumen accounting for about half of these emissions. Several strategies can reduce this footprint. Warm mix asphalt (WMA), now standard in the Netherlands, lowers production temperatures by about 30°C, cutting fuel consumption and emissions by 20–30%. Even more effective is reclaimed asphalt pavement (RAP), where incorporating 50% recycled material reduces emissions by up to 40%. Higher RAP percentages are possible but require specialized plants.

A key innovation is an almost 100% bio-binder developed by Ooms Producten in the Netherlands. Made from bio-components with polymer modification, it functions both as a rejuvenator for aged bitumen and as a low-viscosity binder suitable for WMA applications at around 130°C. When combined with RAP, a 100% bio-binder can reduce emissions by up to 75%—approximately 20 kg CO_2-eq per ton—and even achieve CO_2 neutrality when biogenic carbon capture is included. Pilot projects in Denmark and the Netherlands confirm its excellent workability, even with 100% recycled materials.

The use of a bio-binder demonstrates that circular, climate-neutral asphalt is already feasible and offers a scalable solution for sustainable road construction.

Keywords: Bio-binder, Circular Asphalt, sustainability, CO_2 reduction

1 Introduction

Driven by sustainability goals, the market has been searching for a replacement for conventional bitumen for some time. This study shows that it is indeed possible to produce an innovative binder based on bio-components. Test sections in Denmark and the Netherlands show that asphalt can successfully be produced using this approach. It should be emphasized that replacing the binder is not the simplest way to meet sustainability targets, without compromising the quality of the asphalt pavement [1].

2 CO_2 reduction of asphalt mixtures

A typical produced hot mix asphalt (HMA), without reclaimed asphalt pavement (RAP), is produced at temperatures ranging from 165 °C for a conventional fossil bitumen to 185 °C for polymer modified bitumen (PMB). CO_2 emissions range from about 78 to 100 kg CO_2-eq per ton of asphalt produced at the asphalt plant. About half of these emissions come from the bitumen, the other half come from the other materials and the production process. This is because total CO_2 emissions are calculated based on the entire production chain of all raw materials. It is also important to consider the service life of the asphalt pavement: the longer the service life, the lower the annual CO_2 emissions per ton asphalt. This is reflected in lower CO_2 emissions and ECI (economic cost indicator) per m^2 of asphalt pavement [2].

Table 1. Typical CO_2 emissions from asphalt production per ton of asphalt, based on certified calculations from an asphalt plant (according to the Dutch system [2])

kg CO_2-eq per ton of asphalt production	AC 16 base	AC16 base 50% RAP
Crushed stone	19.3	9.0
RAP*	0.0	0.0
Bitumen	34.1	16.3
Transport	4.7	1.7
Production	17.9	19.6
Total	**76.0**	**46.6**

*) RAP is considered CO_2-neutral and does not cause any additional emissions [2].

2.1 Warm mix asphalt (WMA)

Since early 2025, warm mix asphalt (WMA) has basically been considered the standard in the Netherlands. By producing asphalt at lower temperatures (about 30°C lower), emissions during both production and paving can be reduced by 20-30%. However, this mainly concerns the reduction of fuel consumption during production. The savings typically amount to about 5 kg CO_2-eq per ton of asphalt mixture [3].

2.2 Reuse of asphalt

The use of recycled asphalt granulate in the asphalt mixture leads to the greatest reduction in CO_2 emissions. When applying 50% reclaimed asphalt pavement (RAP), emissions range from about 40 to 70 kg CO_2-eq per ton of asphalt mix, due to the savings on new raw materials such as bitumen and crushed stone. A higher RAP percentage further reduces CO_2 emissions, but asphalt mixtures with a high RAP content (60-70%) require a special asphalt plant with a parallel drum system. Experience in the Netherlands shows that asphalt with RAP performs at least as well as standard asphalt without RAP [4]. Since the early 1990s, the use of RAP has been the standard in all base and binder layers, and this has been incorporated into the Dutch RAW standard specifications for road constructions and is also possible with polymer-modified bitumen [5, 6].

2.3 Bio-binder as fossil bitumen alternative

Research into the development of a bio-binder as a replacement for conventional bitumen has been underway for some time. One such binder is a bio-binder developed by Ooms Producten with 96% bio-components. This binder is based on bio-components in combination with a polymer modification. The bio binder was specifically developed for applications with a high percentage of reclaimed asphalt pavement (at least 50% RAP), thanks to its low viscosity. As a result, the binder also acts as a rejuvenator for the aged bitumen. In addition, the low viscosity makes it possible to mix asphalt at temperatures around 130 °C, suitable for WMA applications. In combination, this yields a significant CO_2 reduction: up to about 20 kg CO_2-eq per ton of asphalt mixture - a saving of about 75%. The bio-based component also sequesters biogenic CO_2. Based on overall figures, this amount of captured CO_2 is about 3,000 kg CO_2-eq per ton of biomass for forestry feedstock (based on 80% carbon and the molecular weight ratio of CO_2 and C, which equals 3.7). If biogenic CO_2 is included, it is even possible to produce a CO_2-neutral asphalt [7].

2.4 Performance of bio-binder

The properties of the bio-binder were tested in the laboratory together with a reference bitumen (grade 70/100) in a blend with bitumen derived from reclaimed asphalt pavement (RAP) with a penetration of approximately 20 dmm. The ratio of bio-binder to RAP bitumen was 33%/67%. This ratio is based on a base course asphalt mixture commonly used in the Netherlands with 65% RAP. The properties of both binders are summarized in table 2.

Table 2. Properties bio-binder compared to reference bitumen 70/100

Property	Test	Bio-binder	Bitumen 70/100	Unit
Penetration	EN 1426	266	70-100	x 0.1 mm
Softening R&B	EN 1427	40.8	43-51	°C
Viscosity @ 185 °C		40		mPa.s
Viscosity @ 150 °C	EN 13302	100		mPa.s
Viscosity @ 135 °C		175		mPa.s

The properties of the blended binders are given in table 3. Furthermore, dynamic shear rheometer (DSR) frequency sweeps were performed between -10 and 70 °C according to EN 14770 to determine the complex modulus G* between 0.01 and 65 Hz for the given temperature range. From this, the master curve for both blends was determined at -10 °C and is shown in Figure 1.

Table 3. Properties blended binders with bitumen from RAP

Property	Test	Bio/RAP	70/100/RAP	Unit
Mixing ratio		33/67	33/67	%
Penetration	EN 1426	49	22	x 0.1 mm
Softening R&B	EN 1427	50.8	62.6	°C

The results show that the reference with 33% standard bitumen 70/100 and 67% reclaimed bitumen from RAP results in a very low penetration of 22 mm (x0.1). So, the bitumen 70/100 is too hard for this combination. The soft bio-binder combination gives a higher penetration of 49 mm (x0.1) and falls within penetration class 40-60. This class is the standard in the Netherlands for bind/base asphalt layers.

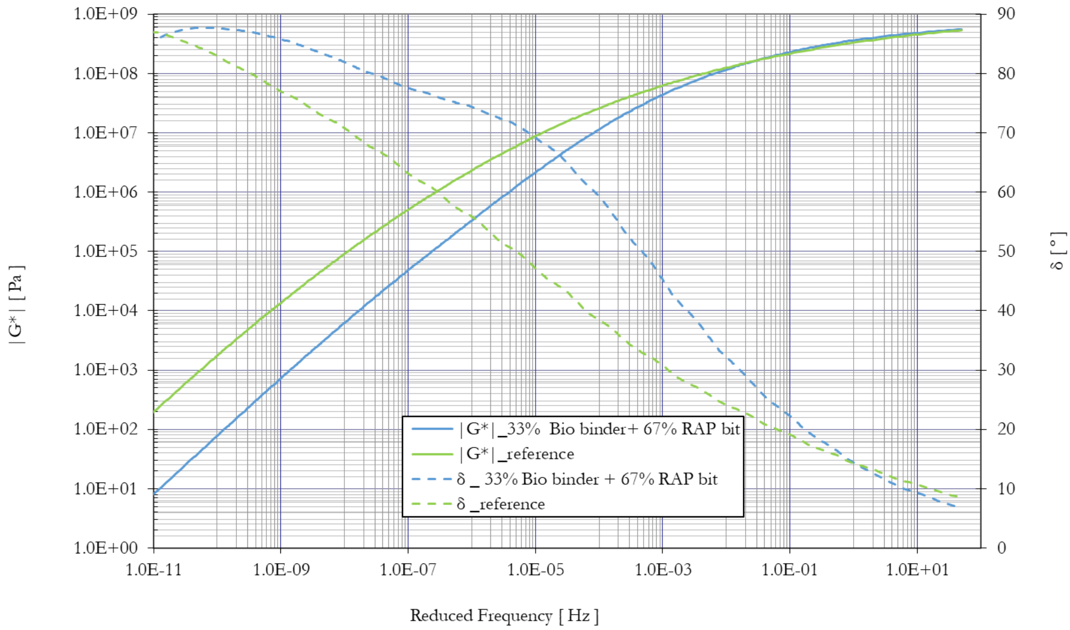

Fig. 1. Master curve blended bio bitumen with RAP and reference at -10 °C.

The complex modulus G* in the master curve at low frequencies of the bio binder combination is clearly lower than the reference combination. This means lower stiffness. This can be explained by the higher penetration of the mixed bitumen blend. At high frequencies (critical conditions for winter behavior), the lines are on top of each other and the stiffness is comparable. This means that the bio-binder combination is expected to perform at least equally to the reference combination.

3 Pilot courses of bio-binder within Europe

The developed bio-binder was first put to practical use in Denmark at the end of 2024. With sustainability in mind, the choice was made to resurface the road surface with asphalt based on bio-bitumen, 50% reclaimed asphalt pavement (RAP) and 50% ECO granulate. This was carried out by a local contractor. The total asphalt production was about 200 tons for both underlay and overlay, based on the contractor's mixture design, with 100% recycled materials (RAP + ECO granulate). Production took place locally, 25 km away. Conditions during construction were not optimal (a lot of manual labor and waiting times). Nevertheless, the asphalt proved to be highly workable at temperatures below 130 °C.

Research into bio-binders is also being conducted in the Netherlands. Within the framework of the Circuroad program of the Dutch Department of Public Works [7], in which Ooms Producten is participating, three SMA-bio test sections were laid for the INNOVA58 project with 40% RAP and bitumen consisting of 30% bio-components. All variants of this asphalt were found to be easily workable. In 2025, various test sections were also constructed using bitumen consisting of 30% bio-components for further validation [8]. Table 4 compares the environmental scores of the various bio-binders with those of fossil bitumen.

Fig. 2. Paving Circuroad test section A58 (December 2024).

Table 4. Indicative environmental score bio-binders compared to fossil bitumen per ton of product. Calculated according to the Dutch system [2].

Environmental score / per ton of bitumen	Bio-binder 96%	Bio-binder 30%	Bitumen	Unit
ECI A1 to A3	123	105	106	€
kg CO_2-eq	1020	704	794	kg
Captured kg CO_2-eq	-2910	-900	0	kg
Total kg CO_2-eq	**-1890**	**-196**	**794**	**kg**

4. Conclusion

Laboratory research, combined with a field trial section, shows that it is possible to produce CO_2-neutral asphalt.

Bio-binders, in combination with at least 50% RAP and warm mix asphalt (WMA) techniques, can potentially result in highly sustainable asphalt pavements. The constructed test sections should demonstrate whether the service life is equal to or better than that of conventional asphalt.

The combined advantages of recycling and WMA make the bio-binder a potentially viable solution. It makes a tangible contribution to the transition toward climate-friendly and circular infrastructure—demonstrating that sustainable innovation is already applicable today.

5. References

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