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PERFORMANCE CHARACTERISATION OF HIGH RA ASPHALT MIXES – A LABORATORY AND FIELD STUDY

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Abstract. The research project highlights the significance of incorporating reclaimed asphalt (RA) into hot mix asphalt (HMA) production for sustainable road construction. Despite limited RA utilization in Hungary in the past decades, the project demonstrates the feasibility of manufacturing HMA with significant RA content using advanced technology. The establishment of a capable asphalt plant and the development of laboratory assessments and mix design methodologies laid a solid foundation for future high RA integration in Hungarian road projects. Large-scale production trials confirmed the practicality of integrating high RA content into heavy-duty asphalt mixes with various binder types, including normal bitumen (B), polymer modified binder (PmB), and rubber modified bitumen (GmB). The large-scale validation project described in this paper was based on crucial binder blend designs carried out prior to the trials. Production control and performance-based laboratory testing proved that asphalt mixes can be designed and manufactured with high RA content while maintaining performance standards. Balancing

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resistance to distress modes like rutting and low-temperature cracking through careful binder blend design and mix design is achievable, even with high RA proportions. Visual assessments and production control indicated the uniformity of high RA content asphalt mixes. The details provided in this paper emphasise the potential for economic and environmental benefits through increased RA utilization in Hungarian road construction.

Keywords: asphalt mix design, performance characterisation, recycled asphalt pavement.

Introduction

Reclaimed asphalt pavement (RAP) or reclaimed asphalt (RA) – as used in the European terminology – is a by-product of road rehabilitation and resurfacing activities and offers valuable recycled material for new asphalt pavement. Despite global RA use, Hungary lags in integrating RA into hot mix asphalt (HMA) design and manufacturing. Unfortunately, incorporating RA into the manufacturing of new hot mix asphalt (HMA) is still very minimal in Hungary, despite the obvious advantages as increased RA use offers economic and environmental benefits, reducing new material demand, transportation costs, and carbon footprint. Based on latest figures from the European Asphalt Pavement Association (European Asphalt Pavement Association, 2021), 11.6 million tonnes of RA were used in Germany and 6 million tonnes in France in 2021. In Hungary, this volume was 157 000 tonnes, which means that in average only 3.2% of the total asphalt production contained RA. The average recycling rate in Germany was 25.6%, while in France this value was 12.8%.

As part of a research and development project, a state-of-the-art parallel drum asphalt plant was set up and commissioned to manufacture HMA containing a substantial proportion of RA. Such an asphalt plant has not been in operation in Hungary before; therefore, throughout the project, the infrastructure for large-scale manufacturing was established, laboratory assessments and mix design methodology were developed, including testing and monitoring of large-scale manufacturing and placement.

Comprehensive data collection, laboratory testing of virgin binder, binder extracted from the RA and various binder blends of these were analysed. Comprehensive laboratory testing was prepared, and plant manufactured asphalt mixes were also tested. The details are summarised below to provide the background of this paper.

As part of the mix design process, the binder blend design has to be developed for local circumstances, which is discussed elsewhere (Rosta & Gáspár, 2023). In an Austroads (2016) study, it was found that the binder blend characterization assuming complete dispersion between the virgin binder, the RA binder and the rejuvenator (if any) was valid for a wide range of asphalt mixes. Therefore, it can be used with confidence for designing the binder blend in mixes containing RA. The use of RA offers significant economic and environmental advantages; however, achieving the desired performance requires careful scientific planning and quality control. Various tests are necessary to ensure that the binder meets requirements for use in asphalt mixtures. The properties of the binder in the reclaimed asphalt and its behaviour when blended with new virgin binder must be understood. A European Standard provides a method to calculate binder blend characteristics using penetration or softening point. Some countries use different methods to determine paving bitumen types relying on dynamic viscosity. While a viscosity-based method is advantageous for monitoring daily production due to its efficiency, it has not been validated for penetration-based bitumen grades before. As part of the research project, the dynamic viscosity measurements of bitumen blends from recycled asphalt and virgin binder were tested and analysed, providing further details for the binder blend design (Rosta & Gáspár, 2023). As part of the overall comprehensive study, the design of the bituminous binder blend for high RA content asphalt mixes was established using binder rheology, ensuring performance and compliance characterization. Complex rheological analysis using the dynamic shear rheometer (DSR) was performed for base bitumen, RA-extracted bitumen, and binder blends. The use of RA is usually restricted (EN13108-1 2022) or limited at 15% (Transport and Main Roads Specifications, 2023) in asphalt mixes manufactured with polymer modified binders. It was demonstrated that paving grade bitumen permits the addition of RA up to 40%, while polymer modified binder (PmB) and rubber modified bitumen (denoted as GmB in Hungarian) allow for 20% and 30% RA content, respectively, without compromising the performance (Toth et al., 2023a).

As part of the overall research program, a pavement structural analysis was also performed using stiffness and fatigue testing of laboratory mixed and large-scale manufactured HMA with 20%–60% RA content. Full depth asphalt (FDA) pavement performance prediction challenged the common perception that high RA mixes showed substandard performance; data indicated rather the opposite, i.e., high RA asphalt mixes showed superior performance. Such mixes provide low in-situ performance risks, subject to accurate mix design, effective RA management, and the use of suitable asphalt plant with the capability of dosing high RA with accuracy (Toth et al., 2023b).

As indicated above, the binder blend and asphalt pavement performance were analysed and assessed in the overall project for high

RA mixes. However, due to the viscoelastic nature of bituminous binders, asphalt mixes need to be assessed for other types of distress modes, such as:

- High temperature behaviour – plastic deformation or rut resistance using the wheel-tracking test;
- Low temperature behaviour – using resistance to cracking at low temperatures test.

This paper provides the test results and analysis of laboratory and large-scale manufactured asphalt mixes with high RA content for the high and low temperature behaviour. For a comprehensive analysis of the data, the grading and binder content results of the RA fractions are also provided and discussed in this paper.

1. Asphalt mix types and RA sources used in the project

In this project, various asphalt types with varying RA contents were assessed; the binder type was also varied. Extensive laboratory testing provided the material parameters of these asphalt mixes, and the variables were as follows:

- Virgin binder type – B (normal bitumen), PmB (polymer modified binder) and GmB (crumb rubber modified binder);
- RA content – varying from 0% to 60%;
- Asphalt type – N (for normal traffic volume), F (for high traffic volume) and mF (for extremely high traffic volume);
- Laboratory and plant mixed asphalt mix;
- No rejuvenating agent was added to any of the mixes. It was discussed elsewhere (Toth et al., 2023b) that for normal bitumen (B), PmB and GmB the utilisation of a higher proportion of RA content was possible without compromising on the overall characteristics of the virgin binder. In case of the paving grade bitumen, a softer grade virgin binder was utilised.

For both laboratory and plant manufactured asphalt mixes RA was sourced from the Zsámbék depot of the Hungarian Main Roads. The unprocessed raw feed of the RA was first screened (without crushing) into 0/11 and 11/22 fractions and stored in 500 tonnes stockpiles. A small amount of oversize material was produced in the process, which was removed and stored separately for future projects where crushing and screening would be utilised. The grading and binder content of each stockpile were tested and utilised for laboratory batching and plant manufacturing batch cards to maintain target grading and

Table 1. Statistical analysis of laboratory test results for 11 RA 0/8

Property	Average	Std	CoV	Range
Binder content, %	6.6	0.5	0.07	1.6
Sieve, mm				
11.2	100.0	0.0	0.00	0.0
8	94.6	0.9	0.01	4.0
5.6	84.6	1.7	0.02	7.0
4	73.4	1.7	0.02	5.0
2	57.4	1.8	0.03	6.0
1	44.9	1.7	0.04	6.0
0.5	35.8	1.3	0.04	5.0
0.25	28.2	0.9	0.03	3.0
0.125	20.3	0.9	0.05	3.0
0.063	17.6	0.6	0.03	1.8
Ring and ball softening point, °C	68.8	4.2	0.06	13.8
Maximum density, Mg/m^3	2.525	0.059	0.023	0.278
Extracted aggregate density, Mg/m^3	2.722	0.014	0.005	0.050

Table 2. Statistical analysis of laboratory test results for 22 RA 0/16

Property	Average	Std	CoV	Range
Binder content, %	4.7	0.1	0.03	0.5
Sieve, mm				
22.4	100.0	0.0	0.00	0.0
16	95.4	1.0	0.01	3.0
11.2	81.0	2.7	0.03	8.0
8	59.2	3.5	0.06	10.0
5.6	48.2	4.3	0.09	12.0
4	41.2	3.5	0.09	11.0
2	34.2	2.6	0.08	9.0
1	28.2	1.9	0.07	7.0
0.5	23.5	1.2	0.05	3.0
0.25	19.2	0.8	0.04	2.0
0.125	13.8	0.9	0.07	3.0
0.063	9.7	1.0	0.10	3.0
Ring and ball softening point, °C	69.0	4.5	0.07	15.8
Maximum density, Mg/m^3	2.576	0.018	0.007	0.078
Extracted aggregate density, Mg/m^3	2.743	0.013	0.005	0.040

binder content identical for the individual mix types. Also, the ring and ball softening point, maximum density and density of the extracted aggregate were tested and analysed for the 11 RA 0/8 and 22 RA 0/16 fractions. For the RA description, the abbreviations provided by EN specifications were used, where the first number stands for the maximum aggregate size, RA stands for recycled asphalt and the second set of numbers stands for the lowest and highest nominal size of the material. For both fractions, 19 lots were produced and tested; the average, standard deviation (Std), coefficient of variation (CoV) and range are provided for the 11 RA 0/8 in Table 1 and for 22 RA 0/16 in Table 2. Based on the CoV (European Commission Directorate General Transport, 2000) values, it can be concluded that all test parameters are considered homogeneous for both RA fractions. Based on our experiences, it was found that if RA was stored, manipulated, processed, and stockpiled correctly, then the variability of the processed RA was kept to a minimum, which in turn kept asphalt manufacturing under control.

2. Laboratory testing of high RA content asphalt mixes

2.1. Volumetric properties of high RA content asphalt mixes

The batch cards of the asphalt mixes with various RA contents were set in a way that the grading and binder content of the laboratory mix and plant produced asphalt mixes were kept identical as close as possible for each asphalt type. This ensured that the volumetric properties of the different mixes were kept unaltered.

Following representative sampling, the constituent materials were transported directly from the asphalt plant stockpile area to the laboratory where the asphalt was mixed in batches. RA stockpiles were quarantined and kept for future large-scale manufacturing through the asphalt plant. The binder contents of all mixes were 5.1% (by total mass of the mix).

2.2. Performance considerations when incorporating high RA content in asphalt mixes

At the start of the RA era, comprehensive literature search conducted by a group of researchers (Enieb et al., 1973) indicated that mixtures containing RA demonstrated the improved resilient modulus, although the higher resilient modulus decreased with rising temperature. When asphalt mixtures are exposed to water and moisture, their performance may be influenced. However, for asphalt mixes with high RA content it was found that the presence of aged binder covering old aggregate in RA improved moisture resistance by preventing water penetration and loss of bonding. It was also found that mixtures with increased RA content enhanced moisture resistance, with 40% RAP mixes showing better performance than virgin mixes and incorporating more than 30% RA into asphalt mixtures enhanced their resistance to permanent deformation. Recycled mixtures outperform conventional asphalt in fatigue cracking resistance, allowing the design of high-quality HMA with up to 50% RAP for preferred fatigue performance. Ranieri et al. found similar outcomes for high RA mixes, i.e., 30% RA mixes showed higher indirect tensile strength, stiffness and cohesiveness compared to the reference asphalt mix (Ranieri et al., 2022). Research conducted by Zaumanis et al. (2023a) found that PMB mixes up to 30% RA showed identical performance to the virgin mix (0% RA) in terms of crack propagation, rutting resistance, stiffness and fatigue resistance.

In this paper, the test results were obtained according to the following test methods:

- Wheel-tracking test was conducted according to EN 12697-22, small size device, procedure B, in air at 60 °C (EN 12697-22, 2003);
- Stiffness of the mixes was tested according to EN 12697-26, Annex C, indirect tension on cylindrical specimens (IT-CY) at 20 °C (EN 12697-26, 2012);
- Resistance to low-temperature cracking was tested on thermal stress restrained specimen test (TSRST) (EN 12697-46, 2012).

Low-temperature cracking is one of the main distresses of asphalt pavements, which reduces their serviceability and leads to water ingress into lower layers of the pavement. The use of modified asphalt mixtures is a way of preventing low-temperature cracking in cold regions (Mansourkhaki & Aghasi, 2021). According to other studies, the thermal or low-temperature cracking of asphalt pavements is a serious problem in many regions. If the pavement is cooled to a low temperature, tensile stresses develop as the pavement contracts. When the tensile stress induced in the pavement equals the strength of the asphalt concrete mixture at that temperature, a microcrack develops. At colder temperatures or repeated temperature cycles, the crack penetrates the full depth and width of the asphalt layer(s). Several material factors can affect the thermal behaviour of asphalt mixes, such as the binder type, aggregate type and grading, bitumen content and air voids content (Jung & Vinson, 1994). Izaks et al. (2022) showed in their study that the low-temperature cracking resistance of dense graded high modulus base layer asphalt did not decline when high RA content was added along with glass fibers.

Since the binder type plays a role in the low-temperature behaviour, the binder blend design is a critical item for asphalt mix designs. Therefore, stiff binder blends should be avoided to improve the resistance to low-temperature cracking. The RA content itself does not describe the asphalt mix behaviour, it is the binder blend, which influences the performance.

Asphalt mixes manufactured with normal bitumen and designed with resistance to plastic deformation are normally expected to have less resistance to cracking at low temperatures due to the high stiffness of such material. PmB and GmB binders are normally used to balance out rutting and low-temperature cracking behaviour; due to the unique characteristics of these binders, rutting resistance can be achieved without compromising the low-temperature cracking resistance. However, the addition of high RA content can 'dilute' the PmB or GmB; therefore, careful binder blend design and asphalt mix design and testing need to be considered. These details are provided in the rest of this paper.

2.3. Performance test results of high RA content asphalt mixes

To make the asphalt mixtures comparable, the mechanical properties of the following three laboratory-mixed asphalt mixtures were analysed. One mix is usually used in the normal loading category, this is AC22 binder (N) B50/70, and the other two mixes are used in the high-stress loading category, AC22 binder (mF) PmB25/55-65 and AC22 binder (mF) GmB45/80-55. The objective was to determine the ideal RA (reclaimed

Table 3. Performance results of AC22 binder (N) asphalt mix manufactured with plain binder and various RA contents, laboratory mixed asphalt

Structural asphalt	AC22 binder (N)		
Targeted binder blend type	B50/70		
Method of mixing	Laboratory prepared asphalt mix		
RA content	0% RA	25% RA	40% RA
Virgin binder type	50/70	70/100	50/70
Mean proportional rut depth, PRD_{AIR}, in air, %	6.8	5.1	3.3
Mean rut depth, RD_{AIR}, in air, %	5.6	4.1	2.7
Failure temperature, $T_{failure}$, °C	–19.2	–22.7	–19.1
Failure stress, $\sigma_{dry,failure}$, MPa	4.1	4.5	4.5

asphalt) dosages for various mixtures through asphalt mechanical tests. Material compositions and test results (wheel-tracking and resistance to low-temperature cracking) are provided in Tables 3–5.

Two alternative mixes were prepared for the AC22 binder (N) B50/70 mix (Table 3). One mix was prepared with 40% RA content intentionally using a stiffer virgin bitumen of B50/70; it was expected that this mix would be more rigid through the stiffer binder blend. Our assumption was largely confirmed during the tests, as the mixture stiffness and resistance to wheel tracking significantly increased compared to the reference mixture. The second alternative was a mix with 25% RA content, deliberately using a softer base bitumen of B70/100. It was expected that this mix would exhibit similar properties to the reference mixture, as the B70/100 virgin bitumen would compensate for the properties of the stiffer RA bitumen.

As published elsewhere (Toth et al., 2023b), the binder blend of the 40% RA mix was expected to deliver higher viscosity compared to the benchmark mix with no RA added. This prediction held true, as indicated by the modulus value of the asphalt mix exceeding that of the benchmark.

In the case of the 25% RA mix with B70/100 binder, the modulus value aligned closely with the benchmark (Toth et al., 2023b), confirming the successful achievement of the binder blend design goals. When using a softer grade bitumen and adding 25% RA, it was possible to achieve similar performance properties to the reference mix. The low-temperature behaviour also improved for this alternative mix, as the failure temperature was lower and the failure stress higher, while the mean proportional rut depth and the mean rut depth indicated no significant changes in the performance.

When using the same virgin binder as in the reference mix (B50/70) and adding 40% RA, the mix became significantly more rut resistant, while the low-temperature behaviour did not show a significant decline. Without using a softer binder grade the asphalt mix was expected to become stiffer compared to the reference mix. With stiffer mixes it is expected that the low-temperature behaviour is compromised; however, this could not be confirmed through the laboratory testing. Zaumanis et al. found similar performance with high RA mixes (Zaumanis et al., 2023b).

AC22 binder (mF) PmB25/55-65 and AC22 binder (mF) GmB45/80-55 asphalt mixes are normally used in high-stress loading situations. Both mixes were prepared with 0% and 30% RA. When comparing the reference mixes (0% RA), it can be observed that the PmB and GmB mixes show lower rut depth (better rutting performance) without compromising on the low temperature behaviour, which is indicated by the lower failure temperature and lower failure stress (Table 4).

For the alternative high RA mix with 30% RA added, the virgin binder type of PmB25/55-65 bitumen was not altered despite adding 30% RA to the mix. During the binder blend analyses, carried out previously and published elsewhere (Toth et al., 2023a) it was observed that the higher RA dosage, while 'diluting' the properties of the PmB, did not transform this binder type entirely into a plain road construction bitumen (B) and the PmB generally retained its original rheological characteristics. However, the binder blend with high RA content did not show the original performance of the virgin PmB either, some decline could be observed through the shifting of the black diagrams (Toth et al, 2023a). Asphalt mechanical test results in Table 4 aligned with the analysis of the black diagram obtained through the dynamic shear rheometer (DSR) tests. 30% RA mix exhibited marginally higher proportional and mean rut depth, indicating a slight decline in the resistance to plastic behaviour. Also, the low temperature performance was compromised by higher failure temperature and increased failure stress when compared to the reference mix containing 0% RA and PmB25/55-65 bitumen.

As for the AC22 binder (mF) GmB45/80-55 mix with 30% RA, the base bitumen also remained unchanged, which was GmB 45/80-55 rubber-modified bitumen. Based on the black diagrams of the binder blends (Toth et al, 2023a), it was found that the RA dosage did not alter the properties of the GmB45/80-55 up to 30% RA content. GmB seems to represent a unique bitumen group type and does not resemble with the

Table 4. Performance results of AC22 binder (mF) asphalt mix manufactured with polymer modified and crumb rubber modified binder and various RA contents, laboratory mixed asphalt

Structural asphalt	AC22 binder (mF)			
Targeted binder blend type	PmB 25/55-65		GmB 45/80-55	
Method of mixing	Laboratory prepared asphalt mix			
RA content	0% RA	30% RA	0% RA	30% RA
Virgin binder type	PmB 25/55-65	PmB 25/55-65	GmB 45/80-55	GmB 45/80-55
Mean proportional rut depth, PRD_{AIR}, in air, %	2.7	2.9	2.7	1.7
Mean rut depth, RD_{AIR}, in air, %	2.3	2.4	2.2	1.4
Failure temperature, $T_{failure}$, °C	–22.2	–20.6	–25.8	–23.2
Failure stress, $\sigma_{dry,failure}$, MPa	3.4	3.8	4.1	4.0

rheological behaviour either of the PmB group or the conventional road construction bitumen (B).

Asphalt mixes manufactured with GmB are less altered by the addition of RA up to 30% and this observation was confirmed by the performance testing (Table 4). Compared to the benchmark mix containing 0% RA and GmB45/80-55 bitumen, the 30% RA mix exhibited lower proportional and mean rut depth, indicating improved resistance to plastic behaviour. The low temperature performance was only slightly compromised regarding the failure temperature, which slightly increased; however, the failure stress remained almost identical compared to the reference mix.

Following the commissioning of the on-site asphalt plant, large-scale production trials were conducted using AC22 binder (F), a heavy-duty asphalt mix manufactured with plain binder (B). In all cases, B70/100 bitumen was used as the virgin binder and the RA content was 30-40-50-60%, respectively (Table 5).

The asphalt mixtures obtained from the production trial were subjected to low temperature behaviour test; for these asphalt mixes wheel tracking test was not completed, as it was expected, based on the laboratory prepared asphalt mixes shown in Table 3, the wheel tracking performance would be increasing with increasing RA content. However, following placement of the production mixes on a controlled trial site, core samples were extracted from the pavement structure and subjected to stiffness test using the IT-CY method (EN 12697-26, 2012) (Table 5). For the AC22 binder (F) B70/100 mixture with 30-40-50-60% RA content the measured IT-CY stiffness values for the core samples

Table 5. Performance results of AC22 binder (F) asphalt mix manufactured with plain binder and various RA contents, plant mixed asphalt

Structural asphalt	AC22 binder (F)			
Targeted binder blend type	B50/70			
Method of mixing	Plant manufactured asphalt mix			
RA content	30% RA	40% RA	50% RA	60% RA
Virgin binder type	70/100	70/100	70/100	70/100
Mean proportional rut depth, PRD_{AIR}, in air, %	N/A	N/A	N/A	N/A
Mean rut depth, RD_{AIR}, in air, %	N/A	N/A	N/A	N/A
Failure temperature, $T_{failure}$, °C	–21.2	–18.9	–22.0	–22.7
Failure stress, $\sigma_{dry,failure}$, MPa	4.1	3.5	4.8	4.2
Stiffness modulus, average, IT-CY, MPa	5115	5526	6466	8372
Stiffness modulus, range, IT-CY, MPa	1789	624	507	520

aligned with the expectations, as higher RA content resulted in higher IT-CY stiffness due to keeping the virgin binder identical (B70/100). In general, IT-CY stiffness modulus showed uniformly low variability (low range), except for the 30% RA mix, which demonstrated high variability. Unfortunately, this phenomenon could not be explained based on production records.

With increasing stiffness, it was expected that the low temperature behaviour would decline; interestingly, this could not be confirmed by the low temperature behaviour test. Although the failure temperature slightly increased and the failure stress slightly decreased for the 40% RA mix, the 50% and 60% RA mixes showed similar low temperature behaviour to the reference mix with 0% RA added. It is believed that the low temperature behaviour is not compromised for higher RA content mixes because a high proportion of the aggregates is 'pre-coated' by bitumen, which normally improves the adhesion properties between the aggregates and the bitumen film.

3. Testing and variability of large-scale manufactured high RA content asphalt mixes

As indicated before, following placement of the production mixes on a trial site, core samples were extracted from the pavement structure. It can be observed in Figures 1 to 3, the high RA asphalt mixes are homogeneous and do not show any visible defects. The virgin aggregate was obtained from a limestone source. The origin of the aggregate in the RA source was unknown, however, it showed a darker colour. The different visual properties enabled further visual assessment of the cores, and it was observed that the virgin aggregate and the RA aggregate were thoroughly mixed, and no visual segregation was apparent.

Production control results provided particle size distribution (Figure 4) and binder content, laboratory air voids and field density ratio (Table 6). It could be concluded that the particle size distribution could be maintained close the target across all mixes, slight variation and marginal non-conformance was observed only on the 11.2 mm sieve for the 60% RA content mix. Binder content and laboratory air voids could be maintained close to tolerances and high in-situ density ratio could be achieved indicating good workability of the high RA content asphalt mixes.

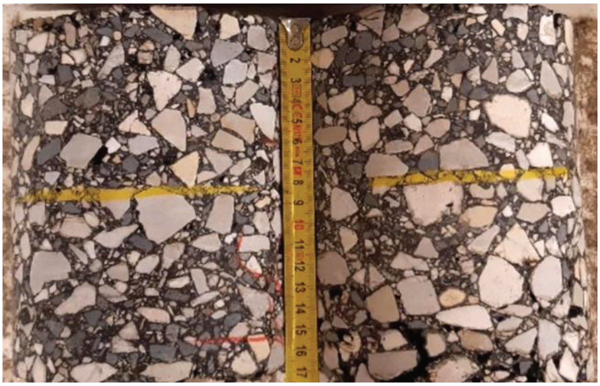

Figure 1. AC22 binder (F) B70/100 (50%RA) – on the top – and AC22 binder (F) B70/100 (30%RA) – bottom

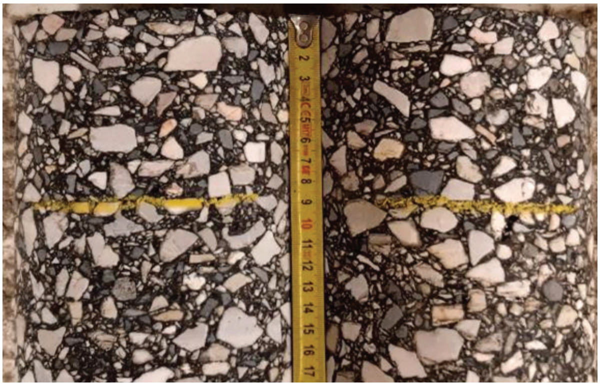

Figure 2. AC22 binder (F) B70/100 (50%RA) – on the top – and AC22 binder (F) B70/100 (40%RA) – bottom

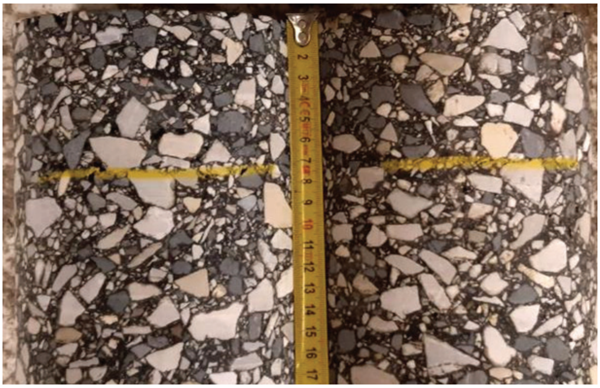

Figure 3. AC22 binder (F) B70/100 (60%RA) – on the top – and AC22 binder (F) B70/100 (40%RA) – bottom

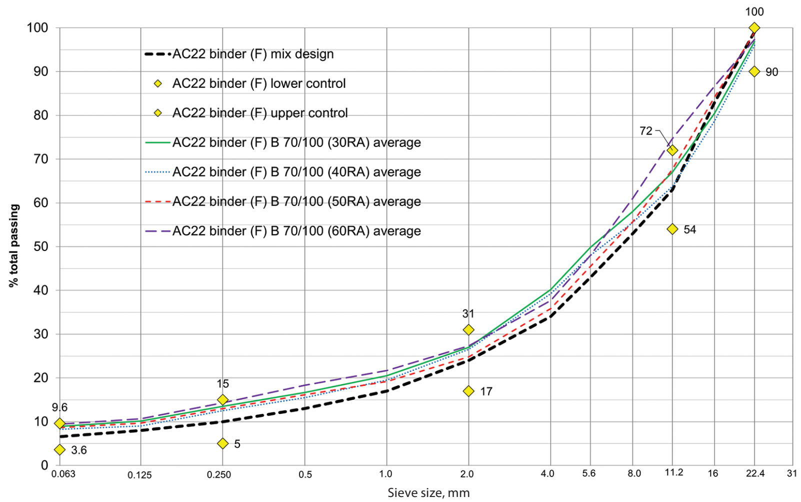

Figure 4. Particle size distribution of AC22 binder (F) asphalt mix manufactured with plain binder and various RAP contents, plant mixed asphalt

Table 6. Volumetric results of AC22 binder (F) asphalt mix manufactured with plain binder and various RAP contents, plant mixed asphalt

Asphalt mix	Property	Binder content	Maximum density	Laboratory air voids	Average field density ratio
	Sample	S, %	ρ_{mv}, Mg/m^3	V_m, %	%
	Limits	3.8 – 5.0	N/A	2.5 – 7.1	Min 98%
AC22 binder (F) B 70/100 (30RA)	1	4.4	2.565	2.9	99.6
	2	4.8	2.558	1.7	
	3	4.9	2.526	0.7	
	4	4.6	2.571	2.2	
AC22 binder (F) B 70/100 (40RA)	1	5.3	2.532	1.4	101.5
	2	5.2	2.546	1.7	
	3	3.8	2.534	1.3	
	4	4.5	2.558	1.7	
	5	4.2	2.579	2.7	
	6	4.6	2.532	0.9	
AC22 binder (F) B 70/100 (50RA)	1	4.3	2.573	3.5	100.2
	2	4.5	2.535	2.1	
	3	4.3	2.560	3.2	
	4	4.5	2.609	5.9	
	5	4.1	2.585	5.8	
	6	4.1	2.575	2.7	
AC22 binder (F) B 70/100 (60RA)	1	4.8	2.546	2.3	99.4
	2	4.1	2.540	1.1	
	3	4.0	2.545	1.5	

4. Conclusions

The integration of reclaimed asphalt (RA) into hot mix asphalt (HMA) manufacturing is a critical step towards sustainability and efficiency in road construction. This research and development project in Hungary highlighted the potential benefits and challenges associated with incorporating RA into asphalt mixes. Despite the relatively low utilization of RA in Hungary, this project has shown that it is possible to manufacture HMA with substantial proportions of RA using a state-of-the-art parallel drum asphalt plant. In conjunction with establishing a capable asphalt plant, laboratory assessments and mix design methodologies – developed as part of this project – have laid the foundation for future high proportion RA integration in Hungarian road construction.

The research emphasised the importance of understanding binder blend characteristics when using RA. It was found that different binder types, such as normal bitumen (B), polymer modified binder (PmB), and rubber modified bitumen (GmB), could accommodate varying levels of RA content without compromising performance. Careful binder blend design is essential to optimize the properties of the asphalt mix. Furthermore, the study investigated the resistance of high RA content mixes to distress modes like rutting and low-temperature cracking. The results indicated that binder blend design played a critical role in achieving a balance between these properties. It was possible to develop asphalt mixtures to meet specific performance criteria, even with the addition of high proportions of RA.

The large-scale production trials described in this paper showcased the feasibility of incorporating high RA content into heavy-duty asphalt mixes. The stiffness of these mixes increased with higher RA content, but surprisingly, low-temperature behaviour remained acceptable, and the rut resistance was not influenced negatively. This suggests that the presence of aged binder in RA contributes to improved low-temperature performance. Visual assessments and production control results confirmed the homogeneity of high RA content asphalt mixes, with minimal or no segregation issues. It was shown that particle size distribution, binder content, laboratory air voids, and in-situ density ratio could be maintained successfully within tolerances when using high RA content.

In conclusion, this research and development project has provided valuable insights into the integration of reclaimed asphalt into hot mix asphalt manufacturing. It highlights the potential for economic and environmental benefits while emphasising the importance of careful binder blend design and quality control. These findings pave the way for increased RA utilization in Hungarian road construction, contributing to a more sustainable and efficient infrastructure development process.

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