20. Kolokvij

ASFALTI, BITUMNI in VOZIŠČA

Največje mednarodno srečanje o gradnji in vzdrževanju vozišč v Sloveniji

Bled, Slovenija • 26. ~ 28. november **2025**

ZBORNIK • Proceeding

The largest international meeting of construction and maintenance of pavements in Slovenia

ASPHALT, BITUMEN and PAVEMENTS

20. Colloquium

ZAS

Združenje asfalterjev Slovenije

Slovenian Asphalt Pavement Association

PETROL

ZAS v sodelovanju s PETROL-om, vodilno slovensko energetsko družbo
ZAS with cooperation of PETROL, the leading Slovenian energy company

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20. kolokvij asfalti, bitumni in vozišča

20th Colloquium Asphalt, Bitumen and Pavements

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Proceedings

Bled, november 2025

20. kolokvij asfalti, bitumni in vozišča

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Uvodnik ~ 20. Kolokvij o asfaltih, bitumnih in voziščih

V skoraj tridesetih letih – dvajseti Kolokvij. Takšna je bilanca poti, ki smo jo prehodili od ustanovitve Združenja asfalterjev Slovenije (ZAS) leta 1996 do danes, ko pišemo leto 2025.

Začeli smo novembra 1996 s prvim strokovnim srečanjem v hotelu Špik v Gozd Martuljku, kjer smo razpravljali o bitumnu – materialu, ki ga v Sloveniji v celoti uvažamo. Vsi dobro vemo, da je bitumen ena ključnih sestavin asfaltne zmesi, saj kot vezivo povezuje kameni agregat, polnilo in dodatke.

Ker bitumna nismo proizvajali, smo si rekli: **»Če ga že ne moremo izdelovati, ga lahko simbolično posnemamo – z dogodkom, ki bo povezoval strokovnjake tako, kot bitumen povezuje zmes«.** Tako se je rodil **Kolokvij o bitumnih,** ki je že novembra 1997 pritegnil številne mednarodne strokovnjake. Spomnimo se ga tudi po tem, da smo takrat prejeli listino o vstopu ZAS v evropsko združenje asfalterjev **EAPA**.

Dogodek je rasel, se razvijal in pridobival na pomenu. Po nekaj letih se je preselil v Kranjsko Goro, razširili smo njegovo ime in ga po desetih letih preoblikovali v bienalno strokovno srečanje. Kasneje smo se preselili na Bled, kjer že več kot desetletje na vsaki dve leti gostimo **Kolokvij o asfaltih, bitumnih in voziščih** (KABV) – danes največje mednarodno srečanje o asfaltu in cestni infrastrukturi v Sloveniji.

Na Kolokviju redno gostimo domače in tuje strokovnjake ter avtoritete iz asfalterske industrije. Cestni transport in logistika sta med najpomembnejšimi gospodarskimi panogami Slovenije, zmogljiva in odporna cestna infrastruktura pa je ključ do njunega razvoja. Ko smo okoli leta 2010 zaključili avtocestni program, smo se v tem delu Evrope lahko pohvalili z eno najboljših cestnih mrež. Še vedno jo uspešno vzdržujemo in upravljamo, a z nadaljnjimi širitvami žal zamujamo – in tu nas čaka še veliko dela.

V vseh teh letih je ZAS dosledno sledil potrebam po razvoju in uporabi kakovostnih, trajnostnih in vzdržljivih asfaltnih zmesi, ki omogočajo gradnjo udobnih, varnih in trajnih voziščnih konstrukcij. Kljub velikim prometnim in vremenskim obremenitvam ostajajo naša vozišča visoko kakovostna – kar potrjujejo tako objektivne meritve kot tudi zadovoljstvo uporabnikov. Doseženi rezultati so plod predanega dela in znanja, ki ga na ogled postavimo na vsakem Kolokviju.

KABV je tako postal osrednje strokovno srečanje domače in mednarodne asfalterske, cestarske ter gradbene stroke. Na njem predstavljamo najnovejše trende, analiziramo uspehe in načrte največjih investitorjev, razpravljamo o prihodnosti in podeljujemo priznanja najzaslužnejšim posameznikom. In, kar je prav tako pomembno – skupaj praznujemo našo skupno zgodbo.

Danes je KABV povsem drugačen, kot je bil leta 1996 – večji, vsebinsko bogatejši in strokovno poglobljen. Ostaja pa nespremenjena ena pomembna vez: **naš zvesti partner, soorganizator in glavni pokrovitelj – družba PETROL**, nekoč naftna, danes energetska družba, s katero že skoraj tri desetletja soustvarjamo ta dogodek.

Iskrena hvala vsem generacijam PETROL-a za izjemno sodelovanje, zaupanje in podporo – ter vsem, ki so v teh letih prispevali k razvoju slovenskega asfalterstva.

Slovenko Henigman, predsednik ZAS

Editorial ~ 20th Colloquium on Asphalt, Bitumen and Pavements

Over nearly three decades – the twentieth Colloquium. This is the milestone marking the path we have taken since the establishment of the Slovenian Asphalt Pavement Association (ZAS) in 1996 up to the present day, as we write the year 2025.

We began in November 1996 with the first professional meeting at Hotel Špik in Gozd Martuljek, where we discussed bitumen – a material that Slovenia imports entirely. We all know well that bitumen is one of the key components of asphalt mixtures, as it binds together the stone aggregate, filler, and additives.

Since we did not produce bitumen ourselves, we said: **if we cannot manufacture it, we can at least symbolically emulate it – with an event that connects professionals just as bitumen connects the mixture.** Thus, the **Colloquium on Bitumen** was born, which already in November 1997 attracted numerous international experts. We also remember that occasion because we received the certificate marking ZAS's entry into the **EAPA** - European Asphalt Pavement Association.

The event grew, developed, and gained importance. After a few years, it moved to Kranjska Gora; we expanded its name and, after ten years, transformed it into a biennial professional meeting. Later, we moved to Bled, where for more than a decade we have hosted, every two years, the **Colloquium on Asphalts, Bitumen and Pavements** (CABP) – today the largest international event on asphalt and road infrastructure in Slovenia.

The Colloquium regularly welcomes domestic and foreign experts and authorities from the asphalt industry. Road transport and logistics are among the most important economic sectors in Slovenia, and a robust and resilient road infrastructure is the key to their development. When the motorway construction program was completed around 2010, this part of Europe could boast one of the best road networks. We still maintain and manage it successfully, but unfortunately, we are falling behind with further expansions – and much work remains to be done.

Throughout all these years, ZAS has consistently followed the needs for the development and use of high-quality, sustainable, and durable asphalt mixtures, enabling the construction of comfortable, safe, and long-lasting pavement structures. Despite heavy traffic and weather loads, our road surfaces remain of high quality – as confirmed by objective measurements and user satisfaction alike. The results achieved are the fruit of dedicated work and expertise, proudly showcased at every Colloquium.

CABP has thus become the central professional meeting for the Slovenian and international asphalt, road, and construction sectors. Here, we present the latest trends, analyse the achievements and plans of major investors, discuss the future, and present awards to the most deserving individuals. And, just as importantly – we celebrate our shared story together.

Today, KABV is very different from the event we started back in 1996 – it has grown in size, depth, and professional scope. Yet one essential link has remained constant: **our long-standing partner, co-organizer, and main sponsor – PETROL.** Once an oil company and today a comprehensive energy provider, PETROL has stood by our side for almost thirty years, helping us shape and grow this event.

Our special thanks go to all generations of PETROL employees for their outstanding cooperation, trust, and support – and to everyone who, over the years, has contributed to the development and advancement of the Slovenian asphalt industry.

Slovenko Henigman, president of ZAS

Spoštovani!

Že več kot osem desetletij v skupini Petrol soustvarjamo razvoj mobilnosti in cestne infrastrukture v Sloveniji ter regiji. Zanesljiva energija, goriva in bitumni so že dolgo jedro našega partnerstva s cestno in gradbeno industrijo – danes pa jih vse bolj dopolnjujejo rešitve, ki zmanjšujejo ogljični odtis, povečujejo učinkovitost in podpirajo prehod v krožno gospodarstvo.

Ponosni smo, da že skoraj 30 let sodelujemo z Združenjem asfalterjev Slovenije, ki združuje najboljše strokovnjake in podjetja naše panoge. Skupaj delimo zavezanost kakovosti, inovacijam in trajnosti – vrednotam, brez katerih si prihodnosti cestne infrastrukture, ki je ključna za razvoj gospodarstva, ne moremo več predstavljati.

Letošnji, jubilejni 20. Kolokvij o asfaltih, bitumnih in voziščih, poteka v času, ko se panoga sooča z zahtevnimi izzivi: od zmanjševanja izpustov toplogrednih plinov in cenovne volatilnosti surovin, do uvajanja digitalnih orodij in novih standardov trajnostne gradnje. Prav zato je sodelovanje med izvajalci, raziskovalnimi ustanovami in naročniki ključnega pomena. Le z izmenjavo znanj in povezovanjem lahko oblikujemo infrastrukturo, ki bo hkrati odporna, trajna in prijazna okolju.

V skupini Petrol v tej preobrazbi nastopamo kot zanesljiv partner pri oskrbi z bitumni, gorivi in energenti, pa tudi kot ponudnik celovitih energetskih rešitev – od optimizacije porabe energije v asfaltnih bazah do uvajanja obnovljivih virov in naprednih logističnih sistemov. S svojimi partnerji razvijamo projekte, ki dokazujejo, da je mogoče združiti gospodarnost, inovativnost in okoljsko odgovornost.

Naša vizija je jasna – biti integriran partner v energetski tranziciji in aktivno prispevati k razogljičenju industrije in prometa. V asfalterski panogi to pomeni več toplih asfaltov, učinkovitejšo rabo energije, večjo uporabo recikliranih materialov in manj emisij. To so cilji, ki nas združujejo in vodijo.

Verjamem, da bo letošnji Kolokvij znova dokazal, da slovenska asfalterska stroka ni le del evropskega prostora, temveč eden njegovih ključnih soustvarjalcev. Prav izmenjava znanj in povezovanje med stroko in gospodarstvom sta temelja, na katerih gradimo odpornejšo, sodobno in trajnostno infrastrukturo prihodnosti.

V letu, ko obeležujemo 80-letnico skupine Petrol, pa s ponosom nadaljujemo naše dolgoletno sodelovanje z Združenjem asfalterjev Slovenije in s partnerji, ki ste predani razvoju cestne infrastrukture. Ta skupna pot nas že desetletja povezuje v isti viziji – ustvarjati zanesljive in trajnostne poti, ki povezujejo ljudi, skupnosti in prihodnost.

Sašo Berger, predsednik uprave skupine Petrol

Dear colleagues,

For more than eight decades, the Petrol Group has been co-shaping the development of mobility and road infrastructure in Slovenia and the broader region. Reliable energy, fuels, and bitumen have long formed the foundation of our partnership with the road construction and civil engineering industries – and today, they are increasingly complemented by solutions that reduce carbon footprints, improve efficiency, and support the transition to a circular economy.

We are proud to have collaborated for nearly 30 years with the Slovenian Asphalt Pavement Association, which brings together the leading experts and companies in our field. Together, we share a commitment to quality, innovation, and sustainability – values without which the future of road infrastructure, essential to economic growth, can no longer be imagined.

This year's 20th Jubilee Colloquium on Asphalts, Bitumen and Pavements takes place at a time when the industry faces major challenges: from lowering the sector's carbon footprint and managing the price volatility of raw materials to adopting digital tools and new standards for sustainable construction. That is why cooperation among contractors, research institutions, and clients is of vital importance. Only through the exchange of knowledge and collaboration can we design infrastructure that is resilient, durable, and environmentally friendly.

At the Petrol Group, we play a reliable role in this transformation – as a trusted supplier of bitumen, fuels, and energy sources, and also as a provider of comprehensive energy solutions: from optimizing energy use at asphalt plants to introducing renewable energy and advanced logistics systems. Together with our partners, we are developing projects that prove economic efficiency, innovation, and environmental responsibility can go hand in hand.

Our vision is clear – to be an integrated partner in the energy transition and to actively contribute to the decarbonization of industry and transport. In the asphalt sector, this means more warm-mix asphalt, more efficient energy use, greater utilization of recycled materials, and lower emissions. These are the goals that unite and guide us.

I believe that this year's Colloquium will once again demonstrate that Slovenian asphalt industry is not just part of the European landscape but one of its key contributors. The exchange of knowledge and the collaboration between industry and business are the foundations on which we build a more resilient, modern, and sustainable infrastructure for the future.

In the year when the Petrol Group celebrates its 80th anniversary, we proudly continue our long-standing cooperation with the Slovenian Asphalt Pavement Association and with all partners dedicated to the development of road infrastructure. This shared journey has united us for decades in the same vision – to create reliable and sustainable roads that connect people, communities, and the future.

Sašo Berger, President of the Management Board, Petrol Group

Program

Sreda, 26. november 2025

16.30 ~ 18.00 OPD - ZAS: Skupni sestanek članov ZAS z največjimi naročniki

18.30 **Otvoritev razstavnih prostorov, skupno druženje in večerja**

Četrtek, 27. november 2025

08.45 ~ 09.00 Uvodni nagovor: **Robert Kuzman**, predsednik NO ZAS

09.00 ~ 10.15 Sekcija 1: RECIKLIRANJE, KROŽNO GOSPODARSTVO IN OSNOVNI MATERIALI V ASFALTU (AGREGATI, BITUMEN, DODATKI)


Zvonko Cotič


Markus Spiegl


Sophie Stüwe


Anja Sörensen

Moderator: **Carsten Karcher, EAPA**

Zvonko Cotič, STRUCTUM (SLO): Primeri dobre prakse - Viadukt Črni Kal in Cesta na Mangart

Markus Spiegl, OMV (A) in **Sophie Stüwe, TU Dunaj** (A): Fizikalno-kemijska analiza 12 veziv 70/100 iz različnih virov

Anja Sörensen, EUROBITUME (B): Eurobitume LCA 4.0 za bitumne

10.15 ~ 10.45 Odmor

10.45 ~ 12.00 Sekcija 2: ZELENI PREHOD IN DIGITALIZACIJA


Vasja Grmek


Paul Schönauer


Marco Bokies


Gilbert Leb

Moderator: **Vasja Grmek, POMGRAD**

Paul Schönauer, TU Dunaj (A): Na poti do EPD-jev za asfaltne zmesi - zakaj, kaj in kako?

Marco Bokies, DAV (D): Okoljske deklaracije izdelkov za asfalt - trenutni razvoj v Nemčiji

Gilbert Leb, Q POINT (A): Celostna digitalna vrednostna veriga (od gradnje prek proizvodnje do stroja) - prednosti in praktični primeri iz celotne Evrope za učinkovito in trajnostno industrijo

12.00 ~ 14.00 **KOSILO**

14.00 ~ 15.00 OTVORITEV 20. KOLOKVIJA


Špela Močnik Paradiž


Slovenko Henigman


Sašo Berger


Ralf Pomp


Nevenka Kržan


Karmen Praprotnik


Andrej Ribič

Moderator: **Špela Močnik Paradiž**

Slovenko Henigman, predsednik ZAS, Združenje asfalterjev Slovenije

Sašo Berger, predsednik uprave Petrol

Ralf Pomp, predsednik EAPA, evropsko asfaltersko združenje

Nevenka Kržan, predsednica uprave Luka Koper

Karmen Praprotnik, direktorica DRSI

Andrej Ribič, predsednik uprave DARS

15.00 ~ 16.15 **VABLJENA PREDAVANJA**


Carsten Karcher


Matic Poznič


Juan José Potti

Moderator: **Slovenko Henigman, predsednik ZAS, Združenje asfalterjev Slovenije**

Carsten Karcher, generalni sekretar EAPA (B): EAPA – kaj se dogaja v Bruslju in drugod?

Matic Poznič, DARS (SLO): Stalna vlaganja kot temelj stabilnosti in razvoja AC omrežja

Juan José Potti, predsednik ASEFMA (ES): Stanje ceste, veliko bolj kot udobje in varnost – poraba goriva/energije in emisije.

16.15 ~ 16.45 Odmor

16.45 ~ 17.30 **VABLJENI PREDAVANJI**

Moderator: **Gregor Ficko, GZS**

Jože P. Damijan (SLO): Analize ekonomskih učinkov zamud pri gradnji 3. razvojne osi

Metod Di Batista (SLO):
Kako rešiti kaos na slovenskih cestah?


Gregor Ficko


Jože P. Damijan


Metod Di Batista

17.30 ~ 18.00 **MOTIVACIJSKO PREDAVANJE**

Simon Marčič, ekstremni motorist in voznik Dakarja


Simon Marčič

18.00 ~ 18.30 **KULTURNI PROGRAM in PODELITEV PRIZNANJ**

20.00 **SKUPNA VEČERJA v Bled Rose hotelu** (Cesta svobode 8, Bled)

Sprejem s penino (pokrovitelj sprejema: podjetje **STRABAG**)

Petek, 28. november 2025

09.00 ~ 10.30 Sekcija **3: PROJEKTIRANJE, GRADNJA IN VZDRŽEVANJE KONSTRUKCIJ ASFALTNIH VOZIŠČ**


Roman Bašelj


Damijan Zore


Franc Pungerčič


Samir Irzayev


Romana Lesjak

Moderator: **Roman Bašelj, IGMAT**

Damijan Zore, IGMAT (SLO): Zgoščevanje asfaltnih plasti

Franc Pungerčič in Samo Gaberšek, VIANOVA (SLO): Površinske prevleke kot del krajinskih in okolijskih ureditev

Samir Irzayev, RETTENMAIER & SÖHNE GmbH + CO KG (D): Odklepanje celotnega potenciala RAP

Romana Lesjak, županja Občine Črna na Koroškem (SLO): Izvajanje asfalterskih del v občini Črna na Koroškem

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10.30 ~ 11.00 Odmor

11.00 ~ 12.00 **TEHNIČNE PREDSTAVITVE PODJETIJ IN NJIHOVIH PRODUKTOV**

Matevž Žiberna

Moderator: **Matevž Žiberna, GGD**

PETROL, MUREXIN, Q POINT in **RENESO**

12.00 ~ 13.00 Sekcija **4: PROIZVODNJA ASFALTNIH ZMESI, TESTIRANJE IN OPREMA**

Marko Žavbi

Dejan Hribar

Lidija Ržek

Matteo Fumagalli

Klemen Šobak

Primož Pavšič

Moderator: **Marko Žavbi, STRABAG**

Dejan Hribar, STRABAG in **Lidija Ržek, ZAG** (SLO): Poskusna polja s toplimi asfalti po postopku penjenega bitumna na odsekih AC 0043 in AC 0067 (Vransko – Blagovica): Način do boljše trajnosti in zmanjšanja ogljičnega odtisa

Matteo Fumagalli, ITERCHIMICA (IT): Dodatki za WMA in/ali izboljšanje vgradnje asfalta: tehnika za trajne asfaltne vozišča

Klemen Šobak, TRGOGRAD in **Primož Pavšič, ZAG** (SLO): Uporaba bitumna »PMB 45/80-65 le« v proizvodnji toplih asfaltnih zmesi

13.00 ~ 13.30 **ZAKLJUČEK 20. KOLOKVIJA 2025**

13.30 ~ 14.30 **KOSILO**

Programme

20. Colloquium
ASPHALT, BITUMEN and PAVEMENTS
Bled ~ Slovenia, 26.~28. november 2025

Wednesday, 26th November 2025

16.30 ~ 18.00 Enterprises and companies committee - ZAS

18.30 **Opening of exhibition spaces and socialising**

Thursday, 27th November 2025

08.45 ~ 09.00 Opening speech: **Robert Kuzman**, President of supervising committee ZAS

09.00 ~ 10.15 Section **1: RECYCLING, CIRCULAR ECONOMY, AND BASIC MATERIALS IN ASPHALT (AGGREGATES, BITUMEN, ADDITIVES)**

Moderator: **Carsten Karcher, EAPA**

Zvonko Cotič, STRUCTUM (SLO): Examples of good practice – the Črni Kal Viaduct and the Road to Mangart

Markus Spiegl, OMV (A) and **Sophie Stüwe, TU Dunaj** (A): Physico-chemical analysis of 12 70/100 binders from different sources

Anja Sörensen, EUROBITUME (B): Eurobitume LCA 4.0 for bitumen

10.15 ~ 10.45 Break

10.45 ~ 12.00 Section **2: GREEN TRANSITION AND DIGITALIZATION**

Moderator: **Vasja Grmek, POMGRAD**

Paul Schönauer, TU Vienna (A): On the road to EPDs for asphalt mixtures – why, what and how?

Marco Bokies, DAV (D): Environmental product declarations for asphalt - current developments in Germany

Gilbert Leb, Q POINT (A): End to end digital value chain (from construction via production to the machine) - benefits and practical examples from across Europe for an efficient and sustainable industry

12.00 ~ 14.00 **LUNCH**

14.00 ~ 15.00 **OPENING OF 20th COLLOQUIUM**

Moderator: **Špela Močnik Paradiž**

Slovenko Henigman, President of ZAS, Slovenian Asphalt Pavement Association

Sašo Berger, President of the Management Board PETROL

Ralf Pomp, President of EAPA, European Asphalt Pavement Association

Nevenka Kržan, President of the Management Board PORT of KOPER

Karmen Praprotnik, Director of Slovenian Infrastructure Agency

Andrej Ribič, President of the Management Board DARS

15.00 ~ 16.15 **INVITED LECTURES**

Moderator: **Slovenko Henigman, President of ZAS**

Carsten Karcher, Secretary General for EAPA (B): The European Asphalt Pavement Association - What is going on in Brussels and beyond?

Matic Poznič, DARS (SLO): Constant investments as the foundation of the stability and development of the motorway network

Juan José Potti, president of ASEFMA (ES): Road condition, much more than confort and safety - fuel/ energy consumption and emission.

16.15 ~ 16.45 Break

16.45 ~ 17.30 **INVITED LECTURES**

Moderator: **Gregor Ficko, GZS**

Jože P. Damijan (SLO): Analysis of the economic impacts of delays in the construction of the 3rd development axis

Metod Di Batista (SLO): How to solve the chaos on Slovenian roads?

17.30 ~ 18.00 **MOTIVATION LECTURE**

Simon Marčič, extreme biker and Dakar driver

18.00 ~ 18.30 **CULTURAL EVENT and ZAS RECOGNITIONS**

20.00 **DINNER – Hotel Bled Rose** (Location: Cesta svobode 8, Bled)

Sparkling Wine Reception (Sponsored by company **STRABAG**)

Friday, 28th November 2025

09.00 ~ 10.30 **Section 3: DESIGN, CONSTRUCTION, AND MAINTENANCE OF ASPHALT PAVEMENT STRUCTURES**

Moderator: **Roman Bašelj, IGMAT**

Damijan Zore, IGMAT (SLO): Compaction of asphalt layers

Franc Pungerčič and Samo Gaberšek, VIANOVA (SLO): Surface coatings as part of landscape and environmental arrangements

Samir Irzayev, RETTENMAIER & SÖHNE GmbH + CO KG (D): Unlocking the full potential of RAP

Romana Lesjak, Mayor of the Municipality of Črna na Koroškem (SLO): Execution of paving works in the Municipality of Črna na Koroškem

10.30 ~ 11.00 Break

11.00 ~ 12.00 **TECHNICAL PRESENTATION OF COMPANIES AND THEIR PRODUCTS**

Moderator: **Matevž Žiberna, GGD**

PETROL, MUREXIN, Q POINT and **RENESO**

12.00 ~ 13.00 Section **4: MANUFACTURE OF ASPHALT MIXTURES, TESTING, AND EQUIPMENT**

Moderator: **Marko Žavbi, STRABAG**

Dejan Hribar, STRABAG and **Lidija Ržek, ZAG** (SLO): Trial sections with warm mix asphalt using the foamed bitumen method on sections AC 0043 and AC 0067 (Vransko – Blagovica): a way to better durability and reduced carbon footprint

Matteo Fumagalli, ITERCHIMICA (IT): WMA and/or asphalt workability aid additives: a technique for durable asphalt pavement

Klemen Šobak, TRGOGRAD and **Primož Pavšič, ZAG** (SLO): Use of bitumen 'PMB 45/80-65 le' in the production of hot mix asphalt

13.00 ~ 13.30 **CLOSING OF 20th COLLOQUIUM 2025**

13.30 ~ 14.30 **LUNCH**

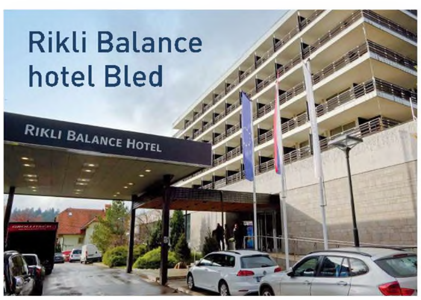
Dejstva 19. kolokvijev | Facts of 19 Colloquiums | 1996 ~ 2023

234 referatov / Papers

334 predavateljev / Lecturers

4.450 udeležencev / Participants

539 razstavljavcev / Exhibitors



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REFERATI SEKCIJA 1: Recikliranje, krožno gospodarstvo in osnovni materiali v asfaltu (agregati, bitumen, dodatki)

LECTURES – SECTION: Recycling, circular economy, and basic materials in asphalt (aggregates, bitumen, additives)

Primeri dobre prakse – viadukt Črni kal in cesta na Mangart

Good practice example –Črni Kal Viaduct and Mangart Road

Zvonko Cotič (Structum, d.o.o.)

Povzetek:

Primer Viadukta Črni Kal in Ceste na Mangart jasno potrjuje, da pravilna izbira bitumna ključno vpliva na dolgo življenjsko dobo asfaltnih vozišč. Na Viaduktu Črni Kal asfalt tudi po dvajsetih letih ohranja odlično stanje, kar je posledica kakovostnega polimernega bitumna, kakovostnih kamenih materialov, ustrezno proizvedenih asfaltnih zmesi in vgrajenih asfaltnih plasti ter večslojne asfaltne konstrukcije vozišča, ki presega običajne standarde. Rezultati preskusov potrjujejo visoko kakovost uporabljenega materiala in njegovo odpornost na obremenitve.
Podobno se je na Cesti na Mangart izkazal bitumen B 160/220 (BIT 200), ki je kljub nižjemu deležu v zmesi omogočil, da asfalt po skoraj štirih desetletjih ostaja v zelo dobrem stanju. Mehkejši tip bitumna se je izkazal kot primerna izbira za gorske in celinske razmere ter za ceste z lažjo prometno obremenitvijo. Oba primera dobre prakse potrjujeta, da premišljena izbira bitumna pomembno prispeva k trajnosti, ekonomičnosti in kakovosti cestne infrastrukture.

Abstract:

The example of the Črni Kal Viaduct and the Mangart Road clearly confirms that the correct choice of bitumen has a crucial impact on the long service life of asphalt pavements. On the Črni Kal Viaduct, the asphalt surface remains in excellent condition even after twenty years, which is the result of high-quality polymer-modified bitumen, premium aggregates, properly produced asphalt mixtures and layers, as well as a multi-layer pavement structure that exceeds standard design requirements. Test results confirm the high quality of the materials used and their resistance to traffic and climatic loads.
Similarly, on the Mangart Road, the B 160/220 (BIT 200) bitumen has proven to be an excellent choice. Despite its lower content in the mixture, the asphalt has remained in very good condition after almost four decades. The softer type of bitumen has proven to be well suited for mountainous and continental climates, as well as for roads with lighter traffic loads. Both examples of good practice demonstrate that a carefully selected bitumen type significantly contributes to the durability, cost-efficiency, and overall quality of road infrastructure.

1. Uvod

Kakovost in trajnost asfaltnih vozišč sta ključna dejavnika za varno in učinkovito delovanje cestne infrastrukture. Eden izmed najpomembnejših elementov, ki vplivajo na obstojnost cestnih površin, je izbira ustreznega bitumna, saj ta določa odpornost asfalta na temperaturne spremembe, prometne obremenitve in staranje materiala. V Sloveniji imamo več primerov, kjer je pravilna izbira bitumna prispevala k izjemni kakovosti in dolgotrajnosti asfaltnih površin.Med izstopajočimi primeri dobre prakse sta Viadukt Črni Kal in Cesta na Mangart. Pri Viaduktu Črni Kal asfaltno vozišče tudi po dvajsetih letih ostaja v odličnem stanju, kar je predvsem posledica uporabe kakovostnega in primerno izbranega polimer modificiranega bitumna. Podoben primer predstavlja Cesta na Mangart, kjer se je s premišljeno izbiro bitumna B 160/220 (BIT 200) dosegla visoka odpornost na vremenske vplive, kljub zahtevnim gorskim razmeram tudi po 38 letih uporabe.

2.0 VIADUKT ČRNI KAL

Viadukt Črni Kal je eden izmed največjih slovenskih gradbenih objektov, saj je 95 metrov visoka, 27 metrov široka in 1.065 metrov dolga konstrukcija. Investitor gradnje je bila Družba za avtoceste v Republiki Sloveniji (DARS), projektant Inženirski biro Ponting d.o.o., izvajalca del SCT d.d. in Primorje d.d., nadzor DDC d.o.o.. Pričetek gradnje je bil septembra 2001, konec gradnje oziroma odprtje odseka primorske avtoceste A1 Klanec - Ankaran in viadukta pa 23. septembra 2004.

Viadukt Črni Kal prečka Osapsko dolino v horizontalnem radiju 800 m, v območju viadukta poteka niveleta v konstantnem vzdolžnem padcu 2,7 %, prečni padec je konstanten in znaša 5,25 %.

Slika 1: Viadukt Črni Kal oktobra 2025, PLDP 30.000 od tega 2.700 tovornih vozil

V letu 2005 je povprečni letni dnevni promet na odseku Črni Kal-razcep Sermin znašal 17.724 vozil, od tega 1.218 tovornih nad 7 ton mase. Čez 10 let je odsek prevozilo v povprečju 22.325 vozil na dan, od tega 1.603 tovornih. V letu 2023 (zadnjem objavljenem štetju) pa je povprečni letni dnevni promet znašal 30.953 vozil, od tega 2.706 tovornih. V obdobju 2005-2023 se je torej promet povečal za 74 odstotkov.
Skladno z TSC – tehničnimi specifikacijami za ceste v Sloveniji asfaltne voziščne konstrukcije projektiramo za dobo 20 let. Po 20 letih uporabe asfaltne voziščne konstrukcije na Viaduktu Črni kal lahko ugotovimo, da je v odličnem stanju.

2.1 Asfaltna voziščna konstrukcija

Voziščno konstrukcijo predstavljata dve vzdolžno omejeni prednapeti betonski škatli, voziščna plošča je široka 12,6 m. Širina asfaltnega vozišča v eni smeri je 10,5 m, površina asfaltnega vozišča na celotnem viaduktu je 23.400 m^2.

Asfaltna voziščna konstrukcija na Viaduktu Črni Kal je sestavljena iz (zgoraj proti spodaj):

- Obrabno zaporni sloj:	DBM 8s (silikat 2/4 in 4/8) v debelini 3,5 cm
- Izravnalni (vezni) sloj:	DBM 8 v povprečni debelini 3,5 cm
- Zaščita hidroizolacije:	DBM 8 v povprečni debelini 3,5 cm
- Hidroizolacija:	Biumenski hidroizolacijski trak
- Betonska vozišćna plošča	

Z začetkom intenzivne gradnje avtocest v Sloveniji je bila za obrabne plasti uvedena nova asfaltna zmes DBM (drobir z bitumenskim mastiksom). Leta 1997 je Združenje asfalterjev Slovenije pripravilo dopolnitev PTP za vezane obrabne in zaporne plasti – drobir z bitumenskim mastiksom. Leta 2000 so bila za DBM izdana dopolnila PTP, leta 2001 pa so za DBM pripravljeni TSC 06.412:2001.

Asfaltne zmesi za Viadukt Črni Kal so se proizvajale v Asfaltnem obratu Laže podjetja Primorja d.d.. Vgrajevalec asfaltnih plasti je bilo podjetje SCT d.d.. Notranja kontrola proizvodne asfaltnih zmesi je izvajala Enota Kontrole kakovosti v sklopu podjetja Primorje d.d.. Notranjo kontrolo vgrajenih plasti je izvajal Inštitut IGMAT d.d.. Zunanjo kontrolo je izvajal ZAG -Zavod za gradbeništvo Slovenije.

Na Viaduktu Črni kal je bilo vgrajenih približno 6.000 ton asfaltnih zmesi (2.000 ton zmesi za zaščito hidroizolacije, 2.000 ton zmesi za izravnavo in 2.000 ton zmesi za obrabnozaporno plast).

2.2 Osnovni materiali za asfaltno zmes DBM 8 in DBM 8s

Podjetje Primorje d.d. je uporabljalo pri proizvodnji DBM naslednje osnovne materiale in sicer:

- kameno moko (tuje polnilo); Laže (odpraševanje pri proizvodnji na drobilnici in separaciji v Lažah),
- drobljeni pesek frakcije 0/2; Laže,
- drobir frakcij 2/4, 4/8; Laže, za zaščito hidroizolacije in za izravnalno plast
- drobir frakcij 2/4, 4/8; Bleiberg (silikatnega porekla), za obrabnozaporno plast,
- polimerni bitumen; Olexobit SMA (PmB tip III. proizvajalca BP, rafinerija Vohburg v Nemčiji).

Za zaščito hidroizolacije in izravnave se je uporabil DBM 8 (karbonatni agregat), za obrabno zaporni sloj pa se je uporabljal DBM 8s (karbonat 0/2, s – silikat 2/4 in 4/8). Za vse asfalte na viaduktu je bila zahteva za vezivo PmB III. Oznaka PmB III pomeni s polimeri modificiran bitumen, ki ima zahtevane lastnosti skladno s Posebnimi tehničnimi pogoji, spremembe in dopolnitve točka 3.1.9 Modificirana bitumenska veziva.

2.2.1 Polimerni bitumen Olexobit SMA

V letu 2004 je bil Olexobit SMA proizvod podjetja BP Bitumen (British Petroleum) in se je dobavljal iz rafinerije Vohburg v Nemčiji. Po letu 2010 je BP svoj bitumenski oddelek v Evropi prodala podjetju Puma Bitumen, ki danes nadaljuje proizvodnjo Olexobit proizvodov. Transporta razdalja od rafinerije do Asfaltnega obrata v Lažah je bila 550 km. Bitumen Olexobit SMA se je uporabljal za vse tri asfaltne sloje na Viaduktu Črni Kal. Dobavljenih je bilo 20 cisteren bitumna, ocenjena količina je cca, 450 ton.

Proizvajalec je navedel, da Olexobit SMA odgovarja tipu PmB III skladno s tabelo 1.0 dopolnjenih Posebnih tehničnih pogojev. S strani pooblaščene institucije Zavoda za gradbeništvo Slovenije je dobavitelj pridobil dokazilo o skladnosti in ustreznosti proizvoda. Pred pričetkom uporabe je notranja kontrola proizvajalca asfaltnih zmesi za vsako dobavljeno cisterno preverila vrednost penetracije in zmehčišča. V preglednica 1 so prikazani rezultati originalnih bitumnov Olexobit SMA na Viaduktu Črni Kal kot povprečne, najmanjše in največje vrednosti dvajsetih preskusov dobavljenega bitumna v obdobju od 24.06.2004 do 07.09.2004. V preglednici 1 so prikazani tudi rezultati penetracije in zmehčišča (P.K.) izvoznika BP, ki so bili prikazani na dobavnici pri vsaki dobavi.

Preglednica 1: Rezultati originalnih bitumnov Olexobit SMA na Viaduktu Črni Kal

Datum dobave	Olexobit SMA vhodni bitumen		Primorje			rezultati Izvoznika	
			P.K. °C	Penet. mm/10	Indeks penet.	P.K. °C	Penet. mm/10
od 24.06.2024 do 07.09.2024	20 preskušancev	povprečna vrednost	**72,4**	**48,9**	**3,1**	**68,8**	**45,6**
		min. vrednost	67,4	44,0	2,3	66,0	44,0
		max. vrednost	81,0	55,0	4,3	74,0	48,0

V preglednici 2 so prikazani rezultati estrahiranega bitumna 26 preskusov vgrajevane zmesi od 24.06.2024 do 09.09.2024 kot povprečna, minimalna in maksimalna vrednost. Prikazana je tudi temperatura zmesi pri odvzemu vzorca zmesi pri vgrajevanju. Preskuse je opravila notranja kontrola Primorja d.d.

Preglednica 2: Rezultati estrahiranih bitumnov Olexobit SMA na Viaduktu Črni Kal

Datum vgrajevanja	Olexobit SMA estrahiran bitumen		P.K. °C	Penet. mm/10	Indeks penet.	Temp. zmesi (°C)
od 24.06.2024 do 09.09.2024	26 preskušancev	povprečna vrednost	**74,0**	**36,9**	**2,7**	**155,7**
		min. vrednost	67,4	33,0	1,8	135,0
		max. vrednost	80,5	41,0	3,6	170,0

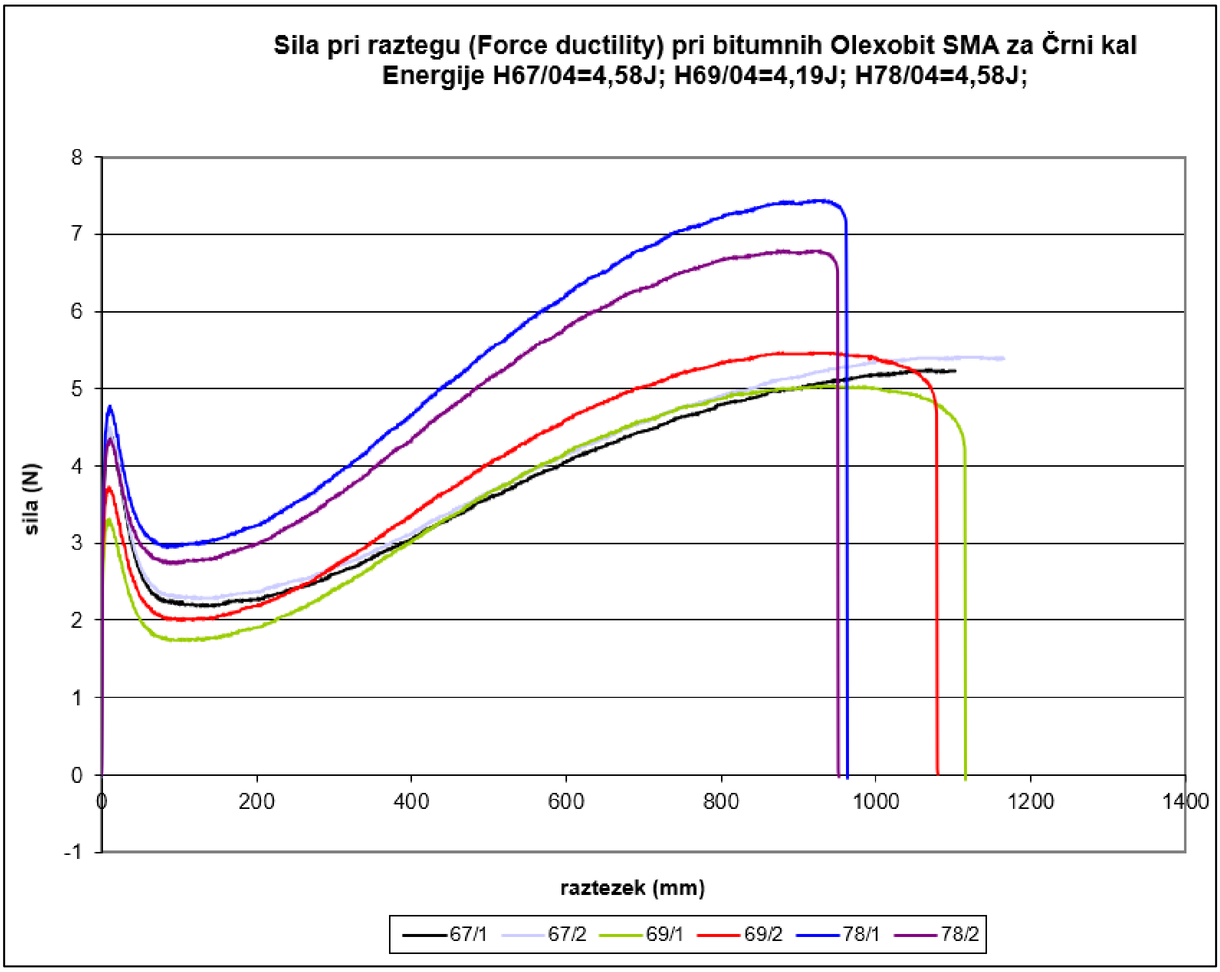
Zunanje kontrolne preskuse penetracije, zmehčišča, pretrgališča, duktilnosti in elastičnega povratka so opravili v Laboratoriju za asfalt na Zavodu za gradbeništvo Slovenije in so prikazani v preglednici 3.

Poleg s PTP zahtevanimi kontrolnimi preskusi so na ZAG-u opravili še preskuse sile in energije pri raztegu. Rezultati so prikazani v preglednici 3. Opis preskusov je predstavil Marjan Tušar v referatu z naslovom Določanje razteznih lastnosti bitumnov na 5. Kolokviju o bitumnih leta 2000.

Preglednica 3: Rezultati zunanje kontrole ZAG originalnih bitumnov Olexobit SMA na Viaduktu Črni Kal

Lastnosti PmB veziva	Enote	Preiskava po standardu	Originalni-vhodni bitumen				Zahteva PTP zap. št. 17	Zahteva SIST 1035:2008
lab oznaka			67/04	69/04	78/04	92/04	PmB III	PmB 45/80-65
datum odvzema			29.06.2004	6.07.2004	19.07.2004	16.08.2004		
penetracija pri 25°C	mm/10	JUS B.H8.612	45	49	47	50	40-70	45-80
zmehčišče po PK	°C	JUS B.H8.613	77,5	77,5	75	70	min. 70	min. 65
pretrgališče po Fraassu	°C	JUS B.H8.616	-12	-19		-16	max. –17	max. –18
duktilnost pri 25°C	cm	JUS B.H8.615	>117	110	96	91,5	min. 80	
el. povratna def. pri 25°C	%	JUS B.H8.615	82	84	83	86,4	min. 70	min. 70
Sila pri raztegu pri 25°C	N	prEN 13589/1999	**5,3**	**5,3**	**7,1**	**5,0**		
Ener. pri raztegu pri 25°C	J/cm^2	prEN 13589/1999	**4,58**	**4,19**	**4,85**	**3,53**	**min. 3 J**	min. 2 J

Na sliki 2 so prikazane sile pri raztegu in energije pri raztegu vhodnih bitumnov Olexobit SMA na Viaduktu Črni Kal. Pri preizkusu duktilnosti pri 25 °C so določili silo pri raztezanju in osnovi le-te izračunali potrebno energijo za pretrg. Energija je površina pod krivuljo. Na sliki sila – raztezek vidimo, da je prva maksimalna sila manjša od druge maksimalne sile kar je zelo ugodno in kaže na odličen PmB.



Slika 2: Sile pri raztegu originalnih bitumnov Olexobit SMA na Viaduktu Črni Kal

2.3 Asfaltne zmesi in asfaltne plasti

Za zaščito hidroizolacije in izravnave se je uporabil DBM 8 (karbonatni agregat) z vezivom Olexobit SMA, za obrabno zaporni sloj pa se je uporabljal DBM 8s z enakim vezivom Olexobit SMA.

V preglednici 4 so prikazani rezultati (povprečne vrednosti) lastnosti proizvedenih asfaltnih zmesi in vgrajenih asfaltnih plasti za zaščito hidroizolacije in izravnave. V preglednici 5 so prikazani rezultati (povprečne vrednosti) lastnosti asfaltnih zmesi in vgrajenih asfaltnih plasti za obrabno zaporno plast DBM 8s. V obeh preglednicah so prikazane tudi predhodne sestave in zahteve posebnih tehničnih pogojev iz leta 2000 in sedanje zahteve TSC iz leta 2009. Vsi rezultati posebej delež bitumna, delež votlin, delež zapolnjenih votlin z bitumnom, stopnja zgoščenosti in delež votlin v plasti so skladni z zahtevami.

Preglednica 4: Rezultati lastnosti proizvedenih asfaltnih zmesi in vgrajenih asfaltnih plasti DBM za zaščito hidroizolacije in izravnav na Viaduktu Črni Kal

Datum proizvodnje in vgrajevanja	VRSTA ZMESI: DBM 8 SMA PSAZ: DBM8-SMA-1 PROIZVAJALEC: Primorje d.d. VGRAJEVALEC: SCT d.d.		BITUMEN Olexobit SMA	LASTNOSTI PROIZVEDENE ASFALTNE ZMESI				LASTNOSTI VGRAJENE ASFALTNE PLASTI		
	Lokacija vgrajevanja	TEMP. VZORCA	CELOKUP. DELEŽ BITUMENA	Nav. spec. masa asf. zmesi	Prostor. masa asfalta	Delež celokup. votlin	Zapolnje. votlin v kam. mat.	Prostor. masa asfalta	Zgoščenost	Delež celokup. votlin
		°C	% (m/m)	Mg/m3	Mg/m3	% (V/V)	% (V/V)	Mg/m3	%	% (V/V)
PREDVIDENE VREDNOSTI (PSAZ)			6,8	2,434	2,360	3,0	83,9			
1.7.2004 - 3.9.2024	Viadukt Črni kal - zaščita HI	157	6,9	2,430	2,329	**4,1**	**79,1**	2,311	**99,2**	**4,9**
30.8.2004 - 6.9.2004	Viadukt Črni kal - izravnava	158	6,9	2,430	2,332	**4,0**	**79,6**	2,326	**99,7**	**4,3**
ZAHTEVA: dopolnitev PTP zap.št.17: 2000						**3,0 - 4,5**	**70 - 85**		**min. 97**	**3,0 - 6,0**
ZAHTEVA: TSC 06.300/06.410:2009			**$B_{min.}$6,5**			**2,5 - 4,5**	**75 - 88**		**min. 97**	**1,5 - 7,5**

Preglednica 5: Rezultati lastnosti proizvedenih asfaltnih zmesi in vgrajenih asfaltnih plasti DBM 8s na Viaduktu Črni Kal

Datum proizvodnje in vgrajevanja	VRSTA ZMESI: DBM 8s SMA PSAZ: DBM8s-SMA-2 PROIZVAJALEC: Primorje d.d. VGRAJEVALEC: SCT d.d.		BITUMEN Olexobit SMA	LASTNOSTI PROIZVEDENE ASFALTNE ZMESI				LASTNOSTI VGRAJENE ASFALTNE PLASTI		
	Lokacija vgrajevanja	TEMP. VZORCA	CELOKUP. DELEŽ BITUMENA	Nav. spec. masa asf. zmesi	Prostor. masa asfalta	Delež celokup. votlin	Zapolnje. votlin v kam. mat.	Prostor. masa asfalta	Zgoščenost	Delež celokup. votlin
		°C	% (m/m)	Mg/m3	Mg/m3	% (V/V)	% (V/V)	Mg/m3	%	% (V/V)
PREDVIDENE VREDNOSTI (PSAZ)			6,7	2,577	2,484	3,6	81,9			
7.9.2004 - 9.9.2004	Viadukt Črni kal - obrabnozaporna plast	157	6,7	2,589	2,476	**4,4**	**78,7**	2,447	**98,8**	**5,5**
ZAHTEVA: dopolnitev PTP zap.št.17: 2000						**3,0 - 4,5**	**70 - 85**		**min. 97**	**3,0 - 6,0**
ZAHTEVA: TSC 06.300/06.410:2009			**$B_{min.}$6,5**			**2,5 - 4,5**	**75 - 88**		**min. 97**	**1,5 - 7,5**

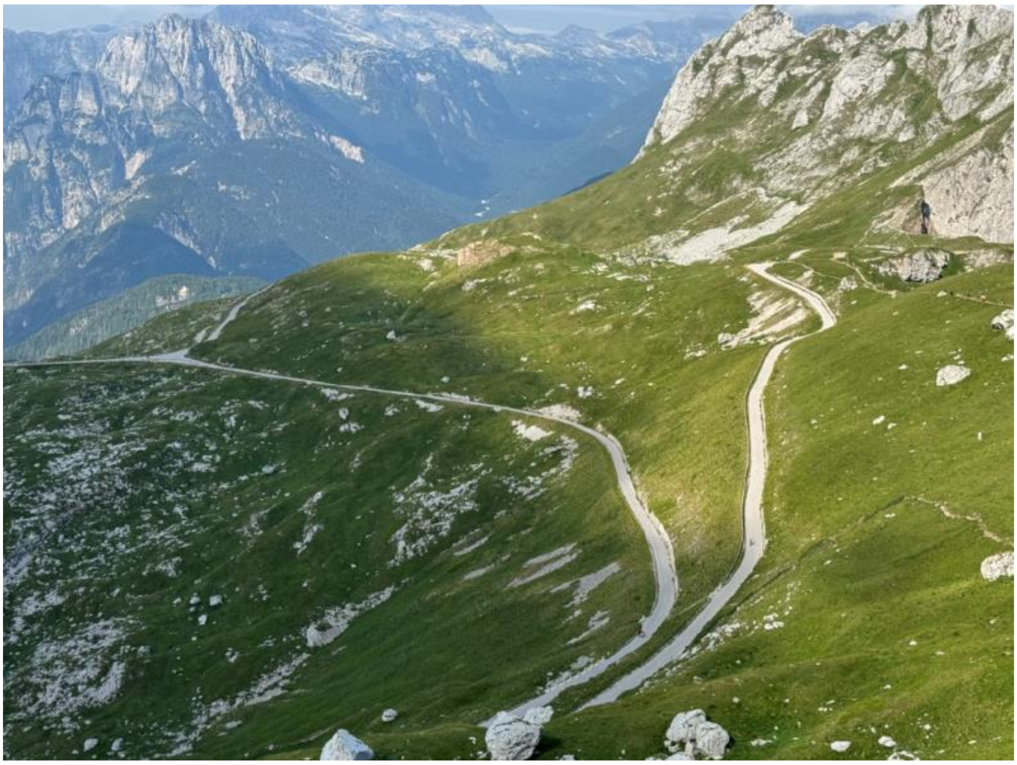
Poleg dobrih rezultatov lahko poudarim tudi odlično sodelovanje vseh deležnikov med proizvodnjo in vgrajevanjem asfalta. Sodelovanje je temeljilo na velikem osebnem zaupanju med vodilnimi inženirji notranje kontrole proizvodnje (Primorje), notranje kontrole vgrajevanja (IGMAT; Sašo Ljubič) in zunanje kontrole (ZAG; Marjan Tušar).

3.0 CESTA NA MANGART

Cesta na Mangart ali Mangartska cesta je visokogorska cesta v Julijskih Alpah, ki se vzpenja od odcepa pod Predelom do Mangartskega sedla na višini 2.055 metrov in je tako najvišje ležeča cesta v Sloveniji. Mangartska cesta je 12 kilometrov dolga asfaltirana ozka (širina asfalta je 2,5 m) cesta, ki premaga 980 metrov nadmorske višine in poteka skozi 5 v apnenčasto skalo izklesanih predorov.

Panoramska cesta, ki so jo leta 1938 zgradili italijanski vojaki, je bila po odsekih večkrat asfaltirana, prvič leta 1987 so bili asfaltirani krajši pododseki serpentin in strmin v skupni dolžini 5 km. Drugič je bila asfaltirana leta 1995 do odcepa za Kočo na Mangartu, tretjič pa leta 2005 ko je bil asfaltiran 1,7 km dolg odsek pentlje na Mangartsko sedlo do višine 2,055 metrov.

Vgrajevanje asfalta je izvajalo Cestno Podjetje Nova Gorica, asfalt je bil proizveden v asfaltnem obratu v Vrtojbi in prepeljan s kamioni na razdalji 100 km.



Slika 3: Asfaltirana Mangartska cesta – pentlja na višini 2.055m v juliju 2025

3.1 Asfaltna voziščna konstrukcija

Voziščno konstrukcijo sestavlja zgornja obrabno zaporna plast z oznako BNOP 16 (bituminizirana nosilno obrabna plast, zrnavostne sestave 0/16 mm) v povprečni debelini 6 cm in tamponski drobljenec karbonatnega izvora v debelini do 20 cm. Podlaga je v glavnem skala iz apnenca.

V juniju 2025 sem opravil ogled asfaltne voziščne konstrukcije na celotni dolžini ceste. Na asfaltni površini je opaziti manjše število prečnih razpok in odprtih delovnih stikov, ostalih poškodb v obliki mrežastih razpok, kolesnic, udarnih jam ni opaziti. Asfaltna voziščna konstrukcija je glede na starost od 20 let do 38 let v zelo dobrem stanju.

3.2 Osnovni materiali za asfaltno zmes BNOP 16

Cestno podjetje Nova Gorica je pri proizvodnji BNOP 16 na asfaltnem obratu v Vrtojbi v letih 1987, 1995 in 2005 uporabljalo naslednje osnovne materiale:

- kameno moko; Tolmin (odpraševanje pri proizvodnji na drobilnici in separaciji v Tolminu),
- drobljeni pesek frakcije 0/4; Tolmin,
- drobir frakcij 4/8, 8/11 in 11/16; Tolmin,
- cestogradbeni bitumen; BIT 200

3.2.1 Cestogradbeni bitumen

Pri proizvodnji asfaltne zmesi BNOP 16 se je za vse odseke Ceste na Mangart uporabljal vhodni bitumen BIT 200. Za odsek vgrajen leta 1987 je bil proizvajalec bitumna rafinerija INA Reka.

V preglednici 6 so prikazane priporočene vrste cestogradbenih bitumnov za nosilnoobrabno plast glede na veljavne tehnične specifikacije. Takrat veljaven jugoslovanski standard JUS U.E9.021 iz leta 1986 je za asfaltno zmes za lahko in zelo lahko prometno obremenitev BNHS 16 priporočal ali BIT 90 ali BIT 130 ali BIT 200. Prav enako je bilo predpisano v TSC 06.310 iz leta 2001. V TSC 06.300-06.410 iz leta 2009 so v preglednici 2.2.1 priporočeni za uporabo naslednji bitumni 50/70 (BIT 60), 70/100 (BIT 90), 100/150 (BIT 130) in 160/220 (BIT 200).

Preglednica 6: Priporočene vrste cestogradbenih bitumnov za nosilno obrabno plast glede na veljavnost tehničnih specifikacij

Vrsta cestogradbenega bitumna za (BNHS 16, BNOP 16, AC 16surf)								
Lastost bitumna	60	50/70	90	70/100	130	100/150	200	160/220
JUS U.E9.021/1986			X		X		X	
TSC 06.310/2001			x		x		x	
TSC 06.300-06.410/2009		x		x		x		x

V preglednici 7 so podane mejne vrednosti lastnosti cestogradbenih bitumnov (penetracija, zmehčišče in pretrgališče) skladno s standardom JUS U.M3.010/1975, ki je veljal do sprejema slovenskega standarda za cestogradbene bitumne SIST EN 12591 v letu 2000. Kot vidimo so mejne vrednosti za bitumen oznake BIT 200 zelo podobne mejnim vrednostim za bitumen 160/220.

Preglednica 7: Mejne vrednosti lastnosti cestogradbenih bitumnov po JUS in SIST EN 12591

Vrsta cestogradbenega bitumna									
Lastost bitumna	Enota	60	50/70	90	70/100	130	100/150	200	160/220
penetracija pri 25°C	mm/10	50-70	50-70	80-100	70-100	120-150	100-150	160-210	160-220
zmehčišče po PK	°C	49-55	46-54	45-51	43-51	41-46	39-47	37-43	35-43
pretrgališče po Fraassu	°C	-8	-8	-11	-10	-13	-12	-15	-15

3.3 Asfaltna zmes

Asfaltne zmesi BNOP 16 za Mangartsko cesto so bile proizvedene na asfaltnem obratu Cestnega podjetja v Vrtojbi. V preglednici 8 so predstavljeni rezultati lastnosti proizvedene asfaltne zmesi z dne 15.07.1987 in vgrajene na Cesto na Mangart v km 7,7. Prikazane so tudi zahteve za asfaltno zmes različnih standardov in specifikacij kot so si sledile do zadnje veljavnih. Ugotovljene vrednosti zmesi iz leta 1987 odstopajo od vseh zahtev standardov pri deležu celokupnih votlin in deležu zapolnjenih votlin z bitumnom. Višji delež votlin in nižji delež zapolnjenosti je posledica nižje vsebnosti bitumna. Današnje zmesi z oznako AC 16 surf imajo delež bitumna za 0,5% višji.

Pri letošnjem ogledu asfaltne površine ni bilo opaziti poškodb, kar bi pričakovali glede na starost asfaltne plasti in glede na slabše lastnosti. Dobro stanje asfalta pripisujem uporabi vhodnega bitumna BIT 200. Prednosti uporabe BIT 200 na Cesti na Mangart: pri daljšem transportu manjše otrjevanje bitumna, boljša odpornost na mraz in temperaturne spremembe, boljša odpornost pri staranju in oksidaciji.

Preglednica 8: Rezultati lastnosti proizvedene asfaltne zmesi z dne 15.07.1987

Datum proizvodnje in vgrajevanja	VRSTA ZMESI: BNOP 16 PROIZVAJALEC: Cestno podjetje Nova Gorica	BITUMEN BIT 200	LASTNOSTI PROIZVEDENE ASFALTNE ZMESI						
	VGRAJEVALEC: Cestno podjetje Nova Gorica	CELOKUP. DELEŽ BITUMENA	Nav. spec. masa asf. zmesi	Prostor. masa asfalta	Delež celokup. votlin	Zapolnje. votlin v kam. mat.	Stabil= nost	Tečenje	Togost
	Lokacija vgrajevanja	% (m/m)	Mg/m3	Mg/m3	% (V/V)	% (V/V)	kN	mm	kN/mm
15.07.1987	Cesta na Mangart - RT 902 odsek 1019 v km 7,7	4,2	2,540	2,400	**5,7**	**63,5**	12,9	3,14	4,1
ZAHTEVA: JUS U.E9.021:1986					**1,0 - 4,0**		**4,0**		**1,4**
ZAHTEVA: PTP SCS:1989					**1,0 - 3,5**	**75 - 82**	**6,0**	**2,5 - 4,5**	
ZAHTEVA: TSC 06.310:2001					**1,0 - 4,0**	**≥ 75**	**≥ 4**		**≥ 1,5**
ZAHTEVA: SIST 1038-1:2008					**1,5 - 5,0**	**75 - 89**			

4.0. ZAKLJUČEK

Asfaltno vozišče na Viaduktu Črni Kal po 20 letih izkazuje odlično stanje kljub povečani prometni in klimatski obremenitvi. Na hidroizolacijski trak so bili vgrajeni trije sloji asfalta v skupni debelini 10,5 cm, kar je več od običajnih 7 cm. Rezultati vhodnih in estrahiranih bitumnov kot tudi proizvedenih in vgrajenih asfaltnih zmesi DBM (sedaj SMA) notranje in zunanje kontrole so skladni z tedanjimi in zdajšnjimi standardi in tehničnimi pogoji. Rezultati v letu 2004 opravljenih preskusov Sile in energije pri raztezanju pri 25 °C na vhodnem bitumnu Olexobit SMA so pokazali najvišje izmerjene vrednosti. Ugotavljamo, da je prav ta preskus najprimernejši za oceno kakovosti polimernega bitumna.

Odsek Ceste na Mangart asfaltiran v letu 1987 je po 38 letih v zelo dobrem stanju kljub nižjemu deležu bitumna. Dobro stanje voziščne konstrukcije pripisujemo uporabi mehkejšega tipa vhodnega bitumna BIT 200, sedanja oznaka B160/220. Bitumen je dobavljiv, njegova trenutna cena je za 2,4% višja od cene največkrat uporabljenega bitumna B 70/100 za nosilno obrabno plast. Uporaba cestogradbenega bitumna tipa B160/220 za nosilno obrabne plasti cest lahke in zelo lahke obremenitve v celinskem klimatskem področju je priporočena, saj dokazano daljša življensko dobo asfalta.

5.0. VIRI

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TSC 06.300/06.410: 2009 Smernice in tehnični pogoji za graditev asfaltnih plasti

JUS U.E9.021:1986 Izrada gornjih nosećih slojeva od bitumeniziranog materiala po vručem postupku, Tehnički uslovi

TSC 06.310: 2001 Vezane zgornje nosilne in nosilnoobrabne plasti z bitumenskimi vezivi

SIST 1038-1: 2008 Bitumimizirane zmesi - Specifikacije materialov - 1. del: Bitumenski beton – Zahteve – Pravila za uporabo SIST EN 13108-1

Fizikalno-kemijska analiza 12 veziv 70/100 iz različnih virov

Physico-Chemical Analysis of 12 Unmodified 70/100 Binders from Different Sources

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Abstract:

The diversity of bitumen has provided significant challenges in the bitumen research and its related industry. Due to the vast molecular diversity and complexity, not every bitumen from the same European specification classification behaves the same during its service life. To tackle this issue, this study presents a comprehensive physico-chemical characterization of 12 unmodified 70/100 bituminous binders originating from different crude oil sources and production routes. The binders were subjected to two different long-term ageing procedures — the standardized Pressure Ageing Vessel (PAV) test and an alternative ageing method, called Viennese Binder Ageing (VBA), which induces thermochemical ageing via the addition of reactive oxygen species, to evaluate the sensitivity of each binder towards different ageing factors. Beside conventional testing using softening point ring and ball and needle penetration, an absolute and relative chemo-mechanical correlation coupling Fourier Transform Infrared (FTIR) spectroscopy and the Dynamic Shear Rheometer (DSR) as utilized. The results reveal that the thermochemical approach from VBA induces significantly higher and more diverse LTA compared to the thermal ageing from the PAV. Binders subjected to non-standardized aging protocols such as the VBA, which intend to provide conditions closer to those found in the field, offer new insights into the diversity of binder aging within the same specification class. Furthermore, the proposed relative chemo-mechanical correlation provides a useful comparative framework for interpreting these differences and supports the selection of materials for enhanced pavement longevity.

Keywords: *bitumen, long-term ageing, rheology, FTIR spectroscopy, chemo-mechanical analysis.*

1. Introduction

Bitumen, a complex colloidal hydrocarbon matrix derived from crude oil, is one of the most chemically and physically diverse materials used in infrastructure construction. Its composition (typically a blend of polar aromatics, asphaltenes, and saturates) strongly depends on the origin of the crude source and the refining route applied during production, leading to substantial variability even among binders within the same specification class [1]. This molecular heterogeneity translates into divergent mechanical performance, oxidation rates, and long-term durability under environmental ageing factors [2].

Ageing significantly affects the durability and mechanical reliability of asphalt pavements, primarily through oxidative processes that increase stiffness and brittleness of the binder. The widely adopted and standardized Pressure Ageing Vessel (PAV) method simulates long-term oxidative ageing under controlled temperature and pressure to predict long-term ageing binder performance. However, this technique primarily accounts for oxygen diffusion under elevated temperatures and pressure and neglects additional factors from the atmosphere that may enhance oxidation in real field environments, such as reactive oxygen species (ROS) including ozone and nitrogen oxides.

To address this gap, alternative laboratory methods such as the Viennese Binder Ageing (VBA) procedure have been developed to incorporate ROS into the ageing atmosphere, inducing thermochemical oxidation to better resemble field ageing. Studies employing VBA highlight that binder composition strongly influences susceptibility to ROS-induced oxidation, revealing differences not captured by conventional PAV testing [3, 4]. Furthermore, understanding binder-specific ageing characteristics which depend on different ageing inducing factors requires a multi-scale approach that integrates both chemical and rheological analyses.

Spectroscopic techniques such as Fourier-transform infrared (FTIR) spectroscopy enable the quantification of oxidation-related chemical indices, notably carbonyl (C=O) and sulfoxide (S=O) groups, which are sensitive markers of oxidative ageing in bitumen [5]. These chemical transformations can be correlated to mechanical parameters obtained from dynamic shear rheometry (DSR), such as complex modulus and phase angle, thus establishing a chemo-mechanical correlation that links molecular alteration to mechanical property change. Such correlations have been shown to facilitate a more physically grounded interpretation of binder performance and ageing susceptibility [6].

Against this background, the present study systematically characterizes 12 unmodified 70/100 bituminous binders from diverse crude origins and production routes using a combination of FTIR spectroscopy, DSR, and conventional mechanical testing. By applying both the standardized PAV ageing and the thermochemical VBA method, the study aims to provide a comparative framework for assessing binder-specific ageing susceptibilities. Furthermore, by correlating chemical indices with rheological responses, this work establishes a relative chemo-mechanical correlation that quantifies ageing susceptibility. This offers novel insights into the interplay between chemical composition and mechanical degradation that govern long-term binder performance.

2. Materials and Methods

2.1 Materials

12 unmodified 70/100 binders were selected and tested in this study. Most of the bitumen originated from different crude oil sources and potentially different crude oil refinement procedures. They are labeled as B1331 – B1344. B1332 and B1337 were removed from the sample pool (originally 14 binders) as they were similar as two of the remaining 12 binders (which explains the gap in the binder labeling).

2.2. Methods

Laboratory Ageing Methods

Figure **1** shows an overview of the ageing schedule for the 12 different binders. A total of two STA and LTA procedures were applied. The first laboratory long-term ageing (LTA) method was the standardized procedure using a combination of the Rolling Thin Film Oven Test (RTFOT) for short-term ageing and the Pressure Ageing Vessel (PAV) test for long-term ageing. The RTFOT was performed according to the EN 12607-1 (163°C for 75 minutes) [7], while the PAV was conducted following the EN 14679 [8] with a pressure of 2.1 MPa, a temperature of 100°C and an ageing duration of 20 hours.

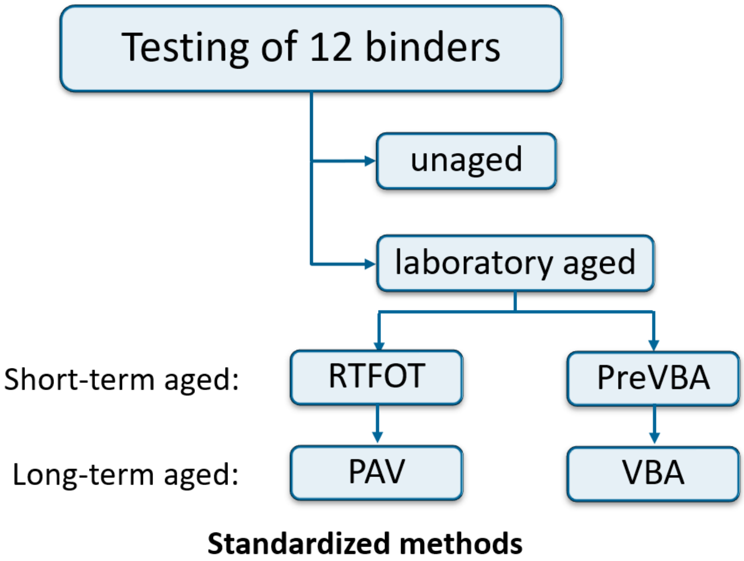

Figure 1: Overview of the ageing schedule for the 12 binders

The second LTA procedure applied in this study was the thermochemical ageing procedure known as the Viennese Binder Ageing (VBA) method. This method exposes the binder to an atmosphere containing traces of reactive oxygen species (ROS) such as ozone (O_3) and nitrogen oxides (NO_x) under elevated thermal conditions of 80 °C.

Prior to VBA the unaged binder was short-term aged using the so-called “PreVBA” method. In this procedure, 8 g of binder were placed in a metal container with a diameter of 14 cm, identical to that used in the Pressure Ageing Vessel (PAV) test. The container was then placed inside a ventilated oven maintained at 163 °C for a total of 65 minutes. After the first 15 minutes of heating, the container was temporarily removed from the oven, and the binder surface was manually levelled to achieve a uniform film thickness of approximately 0.5 mm. Subsequently, the sample was returned to the oven and the Short-Term Ageing (STA) process continued for the remaining 50 minutes. Once this is finished, the sample is placed in the VBA ageing cell and the ageing temperature was maintained at 80 °C for a duration of three days. During the VBA process, compressed air is lead through an ozone generator at a flow rate of 50 L/min. Based on previous studies [9, 10] , this leads to an ozone concentration of 4 g/m³ and 25 ppm of NO_x, which was applied to all experiments. After the ageing duration of three days, the binder was removed from the VBA cell and transferred into a preheated oven at 163 °C for five minutes, followed by homogenization and sample collection.

Conventional Testing

All 12 binders were subjected to conventional bitumen testing involving the evaluation of the needle penetration according to the EN 1426 [11] as well as the softening point ring and ball according to the EN 1427 [11]. The results for all 12 binders are shown as bar diagrams in the results.

Rheological Testing

The rheological performance of all 12 binders was assessed using an Anton Paar MCR 302 Dynamic Shear Rheometer (DSR) equipped with a 25 mm parallel-plate geometry. The tests were performed in accordance with EN 14770 [12], applying a high-temperature frequency sweep protocol.

Measurements were carried out at temperatures of 40, 46, 52, 58, 64, 70, 76, and 82 °C. For each temperature, the frequency was varied over the following range: 0.1, 0.3, 1, 1.592, 3, 5, 8, 10, 20, 30, and 40 rad/s. To ensure reproducibility, two replicate tests were performed for every sample, and the mean values were used for data interpretation.

The rheological results are used in the relative chemo-mechanical correlation, which will be described later on.

FTIR Spectroscopy

For each spectroscopic measurement, approximately 0.5 g of binder was taken from the storage container, placed on a metal spoon, and gently heated until reaching a liquid-like state. From the molten material, four small droplets were deposited on silicone-coated paper and allowed to cool to room temperature prior to analysis. Overall, established procedures from the literature were followed, ensuring adequate homogenization and minimal thermal exposure of the materials [13, 14].

Infrared spectra of all 12 binders were acquired using a Bruker Alpha II FTIR spectrometer, equipped with an attenuated total reflection (ATR) module featuring a diamond crystal and a DTGS detector. Spectra were recorded over a wavenumber range of 4000–680 cm^{-1}, with a resolution of 4 cm^{-1} and 24 scans per measurement. Before each sample measurement, a background spectrum of the clean ATR crystal was recorded. The sample was then positioned on the crystal, and gentle pressure was applied using the lever to ensure proper contact between the sample and the crystal during the measurement.

Each specimen was measured four times, yielding four spectra per sample. Since four replicate specimens were prepared for each binder, a total of 16 spectra per bitumen were obtained. These spectra were subsequently used to derive FTIR-based ageing indices for use in the chemo-mechanical correlation.

For post-processing, all spectra were imported into the OPUS software, where min–max normalization was applied within the 2800–3200 cm^{-1} region. Normalized spectra were then subjected to full baseline integration across three specific spectral regions:

- Carbonyl band: 1660–1800 cm^{-1}
- Sulfoxide band: 984–1079 cm^{-1}
- Polarity-related region: 1330–1100 cm^{-1} (known to increase in intensity with ageing due to changes in the materials polarity gradient [15, 16])

The FTIR ageing index was determined by summing the integrated areas of these three regions. These indices were exclusively employed in the chemo-mechanical correlation, where their absolute and relative values were compared to the corresponding changes in stiffness (specific equations are presented in the respective section).

Chemo-Mechanical Correlation

The chemo-mechanical correlation (CMC) establishes a link between the outcomes of rheological and spectroscopic analyses. This relationship provides insight into how variations in the chemical composition, particularly in oxygen-containing functional groups, influence the mechanical performance of the binder material [17]. In the first section of the results, the DSR results at 1.592 Hz and 46 °C were used for the y-axis, while the FTIR ageing index (sum of all three functional groups mentioned above) was plotted on the x-axis. However, direct comparison of absolute values may lead to misleading interpretations, since some of these binders, even though they are within the same European specification class, can start on different chemical and mechanical levels. Thus, a relative representation of both datasets was applied, as follows:

- DSR: $|G^*|_{aged}/|G^*|_{unaged}$
- FTIR: $AIFTIR_{aged}$ - $AIFTIR_{unaged}$

The benefit of this second representation is that all the unaged states are put on the same level [9]. However, it should also be noted that this representation requires data from the unaged binders, which might not always be available.

Regardless, for the rheological aspect, the ratio of aged to unaged complex modulus (G*) indicates the degree of stiffness increase caused by the two different LTA methods. Consequently, each unaged binder is assigned a rheological value of 1, whereas LTA-aged samples yield values greater than 1, reflecting material ageing or increase in stiffness.

In the chemical evaluation, the FTIR ageing index of the aged binder—obtained through full-baseline integration—is subtracted from that of the unaged binder. The resulting difference quantifies the net spectral contribution attributable to ageing processes such as the formation of carbonyl and sulfoxide groups via an increase in the respective absorbance.

3. Results and Discussion

3.1 Conventional Tests

Figure 2 shows the results of the conventional testing of the 12 binders. The results from the needle penetration are displayed on the left, while the results from the softening point ring and ball is shown on the right. Looking at the results from the needle penetration, it can be seen that four binders (1331, 1333, 1335 and 1341) are close to the 100 1/10 mm mark, while three binders (1334, 1340 and 1344) are close to the 80 1/10 mm mark. The remaining samples are all in between. For the softening point, an even smaller gap between the 12 binders is observable with a temperature range of 47 – 52°C.

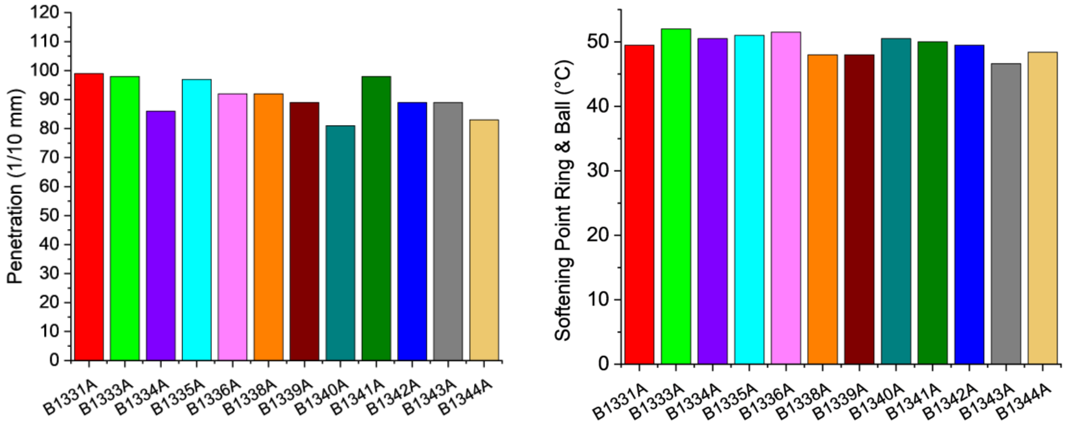

Figure 2: Results from needle penetration (left) and softening point ring and ball (right) of all 12 investigated bitumen.

3.2 Standard Chemo-Mechanical Correlation

Figure 3 shows the results of the standard chemo-mechanical correlation. The left side displays the results of the 12 unaged binders. Looking at the rheological level, it can be said that all 12 binders are on a similar level in terms of stiffness, which is quite comprehensible, as they are all in the same European specification class. However, some differences are observable on the chemical level, where binder B1343 (grey), B1340 (dark green) and B1336 (pink) have higher FTIR ageing indices than the rest of the binders. After laboratory STA and LTA using the RTFOT and PAV a very similar trend can be seen, with binder B1340 (dark green) and B1336 (pink) still sitting at a higher ageing level in terms of FTIR spectroscopy. However, on a rheological level all binders are very close to each other. Thus, the question can be raised whether this high level indicates a higher ageing state or ageing susceptibility. From the results in Figure 3 it is rather difficult to judge whether binder B1336 or B1340 experience more ageing compared to the rest of the binders. Thus, the relative chemo-mechanical correlation was deployed.

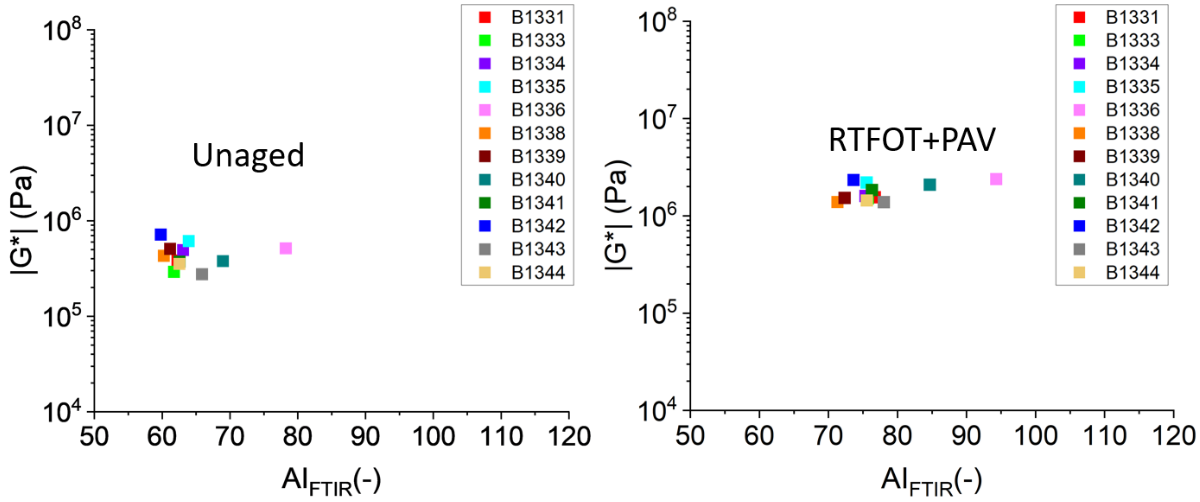

Figure 3: Chemo-mechanical correlation of the 12 unaged binders (left) and RTFOT+PAV aged binders (right).

3.3 Relative Chemo-Mechanical Correlation

Figure 4 shows the results of the relative chemo-mechanical correlation of the RTFOT and PAV aged binders. It should be noted that the unaged binders represent the reference point at the "zero position" (rheological value of 1 and FTIR index of 0). The RTFOT aged binders are all grouped up rather close, with only binder B1342 (blue) showing the highest FTIR ageing index after short-term ageing, while B1343 (gray) shows the highest rheological ageing level. After subsequent LTA using the PAV, all samples are again quite grouped. However, judging by the distance from the zero point, differences in ageing level can be observed. And again, identical to the absolute chemo-mechanical correlation, binder B1340 (dark green) and B1336 (pink) can be found at the highest ageing level, being the farthest away from the zero point, even though their STA states are in the bulk of all 12 binders. This indicates that these two binders might be more ageing susceptible to thermal LTA. Other binders like B1338 (orange) or B1339 (dark red) are closest to the zero point, indicating that thermal ageing induces significantly less ageing compared to the other binders, especially in comparison to B1336 (pink) and B1340 (dark green).

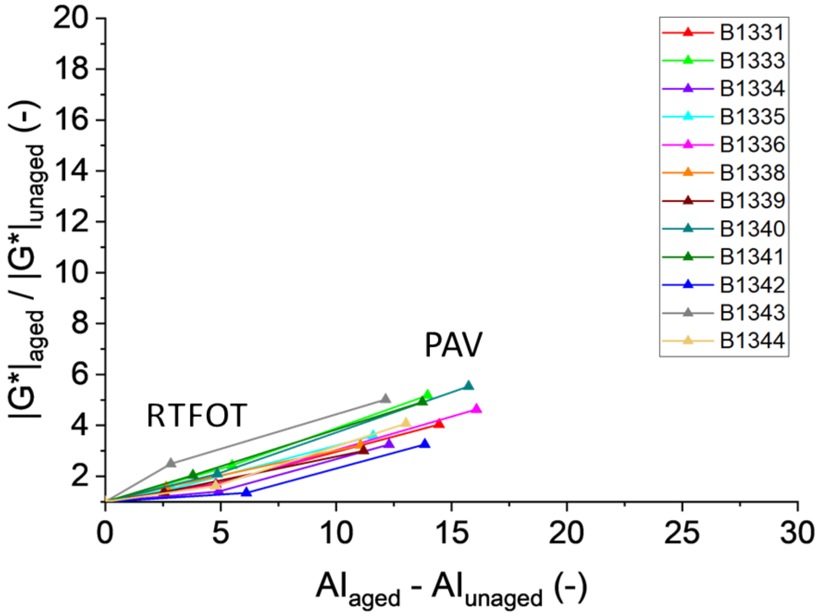

Figure 4: Relative Chemo-mechanical correlation of the 12 RTFOT+PAV aged binders

Figure 5 shows the results of the second LTA method, where the binders were exposed to thermochemical ageing via the VBA method. The overall ageing level after short-term ageing using the PreVBA method is more scattered compared to the binders after RTFOT ageing in Figure 4.

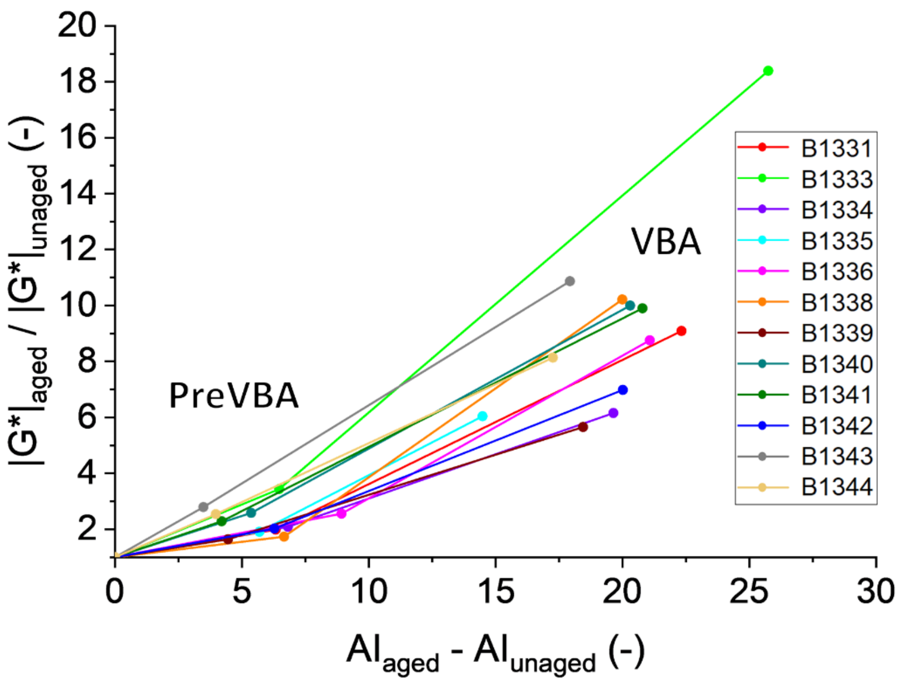

Figure 5: Relative Chemo-mechanical correlation of the 12 VBA aged binders

Thus, it can be said that PreVBA induces similar levels in terms of rheology but provides a slightly higher scattering of the binders in FTIR spectroscopy. Comparing the general LTA trends with the results from pure thermal ageing in Figure 4, a clear difference can be observed. In general, all 12 binders are severely more aged during VBA compared to PAV. Furthermore, distinctive binders, like B1333 (bright green) show a significantly higher ageing level in both rheology and spectroscopy compared to the rest of the binders. On the other hand, B1335 (turquoise) shows the lowest ageing level, being in close proximity to the PAV aged binders. Thus, VBA is capable of highlighting significant differences in ageing susceptibility of various bitumen from the same specification class but different sources, which can significantly impact their LTA performance in the field.

4. Conclusions

This study conducted a physico-chemical characterization of 12 unmodified 70/100 bituminous binders from different crude origins and production routes to investigate binder-specific ageing behavior. The conventional needle penetration and softening point tests revealed only minor variations within the specification range, confirming their limited sensitivity to compositional differences among binders.

The standard chemo-mechanical correlation based on FTIR spectroscopy and DSR analysis demonstrated that, despite similar rheological behavior, distinct chemical ageing differences exist across the binders. Two binders exhibited elevated chemical ageing indicators even before long-term ageing, suggesting compositional differences.

The application of the relative chemo-mechanical correlation proved more sensitive in distinguishing binder-specific ageing susceptibilities. After PAV-induced long-term ageing, two binders were located further away from the reference unaged state, indicating greater susceptibility to thermal oxidation. Conversely, some binders appeared more resistant, showing lower deviation in both rheological and chemical ageing parameters.

Comparing the impact of pure thermal ageing to thermochemical ageing via the VBA, a clear difference in terms of ageing level was observed. Overall, all binders were more severely aged by VBA, with one binder showing a drastically higher aging level compared to the rest of the binders. However, similarly to thermal ageing, some binders exhibited a lower ageing susceptibility towards reactive oxygen species, being located at a much lower overall ageing level compared to the rest of the binders. The results indicate that thermochemical aging produces greater variability, facilitating a clearer differentiation between the aging susceptibility of the binders.

Overall, the establishment of a relative chemo-mechanical correlation provided a robust comparative framework for quantifying binder-specific ageing sensitivity and susceptibility towards different ageing inducing factors. This approach enhances the interpretive power of advanced mechanical testing and spectroscopy and can support more informed binder selection for improved long-term pavement durability.

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Eurobitume LCA 4.0 za bitumne

Eurobitume LCA 4.0 for bitumen

Anja Sörensen (EUROBITUME)

Life cycle Assessment for bitumen

Reliable and representative environmental data is needed to take account of the impact of road infrastructure construction and maintenance operations on the environment. To this end, Eurobitume provides stakeholders with a bitumen life cycle inventory representative of bitumen production in Europe for more than 25 years.

The fourth bitumen life cycle inventory was published in March 2025 [1]. The life cycle assessment (LCA) study was carried out by Sphera in accordance with ISO 14040:2006 and ISO 14044:2006 standards. The detailed report is available on the Eurobitume website. This report includes a synthesis of the third-party verification carried out by Solinnen in accordance with ISO 14071:2024.

The LCA 4.0 study (2025) replaces the Life Cycle Inventory (LCI) published by Eurobitume in 2020 (LCI 3.0) and updated in 2022 (LCI 3.1). Two areas for improvement were identified in the third-party verification phase of the previous study: the first related to the choice of crude oil database, and the second concerned the potential use of more primary data. The LCA 4.0 responds to these two main comments.

The study focuses on the environmental impacts associated with the production of one tonne of bitumen. The results can be used in other LCA studies of bitumen-based construction materials, for example to draw up an environmental product declaration (EPD) in accordance with standard EN 15804+A2 [2].

Scope and representativeness of the study

Two categories of bitumen are considered:

- an average paving grade bitumen, obtained by vacuum distillation of a selection of crude oils in the refinery and mainly used in road applications;
- an average oxidised bitumen, produced in a refinery from the straight-run bitumen and an additional bitumen oxidation unit. This process involves passing an air stream through the bitumen at high temperatures to significantly modify its physical properties. Oxidised bitumen is mainly used for roofing and waterproofing.

The scope covers the production of bitumen from ‘cradle to gate’, i.e. it takes into account the environmental impacts associated with the extraction of crude oil, its transport to a refinery, the distillation (and possibly oxidation) processes and the storage of bitumen at the refinery (see Figure 1). This scope corresponds to modules A1, A2 and A3 of standard EN 15804+A2.

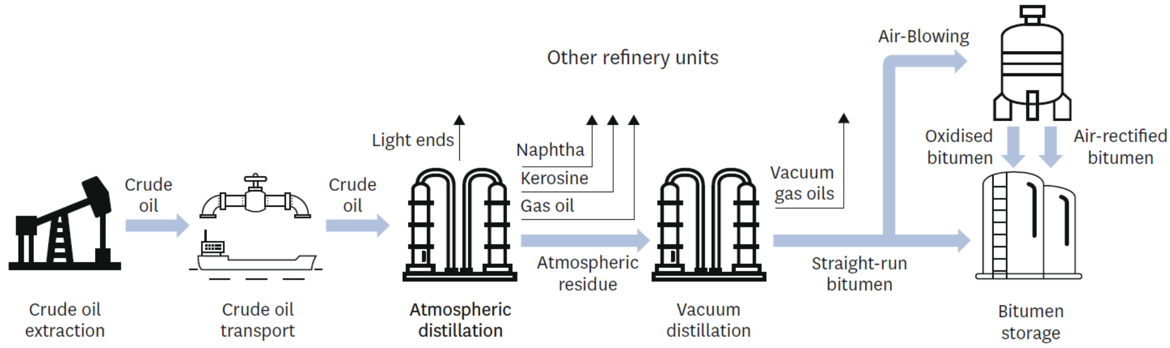

Figure 1. Simplified production process of bitumen and bituminous binders

The study was based on data collection from 17 refineries operated by Eurobitume members in Europe. The data collected and included represents operations in 8 countries in EU and UK, accounting for over 75% of Eurobitume members' bitumen production.

Main modelling assumptions

Modelling was carried out using Sphera FE LCA software, using primary data supplied by Eurobitume member refineries when available. Data from the Sphera 2024.1 MLC (Managed LCA Content) database [3] was used primarily as secondary data to model extraction processes, feedstock transport, energy supply from external sources (fuels and electricity), and electricity generation from external sources.

Crude oil production is also modelled using the Sphera MLC 2024.1 database. These data represent the estimated impacts of crude oil extraction in each country of origin, taking into account the combination of extraction technologies used (conventional or non-conventional, as well as onshore or offshore). The relative share of countries from which crude oil is imported can vary over time. It has therefore been assumed that the average feedstock mix weighted by bitumen production from the included refineries is a 3-year average (from 2021 to 2023) in order to reduce any fluctuations over time.

In order to preserve the confidentiality of information on the country of origin of crude oils, the weighted average has been aggregated at the continental/regional level in Figure 2.

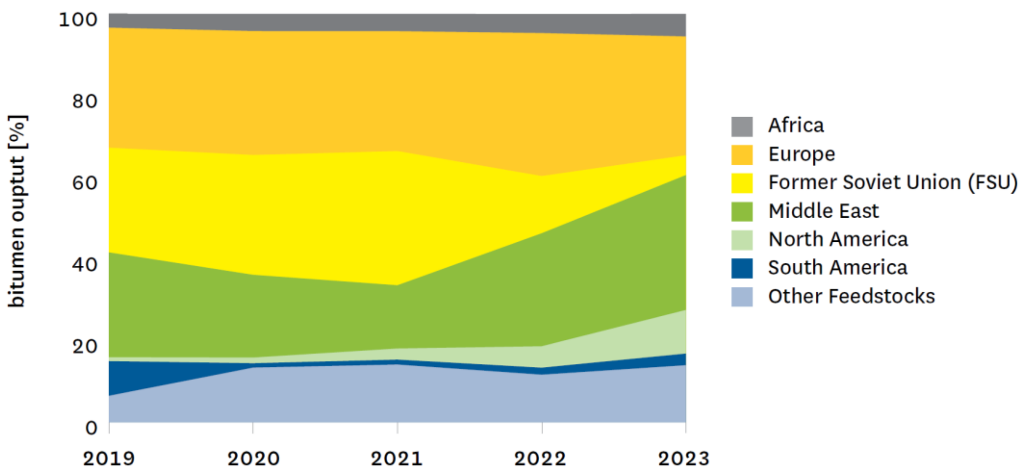

Figure 2. Evolution of the crude oil basket over the 2019-2023 period, weighted by bitumen output

The environmental impact of crude oil production varies significantly depending on the country of origin. The main factors influencing these variations relate to venting, flaring and fugitives (VFF). The reference database used to model methane emissions in Sphera MLC is the "Global Methane Tracker " tool developed by the International Energy Agency (IEA) [4].

The transport of crude oil from the country of origin to the refinery is modelled using a combination of pipelines and shipping. For each of the crude oil blends from the different countries, a specific combination and the associated distances have been established on the basis of the primary data collected.

Bitumen is obtained by successive atmospheric and vacuum distillations at the refinery. The energy consumption of the distillation process is calculated using the primary data collected from the refineries and by applying an energy allocation.

The bitumen products are then stored in heated and insulated tanks in the refineries. This stage was also modelled using primary data.

Other processes are taken into account at the refinery:

- Electricity supply: a fraction of electricity consumption (around 34%) is typically generated by an on-site combined heat and power plant. The remainder (around 66%) comes from the respective national grid;
- Steam and heat production: for the direct combustion of fuels in refinery units to produce heat or steam, CO_2 emissions have been calculated on the basis of emission factors from the IPCC's Sixth Assessment Report [5].

Life cycle inventory and impact indicators

The life cycle inventory (LCI) lists the elementary flows into and out of the system: resources and emissions into the air, water and soil. As the full inventory comprises hundreds of flows, it is not presented in this article. It is intended for LCA experts wishing to model bitumen-based products in LCA software. The bitumen life cycle inventory is publicly available in ILCD format (International Life Cycle Data system) on the Eurobitume website via a simple request form (https://eurobitume.eu/lci_4-0_request/). The ILCD format is a neutral format for structuring and exchanging LCA data, developed by the European Commission's Joint Research Centre (JRC). Its aim is to promote the transparency, interoperability and quality of LCA databases in Europe, by structuring information in a rigorous manner in accordance with common practices.

Based on the results of the life cycle inventory, various impact assessment methodologies can be used in the European context. As this study can be used as background information in Environmental Product Declarations (EPDs) for products containing bitumen, the impact assessment methods required for EPDs in accordance with EN 15804+A2:2019 [2] have been applied. EN 15804+A2:2019 refers to the latest available version of the Environmental Footprint (EF) impact assessment method, which is currently EF 3.1. The characterisation factors in EF 3.1 are considered robust and relevant to the European context, and are widely used and respected within the LCA practitioner community.

In particular, the Global Warming Potential (GWP) impact category is assessed on the basis of the current IPCC characterisation factors taken from the 6th Assessment Report (AR6) [4] for a 100-year period (GWP_{100}).

The rest of this article focuses on the GWP_{100} (greenhouse gas emissions) indicator, as it is commonly used by road infrastructure stakeholders, and increasingly so in the context of public procurement contracts. The study report published by Eurobitume includes the results of the 38 indicators specified in standard EN 15804+A2:2019 (acidification, eutrophication, depletion of the ozone layer, depletion of resources, water requirements, etc.) for each stage of bitumen production.

Greenhouse gas emissions

The quantified results for greenhouse gas emissions (GWP_{100}) are shown in Figure 3. The GWP_{100} for bitumen is 530 kg CO_2 eq./t of bitumen. The air blowing units required to produce the oxidised bitumen consume a certain amount of energy, attributing approximately 86 kg CO_2 eq./t to the oxidation process. The GWP_{100} of oxidised bitumen is therefore 616 kg CO_2 eq./t of bitumen (+16% compared with bitumen).

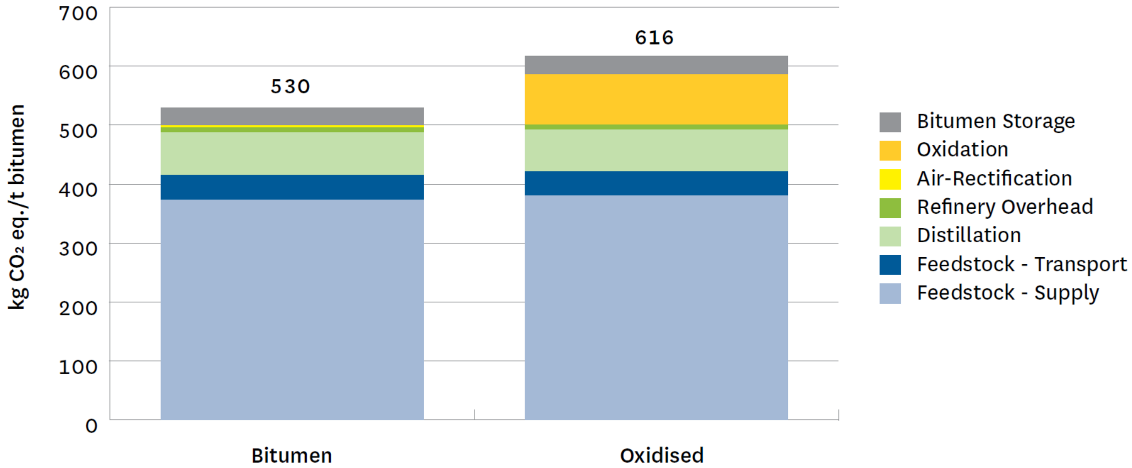

Figure 3. GWP_{100} for bitumen products

The main process contributing to greenhouse gas emissions is the extraction of crude oil used as feedstock supply for the refinery (accounting for 70% and 62% for road bitumen and oxidised bitumen, respectively). Transporting the crude oil to the refinery contributes a further 8% and 7% for the respective products. Atmospheric and vacuum distillation contribute 14% of the GWP_{100} for road bitumen and 11% for oxidised bitumen. Finally, storage accounts for around 6%. Methane (CH_4) emissions account for 46% of bitumen's GHG emissions, while CO_2 emissions account for 54% (see Figure 4) Methane emissions are mainly explained by the contribution of crude oil extraction (venting, flaring and fugitives).

Nitrous oxide (N_2O) and other GHG emissions are negligible.

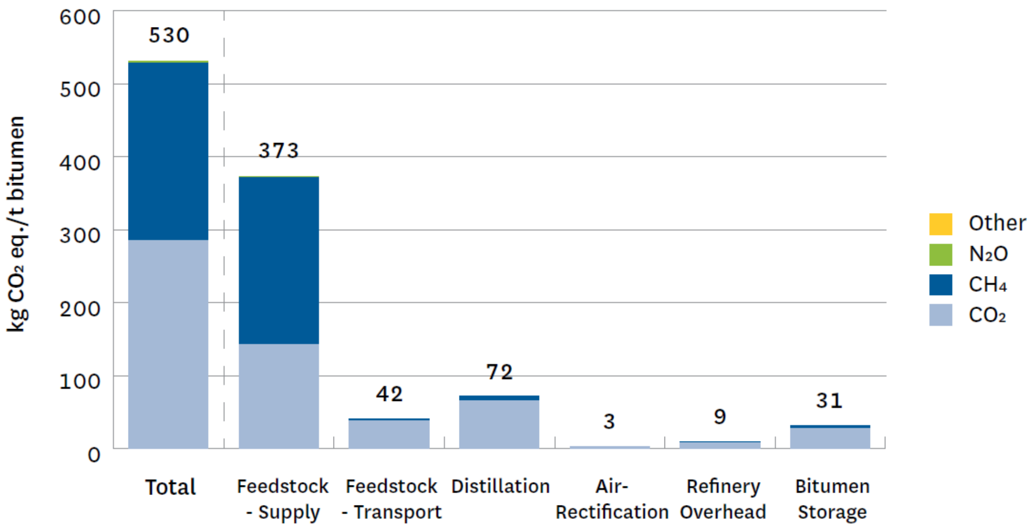

Figure 4. Individual GHGs for bitumen's GWP_{100}

Comparison with the previous study

A comparison of the GWP_{100} indicator between LCI 3.1 (2022) and LCA 4.0 (2025) is shown in Figure. The GWP_{100} for bitumen in LCA 4.0 is 145% higher than the reference value with infrastructure in LCI 3.1.

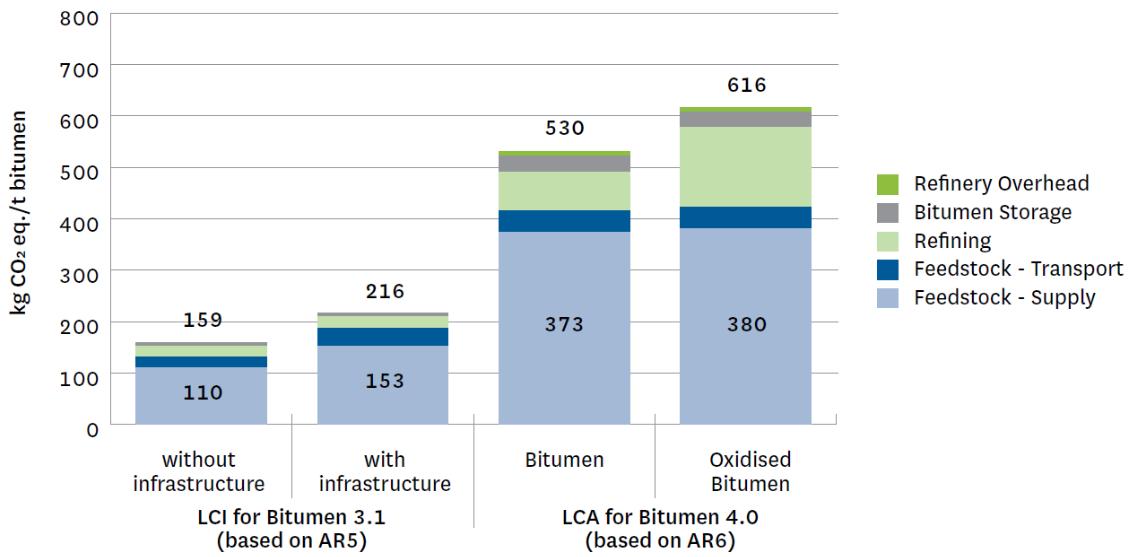

Figure 5. Comparison of GWP_{100} between Eurobitume LCI 3.1 and LCA 4.0

The first factor explaining this discrepancy is the method used to model crude oil production, which accounts for the majority of bitumen's environmental impacts (see Figure 6). The environmental data used for crude oil is now taken from Sphera's MLC (Managed LCA Content) database [3], based on average crude oils by country of origin, whereas LCI 3.1 was based on the IOGP database [6] referring to crude oils averaged by region or continent.

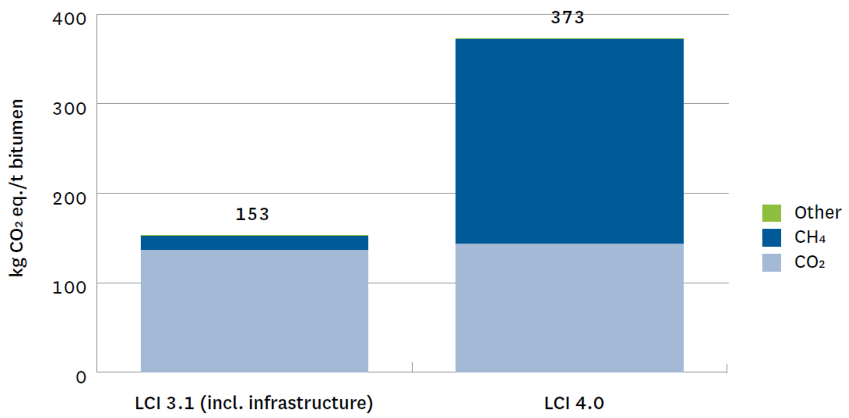

Figure 6. Comparison of the individual GHGs between LCI 3.1 and LCA 4.0

The quality of crude oil modelling has been improved by two factors:

- a better level of detail used to average the impact of crude oil by geographical origin ;
- the method used to take into account venting, flaring and fugitives related to crude oil production. The reference used to assess these emissions in the Sphera MLC database is Global Methane Tracker developed by the International Energy Agency's (IEA) [4]. The variability of emissions associated with these

processes can be very significant from one country to another.

The second factor with a significant influence on the results is the average crude oil mix. In LCA 4.0, this is calculated on the basis of crude oil supply data by country of origin, collected and weighted for each refinery. As the share of countries from which crude oil is imported can vary over time, a three-year average (2021-2023) has been used as the reference scenario for the feedstock supply mix.

The impact of the crude oil mix cannot be compared directly between LCI 3.1 and LCA 4.0, as the crude oil database used for the calculations is different in both studies. However, to better understand the impact that possible changes in the average composition of the feedstock supply could have, a sensitivity analysis was carried out. The three-year average of the reference feedstock supply was compared with (a) a five-year average for 2019-2023 and (b) the average mix for 2023 (see Figure). The results are shown in Figure 7.

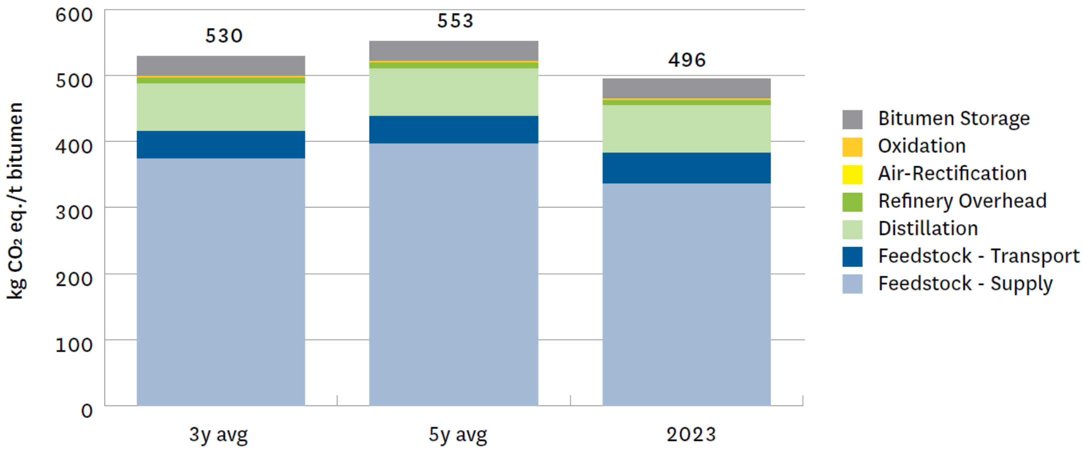

Figure7. Impact of the time averaging on the GWP_{100} indicator

The time average has a significant impact on the GWP_{100} indicator, mainly due to the substitution from 2022 onwards, of crude from the former Soviet Union (FSU) by crude from other regions. The carbon footprint of crude from the former Soviet Union is not particularly high (it is in the middle of the spectrum), but it is mostly replaced by crudes with a lower carbon intensity.

The five-year average is only very partially representative of the last few years, during which crude oil from the former Soviet Union is no longer used in the average mix. The average mix for 2023 may not take sufficient account of long-term variations. As a result, the three-year average was considered to be a good balance and was adopted as the reference scenario.

Finally, the change in the modelling of distillation processes in LCA 4.0 compared to LCI 3.1 is the third main factor:

- The LCA 4.0 reference scenario addresses the issue of multifunctionality by applying the energy allocation method on the basis of primary data collected for the 17 refineries;
- LCI 3.1 used the sensible heat method: this approach assumes that the fraction of crude oil corresponding to bitumen remains in the liquid phase and does not change state. It is therefore based on a simplified thermodynamic approach for estimating the energy required to produce bitumen on the basis of its heat capacity.

The results of the sensitivity analysis are shown in Figure 8.

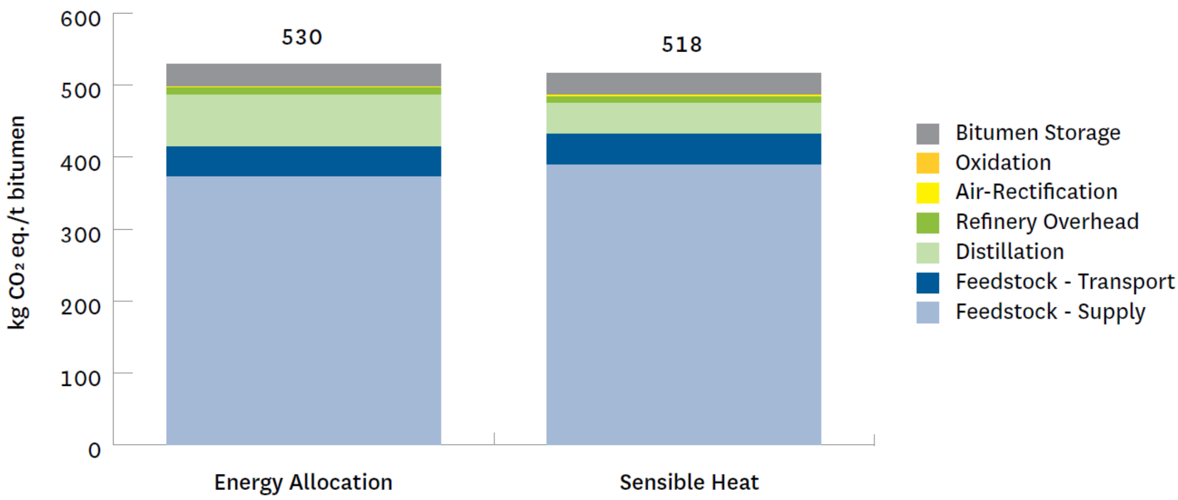

Figure 8. Sensitivity analysis on the GWP100 when the multifunctionality approach is varied

The allocation method at the refinery has a very limited impact on the GWP_{100} of bitumen: a reduction of 2% for the sensible heat method compared with the reference scenario based on energy allocation. However, for the distillation stage alone, the difference represents around -40%. The energy allocation method was chosen in LCA 4.0 because primary data is available for the various refining processes. The robustness of the thermodynamic method is not questioned, but it could be assessed in greater detail in future studies.

Conclusion

The results of the life cycle analysis of bitumen 4.0 constitute new reference data in Europe. They can be imported into LCA or eco-comparator software to assess and compare the environmental footprint of bitumen-based road infrastructures.

Compared with other data available in the literature, they have the advantage of being based on representative primary data collected from bitumen-producing refineries.

The full study report, including all the assumptions and results, is publicly available. It is completed by a summary on the climate change indicator, commonly used by stakeholders, and a comparative analysis with the previous study.

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REFERATI SEKCIJA 2: Zeleni prehod in digitalizacija

LECTURES – SECTION 2: Green transition and digitalizatio

Na poti do EPD-jev za asfaltne zmesi – zakaj, kaj in kako?

On the road to EPDs for Asphalt Mixtures – Why, What and How?

Paul Schönauer; M.R. Gruber; B. Hofko (Institute of Transportation, TU Wien)

Abstract

The paper gives an overview on environmental assessment, life cycle assessment (LCA) and environmental product declarations (EPD). It provides information, why this will become relevant for asphalt mix producers and road agencies. Further, outcomes of a recent Austrian study will be presented that laid the groundwork for EPDs for the Austrian pavement industry. Relevant terms, like product category rules (PCR) are described and a tool is presented that empowers asphalt mix producers to create their EPD drafts easily and without the need of an additional expert for life cycle assessment and that is adaptable to any national PCR

***Keywords**: Life Cycle Assessment (LCA), Environmental Product Declaration (EPD), Product Category Rule (PCR), asphalt mixture*

1. Introduction

Climate change is among the defining challenges of our time. It denotes sustained shifts in global temperatures and weather patterns, driven predominantly by human activities - especially the combustion of fossil fuels and the extraction and use of non-renewable resources. The impacts are far-reaching, including sea-level rise, more frequent and intense extreme weather, and widespread ecological disruption. Mitigating—or at least slowing—these changes require action across the entire value chain, from producers to consumers. To target measures where they are most effective and efficient, a harmonized framework for assessing environmental impacts is essential, enabling robust comparison of alternatives.

While there are standardized test procedures and parameters for assessing the technical performance of construction products, there is a lack of specifications for the ecological assessment of construction products. Life Cycle Assessment (LCA) according to ISO 14040 [1] and ISO 14044 [2] is a methodology to assess environmental impacts of a product, service or facility associated over its whole lifetime and can be distinguished into 4 steps:

1. Goal & scope; specifying studies purpose, defining functional or declared unit, defining system boundaries etc.
2. Life Cycle Inventory (LCI); Collecting and modelling all relevant inputs and outputs for each process in the system (materials, energy, emissions, waste)
3. Life Cycle Impact Assessment (LCIA); Assessing the environmental impacts the data collected from LCI by applying environmental indicators e.g. Global Warming Potential (GWP)
4. Results & Discussion; Evaluating the results for completeness, sensitivity and consistency

ISO standards are intended to apply to all construction products; consequently, their LCA provisions are deliberately general. This breadth leaves substantial room for interpretation and can impede comparability. To improve consistency, Environmental Product Declarations (EPDs) were introduced. EPDs are Type III environmental declarations under ISO 14025 [3] that disclose quantified, product-specific indicators derived from LCA and verified by a third party.

A major difference between an EPD and a conventional LCA is that in addition to the requirements of ISO 14040/44 [1, 2], EPDs must follow a product category rule (PCR) defined by a program operator. For construction products specifically, these PCR requirements are standardized by EN 15804 [4], which provides the core rules to ensure consistency and comparability. The relation between EPD and LCA is illustrated in Figure 1. By grouping products with similar functions, PCRs establish category-specific modeling requirements across life-cycle stages (e.g. system boundaries, functional or declared unit, environmental indicators etc.), enabling more uniform assessment within a given product category.

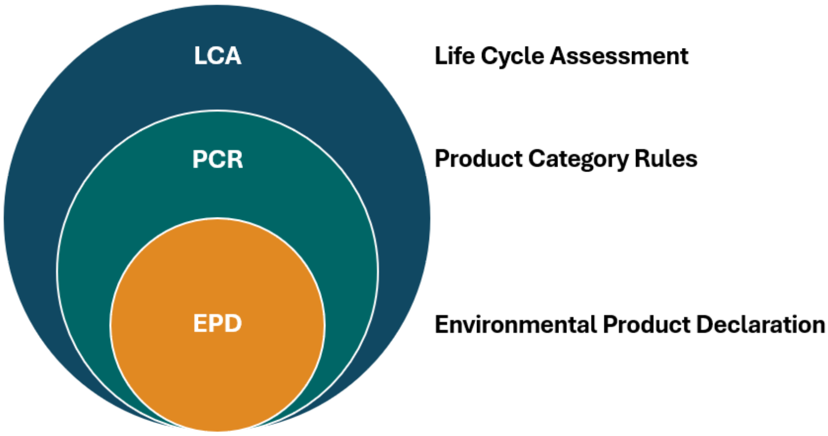


Figure 1: Relation between LCA and EPD

For construction products in Europe, PCRs must align with the core PCR (EN 15804 [4]) and are issued by an EPD program operator. A PCR is formally valid within the issuing program, unless adopted or mutually recognized elsewhere. Because there is often no single, harmonized complementary PCR (c-PCR) for a given product group, EPDs covering the same product group can still differ across programs. Consequently, direct comparability is only warranted when EPDs follow the same PCR version and consistent modeling assumptions.

EN 15804 [4] distinguishes the life cycle stages into four stages: product stage (Module A1-A3), construction process stage (Module A4-A5), use stage (Module B1-B7) and end of life stage (Module C1-C4), whereby these stages can be further distinguished into Modules, as presented in Figure . Additionally, it also considers the stage of benefits & loads (Module D) beyond system boundaries, which does not make part of the life cycle but is more an additional information of the entire life cycle.

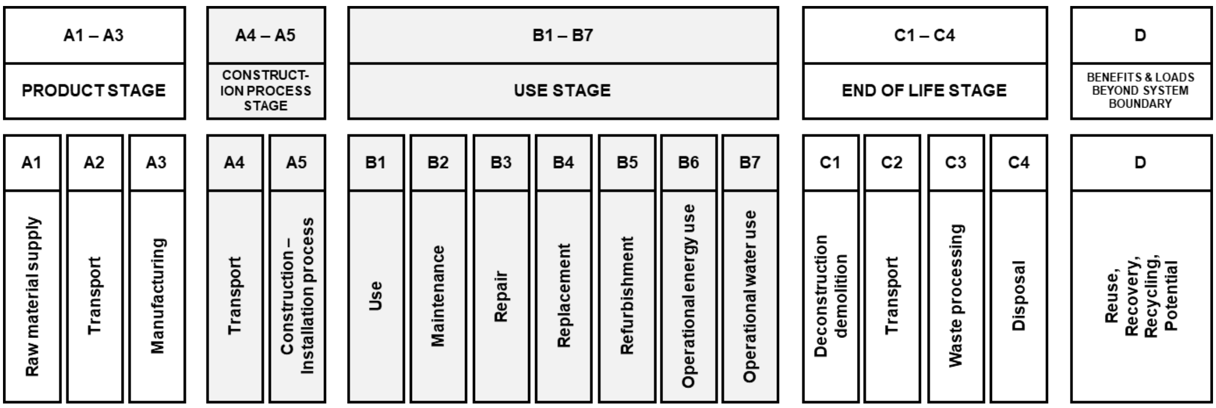


Figure 2: Life cycle stages according EN 15804

To date, the cradle-to-gate approach - limited to the product stage (Module A1–A3)—has predominated. Under EN 15804:2022 [4], the default scope now requires inclusion of the product stage, the end-of-life stage (Module C1–C4), and benefits and loads beyond the system boundary (Module D), which are highlighted in white in Figure 2. This applies equally to asphalt mixtures. Module A1 covers raw-material supply, including crude extraction and refining to bitumen; quarrying and processing of aggregates and fillers; and preparation of reclaimed asphalt (RAP) and specified additives. Module A2 covers transport of all required components of the asphalt mixture from the manufacturer site to the asphalt mix plant. Module A3 covers plant operations to produce the asphalt mixture. At end of life, Module C1 comprises deconstruction/milling; Module C2 transport of milled material to the processing plant, asphalt mix plant or to landfill; Module C3 waste processing; and Module C4 final disposal of any unrecovered matter. Module D reports the recycling potential of the given asphalt mix design.

Beyond the required life cycle stages, EN 15804 [4] also standardizes the environmental indicator that EPDs must report - moving the field beyond a focus on global warming potential (GWP) toward a broader suite (e.g., ozone depletion, acidification, eutrophication, resource and water use, plus waste and output flows). This expansion aligns with the recast Construction Products Regulation (CPR), Regulation (EU) 2024/3110 [5], which requires manufacturers to declare environmental-sustainability performance in the Declaration of Performance and Conformity (DoPC) and permits CE marking. Table 1 lists the environmental indicators that will be required under the CPR [5].

Table 1: Required environmental indicators according to CPR [5]

a) Climate change effects -total	j) Photochemical ozone
b) Climate change effects – fossil fuels	k) Abiotic depletion – minerals, metals
c) Climate change effects – biogenic	l) Abiotic depletion – fossil fuels
d) Climate change effects – land use and land use change	m) Water use
	n) Particulate matter
e) Ozone depletion	o) Ionising radiation, human health
f) Acidification potential	p) Eco-toxicity, freshwater
g) Eutrophication aquatic freshwater	q) Human toxicity, cancer
h) Eutrophication aquatic marine	r) Human toxicity, non-cancer
i) Eutrophication terrestrial	s) Land use related impacts

Alongside contracting authorities' existing interest in evaluating the environmental impact of their projects based on comparable life-cycle assessments, the obligation to declare the environmental performance of construction products, also the interest of asphalt industry has been growing simultaneously.

The creation of product-specific EPDs can be costly and slow; asphalt mix plants manage numerous asphalt mix designs whose environmental profiles differ primarily in Module A1. To generate an EPD, an LCA practitioner must first collect and verify plant base data (e.g. production statistics, energy consumption and transport distances) before creating the product specific LCA. Since this sequence needs to be repeated for each asphalt mix design it is well-suited for a tool-based implementation. Once the base data is verified, asphalt mix plant operators have the possibility to create an EPD at any time without the aid of LCA experts.

The METAsphalt project, funded by GESTRATA (Austrian asphalt pavement association), laid the groundwork for developing EPDs for asphalt mixtures in the Austrian pavement industry. The project pursued two objectives: (1) to compile a harmonized, EN 15804–aligned database covering the required life-cycle stages, with particular emphasis on the energy consumption of the drying process in Module A3; and (2) to prepare the Austrian pavement industry to generate plant-specific EPDs by collecting the necessary input data. To this end, a web-based tool was developed that enables asphalt-mix plant operators to produce EPDs for individual asphalt mix designs without external LCA expertise. This paper presents the life-cycle assessment (LCA) results for two asphalt mixtures, calculated with an EPD tool. In addition, module-level parametric studies are conducted to illustrate how variations in selected parameters influence the outcomes.

2. Methods

Extensive primary data are required for EPD compilation. In this study, primary data were gathered from three quarries, four asphalt-mix plants, and two road-paving sites; additionally, the annual operational balance of a roadworks contractor was obtained. Other data that could not be collected on site was modeled by using own assumptions. Environmental impacts were quantified by modelling with background LCI data from ecoinvent v3.9.1 [6], while bitumen inventories were taken from Eurobitume 2025 [7].

To illustrate the tool's outputs, two representative asphalt mixtures are modelled, which are displayed in Table 2, and results are reported for Modules A1-A3, C1-C4, and D. The declared unit is one metric tonof asphalt mixture. To clarity the influene of key inputs, a targeted parameter study is conducted. For ease of comparability, the presentation focuses on the EN 15804 [4] indicator global warming potential - total (GWP_{total}), while noting that the tool calculates the full indicator set.

Table 2: Asphalt mix designs

Component	Amount [kg] Base layer, AC32 base 70/100	Surface layer, SMA 11 surf PMB 45/80-75
0/2	235	205
2/4	98	80
4/8	95	163
8/11	80	410
11/16	95	-
16/22	125	-
22/32	171	-
Natural filler	23	15
Filler (dolomite)	38	44
Unmodified bitumen	40	-
Polymer modified Bitumen	-	58
Hydrated lime	-	22
Fibers	-	3

3. Results & Discussion

In the following chapter the LCA results of a base layer and a surface layer, which are presented in chapter 2 in Table 2, are presented. For clarity, the assessed life-cycle stages are presented as subsections. Stages with a minor contribution to the overall results are consolidated and not treated in separate sections.

Note that the results report only GWP. Therefore, since technical performance and functional equivalence are not assessed, a like-for-like comparison is not valid, and no conclusion can be drawn about which product is more sustainable.

3.1 Raw material provision (Module A1)

In Figure 3, the GWP for Module A1 is shown for the two asphalt mixtures broken down by the components used. It is apparent that bitumen accounts for the majority of GWP in Module A1. For the AC, unmodified bitumen represents 84% of the total GWP, whereas for the SMA the polymer-modified bitumen (PmB) accounts for 62%. This is due to the contribution of hydrated lime in the SMA mixture, which causes about 33% of the total GWP. In a direct comparison, the AC exhibits roughly 38 kg CO_2-eq per ton lower GWP than the SMA. However, it should be noted that this comparison does not consider the performance of the two mixtures: an AC 32 base layer with unmodified bitumen is used as a base course in lower load classes, while an SMA 11 surface layer with PmB and hydrated lime is used in the highest load classes.

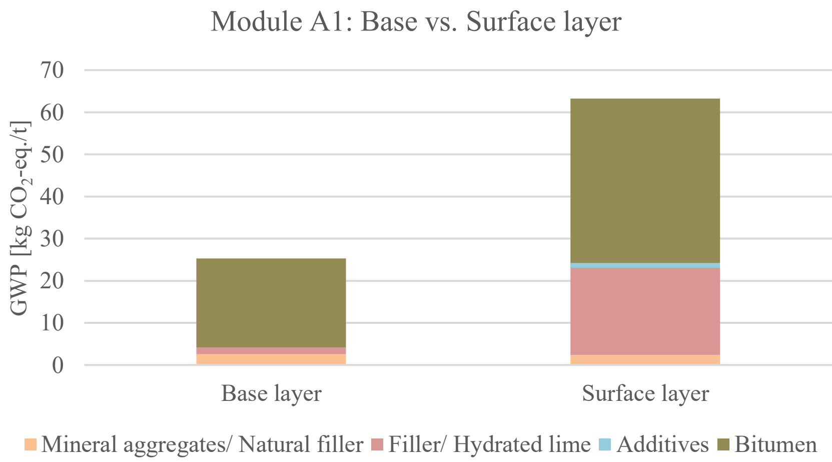


Figure 3: Module A1 - raw material provision

3.2 Transport of the raw materials to the asphalt mix plant (Module A2)

To illustrate the influence of transport distances, the transport distance for the aggregates was varied. The other transport distances are set constant. Table 3 lists the four considered transport scenarios.

Table 3: Transport scenarios Module A2

Distance scenario	Aggregates / natural filler	Bitumen	Additives	Filler / hydrated lime
1	25	100	250	100
2	50	100	250	100
3	75	100	250	100
4	100	100	250	100

Figure 4 shows the GWP of the two asphalt mix designs as a function of transport distance. The results indicate that the aggregates have by far the greatest influence on the transport-related environmental impacts. This is attributable to the high percentage share of aggregates in both asphalt mixtures. Consequently, the transport-related impacts do not differ substantially between the two asphalt mix designs.

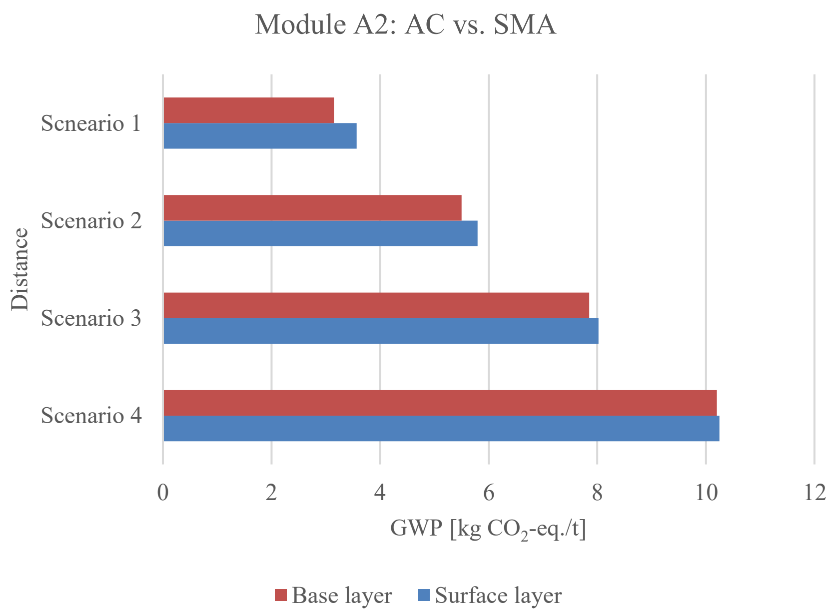


Figure 4: Module A2 – transport

3.3 Asphalt mixture production (Module A3)

For Module A3, which represents production stage of the asphalt mixture, an average dryer drum fuel consumption of 70 kWh per ton (kWh/t) of asphalt mixture is assumed. To illustrate the influence of the fuel's environmental impacts, the following scenarios are considered:

- Scenario 1: 100% heating oil
- Scenario 2: 50% heating oil and 50% natural gas
- Scenario 3: 100% natural gas

For all scenarios an average electricity consumption of 6 kWh/t and an average diesel consumption of 0.08 L/t for operating the wheel loaders are assumed. Additionally, also assumptions have been made to consider the environmental impact of the infrastructure needed for asphalt mixture production. Figure 5 presents the GWP of the individual fuel scenarios graphically. It is evident, first, that the GWP depends primarily on the dryer drum's fuel consumption and, second, that using natural gas compared to heating oil offers substantial savings potential.

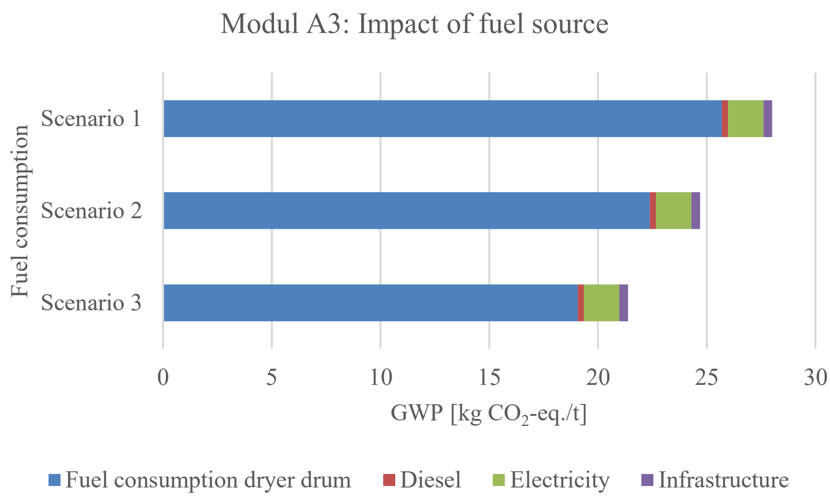


Figure 5: Module A3 - asphalt mixture production

If the dryer drum is operated exclusively on heating oil as the energy source, the - without reducing the energy demand of the drying process itself - substituting 50% of the heating oil with natural gas (on a lower-heating-value basis) yields a 12% reduction in GWP. If the dryer drum is operated entirely on natural gas, the saving increases to 24%.

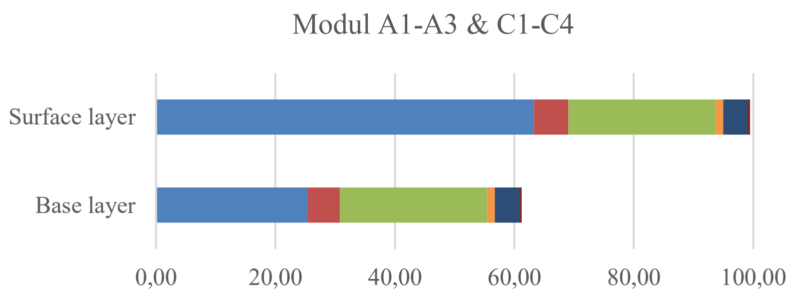
3.4 End of life stage & recycling potential (Module C1-C4 & D)

It is assumed that both asphalt mix designs are treated identically at end-of-life. Deconstruction (Module C1) is assigned a GWP of 1.22 kg CO_2-eq/t asphalt mixture. The recovered material is then transported 40 km by diesel truck to a processing plant (Module C2), adding 4.08 kg CO_2-eq/t. Processing (Module C3) contributes a further 0.42 kg CO_2-eq per ton. Because 100% of the material is reused, either as recycling asphalt pavement or mineral aggregate there is no disposal; therefore, Module C4 is equal to 0.

Module D was determined from statistical data on the end uses of reclaimed (as-removed) asphalt, allocating shares to reuse in recycled asphalt pavement versus use as mineral aggregate. On this basis, the Module D GWP is -12.1 kg CO_2-eq/t for AC and -19.2 kg CO_2-eq/t for SMA. In general, the higher the upstream GWP in Modules A1–A2 for the substituted materials and their transport, the larger the potential credit reported in Module D.

3.5 Overview results (Module A1-A3 & C1-C4 without D)

Figure 6 consolidates the above-mentioned Modules for the two asphalt mixtures. For raw material transport, distance scenario 2 was applied, in which the aggregate has a transport distance of 50 km; the transport distances for the remaining components are given in Table 3. For manufacturing, scenario 2 was assumed, i.e., operation of the dryer drum with 50% heating oil and 50% natural gas. Under these assumptions, the resulting GWP is approximately 61 kg CO_2-eq/t of AC and approximately 99 kg CO_2-eq/t of SMA.



	Base layer	Surface layer
A1	25,31	63,25
A2	5,50	5,80
A3	24,70	24,70
C1	1,22	1,22
C2	4,08	4,08
C3	0,42	0,42
C4	0,00	0,00

GWP [kg CO_2-eq./t]

Figure 6: Module A1-A3, C1-C4 (without D) – Overview LCA results

It is evident that, for both asphalt mixtures, the product stage (Modules A1–A3) dominates the total GWP - 91% for AC and 94% for SMA - with Modules A1 and A3 as the principal contributors. For AC, these two Modules together account for about 82% of total GWP; for SMA, about 88%. The higher total GWP of SMA is primarily driven by Module A1, which alone contributes roughly 64%. Given economically realistic transport distances, transport contributes only a modest share. Nevertheless, it is not negligible: an additional 50 km of aggregate transport increases GWP by approximately 5 kg CO_2-eq/t.

4. Conclusion

The environmental performance of construction products is becoming central to design and procurement, with growing emphasis on whole-life-cycle assessment at the building level. Environmental Product Declarations (EPDs) are the predominant method for determining product impacts and are increasingly mandated. Following in accordance with Product Category Rules (PCRs) - which specify how the life-cycle assessment (LCA) must be conducted - EPDs provide transparent, comparable information and form a robust foundation for subsequent building-level assessments.

Looking ahead, issuing EPDs for all asphalt mix designs will become necessary. Consequently, it will be crucial that asphalt mix plant operators can create product specific EPDs themselves, on demand. Asphalt mix plants typically manage a large number of different asphalt mix designs and since the creation of EPDs is largely the same for each individual asphalt mixture, the workflow is inherently repetitive. This loop-like process makes it especially suitable for digitization: a dedicated tool can reuse verified base data (i.e. energy consumption), enforce consistent assumptions, and generate auditable EPDs quickly for any asphalt mix design as needed.

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Okoljske deklaracije izdelkov za asfalt – trenutni razvoj v Nemčiji

Environmental product declarations for asphalt – Current developments in Germany

Marco Bokies (Deutscher Asphaltverband e.V. DAV)

1. Introduction

Progressive climate change and the social and political discussions surrounding it have led to a significant change in the perception of industry, trade and consumption in recent decades. There is a broad international consensus that, in addition to adaptation strategies, global warming must above all include measures to limit the rise in temperature. The climate agreements concluded in the past and still in force, to whose goals Germany has also made a comprehensive commitment, focus on reducing greenhouse gas (GHG) emissions as far as possible.

The Paris Climate Agreement of 2015 and the UN Sustainable Development Goals, as well as the European Green Deal of 2019, are examples of how these objectives are to be transformed into a normative structure. In 2019, Germany also launched a national climate protection law, which sets out binding targets for reducing greenhouse gas emissions by the middle of the century. Climate protection has become of paramount importance for political action, not least due to the decision of the Federal Constitutional Court in 2021, as the court emphasises that the fundamental rights of future generations are affected as a constitutionally required benchmark for current environmental policy action. In recent years, public perception of the topic has also been characterised by socio-political movements that have managed to drastically thematise climate change and the conclusions to be drawn from it. The protest movements in Germany around, for example, fridays-for-future or the controversial actions of the so-called Last Generation have - as controversial as they have sometimes been - made up a considerable proportion of the reporting on climate change and have characterised political events.

In the course of the development described above, the importance of so-called sustainable management has also increased. Whether industry, trade, agriculture or administration: in almost all of these sectors, strategies have been and continue to be presented that emphasise the particularly ‘sustainable’ activities of the industry, company or administration. The protagonists almost always understand this to mean measures that appear above all ecologically sensible and environmentally friendly.

However, the scientific understanding of sustainability is more comprehensive: the so-called three-pillar model of sustainability was already formulated in the 1990s and shows that economy, ecology and social issues make equal contributions to sustainable development. Despite this more comprehensive approach, however, it must be recognised that the sustainability debate, as soon as it is translated into concrete legislative or executive action by the administration, is conducted with a focus on the ecological part - and specifically on CO2 reduction.

It is therefore not surprising that awareness of ecological aspects has also grown significantly in road construction in recent years.

More and more contractors, authorities and other interest groups are placing greater emphasis on environmental aspects when selecting products, for example, in order to fulfil the requirements for sustainable construction. This is a development that was already foreseeable in building construction and the erection of buildings and which is now also being fully reflected in transport infrastructure and, more specifically, in asphalt road construction.

However, this raises the challenge of how the (ecological) sustainability of construction products can be made measurable and - in the question of selection decisions - comparable at all. Some evaluation systems, which utilise, among other things, incentives relevant to the award of contracts, take so-called environmental product declarations as a basis for this. Some of these evaluation systems have already become established in other European countries and are described below. Environmental product declarations (EPDs) from manufacturers for asphalt mix types and grades can form a reliable basis for carrying out a standardised ecological assessment.

2. Environmental Product Declarations (EPD) and their significance for asphalt road construction

EPD assessment tool

Sustainable construction with asphalt firstly requires that manufacturers and users have an idea of the impact of the use of certain raw materials and fuels, the sources of supply and/or the production processes used and the effects of the specific use of binders and asphalt granulate. The transport distances of the construction materials and raw materials to the mixing plants and construction sites also play a role.

The reliable collection of data and the creation of a knowledge base for your own company is essential for this. With the appropriate data basis, each type and grade of asphalt mix in road construction can then be closely examined and analysed. Every raw material influences the environmental impact of the end product.

When considering the most environmentally friendly and resource-efficient production of asphalt, it should not be forgotten that durability also plays a significant role in the overall assessment of sustainability. The longer the utilisation phase of the asphalt road, the greater the savings effects in terms of environmental indicators. In addition to the more environmental factors, the structural requirements therefore continue to form a very important component for sustainable development in asphalt road construction.

Environmental Product Declarations (hereinafter referred to as EPDs) serve as an instrument for visualising these significant environmental impacts. They depict all phases of the product's life cycle and also provide a view of the potential after the end of a building material's use.

The EPD is a so-called Type III environmental declaration that provides comprehensive information on the environmental impact and technical properties of a product, in this case asphalt mix: asphalt mix. The centrepiece is the life cycle assessment, which considers the environmental impact over the entire life cycle of the product - from raw material extraction to disposal or reuse. An EPD contains objective, verified data on various environmental impacts such as global warming potential, acidification or eutrophication. However, it does not assess product quality, but is a reliable source of information for ecological assessment. The EPD is not a certificate, but a document reviewed by independent experts, which in this respect stands for transparency and facilitates the exchange of environmental information between contractors, authorities and other stakeholders.

Importance of environmental indicators in regulations and tenders

The new EU Construction Products Regulation (CPR) emphasises the importance of taking various environmental criteria into account. In addition to analysing CO2 emissions, the regulation also focuses on other environmental characteristics in order to enable a holistic and sustainable assessment. This development shows that the CO2 factor alone is not sufficient to fully capture the environmental impact. Thanks to the integration of these characteristics in the EPDs in accordance with international standards, the environmental information to be provided from around 2030 as a result of the CPR can already be recorded now.

A key driver for the use of EPDs is a corresponding procurement practice that considers environmental indicators as a key evaluation factor alongside price. For example, there are already projects in Germany that aim to reduce CO2 emissions in road construction. In 2024, for example, the federal motorway company Autobahn GmbH, Southwest branch, carried out a tender in which 70% of the price was based on the product price and 30% on the total CO2e emissions during the production and transport of the asphalt.

For the calculation of CO2e emissions, special Excel tables were provided to determine the emissions in detail. It can be assumed that the projects will be adapted to provide ever more detailed information on the individual environmental indicators. In their own terms, these pilot tenders are an interim solution until the establishment of an assessment procedure in which EPDs play the central role. Other similar projects are being pursued in the federal states of Bavaria, Baden-Württemberg and Hesse.

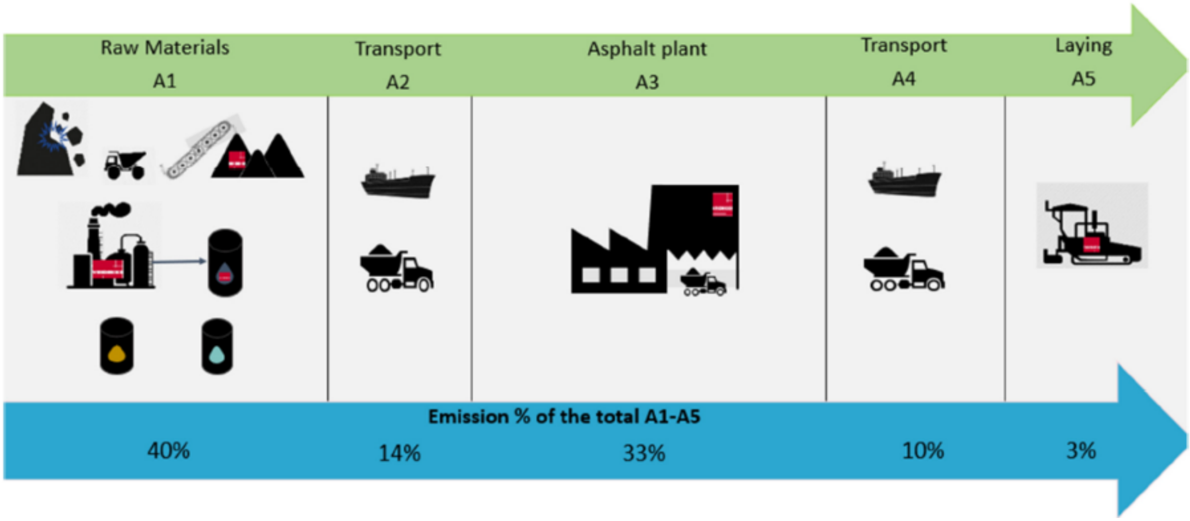
While sustainability indicators are being used to some extent in the evaluation of tenders in Germany, EPDs have long been an integral part of tenders for asphalt roads in other European countries.

In the area of environmental product declarations (EPDs) for asphalt mixes, countries such as Norway and the Netherlands are playing a pioneering role within Europe. As early as 2017, Norway introduced a specific PCR Part B (‘PCR - Part B for Asphalt’), which defines clear requirements for the creation of EPDs for asphalt mixtures. The majority of contracts awarded in Norway now include and evaluate the environmental information from the EPDs of individual national suppliers of asphalt mixes.

The Netherlands has also made significant progress in this area. Compared to Norway, they have an even more precise and detailed PCR entitled ‘Product Category Rules voor bitumineuze materialen in verkeersdragers en waterwerken in Nederland (’PCR Asfalt‘)’ . This regulation allows the environmental impact of asphalt products to be recorded accurately and comparably and helps those involved in road construction to make well-founded decisions in the context of tendering procedures. The EPDs for asphalt are the central starting point for the creation of an evaluation matrix (‘environmental cost index’), according to which a significant part of the award decision must be orientated.

Both countries are regarded as role models in the European context when it comes to standardised Type III environmental declarations for asphalt products. They successfully demonstrate how a structured and technically sound basis for EPDs can be established in road construction. At the same time, the PCR Part B enables scientifically based and fair decision-making in tenders and also offers an incentive to continuously optimise the environmental performance of asphalt products.

The implementation of the consideration of EPDs in the tendering process in Norway, for example, has provided helpful insights into which life cycle processes have the greatest influence on overall CO2 emissions:



Source: EBA – Norwegian Contractors Association

__The PCR as a basis for the creation of EPDs for asphalt__

This explains another terminology: So far, the future significance of EPDs for asphalt mix types and grades in German road construction has been explained. But what is meant by the aforementioned PCR in this context?

A PCR (Product Category Rules) is a collection of specific specifications and requirements that regulate the creation of a Type III environmental declaration for a specific product group.

Two PCR documents, Parts A and B, apply to the development of an EPD for asphalt mix types and grades as part of the Environmental Product Declarations programme of Institut Bauen und Umwelt e.V. (IBU):

PCR - Part A 'Calculation rules for the life cycle assessment and requirements for the project report in accordance with EN 15804 + A2:2019' contains general specifications that apply to all product categories in the construction industry. These include basic specifications on the calculation methods for the life cycle assessment (LCA) and requirements for the documentation of the life cycle assessment in the background report (project report).

PCR - Part B 'Requirements for the EPD for asphalt' is specifically tailored to the 'asphalt' product group and supplements Part A. This document contains detailed and product-specific specifications for the preparation of the EPD.

All current PCR documents are available after free registration on the IBU's EPD online platform at the following link: https://epd-online.com/.

The PCR documents in turn are based on internationally recognised standards and norms for environmental product declarations in order to ensure a reliable and standardised basis for the creation of EPDs:

- DIN EN ISO 14025 'Environmental labelling and declarations - Type III environmental declarations - Principles and procedures' specifies the requirements for Type III environmental declarations, which include the EPD. In contrast to Type I and Type II environmental labels, which evaluate product quality, the EPD focuses on providing quantified environmental information without evaluating the product itself.

- DIN EN 15804 'Sustainability of construction works - Environmental product declarations - Basic rules for the product category of construction products' defines the principles for the preparation of EPDs for construction products and services and is regarded as the core PCR. This standard ensures that EPDs are created, checked and used in a standardised manner throughout Europe in order to enable a transparent and comparable assessment of the environmental impacts of construction products.

- The standards DIN EN ISO 14040 'Environmental management - Life cycle assessment - Principles and framework' and DIN EN ISO 14044 'Environmental management - Life cycle assessment - Requirements and guidance' form the basis for the preparation of the life cycle assessment and ensure that the data is collected in accordance with recognised international standards.

Germany urgently needed to catch up in this regard and first had to develop a comparable PCR Part B for asphalt in order to meet international requirements and promote environmental sustainability in road construction. An important step was taken in October 2024: The PCR Part B 'Requirements for the EPD for asphalt' was published on the platform of Institut Bauen und Umwelt e.V.. The task now is to consistently implement further measures such as integration into award procedures in order to enable Germany to play a leading role in the European and global debate on sustainable construction in the long term.

At the same time, intensive work is being carried out at European level on a standardised technical specification. The challenge here is that various countries have already introduced and established their own PCRs. A European solution therefore requires these different national regulations to be taken into account and integrated into a common framework - otherwise true harmonisation will be difficult.

A standardised methodology is almost essential so that manufacturers, contractors, clients and other stakeholders can evaluate and compare the sustainability of different asphalt mixtures and take targeted measures to reduce their environmental impact. The developed PCR Part B does not fully fulfil this requirement due to systemic-structural specifications of the Institute for Building and Environment (IBU). Unlike, for example, the aforementioned Dutch PCR Part B Asphalt, which contains very detailed specifications for creating an EPD for asphalt, the national PCR for asphalt is more of a rough framework. The PCR - Part B 'Requirements for the EPD for asphalt' as part of the IBU's EPD programme only allows for limited specifications. This is mainly due to the fact that the PCR - Part B both determines the content of the EPDs and serves as a template within the IBU's EPD online platform. This limits the comparability of different EPDs because uniform standardisation of the data and formats is only possible to a limited extent. In order to fulfil the task of comparability, further accompanying specifications therefore had to be developed.

Concretisation through the c-PCR ‘Product group-specific rules for the uniform preparation of EPDs for asphalt’

The c-PCR ‘Product group-specific rules for the uniform preparation of EPDs for asphalt’ contains these special specifications for the product category and serves as a supplementary guide to the general calculation rules, namely PCR - Part A ‘Calculation rules for the life cycle assessment and requirements for the project report in accordance with EN 15804 + A2:2019’ and PCR - Part B ‘Requirements for the EPD for asphalt’. The c-PCR was developed by the Steinbeis Transfer Centre for Infrastructure Management in Transport (IMV) in Karlsruhe on behalf of the German Asphalt Association (DAV).

The aim of this document is to create a standardised basis for the creation of EPDs for asphalt mix types and grades in German road construction. Using a standardised methodology, manufacturers, contractors, clients and other interest groups can evaluate and compare the sustainability of different asphalt mixtures and take targeted measures to reduce the environmental impact of road construction production. For its part, the c-PCR is based on internationally recognised norms and standards, such as DIN EN ISO 14040:2021-02 and DIN EN 15804:2022-03, and takes into account various phases of the life cycle of asphalt mixes - from raw material extraction to reuse and further use. It specifies which processes in these phases are to be included in the EPD.

Essentially, the c-PCR defines which secondary data (e.g. raw materials, energy, fuels, transport, waste treatment) should be used in order to ensure comparability of the EPDs produced. It also defines requirements for the quality of the primary data and the period under review.

The c-PCR was published in December 2024 as a supplementary set of rules of the DAV for the preparation of EPDs and is available at the following link: https://www.asphalt.de/themen/umwelt/pcrs-fuer-asphaltmischgut/.

Institut Bauen und Umwelt e. V. (IBU) and EPD typifications

The “Institut für Bauen und Umwelt e. V. (IBU)” is an association dedicated to promoting the ecological dimension of sustainability in the construction industry. With more than 300 members from companies and associations, the IBU is one of the most important associations of manufacturers in the building materials industry.

In cooperation with building and environmental authorities as well as international standardisation bodies, the IBU has established an EPD programme that primarily serves the transparent presentation of environmental information on building products - including in the form of environmental product declarations. The Product Category Rules (PCR) - both Part A and Part B - co-developed and published by the IBU form the basis for the creation of these EPDs. IBU members can create EPDs for their products on the basis of these rules, which are then checked, validated and published by independent verifiers. An independent expert council accompanies and monitors this process on an ongoing basis. The German Asphalt Association has also been a member of the IBU since 2023. At both national and international level, the IBU plays a key role as a programme operator for EPDs and their publication in the construction industry. In addition, the Institute is actively involved in the international recognition of these declarations. In close cooperation with other European and global EPD programme operators, the IBU is working to strengthen the acceptance and application of EPDs in a cross-border context.

The following types of EPDs can be created under the IBU EPD programme:

- Specific EPD: Describes the environmental performance of a specific product from a single manufacturer or group of manufacturers.
- Average EPD: Indicates the average environmental performance of several similar products or those from a common product class of a manufacturer or group.
- Representative EPD: Documents the environmental performance of a specific product that is demonstrably representative of several similar products from the same manufacturer group.
- Model EPD: Refers to the product of a manufacturer or group that has the highest potential environmental impact within a product class (worst-case scenario). If the material composition is largely identical, this product can be used and declared as an example for all products in the class with a lower environmental impact.

The process of creating an EPD for asphalt products

As already explained, the creation of an EPD for asphalt products is based on PCR Parts A and B, the c-PCR 'Product group-specific rules for the standardised creation of EPDs for asphalt' and the associated guidelines. These form the basis for the creation of EPDs for different asphalt mix types and grades, which are comparable with each other. Each EPD is based on these guidelines to ensure that the environmental impact of the products is documented in a standardised and comparable manner. The starting point for creating an EPD is a life cycle assessment, for which the necessary primary data is collected directly at the asphalt mixing plant. This data can be collected either internally within the company or by an external service provider for life cycle assessments.

In addition to the primary data, secondary data defined in the c-PCR is also used for the LCA. These data sets facilitate and standardise the life cycle assessment, making it comparable. Once the life cycle assessment has been calculated, the data obtained is transferred to the EPD template. At the same time, a detailed background report is created. Once all the data is complete, the EPD can be submitted to the IBU for verification.

The submitted EPD is then assigned to an independent verifier who checks both the EPD and the background report in accordance with the requirements of DIN EN ISO 14025, DIN EN 15804 and the IBU programme guidelines. As part of this review, the completeness, plausibility and consistency of the calculations and the accuracy of the information are checked.

It should be emphasised that the verifiers are not permitted to offer consultancy services. If the submitted EPD contains deficiencies, the verification process is cancelled. The duration of the verification process varies depending on the complexity of the product, the quality of the submitted data and the necessary corrections, whereby several weeks should generally be planned.

Once the verification has been successfully completed and the approval process has been carried out by the IBU, the EPD is published both as a PDF document and as an XML dataset. The EPD is then valid for a maximum of five years before an update is required.

There are now a number of providers on the market that offer so-called pre-verified software tools, which companies can use to create EPDs more quickly and cost-effectively.

3. Conclusion/Outlook/Expectations

Developments in the consideration of sustainability aspects in road construction point in a clear direction: they will become increasingly important and will be a decisive factor in the commissioning of asphalt roads in the future. In particular, ecological benchmarks such as environmental indicators will also become an elementary part of the award procedures in Germany, which is thus following the example of other European countries. The environmental/climate protection indicators will play the largest role within the functional part 'sustainability'. Within this, the CO2 values will occupy the most important position due to the current focus on climate protection, but will gradually be supplemented by other environmental indicators. Environmental product declarations in accordance with EN 15804 + A2 will play an important role in the presentation of the relevant environmental indicators. The European Construction Products Regulation is already guiding this development. With the PCR Part B and c-PCR for asphalt now available, the prerequisites have been created for companies to be able to create EPDs for asphalt mixtures in future.

At the same time, this means that the awarding of contracts will become more complex on both the client and contractor side. Advancing digitalisation and the provision of corresponding online tools will also simplify the collection and preparation of life cycle assessment data. Corporate efficiency in the area of sustainability will therefore become an even stronger factor by supplementing the previous purely price-driven competition in awarding contracts. On the government side, in turn, future investments will be increasingly subject to the proviso of benefits in the context of the relevant sustainability aspects.

Združenje asfalterjev Slovenije

VABLJENA PREDAVANJA

INVITED LECTURES

Stalna vlaganja kot temelj stabilnosti in razvoja AC omrežja

Sustained Investment as a Key to a Stable and Evolving Motorway Network

Matic Poznič, Andrej Zajec; (DARS d.d. Slovenija)

Povzetek

Slovenija je zaradi svoje geografske lege del evropskih koridorjev, ki so temelj za pretok ljudi, blaga in storitev med zahodno, srednjo in jugovzhodno Evropo. Ravno zaradi te prometne vloge je kakovost in zanesjivost slovenskega avtocestnega omrel'ja izrednega pomena - ne le za domači promet, temveč tudi v širšem evropskem prostoru. V zadnjih desetletjihje Slovenija razvila obsežno in sodobno avtocestno mrežo. Za ohranjanje prometne varnosti, pretočnosti in funkcionalnosti zgrajenega omrežja so potrebna stalna vlaganja v obstoječe avtocestno omrežje. Zaradi naraščajočih prometnih obremenitev, zlasti tovornega prometa, in vplivov staranja konstrukcijskih elementov je stalno ter skrbno načrtovano izvajanje obnovitvenih del postalo ključen dejavnik ohranjanja zgrajenega omrežja, pri čemer se upošteva trajnostno upravljanje infrastrukture in prilagajanje na bodoče izzive. Modernizacija in širitev avtocestne mreže ne pripomore le k večji pretočnosti prometa, temveč tudi k manjši obremenitvi drugih prometnih poti, zmanjšuje negativne okoljske vplive ter prispeva k večji gospodarski rasti.

V nadaljevanju članka bomo predstavili pomen stalnih obnovitvenih del kot ključnega elementa dolgoročnega upravljanja avtocest, izpostavili aktualne izzive pri načrtovanju in izvedbi obnovitvenih del ter prikazali dobre prakse in pristope, ki bodo v nadaljevanju omogočali posodobitev funkcionalnosti zgrajenega omrežja, kot odgovor na pričakovane povečane prometne obremenitve.

Abstract

Due to its geographical position, Slovenia forms part of European transport corridors that enable the movement of people, goods, and services between Western, Central, and South-Eastern Europe. Owing to this strategic transport role, the quality and reliability of Slovenia's motorway network are of exceptional importance — not only for national mobility but also within the broader European transport system. Over the past decades, Slovenia has developed an extensive and modern motorway network. To ensure continuous traffic safety, efficiency, and functionality, ongoing investment in the existing motorway infrastructure is essential. Increasing traffic volumes, particularly heavy freight transport, together with the ageing of structural elements, have made systematic and carefully planned reconstruction works a key factor in maintaining the long-term performance and safety of the network, while also supporting the principles of sustainable infrastructure management and adaptation to future challenges. The modernization and expansion of the motorway network not only improve traffic flow but also helps to reduce use of alternative routes, mitigate environmental impacts, and contribute to overall economic growth.

This paper presents the importance of continuous reconstruction activities as a fundamental component of long-term motorway asset management. It highlights current challenges in the planning and implementation of reconstruction works and showcases examples of good practice and innovative approaches that will support the future modernization and functional improvement of Slovenia's motorway network in response to expected increases in traffic demand.

1. Uvod

S povečevanjem in staranjem avtocestnega (AC) omrežja ter hkratnim naraščanjem prometnih obremenitev, zlasti težkega tovornega prometa, se sorazmerno povečuje tudi obseg potrebnih obnovitvenih del. Ker se vsa tovrstna dela izvajajo pod prometnimi zaporami je nujno, da so skrbno načrtovana tako z vsebinskega kot tudi s časovnega vidika, da se zagotovi čim manjše motnje v prometu in optimalna izvedba del. Vstopamo v obdobje, ko obnovitvena dela ne predstavljajo več zgolj sanacije poškodb in ohranjanja ustreznega prometno tehničnega stanja infrastrukture, temveč postajajo ključni del modernizacije obstoječega omrežja. Z načrtovanimi širitvami in prometno tehničnimi posodobitvami se bo zagotavljala dolgoročna funkcionalnost avtocest tudi ob nadaljnjem povečevanju prometnih obremenitev.

Na večini odsekov, kjer je razširitev nujna, se potreba po širitvi ujema tudi s stanjem infrastrukture, ki narekuje celovito obnovo. Zato bodo pri izvedbi teh projektov posodobljeni vsi bistveni elementi cestne infrastrukture, vključno z zamenjavo ali rekonstrukcijo premostitvenih objektov, kjer bo to potrebno. Takšen celosten pristop omogoča učinkovitejše načrtovanje, večjo trajnost infrastrukture in dolgoročno optimizacijo stroškov vzdrževanja.

2. Princip gospodarjenja z infrastrukturo

S povečevanjem obsega obnovitvenih del ter vse večji potrebi po racionalni porabi finančnih sredstev za obnove, se je že pred leti pokazala nuja po vzpostavitvi celovitega sistema za gospodarjenje z avtocestno infrastrukturo. Ta zajema upravljanje z vozišči, premostitvenimi objekti, predori, opornimi in podpornimi konstrukcijami, sistemi za odvodnjavanje, protihrupnimi, varnostnimi in varovalnimi ograjami, cestno opremo ter obcestnim prostorom. Največji napredek je bil do sedaj dosežen na področju gospodarjenja z vozišči in premostitveni objekti, kjer se za podporo odločanju uporabljata namensko razvita ekspertna sistema. Koncept gospodarjenja z infrastrukturo temelji na sistematičnem spremljanju njenega stanja, oblikovanju modelov propadanja posameznih elementov ter pripravi različnih scenarijev razvoja stanja infrastrukture v prihodnosti, pri čemer se upoštevajo različni robni pogoji in možnosti prihodnjih vlaganj. Modeli propadanja vključujejo osnovne značilnosti zgrajene infrastrukture, kakovost vgrajenih materialov, obseg in učinkovitost izvajanja rednega vzdrževanja ter predvidene prihodnje prometne obremenitve, ki bistveno vplivajo na hitrost propadanja in zmanjševanja funkcionalnosti infrastrukture. Takšno poslabšanje ne zahteva le sanacije poškodovanih delov, temveč pogosto tudi funkcionalne nadgradnje, zlasti v obliki povečanja prometnih zmogljivosti in prilagoditve infrastrukture novim prometnim zahtevam. Nekoliko drugačen je pristopi pri elektro strojni opremi cest, kjer menjavo ali nadgradnjo opreme zahteva tehnološki razvoj.

Družba DARS mora kot upravljavec avtocestnega omrežja uporabnikom zagotavljati varno in udobno vožnjo ob optimalni porabi razpoložljivih sredstev za vzdrževanje in obnovo infrastrukture. Zmanjšanje obsega finančnih vlaganj v obnove avtocestnega omrežja bi neposredno vplivalo na nižjo raven storitev za uporabnike, zmanjšano prometno varnost in udobje vožnje, hkrati pa povzroča povečanje njihovih stroškov, saj se zaradi nižjih voznih hitrosti podaljšuje potovalni čas, povečuje poraba goriva ter naraščajo stroški prevoza blaga.

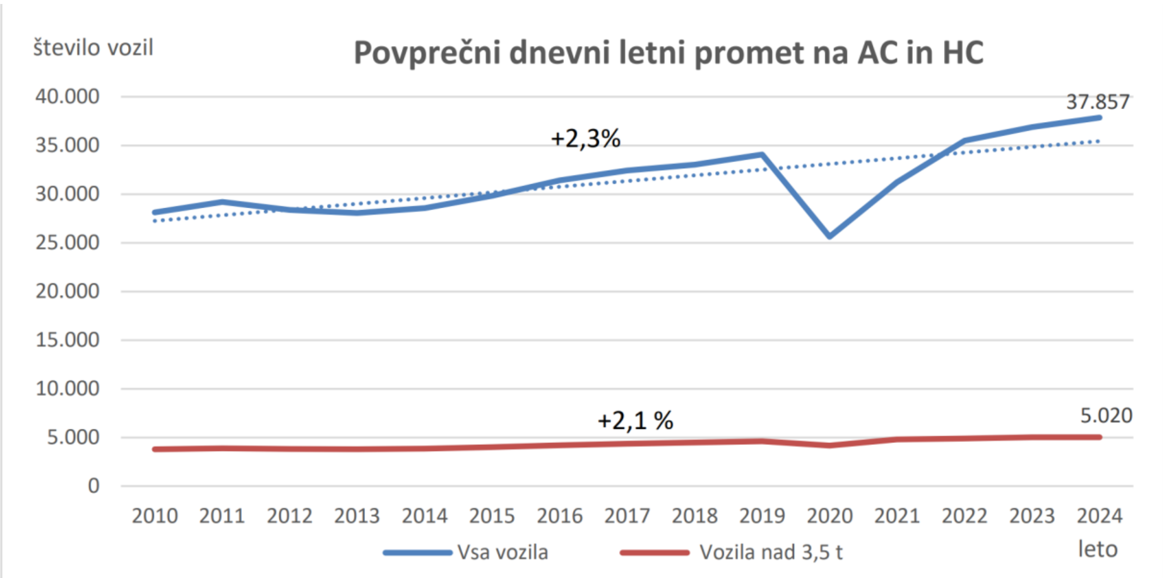
Cilj sistema gospodarjenja s cestno infrastrukturo je določitev optimalnega scenarija vlaganj v obnove, ki zagotavlja minimalne skupne stroške tako upravljavca kot uporabnikov cestnega omrežja.

Obseg infrastrukture v upravljanju DARS zahteva redna in znatna vlaganja v obnove, vse z namenom ohranjanja ustreznega stanja, namena uporabe in razvoja. Trenutno ima DARS v upravljanju 1.240,5 km smernih vozišč odsekov, 172,7 km priključkov ter 41,2 km počivališč, servisnih in kamionskih cest, kar skupaj znaša 1.454,4 km smernih vozišč. Skupno je na AC omrežju 1.090 premostitvenih objektov, 45 predorov v skupni dolžini 42,3 km, 35 pokritih vkopov v skupni dolžini 6,8 km ter 378 geotehničnih objektov v skupni dolžini 40,0 km. Iz naslova obsega potrebnih vlaganj so pomembni tudi še nekateri drugi segmenti infrastrukture, DARS trenutno tako že upravlja s 171,2 km protihrupnih ograj v skupni površini 536.552 m2 in protihrupnimi nasipi v dolžini 48,6 km.

Za obvladovanje tako obsežne cestne infrastrukture je nujna uporaba naprednih GIS orodij, ki nam omogočajo optimalno pregledovanje in vključevanje vseh elementov cestne infrastrukture v enotne projekte za izvedbo. DARS ima za te potrebe razvito aplikacijo, ki omogoča učinkovito načrtovanje vseh potrebnih vlaganj, kar je osnova za pripravo ključnega planskega dokumenta, ki izhaja iz stanja cestne infrastrukture in se letno pripravlja po principu drsnega načrtovanja za prihodnja tri leta.

3. Prometne obremenitve

Ob upoštevanju podatkov daljšega časovnega obdobja so prometne obremenitve na avtocestnem omrežju v Sloveniji ves čas v porastu. Vzrokov za to je več: avtocesta je varna, zanesljiva in hitra prometna povezava; geografska lega Slovenije oz. potek evropskih koridorjev čez njeno ozemlje generira tovorni in turistični tranzitni promet; za slovenski prostor je zaradi poselitvene razdrobljenosti značilen trend dnevnih delovnih migracij v večja mesta, pri čemer najbolj izstopa Ljubljana. Posledica je stalna rast skupnih prometnih obremenitev, dodatno skrb pa povzroča nenehna rast tovornega prometa, ki sledi rasti slovenskega in evropskega gospodarstva.



Graf 1: Povprečni dnevni letni promet na AC in HC v letih 2010-2024

Po podatkih z avtomatskih števcev prometa se je skupni promet v zadnjih 15 letih povečal za 35 %, v istem obdobju tovorni promet za 32 %, v zadnjih šestih letih pa za 11 %, oz. tovorni promet za 9 %. Rast osebnih in tovornih vozil je bila v tem obdobju enakomerna, promet osebnih vozil je v tem času naraščal v povprečju 2,3 % na leto, promet tovornih vozila pa 2,1 % na leto. Izjema je obdobje v času razglašene pandemije koronavirusa, a že leta 2022 so prometne obremenitve presegle vrednosti iz leta 2019. Podatki o rasti prometnih obremenitev na celotnem AC omrežju niso merodajni za načrtovanje ukrepov, kažejo le na splošen trend, ki na posameznih odsekih omrežja lahko bistveno odstopa. Vse več je odsekov, kjer prometne obremenitve že dosegajo računsko kapaciteto štiripasovne avtoceste ter povzročajo vsakodnevne zastoje v obeh prometnih konicah, ki se tudi časovno daljšajo. Tako so na AC omrežju na območju Ljubljane že odseki, kjer povprečni letni dnevni promet presega 75.000 vozil, pri tem pa lahko delež težkih tovornih vozil presega 10 %. Pričakovati je, da se bo v povprečju rast prometnih obremenitev nadaljevala, stopnja rasti na posameznem območju pa bo odvisna od že dosežene zasičenosti s prometom, lokalnim razvojem območji, ki generirajo promet ter splošnim gospodarskim stanjem širše regije.

Ker trenutnih in prihodnjih prometnih obremenitev obstoječe avtocestno omrežje ne more prenesti brez vse pogostejših motenj v prometnem toku, se postavi logično vprašanje, kaj storiti, da se bodo razmere izboljšale oz. da bo tudi v prihodnje avtocesta nudila ustrezno raven uslug uporabnikom in zagotavljala prometno varno odvijanje prometa. Poleg ukrepov za zagotavljanje ustrezne vozne površine v smislu pravočasnih izvajanj obnovitvenih del je treba pravočasno pristopiti tudi k načrtovanju infrastrukturnih ukrepov za povečanje kapacitete, saj njihova realizacija zahteva bistveno več časa za načrtovanje in izvedbo.

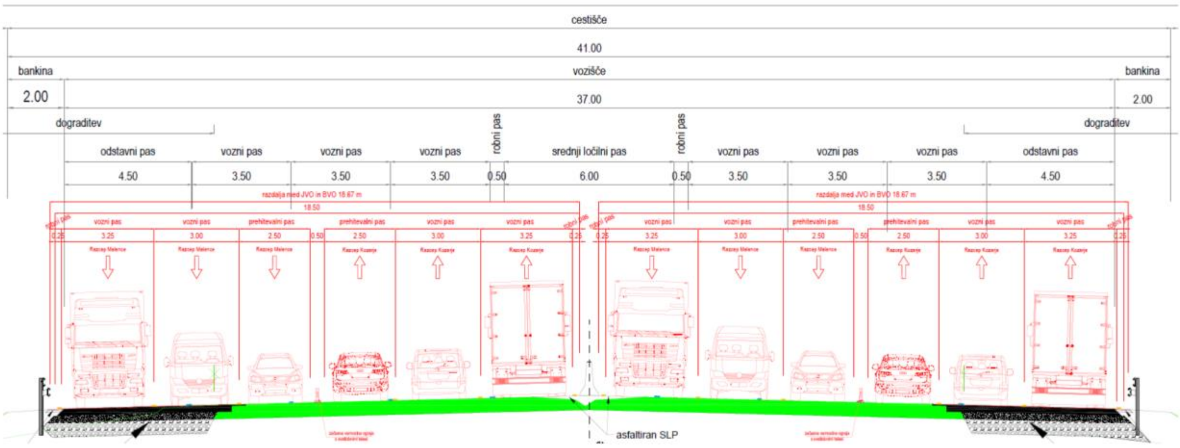
Trenutne in predvidene prometne obremenitve se upoštevajo tako pri izdelavi scenarijev za definiranje bodočih potreb, kot tudi na projektnem nivoju za detajlno načrtovanje obnovitvenih ukrepov in določitev tipa zapore, pod katero se bodo dela odvijala. Če k temu dodamo še potrebo po povečanju kapacitete v primeru izredno visokih prometnih obremenitev, dobimo nabor projektov z veliko koristjo za uporabnike AC. Tak primer je celovita obnova na odsekih Domžale-Zadobrova in Kozarje- Vrhnika, kjer se bo ob rekonstrukciji vozišča, ki je v zelo slabem stanju in nujno potrebno obnove, izvedla tudi širitev vozišča in s preureditvijo odstavnega pasu v 3. prometni pas izrazito povečala kapaciteta ceste na obravnavanih odsekih.

Prometne obremenitve so po posameznih AC odsekih zelo različne. Zato so tudi obnovitvenih ukrepi temu prilagojeni. Na odsekih z zmerno prometno obremenitvijo se najbolj pogosto izvajajo ukrepi za ureditev vozne površine, kar vključuje popravilo poškodovanih asfaltov in nadgradnja z novo obrabno plastjo. To so v večini novejši odseki, z zadostno debelino asfaltnih plasti ter kjer voziščna konstrukcija še ni v celoti strukturno iztrošena. V nasprotnem primeru se izvede ukrep celovite obnove kjer obnovljene dele omrežja prilagodimo najnovejšim zahtevam. V teh primerih izvedemo razširitev odstavnega pasu, strukturno obnovimo voziščno konstrukcijo z namenom prevzema bodoči prometnih obremenitev, vgradimo ustrezno prometno varnostno opremo, uredimo sredinski ločilni pas v t.i. nezeleni izvedbi ter izvedemo vsa ostala potrebna dela, da bo na vseh elementih ceste dosežena enaka planska doba.

Prometne obremenitve na posameznem odseku pa ključno vplivajo tudi na pristop k izvedbi del. Cilj je, da se dela izvajajo pod zaporami, ki še vedno omogočajo zadostno prepustnost odseka, da ne prihaja do rednih daljših zastojev. Na odsekih z manj prometa se lahko dela izvaja pod zaporo enega smernega vozišča, na nasprotnem smernem vozišču pa se vzpostavi v vsako smer po en prometni pas (tip zapore C1+1). V kolikor je na odseku izrazita jutranja in popoldanska konica, se vzpostavi režim vožnje, ko sta dva prometna pasova v smer povečanega prometa, v nasprotno smer pa je na voljo en prometni pas (tip zapore C2+1 z obračanjem). V tem primeru ni potrebnih dodatnih vlaganj v razširitve za potrebe zagotavljanja dovolj voznih pasov v času izvedbe del.

Na obremenjenih odsekih pa lahko ta cilj dosežemo le tako, da se v času izvajanja del zagotovi enako število zožanih prometnih pasov na območju gradbišča, kot jih je bilo pred zaporo na odseku, ki se obnavlja. Ker večina odsekov AC nima zadostnih širin, da bi na eni polovici AC vzpostavili 4 zožane pasove, torej dva v vsako smer, imamo dve možnosti. Ali dela izvajamo na način, da ob gradbišču še vedno teče en prometni pas, en pa se preusmeri na nasprotno smerno vozišče (tip zapore C2+1+1) ali pa zagotovimo ustrezno širitev vozišča. DARS je že leta 2016 sprejel lastne usmeritve, da se v primeru rekonstrukcij zagotavlja odstavni pas širine 3,5 m, kar poleg dviga prometne varnosti v primeru ustavljanja vozil, pomeni tudi dovolj asfaltnih površin za izvedbo zapore s štirimi zožanimi pasovi (tip zapore C2+2) na enem smernem vozišču. Tako je v bodoče pri načrtovanju novih avtocest oz. gradnje 6 pasovnic potrebno zagotoviti ustrezne širine, ki bodo omogočale enako skupno število zožanih pasov na enem smernem vozišču. V primeru načrtovanja razširitve južne ljubljanske obvoznice je bil s tem namenom zasnovan za 2 m širši prečni profil bodoče 6 pasovnice v skupni širini 37 m.

Ravno potreba po dodatnih razširitvah za potrebe zagotavljanja pretočnosti v času izvedbe del je vzrok, da se povečuje obseg preostalih del v sklopu obnove odseka, pri čemer je osnovni namen izvedba obnove za ohranjanje ustreznega stanja omrežja.



Slika 1: Predviden prečni profil bodoče šest pasovnice

4. Uvajanje novih tehnologij

DARS je zavezan k trajnostnim načinom izvajanja investicij, zato želi pri gradnji in obnavljanju avtocest vpeljati trajnostne zelene tehnologije in postopke izvedbe del. S tem namenom se v okviru obnovitvenih del v zadnjih letih vse več pozornosti namenja uvajanju novih tehnologij. Njihova učinkovitost in ustreznost se preverjata z izvedbo in spremljanjem preskusnih polj ter z izvajanjem raz- vojno-raziskovalnih nalog. Tako je bilo preizkušenih več tehnoloških novosti na področju asfalterstva, med drugim so bila izvedena preskusna polja z manj hrupnimi asfalti, asfalti z večjim deležem dodanega rezkanca, asfalti s specialnimi bitumni ter v zadnjem obdobju tudi s t. i. toplimi asfalti.

Ena pomembnejših razvojnih smeri je širša ponovna uporaba asfaltnega rezkanca, kar je bilo v preteklosti omejeno zaradi tehnične regulative, ki je ponovno uporabo rezkanca dovoljevala zgolj v nosilnih asfaltnih plasteh. S tem namenom je bila izvedena razvojno-raziskovalna naloga, v okviru katere je izvajalec s preizkušanjem različnih deležev rezkanca in dodatkov za pomlajevanje analiziral lastnosti proizvedenih asfaltnih zmesi. Na avtocestnem odseku so bila nato izvedena tudi preskusna polja, s katerimi so se preverjale lastnosti vgrajenih asfaltnih plasti. Na podlagi rezultatov raziskave in analiz testnih polj je DARS posredoval na Slovenski inštitut za standardizacijo (SIST) predlog za dopolnitev slovenskega standarda SIST 1038. Predlog je bil sprejet maja 2022, ko je bil standard dopolnjen v točki 4.4 *Ponovno uporabljen asfalt (asfaltni granulat)*. S sprejeto dopolnitvijo je omogočena uporaba asfaltnega granulata v vseh vrstah asfaltnih zmesi, z izjemo obrabnih plasti razredov A1 in A2. DARS je dopustno določilo z vključevanjem v razpisne pogoje za izvedbo del nadgradil v obvezno zahtevo, da nosilne in vezne asfaltne plasti vsebujejo najmanj 15-odstotni delež dodanega rezkanca.

S tem ukrepom je DARS pomembno prispeval k večji trajnostni naravnanosti obnove cestne infrastrukture, zmanjšanju porabe naravnih surovin in znižanju ogljičnega odtisa pri proizvodnji asfaltnih zmesi. Uvedene spremembe predstavljajo pomemben korak k sistematični uvedbi krožnega gospodarstva v prakso gradnje in vzdrževanja slovenskih cest.

Med tehnologije, ki prispevajo k znižanju ogljičnega odtisa, sodijo tudi t. i. topli asfalti. V Sloveniji smo v letu 2021 sprejeli tehnično specifikacijo: »Zgornji ustroj cest - Tople asfaltne zmesi - TSPI - PGV.06.460: 2021«, z dne 29.4.2021. Tople asfaltne zmesi se od klasičnih ločijo s proizvodno temperaturo, ki je za vsaj 20 st. C nižja od običajne oziroma v temperaturnem razponu med 100 do 150 st. C.

DARS je v letu 2023 podal splošno pobudo za uporabo asfaltnih zmesi z nižjo proizvodno temperaturo. Namen pobude je, da izvajalci po eni od znanih tehnologij za izvedbo toplih asfaltnih zmesi izvedejo začetni tipski preskus, poskusno proizvodnjo in poskusno vgrajevanje najbolj pogosto uporabljenih zmesi na AC. Na osnovi uspešno izvedene poskusne proizvodnje in poskusnega vgrajevanja toplih asfaltov izvajalec pripravi tehnološki elaborat za izvedbo preskusnega polja na AC odseku v primernem obsegu. DARS zagotovi izvedbo dogovorjenega obsega preiskav na preskusnem polju, nato se ob upoštevanju predhodnih podatkov in podatkov notranje kontrole kakovosti pripravil poročilo o izvedbi preskusnega polja. Trenutno stanje aktivnosti na podlagi podane pobude je razvidno iz spodnje preglednice.

Izvajalec	**Asfaltna zmes**	**Tehnologija proizvodnje**	**Testno polje izven AC**	**Izpolnjeni pogoji za AC**	**Testno polje na AC**
1	AC 22 base B50/70	penjeni bitumen	NE	NE	
	AC 22 bin PmB	modificiran bitumen LE	NE	NE	
	SMA 11 PmB	modificiran bitumen LE	NE	NE	
2	AC 22 base PmB	modificiran bitumen LE	DA	DA	
	AC 22 bin PmB	modificiran bitumen LE	DA	DA	DA
	SMA 11 PmB	modificiran bitumen LE	DA	DA	DA
3	AC 22 bin PmB	kemijski dodatek	DA	DA	
	SMA 11 PmB	kemijski dodatek	DA	DA	
4	AC 32 base B50/70	penjeni bitumen	DA	DA	
	AC 22 bin PmB	penjeni bitumen	DA	DA	DA
	SMA 11 PmB	penjeni bitumen	DA	DA	
5	AC 32 base B50/70	modificiran bitumen LE	DA	DA	DA
	AC 22 bin PmB	modificiran bitumen LE	DA	DA	DA
	SMA 11 PmB	modificiran bitumen LE	DA	DA	DA
6	AC 22 bin PmB	kemijski dodatek	DA	DA	DA
	SMA 11 PmB	kemijski dodatek	DA	DA	DA
7	AC 32 base PmB	organski dodatek	DA	DA	
	AC 22 bin PmB	organski dodatek	DA	DA	
	SMA 11 PmB	organski dodatek	DA	DA	
8	AC 32 base B50/70	penjeni bitumen	DA	DA	
	AC 22 bin PmB	penjeni bitumen	DA	DA	
9	SMA 11 PmB	penjeni bitumen	DA	DA	
10	AC 32 base B50/70	penjeni bitumen	DA	NE	
	AC 22 bin PmB	kemijski dodatek	DA	NE	
11	AC 22 base PmB	modificiran bitumen LE	DA	DA	
	AC 22 bin PmB	modificiran bitumen LE	DA	DA	
	SMA 11 PmB	modificiran bitumen LE	DA	DA	
SKUPAJ:			**10**	**9**	**4**

Preglednica 1: Stanje aktivnosti pri izvedbi preskusnih polj toplih asfaltov

Cilj pobude je vpeljava toplih asfaltov v splošno uporabo v prihodnjih letih. Razvidno je, da trenutne aktivnosti ne zadoščajo, da bi bilo možno tople asfalte vpeljati v splošno uporabo na AC že v letu 2026, zato je potrebno aktivnosti pospešiti, saj bo DARS tople asfalte pričel vključevati v javna naročila za izvedbo asfalterskih del. Pri tem poudarjamo, da bo zahteva po uporabi vsaj 15 % deleža dodanega rezkanca veljala tudi v primeru proizvodnje toplih asfaltnih zmesi.

Podobno velja tudi za druge asfaltne zmesi, za katere se pričakuje, da bodo v bodoče na podlagi preskusnih polj primerne za splošno uporabo. Med temi so tople asfaltne zmesi s povečanim deležem uporabljenega rezkanca (>30 %) ter zmesi z uporabo specialnih bitumnov za namen proizvodnje visoko zmogljivih asfaltnih plasti.

5. Obseg vlaganj

V nadaljevanju je prikazan pregled vlaganj v obstoječe AC v obdobju zadnjih petnajstih let. Družba DARS vodi evidenco vlaganj glede na prevladujočo vsebino posamezne investicije, kar omogoča sistematično spremljanje strukture in namembnosti finančnih sredstev. Pri tem je treba poudariti, da so posamezne vrste del vključene v širše investicijske sklope. Tako so na primer naložbe v prometno opremo (signalizacija, varnostne ograje ipd.) praviloma zajete v investicijah obnove voziščnih konstrukcij ali premostitvenih objektov. Samostojno se beležijo zgolj tiste investicije, katerih glavni namen je izboljšanje prometne varnosti oziroma posodobitev prometne opreme. Podoben pristop velja tudi za področje elektro-strojne opreme, kjer se samostojne investicije evidentirajo le v primerih, ko gre za večje nadgradnje ali zamenjave sistemov. Ves čas so ločeno evidentirane naložbe v protihrupno zaščito, saj te predstavljajo izvedbo ukrepov iz Operativnih programov varstva pred hrupom. Gre za specifična vlaganja, ki po svoji naravi niso del obnavljanja ampak gre za naložbe s področja varovanja okolja.

Gradbene obnove AC vsebujejo investicije na področju obnavljanja vozišč, cestnih objektov, geoteh- ničnih objektov, odvodnjavanja ter prometne opreme in naprav. V prikazu je vključen tudi strošek pridobivanja potrebne dokumentacije za izvedbo del, strošek inženirja v vseh fazah investicije ter strošek zapor, ki so potrebne za izvedbo del. V obdobju med 2010 in 2024 je bilo izvedenih 603,13 mio EUR investicij, v povprečju 40,21 mio EUR na leto. V zadnjih petih letih je bilo povprečje vlaganj na tem področju 63,23 mio EUR.

Graf 2: Realizacija gradbene obnove AC v letih 2010-2014

Pri obnavljanju vozišč se spremlja tudi materialni kazalnik obsega obnovljenih smernih vozišč v posameznem letu. DARS ima zadnja leta postavljen strateški cilj, da v povprečju obnavlja 55 km/leto, kar je minimalen obseg izvajanja del na področju vozišč, ki še zagotavlja dolgoročno uporabo zgrajenih AC. Kazalnik je bil v povprečju dosežen v zadnjih osmih letih, na spodnjem grafu pa je prikazano vsakoletni obseg, ki smo ga za boljšo primerjavo povprečili za posamezno pet letno obdobje.

Graf 3: Kilometri obnovljenih smernih vozišč v letih 2010-2024

Podobno kot pri finančnem obsegu vlaganj se tudi v tem primeru v drugem obravnavanem petletnem obdobju obseg izvedenih obnov približno podvoji. V zadnjem petletnem obdobju je zaznati nekoliko manjši porast fizičnega obsega izvedb v primerjavi s finančnim povečanjem. Takšen razkorak je predvsem posledica dviga cen gradbenih materialov in storitev ter povečanih stroškov pri obnovi preostalih elementov cestne infrastrukture, ki zahtevajo zahtevnejše posege. V prikazanih podatkih o obnovljenih kilometrih so zajeti vsi izvedeni ukrepi, ne glede na njihovo vrsto oziroma zahtevnost. Posledično razmerje med vloženimi sredstvi in obsegom obnovljenih odsekov ni linearno, temveč je močno odvisno od strukture izvedenih del. Največji učinek vloženih finančnih sredstev na izboljšanje stanja vozišč predstavljajo preplastitve vozišč, medtem ko se pri ukrepu celovite obnove, pri katerih se obnovljeni odseki ceste prilagodijo najnovejšim tehničnim zahtevam in standardom, znaten delež vloženih sredstev nameni ostalim elementom cestne infrastrukture. Pri tem je nezanemarljiv delež sredstev, ki je namenjen razširitvam odstavnih pasov za potrebe vzpostavitve zadostnih zožanih pasov v času gradnje. Trenutno se tudi projekti za vzpostavitev 3. prometnega pasu na štajerski in primorski vpadnici vodijo kot projekti obnov vozišč, zato bodo v prihodnje vključeni v enake finančne in materialne kazalnike. Potrebna sredstva za obnovo odsekov se bodo dvignila tudi iz naslova povečanih vlaganja v premostitvene objekte.

Poleg rednih investicij so bile v obravnavanem obdobju izvedene tudi izredne naložbe. Med takšne primere sodijo rušenje cestninskih postaj po uvedbi sistema DARSGO, rekonstrukcije priključkov v središču BTC ter v zadnjem obdobju tudi vlaganja na območju avtocestnih počivališč, katerih namen je izboljšanje funkcionalnosti, varnosti in udobja uporabnikov ter povečevanje kapacitet parkirnih mest za tovorna vozila.

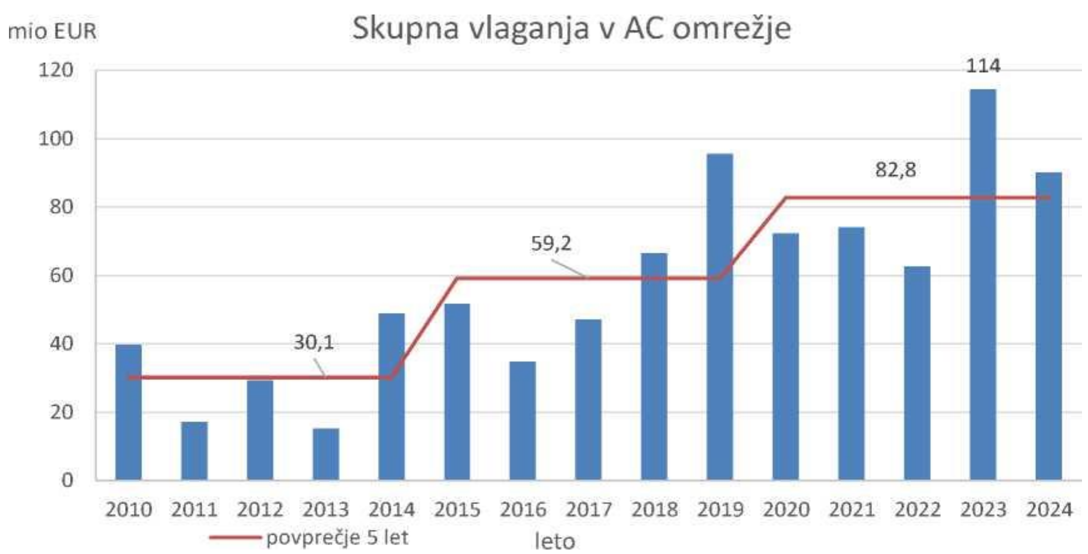
Vsem tovrstnim investicijam je skupno to, da se v veliki večini primerov izvajajo na podlagi Zakona o cestah (ZCes-2) in Pravilnikom za izvedbo investicijskih vzdrževalnih del in vzdrževalnih del v javno korist na javnih cestah, za katere ni potrebno pridobiti gradbenega dovoljenja.

Celoten obseg vlaganj v obstoječe AC omrežje, ki vključuje gradbene obnove, obnove elektro strojne opreme, naložbe v zaščito pred hrupom ter izredne naložbe znaša v tem obdobju 860,47 mio EUR investicij, v povprečju 57,36 mio EUR na leto. V zadnjih petih letih je bilo povprečje vlaganj v obstoječe AC omrežje 82,77 mio EUR.

V naslednji tabeli je prikaz vlaganj v zadnjem 10 letnem obdobju, deljeno po vrsti spremljanih investicij.

Realizacija v mio EUR	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**	**SKUPAJ**
Gradbena dela pri obnavljanju AC	29,29	27,97	36,32	41,56	51,57	56,36	62,13	44,16	86,13	67,38	502,87
Elektro-strojna dela in ITS	7,40	3,34	7,45	7,23	10,33	8,95	5,19	6,12	13,93	12,61	82,55
Izbolj큄anje prometne varnosti	1,46	2,49	2,82	1,59	3,37	1,15	2,50	0,31	2,02	5,00	22,71
Preureditev malih po훾ivali큄훾					0,08	0,12	0,02	6,43	4,46	0,82	11,93
Skupaj obnavljanje in nalo탑be	**38,16**	**33,80**	**46,59**	**50,38**	**65,34**	**66,58**	**69,85**	**57,02**	**106,53**	**85,82**	**620,06**
Izvedba PH ukrepov	13,51	0,88	0,22	1,80	5,29	0,46	0,47	0,30	4,89	3,22	31,05
Ru큄enje CP ob uvedbi DARSGO	0,07	0,18	0,28	14,11	24,62	5,20	1,71	0,25			46,41
Rekonstrukcija priklju훾kov BTC			0,04	0,25	0,41	0,19	2,10	5,17	2,98	1,05	12,19
Skupaj investicije v obstoje훾e AC	**51,74**	**34,86**	**47,13**	**66,53**	**95,66**	**72,43**	**74,13**	**62,74**	**114,41**	**90,08**	**709,72**

Preglednica 2: Prikaz vlaganj v obdobju v letih 2015-2024



Graf 4: Skupna vlaganja v AC omre탑je v letih 2010-2024

6. Prihodnja vlaganja

Investicijski cikel vlaganj v obstoje훾e avtocestno omre탑je se bo v prihodnjih letih neprekinjeno nadaljeval. Na podlagi trenutnega stanja infrastrukture, njene starosti, pove훾anih prometnih obremenitev ter potrebe po izbolj큄anju funkcionalnosti in prometne varnosti je pri훾akovati nadaljnjo rast obsega in vrednosti investicij v obnovo ter posodobitev avtocestnega sistema.

Na to 탑e ka탑e predviden obseg realizacije v letu 2025, ki bo bistveno presegel vrednosti iz preteklih let. Na podro훾ju gradbenih del, povezanih z obnovo avtocest, je ocenjena vrednost investicij pribli탑no 100 mio EUR, skupno predvidena vlaganja v obstoje훾e AC omre탑je pa bodo presegala 130 mio EUR.

Trenutno je v izvajanju ve훾je 큄tevilo projektov obnov, s katerimi bo v prihodnjih letih izvedeno 84,6 kilometra smernih vozi큄훾. Poleg tega so v teku postopki javnega naro훾anja za dodatnih 53,6 kilometra smernih vozi큄훾, kar potrjuje kontinuiran in dolgoro훾no na훾rtovan pristop k obnovi obstoje훾ega omre탑ja.

V prihodnjem obdobju je pričakovati tudi finančne spodbude za projekte z dvojno rabo. Ti projekti so posebej usmerjeni v izboljšanje infrastrukture tako, da poleg vsakodnevne prometne funkcionalnosti omogočajo tudi uporabo za posebne obremenitve v primeru obrambnih potreb. Pri tem bo osrednji poudarek na premostitvenih objektih, kot so mostovi in viadukti z omejeno nosilnostjo, ki bodo načrtovani ali rekonstruirani tako, da bodo lahko prenesli povečano obtežbo, ne da bi bila ogrožena njihova stabilnost in dolgoročna uporabnost. DARS v ta namen skrbno spremlja razpoložljive evropske finančne instrumente ter možnosti vključitve tovrstnih projektov v sofinanciranje.

Pomemben del prihodnjih vlaganj bo namenjen tudi izvedbi protihrupnih ukrepov, saj se zaradi stalnega večanja prometnih obremenitev potrebe po zaščiti pred hrupom povečujejo. Na podlagi zadnjega izvedenega monitoringa hrupa je bilo identificiranih 19 večjih območij, kjer je potrebno pristopiti k izvedbi ukrepov za zmanjšanje vplivov cestnega prometa na bivalno okolje. Večina teh odsekov se prostorsko prekriva z odseki, predvidenimi za obnovo, zato je načrtovano, da se protihrupni ukrepi izvedejo sočasno s celovito obnovo posameznih cestnih odsekov. Takšen pristop omogoča učinkovitejšo izvedbo, racionalnejšo porabo sredstev ter manjše obremenitve za uporabnike cest.

Največji izziv predstavljajo projekti, ki bodo namenjeni bistvenemu povečanju kapacitete obstoječe avtoceste. Širitev ljubljanskega obroča je tema, ki se obravnava že več kot desetletje, ves čas podprta z ustreznimi napovedmi o rasti prometa. DARS je v zadnjih letih na tem področju izvedel številne dodatne aktivnosti. Za zahodno obvoznico je v teku izdelava projektne dokumentacije za izvedbo del ter pridobitev gradbenega dovoljenja. Gre za območje, za katerega je bil državni prostorski načrt že sprejet. Za preostala območja je bila izdelana novelacija elaborata Prikaz rešitev na zemljiškem katastru in preveritev možnosti njihove izvedbe v okviru vzdrževalnih del v javno korist (VDJK), v katerem je bilo preverjeno, katere predvidene ukrepe za širitev avtoceste na območju ljubljanskega AC obroča in vpadnih AC je mogoče izvajati v okviru vzdrževalnih del v javno korist oziroma kateri ukrepi se bodo lahko izvajali na podlagi sprejetih prostorskih izvedbenih aktov (državni prostorski načrt oz. občinski prostorski načrt). Iz elaborata izhaja, da je večino širitev mogoče izvesti v okviru VDJK, vendar pa je potrebna sprememba Občinskega prostorskega načrta Mestne občine Ljubljana. Ker je ravno v teku sprememba OPN MOL, so bile izdelane strokovne podlage za obseg predhodne pobude DARS za ureditev južne obvoznice in del vzhodne obvoznice ljubljanskega avtocestnega obroča. S sprejetjem spremembe OPN MOL bo zagotovljena prostorska podlaga za izvedbo celovite razširitve tega dela ljubljanskega obroča. Zaradi zahtevnosti razširitve dolenjskega avtocestnega kraka je bil za ta odsek predlagan postopek sprejema DPN za ureditev dolenjskega kraka AC od razcepa Malence do priključka Grosuplje vzhod.

Ne glede na to, da za del posegov širitve ljubljanskega obroča ne bo potrebno pridobiti gradbenega dovoljenja, pa bo investicija zelo zahtevna iz razloga omejenega prostora in zagotavljanja dodatnih nepremičnin za gradnjo, tehničnih pogojev gradnje na barjanskih tleh in sočasnih vplivov na obstoječe vozišče, po katerem se bo ves čas moral odvijati promet ter nenazadnje zaradi postopkov pridobivanja vseh drugih potrebnih dovoljen, med katere sodi tudi pridobitev okoljevarstvenega soglasja za nameravan poseg.

7. Izzivi in tveganja pri vlaganju v cestno infrastrukturo

Za uspešno vlaganje v cestno infrastrukturo je ključno celovito obvladovanje tveganj že v fazi načrtovanja ukrepov. Identificiranih je več izzivov in tveganj v povezavi z gospodarjenjem s cestno infrastrukturo in pripravo nabora ukrepov.

- Nezanesljive napovedi življenjske dobe lahko privedejo do podcenjevanja potrebnih investicij za vzdrževanje ali prezgodnjega začetka potrebnih obnov, kar vodi v povečanje stroškov ali nezadostno vzdrževanje.
- Nezanesljivost podatkov o trenutnem stanju infrastrukture oteži natančno

oceno potrebnih popravkov ali nadgradenj, napačne ali nepopolne informacije o materialih, starosti, stopnji obrabe ali prometnih obremenitvah pa lahko privedejo do napačnih odločitev pri vlaganjih.
- Spremembe okolja in podnebja vplivajo na stanje cestne infrastrukture, saj lahko vremenske razmere, kot so ekstremni dež, vročina ali zmrzal povzročijo drugačno obrabo cestišč in mostov. Dolgoročne napovedi podnebnih sprememb so pogosto negotove, kar otežuje oceno vpliva teh spremembe na vzdrževanje in investicije.
- Spreminjajoče se prometne obremenitve otežujejo dolgoročne napovedi potrebnih prilagoditev infrastrukture.
- Tehnološki napredek, kot so napredni materiali, pametne ceste in sistemi za avtomatizacijo prometa, lahko vplivajo na trajnost in potrebo po prilagoditvah obstoječe infrastrukture. Negotovo pa je napovedati, kdaj in kako bodo te tehnologije postale široko dostopne in uporabljene.
- Kritična infrastruktura in nepredvideni dogodki, saj je cestna infrastruktura pogosto povezana z drugimi vrstami infrastrukture, kot so električna omrežja, vodovod in kanalizacija. Naravne nesreče ali drugi nepričakovani dogodki, lahko povzročijo nenadne poškodbe cest ali drugih pomembnih objektov, ki niso zajeti v običajnih načrtih za vzdrževanje in obnovo.
- Pomanjkanje finančnih virov saj cestna infrastruktura zahteva velika finančna vlaganja, tako za izgradnjo kot za redno vzdrževanje. Finančne omejitve lahko povzročijo, da se vlaganja v infrastrukturo preloži ali zmanjšajo, kar lahko povzroči poslabšanje stanja cest in posledično dolgoročno večje stroške.

Za učinkovito obvladovanje tveganj smo uvedli vrsto mehanizmov. Pri tem uporabljamo modele napovedovanja stanja infrastrukture, ki temeljijo na umetni inteligenci, strojnem učenju in naprednih statističnih metodah, kar omogoča natančnejše in zanesljivejše napovedi. Z zbiranjem in sprotno analizo podatkov o stanju infrastrukture v realnem času prilagajamo dolgoročne napovedi ter posledično optimalno usmerjamo razpoložljiva sredstva. Pomemben del sistema predstavlja tudi fleksibilnost načrtovanja, ki omogoča sprotno vključevanje novih informacij, sprememb prometnih obremenitev ter podnebnih dejavnikov. Poleg tega redno podpiramo in vlagamo v raziskave o novih materialih, tehnologijah in gradbenih postopkih, kar povečuje prilagodljivost in trajnost infrastrukture v prihodnosti.

Vse predstavljene načrtovane aktivnosti lahko ostanejo zgolj na ravni načrtov, če ne bodo zagotovljene zadostne kapacitete vseh potrebnih resursov za njihovo učinkovito izvedbo. Za uspešno realizacijo investicij je ključno, da so zagotovljeni ustrezni kadrovski, tehnični, finančni in organizacijski pogoji, ki omogočajo pravočasno in kakovostno izvedbo projektov.

DARS dodatno pozornost namenja temu, da bodo investicije načrtovane učinkovito in celovito, s standardiziranimi in preverjenimi tehničnimi rešitvami. Takšen pristop prispeva k večji ponovljivosti, krajšim časom izvedbe in zmanjšanju tveganj v fazi gradnje. Na strani gradbene in inženirske panoge pa je odgovornost, da vzpostavi in razvija napredne tehnološke rešitve in inovativne pristope, ki bodo omogočali dodatno optimizacijo gradnje, zmanjšanje okoljskih vplivov in učinkovitejšo rabo virov.

Kljub temu ostaja eden največjih izzivov zagotavljanje ustrezno usposobljenega inženirskega ter tehničnega kadra, ki ima dovolj znanja in izkušenj za načrtovanje, vodenje in izvedbo zahtevnih infrastrukturnih projektov. Dolgoročno bo zato potrebno vlagati tudi v izobraževanje, prenos znanja in krepitev strokovnih kompetenc, kar bo omogočilo trajno ohranjanje in nadgradnjo trenutnih zmogljivosti slovenskega gradbenega sektorja

8. Zaključek

Skupni imenovalec večine predvidenih projektov je zagotavljanje ustreznega stanja cestne infrastrukture ob pričakovani nadaljnji rasti prometnih obremenitev. Obnovitvena dela ne pomenijo več zgolj sanacije dotrajanih odsekov, temveč vključujejo tudi tehnološko in funkcionalno nadgradnjo cestnih elementov, ki bodo lahko v prihodnje prevzeli večje prometne obremenitve ter učinkoviteje naslovili sodobne izzive, med katerimi ima pomembno vlogo tudi trajnostna mobilnost.

Ukrepi, ki jih DARS izvaja oziroma jih načrtuje v bližnji prihodnosti, sledijo principom trajnostne mobilnosti. Širitev avtocestnih odsekov z dodatnimi voznimi pasovi sama po sebi ne pomeni spodbujanja dodatnega lokalnega prometa. Povečanje prometnih tokov se pojavi predvsem takrat, ko uporabniki nimajo na voljo ustreznih alternativnih načinov mobilnosti. Z uvedbo učinkovitih ukrepov trajnostne mobilnosti izven avtocestnega omrežja bo mogoče trenutno predvidene infrastrukturne prilagoditve z manjšimi nadgradnjami prometne in cestne opreme v prihodnje uporabiti tudi za razvoj bolj trajnostnih prometnih rešitev.

Kakovostna in vzdrževana infrastruktura predstavlja temelj razvoja sodobne družbe ter prilagajanja potovalnim navadam prebivalcev. V članku je predstavljen sistematičen pristop k stalnim vlaganjem v obstoječe avtocestno omrežje, vendar je treba poudariti, da ob predvidenem razvoju mobilnosti to samo po sebi ne bo zadostovalo. Za dolgoročno učinkovitost bo potrebna tudi interdisciplinarna nadgradnja celotne prometne infrastrukture ter družbene prilagoditve, ki bodo prispevale k postopni spremembi tradicionalnih načinov prevoza.

Skupni cilj ostaja jasen - ustvariti uravnotežen, učinkovit in okolju prijazen prometni sistem, ki bo izboljšal kakovost življenja prebivalcev, zmanjšal vplive na okolje ter omogočil trajnostno gospodarsko rast. Za dosego tega cilja, pa bo potrebno ohraniti oz. še nadgraditi stalna vlaganja v obstoječo infrastrukturo tudi v bodoče.

Stanje ceste, veliko bolj kot udobje in varnost – poraba goriva / energije in emisije

Road condition, much more than comfort and safety: fuel consumption and emission

Juan José Potti (Dr, Executive President of Asefma, Spain, jjpotti@asefma.com.es)

Abstract

Road transport generates over 20% of EU greenhouse gas emissions, and pavement condition has a strong impact on vehicle fuel efficiency. Poor road surfaces increase rolling resistance, fuel consumption, emissions, tire wear, and vehicle damage. Spain's deteriorating road network illustrates these consequences clearly. Using connected vehicle data on Madrid's M-50 highway, researchers measured conditions before and after pavement rehabilitation. Roughness (IRI) significantly decreased, improving comfort, safety, and energy performance. Fuel consumption and CO_2 emissions dropped by roughly 9–10% across rehabilitated sections. Annually, this equates to millions of liters of fuel and tens of thousands of tonnes of CO_2 saved. Economic benefits exceed €17 million per year in fuel savings alone. The study proposes a new CARES philosophy: Comfort, Safety, and reducing Emissions, Consumption, and Energy. Reframing maintenance as climate action can unlock funding, improve public communication, and accelerate decarbonization..

Key words. *Pavement Rehabilitation, Fuel Consumption, CO_2 Emissions, Connected Vehicles, Road Roughness (IRI), Rolling Resistance, CARES Philosophy.*

1. Introduction

Road transport represents one of the most significant contributors to greenhouse gas emissions in the European Union, accounting for more than 20% of total emissions. While considerable attention has been devoted to developing cleaner fuels, improving engine efficiency, and promoting electric vehicles, the condition of road infrastructure itself has received comparatively less scrutiny as a factor influencing environmental impact. However, emerging evidence suggests that the quality of road pavements plays a crucial role in determining vehicle fuel consumption and associated CO_2 emissions, presenting an often-overlooked opportunity for environmental improvement.

The proper maintenance of road networks is fundamental not only for preserving and improving citizens' quality of life but also for ensuring economic competitiveness and environmental sustainability of transportation systems. Well-maintained road infrastructures enable smooth, safe, and efficient circulation, minimizing both accident risk and vehicle energy consumption.

Conversely, pavements in poor condition generate significant negative impacts: they increase fuel consumption, accelerate tire wear, elevate pollutant emissions—particularly greenhouse gases (GHG)—and can even cause structural damage to vehicles. These effects, beyond direct economic implications for users and operators, also represent a growing environmental burden and a reduction in the quality of public mobility services.

In Spain, the state of road network conservation has progressively deteriorated over recent decades. According to the 2020 report by the Spanish Road Association (Asociación Española de la Carretera), Spanish roads are in a "deficient" state, very close to the "very deficient" level. One in every thirteen kilometers of the national network presents significant damage on more than half of the pavement surface, with the presence of potholes, ruts, and longitudinal and transverse cracks.

This lack of conservation has caused a loss of asset value of 36% on state roads and 38% on roads managed by Autonomous Communities and Provincial Councils between 2001 and 2017. This progressive degradation directly impacts road safety, transport energy efficiency, and territorial competitiveness, while simultaneously increasing maintenance costs and generating higher pollutant emissions.

The first Spanish institution to demonstrate to public managers the importance of proper road network maintenance—not only to guarantee comfortable and safe driving but also to combat the transport sector's contribution to CO_2 emission levels—was the Spanish Association of Asphalt Mixture Manufacturers (ASEFMA). For more than ten years, alongside its European counterpart EAPA (European Asphalt Pavement Association), ASEFMA has been working to demonstrate how good pavement condition results in fuel savings and, consequently, reduced pollutant emissions.

Together, ASEFMA and EAPA, with the invaluable drive of Spanish president Juan José Potti, developed the EMIPAV project (www.emipav.eu) as well as the International Road Maintenance Day (IRMD), celebrated on the first Thursday of April each year since 2017, to raise awareness about this reality and seek a new vision for road maintenance investments.

Eight years have passed since the parliamentary breakfast of November 18, 2016, when EAPA, EUPAVE, and FEHRL presented their groundbreaking document highlighting the huge CO_2 savings offered by maintaining and upgrading roads. Now, with the availability of big data and advanced analytics from connected vehicles, we can accurately quantify the savings in emissions and energy that can be achieved through improved road conditions. This new understanding demands a strategic shift in how we approach, communicate, and advocate for road maintenance. If more than 20% of emissions generated in the European Union come from road transport, and if we can now accurately quantify how much energy and emissions we can save annually through proper road maintenance, isn't it time to act and propose a new strategy to defend the need to properly maintain roads?

The present study, developed by the state-owned company SEITT in collaboration with the Polytechnic University of Valencia and the company XOUBA, takes as its starting point the hypotheses launched by these institutions to precisely demonstrate their veracity. The study proceeds to measure real characteristics of the pavement, user fleet, and emissions before and after carrying out comprehensive pavement rehabilitation works, in order to scientifically quantify the possible fuel savings and their impact on reducing greenhouse gas emissions.

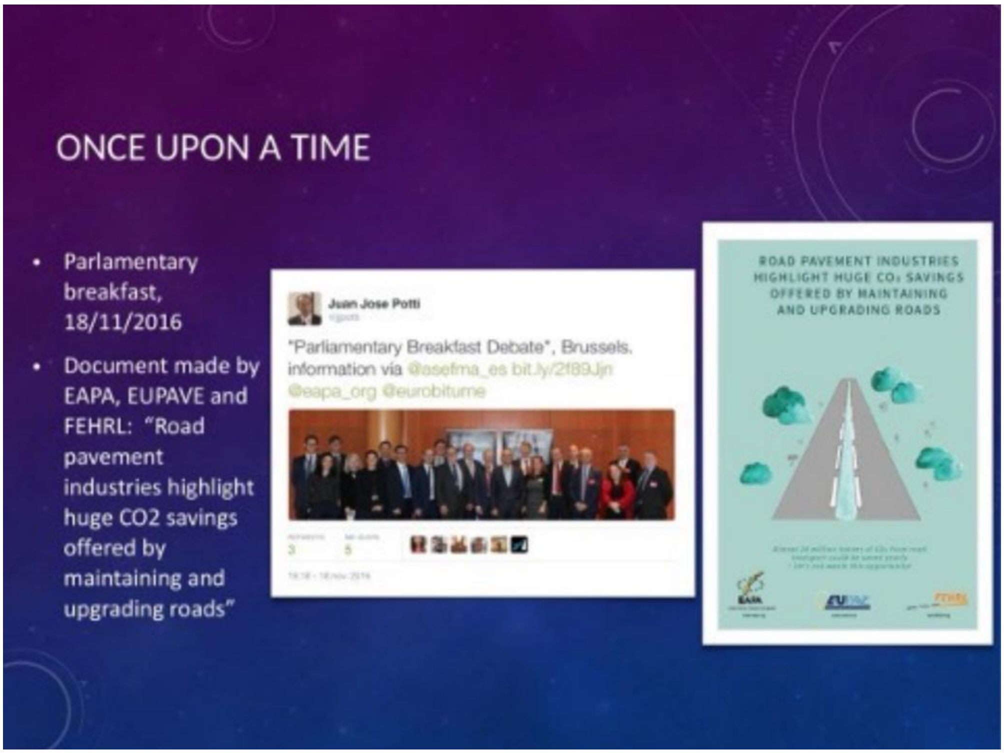


Fig. 1: Parlamentary breakfast 18/11/2016 to present the document: "Road pavement industries highlight huge CO2 savings offered by maintaining and upgrading roads"

2 CONTEXT: THE M-50 HIGHWAY

The M-50 is a high-capacity highway that partially encircles the Spanish capital of Madrid, with a total length of 85 kilometers and average daily traffic that, in some sections, exceeds 100,000 vehicles. This infrastructure forms part of the network managed by the State Society for Land Transport Infrastructures (SEITT), a public company attached to the Ministry of Transport that operates more than 700 km of toll roads (415 km) and motorways (285 km), after assuming in 2019 the management of the operation of 9 toll roads previously managed by eight concession companies that had entered bankruptcy proceedings in 2012.

Within the framework of its 2023-2027 investment plan, SEITT contemplated an investment of 73 million euros in improving the pavement of the M-50 highway. This represented a perfect opportunity to analyze, through a before-and-after approach and with data from connected vehicles, the effect of interventions on several factors: the surface condition of the pavement, circulation speed, consumption, and emissions associated with transport. The M-50 study focuses specifically on 28.10 km of rehabilitated sections, with an estimated annual average daily traffic (AADT) of 115,000 vehicles in 2025.

3 METHODOLOGY

The study was structured around a comprehensive five-phase methodology designed to isolate the effect of pavement condition on vehicle energy consumption while minimizing the influence of external factors such as traffic congestion and meteorological conditions. This rigorous approach ensures that observed differences in vehicle performance can be attributed with greater certainty to road infrastructure conditions.

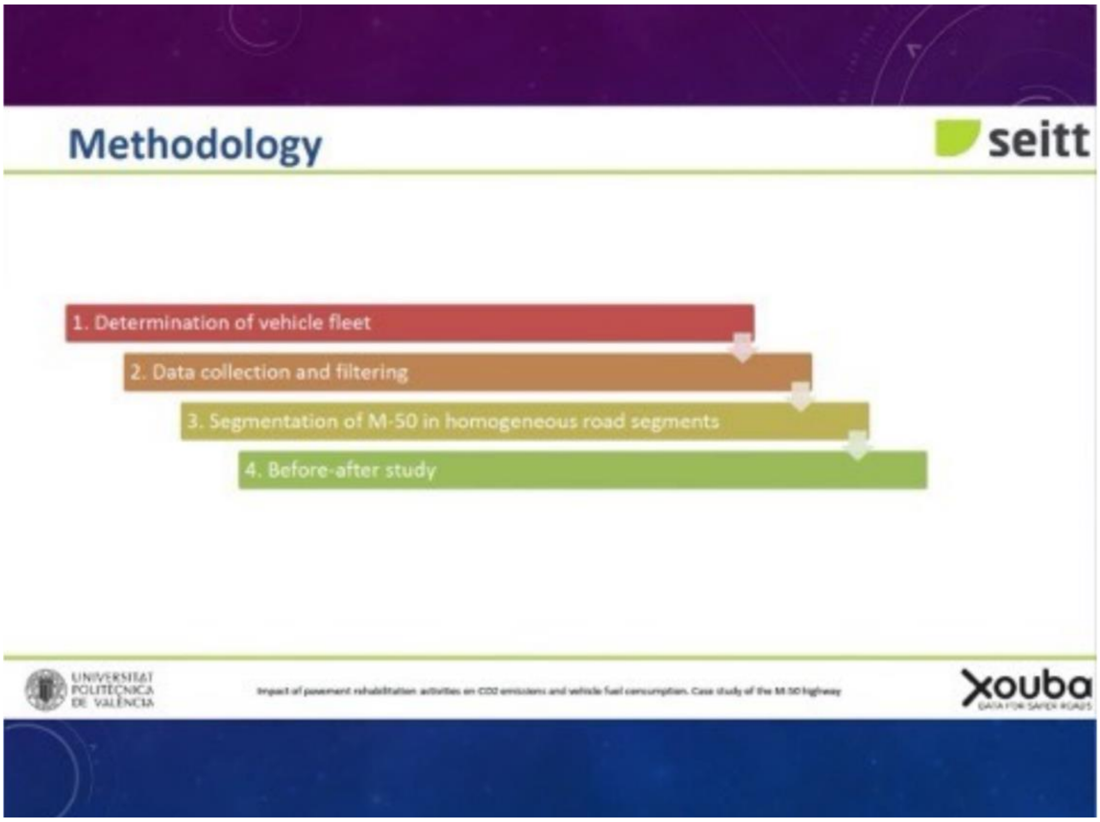


Fig. 2: Methodology used in the study

3.1 Validation of Roughness Data from Connected and Autonomous Vehicles

Prior to developing the study, it was necessary to verify the validity of surface roughness data provided by connected and autonomous vehicles (CAVs), given that they constitute the basis for road segmentation and estimation of the impact of interventions. For this purpose, a direct comparison was carried out between the International Roughness Index (IRI) values derived from CAVs and those obtained through survey campaigns with specialized equipment, specifically for the same observation dates (November 2023).

The comparison revealed that while CAV-derived values show a systematic offset compared to traditional auscultation equipment, the evolution of values along the road axis coincides remarkably well. This difference, already identified in previous studies—including one developed by the authors of this work—is explained by the different nature of the measurement methods: while CAVs capture the dynamic behavior of rolling under real driving conditions, auscultation equipment employs high-precision sensors under controlled conditions. Despite this offset, the coincidence in the evolution of values along the road axis validates the reliability of CAV data for analytical purposes, especially when the objective is to compare relative differences rather than absolute values. Since this study focuses on evaluating the improvement in roughness after rehabilitation interventions—that is, on relative variations in IRI—the data provided by CAVs are considered sufficiently valid and representative.

3.2 Determination of Vehicle Fleet Composition

Accurate characterization of the vehicle fleet circulating on the M-50 is essential for properly weighting the energy and environmental impact of rehabilitation interventions, given that each vehicle typology presents differentiated consumption and emission patterns. To achieve this characterization, traffic data provided by the General Directorate of

Traffic (DGT) were used, obtained from traffic cameras installed in both directions of circulation in the vicinity of kilometer points PK 18+000 and PK 50+000.

These devices allowed detailed information to be collected for each vehicle, including vehicle type, fuel type, year of registration, and environmental label. After a process of filtering and classification, the distribution of the vehicle fleet for weekdays was established, discarding minority categories. The data reveal that the fleet is composed mainly of diesel passenger cars (45%), gasoline passenger cars (30%), diesel vans (12%), diesel trucks (8%), and diesel buses (5%).

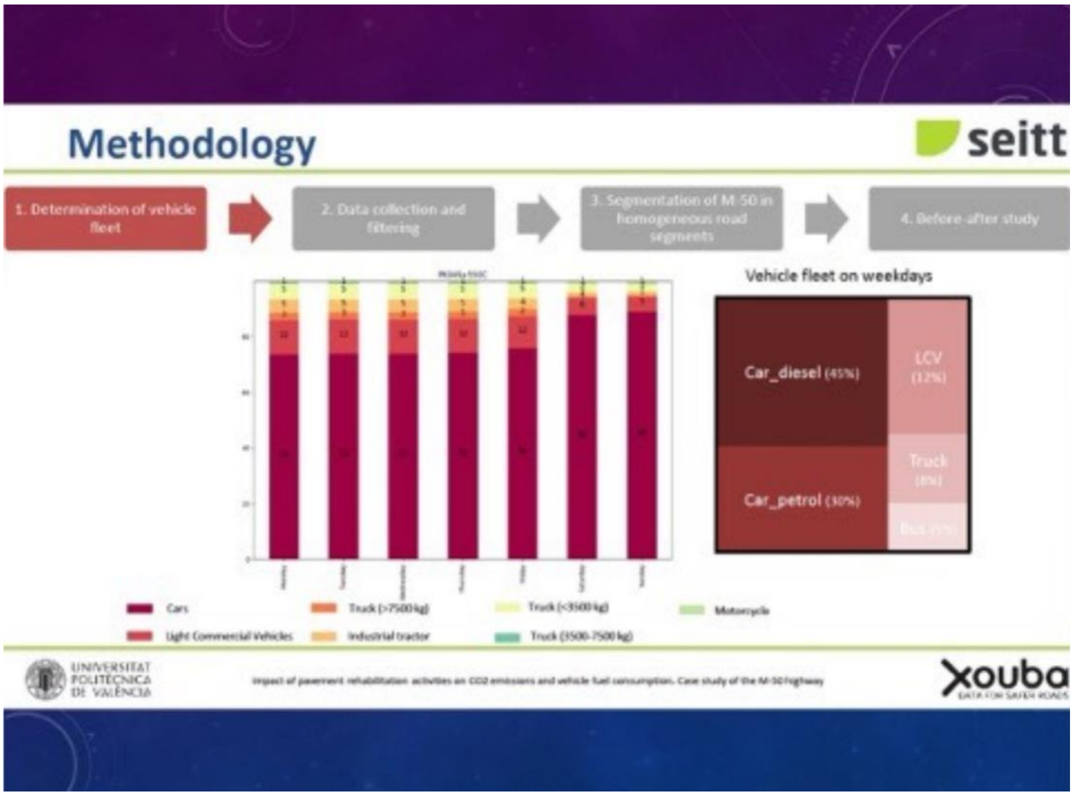


Fig. 3: Evolution of the traffic during the week and vehicle fleet

On holidays, as expected, a significant reduction was observed in the circulation of commercial vehicles (vans, trucks, and buses), while the proportion of passenger cars increased. Additionally, from the hourly traffic intensity curves obtained at the two observation points, off-peak hours for weekdays were identified. These time slots—from 00:00 to 07:00, from 10:00 to 13:00, and from 19:00 to 00:00—were selected as reference for the before-and-after analysis, since they allow isolating the effect of pavement condition without congestion or other factors associated with traffic volume interfering with fuel consumption. This approach ensures that observed differences in vehicle energy performance can be attributed with greater certainty to road infrastructure conditions.

3.3 Data from Connected and Autonomous Vehicles

The second phase of the study is based on the use of data provided by connected and autonomous vehicles (CAVs), an emerging source of information that allows expanding the coverage and frequency of monitoring the state of road infrastructures. These vehicles, equipped with sensors integrated by manufacturers (OEM), such as accelerometers, speed sensors, and positioning and mobile connectivity systems, continuously generate relevant data for evaluating the operational behavior of the road.

Unlike traditional auscultation or visual inspection methods—which require specific equipment, technical personnel, and deployment on the ground—the CAV-based approach offers a more efficient and less costly alternative for obtaining detailed information about the surface quality of the pavement. In this study, data from November 2023 and 2024 have been used, although for methodological conceptualization and validation, additional data corresponding to other months have also been utilized.

The main variables analyzed have been circulation speed, fuel consumption, and surface roughness. Speed and consumption have been provided by the suppliers Webfleet and INRIX, which deliver temporal records with a variable frequency depending on vehicle make and model, at intervals of several seconds. For its part, information relating to pavement roughness has been supplied by NIRA Dynamics, based on the aggregated analysis of data from vehicles that routinely circulate on the road network. In this sense, the supplier delivers information referring to road segments of approximately 20 meters in length, generated from commercial cartographies used by navigation applications. For the development of this study, the values provided have been used to estimate roughness per hectometer of road in dm/hm.

The use of this type of data represents a significant advantage over conventional methods, not only by reducing costs and eliminating subjectivities but also by increasing the reliability of measurements. By having multiple observations generated by complete vehicle fleets in real circulation, it is possible to characterize the state of the road with greater precision, detect deterioration zones, and carry out continuous monitoring of pavement evolution without the need to instrument vehicles or deploy periodic survey campaigns.

3.4 Identification of Homogeneous Road Segments

The third methodological phase consists of segmenting the M-50 highway into homogeneous sections, with the objective of ensuring that the conditions analyzed in each study unit are comparable and allow precisely attributing the observed effects to pavement condition. To achieve this, three fundamental criteria were considered.

First, information relating to the planning and execution of pavement rehabilitation activities provided by SEITT was incorporated. This allowed identifying and delimiting the sections in which interventions were effectively executed between November 2023 and November 2024, ensuring the consistency of the before-and-after analysis. The second criterion considered was the vertical alignment of the road, given that the longitudinal inclination of the road significantly influences the energy consumption of vehicles, especially in heavy fleets. Likewise, the state of the surface condition of the pavement has been included as a third criterion, represented by the pavement roughness values available for November 2023, that is, before the execution of rehabilitation works.

Given that roughness data present certain local variability associated with the measurement method and circulation environment, different moving average sizes (500 meters, 1 kilometer, 2 kilometers, and 5 kilometers) were applied to smooth point oscillations and detect significant trend changes in pavement quality. This technique allowed more robustly identifying the boundaries between segments with clearly differentiated conditions.

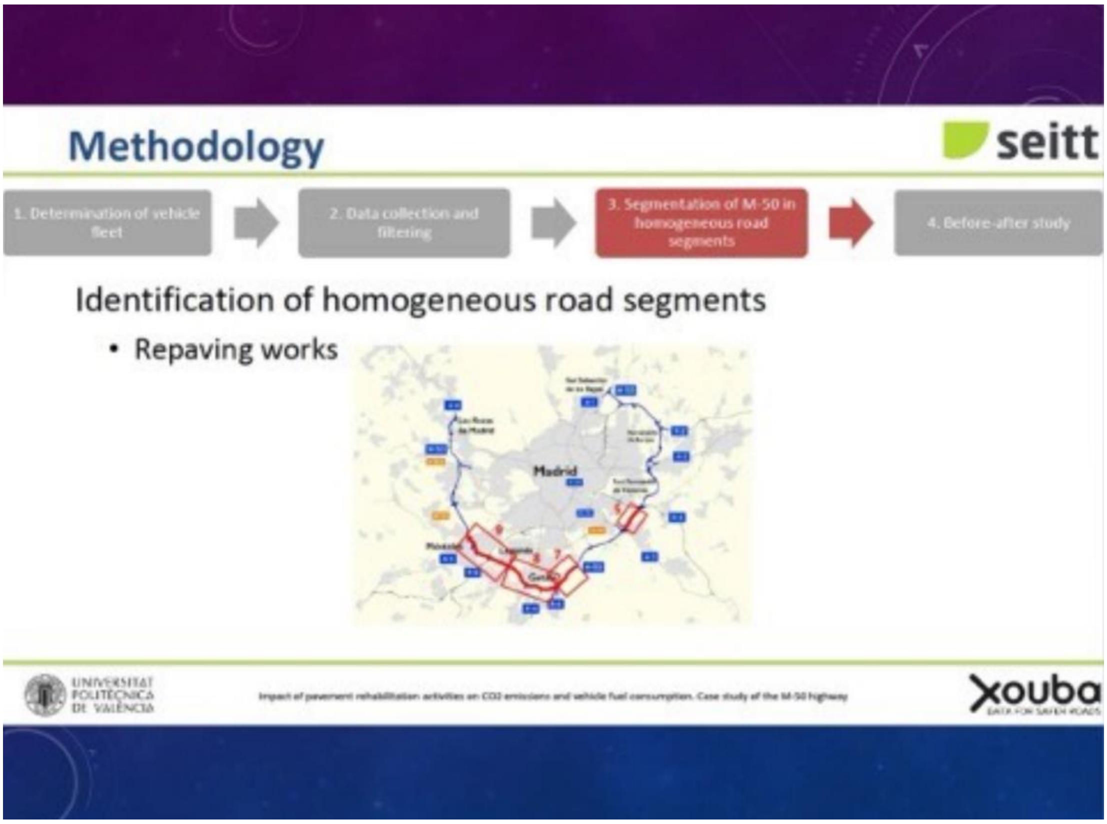


Fig. 4: Identification of the homogeneous road segments

As a result of the segmentation process, a total of 23 homogeneous sections were identified along the route of the M-50 in the increasing direction. Of these, seven sections were selected for the development of detailed analysis, corresponding to those in which, as of November 2024, rehabilitation interventions had already been completed. These sections represent a diverse sample in terms of layout and previous condition, which allows evaluating the impact of pavement improvements in different operational contexts.

The seven analyzed sections vary in length from 1.30 km to 9.90 km, with average gradients ranging from -2.30% to 2.07%, and initial roughness values (November 2023) between 1.07 and 2.53 dm/hm. This diversity ensures that the study captures the impact of rehabilitation under various geometric and surface condition scenarios.

3.5 **Before-After Comparative Study**

The fourth and final methodological phase corresponds to the comparative before-and-after analysis of fuel consumption and CO_2 emissions, with the objective of quantifying the impact derived from pavement rehabilitation interventions. This analysis is developed exclusively on the seven homogeneous sections previously identified in which, as of November 2024, pavement improvement works had already been completed. The comparison is made between data corresponding to November 2023 (previous situation) and November 2024 (subsequent situation), thus guaranteeing equivalent climatic conditions and avoiding seasonal biases.

The procedure begins with the calculation of fuel consumption for each individual vehicle. From the data provided by connected vehicles, temporal records are available of the amount of fuel consumed between two consecutive measurement points, which allows estimating the average consumption between them and, subsequently, per hectometer. Once individual values are determined, data are aggregated to obtain the average consumption per hectometer for each combination of vehicle type and fuel type.

It should be noted that, in order to minimize the influence of congestion or other factors external to pavement condition, all calculations have been performed exclusively with data corresponding to off-peak hours identified on weekdays. These time slots—from 00:00 to 07:00, from 10:00 to 13:00, and from 19:00 to 00:00—represent circulation conditions in free-flow regime, which allows attributing with greater certainty the differences in consumption and emissions to road infrastructure conditions.

Based on the distribution of the M-50 vehicle fleet on weekdays, a typical vehicle or design vehicle is constructed, composed of a weighted combination of diesel passenger cars (45%), gasoline passenger cars (30%), light vans (12%), trucks (8%), and buses (5%). This composition allows performing a representative calculation of the average traffic behavior on the road. The average consumption per hectometer of the design vehicle is calculated by weighting the values obtained by vehicle type and fuel, according to their relative weight in the fleet.

Subsequently, the fuel consumption of each vehicle is converted into CO_2 emissions using the conversion factors established by the Ministry for Ecological Transition and Demographic Challenge: 2.64 kg CO_2/liter for diesel and 2.35 kg CO_2/liter for gasoline. From these conversions, individual emission per hectometer is determined, which is aggregated by vehicle type and, finally, weighted to estimate the emissions of the design vehicle.

This approach allows estimating, with high spatial resolution and under real operating conditions, the average fuel consumption and CO_2 emissions in each of the analyzed sections, both before and after the interventions. In this way, it is possible to isolate the direct effect of surface roughness improvement on the energy and environmental performance of vehicles after the execution of pavement rehabilitation interventions on the M-50 highway, specifically in the increasing direction of circulation.

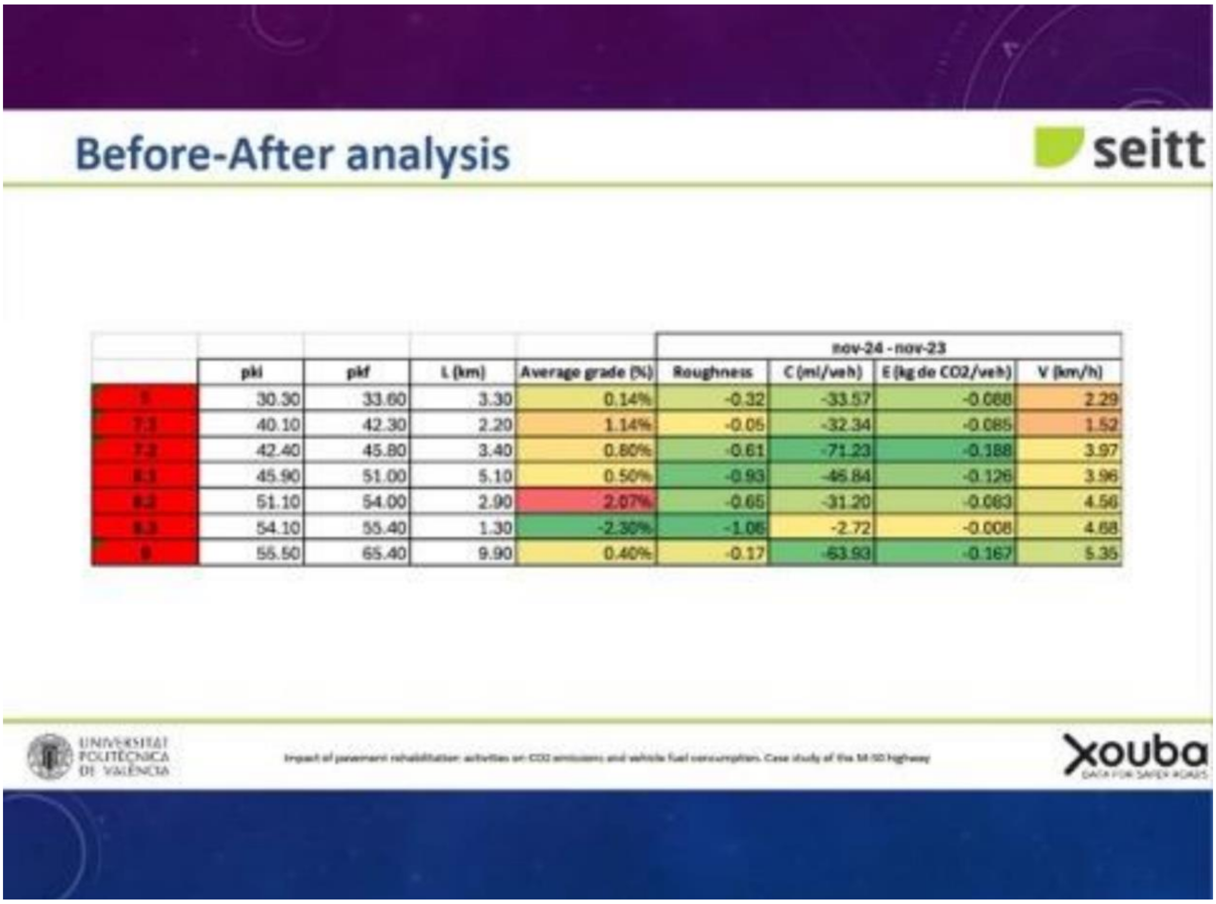
4 Results: Before-After Analysis

The comparative analysis revealed significant improvements in road condition and a corresponding reduction in fuel consumption and CO_2 emissions across all seven rehabilitated sections. The results demonstrate a clear correlation between reduced pavement roughness and improved vehicle energy efficiency, providing compelling evidence for the environmental benefits of road maintenance.

The data show that after rehabilitation, all seven sections experienced substantial reductions in surface roughness. The roughness improvements ranged from -0.05 dm/hm in section 7.1 to -1.06 dm/hm in section 8.3, with most sections showing reductions between -0.32 and -0.93 dm/hm.

These improvements in pavement quality translated directly into measurable reductions in fuel consumption and emissions.

Fuel consumption reductions were observed across all sections, with decreases ranging from -2.72 ml/vehicle in section 8.3 to -71.23 ml/vehicle in section 7.2. The magnitude of these reductions varied depending on several factors, including the initial pavement condition, the extent of roughness improvement, and the vertical alignment characteristics of each section. Sections with steeper gradients generally showed greater absolute reductions in fuel consumption, as the improved pavement condition reduced the additional energy required to overcome both rolling resistance and gravitational forces.



					nov-24 - nov-23			
	pki	pkf	L (km)	Average grade (%)	Roughness	C (ml/veh)	E (kg de CO2/veh)	V (km/h)
5	30.30	33.60	3.30	0.14%	-0.32	-33.57	-0.088	2.29
7.1	40.10	42.30	2.20	1.14%	-0.05	-32.34	-0.085	1.52
7.2	42.40	45.80	3.40	0.80%	-0.61	-71.23	-0.188	3.97
8.1	45.90	51.00	5.10	0.50%	-0.93	-46.84	-0.126	3.96
8.2	51.10	54.00	2.90	2.07%	-0.65	-31.20	-0.083	4.56
8.3	54.10	55.40	1.30	-2.30%	-1.06	-2.72	-0.008	4.68
9	55.50	65.40	9.90	0.40%	-0.17	-63.93	-0.167	5.35

The corresponding reductions in CO_2 emissions ranged from -0.008 kg CO_2/vehicle in section 8.3 to -0.188 kg CO_2/vehicle in section 7.2. When these reductions are scaled up to account for the traffic volume on the M-50, the environmental impact becomes substantial. With an average daily traffic of approximately 115,000 vehicles and assuming a 50-50 directional split, the rehabilitated sections in the increasing direction experience approximately 57,500 vehicle passages per day.

An important finding from the analysis is the influence of vertical alignment on the magnitude of benefits achieved. Sections with greater average gradients, such as section 8.2 with a 2.07% gradient, showed particularly significant improvements. This can be explained by the fact that on inclined sections, vehicles operate at higher power outputs, and any reduction in rolling resistance due to improved pavement condition has a proportionally greater effect on fuel consumption.

Average circulation speeds also increased following rehabilitation, with improvements ranging from 1.52 km/h to 5.35 km/h. These speed increases reflect not only the improved comfort and safety of the road surface but also the reduced energy losses that allow vehicles to maintain higher speeds with the same power output. The speed improvements contribute to reduced travel times and improved traffic flow efficiency, adding economic benefits to the environmental gains.

5 Estimate of Savings and Environmental Impact

The comparative analysis revealed significant improvements in road condition and a The quantification of savings resulting from the M-50 rehabilitation project reveals impressive environmental and economic benefits. Based on the before-and-after analysis of the seven rehabilitated sections totaling 28.10 km, and considering the traffic characteristics of the highway, the study projects substantial annual savings in both fuel consumption and CO_2 emissions.

With an average annual daily traffic (AADT) of 115,000 vehicles in 2025 and assuming a 50-50 directional split between the two directions of circulation, approximately 57,500 vehicles traverse the rehabilitated sections in the increasing direction each day. The weighted average reduction in fuel consumption across all seven sections is approximately 9-10%, which translates to significant daily and annual savings.

The study estimates daily savings in the rehabilitated sections of 16,206 liters of fuel and 43.75 tonnes of CO_2. When extrapolated to an annual basis, these figures become even more impressive: approximately 6 million liters of fuel and nearly 16,000 tonnes of CO_2 saved per year. In the specific calculation presented for the 28.10 km of rehabilitated road, the annual savings amount to 11,830,380 liters of fuel and 31,280.5 tonnes of CO_2.

In monetary terms, these savings represent substantial economic value. Using current fuel prices, the annual fuel savings are valued at approximately €17.75 million. Additionally, using carbon pricing mechanisms, the CO_2 emission reductions represent a value of approximately €2.19 million per year. These figures demonstrate that pavement rehabilitation is not only an environmental imperative but also an economically sound investment with measurable returns.

It is important to note that these estimates are conservative, as they only account for the direct effects on fuel consumption and emissions during vehicle operation. They do not include additional benefits such as reduced vehicle maintenance costs, decreased tire wear, improved safety outcomes, reduced noise pollution, or the extended lifespan of the pavement itself due to proper maintenance. When these additional factors are considered, the total benefit-cost ratio of pavement rehabilitation becomes even more favorable.

Furthermore, these savings are achieved without requiring any changes in vehicle technology, driver behavior, or traffic patterns. They represent a passive improvement that benefits all road users automatically, making pavement rehabilitation one of the most cost-effective strategies for reducing transportation-related emissions.

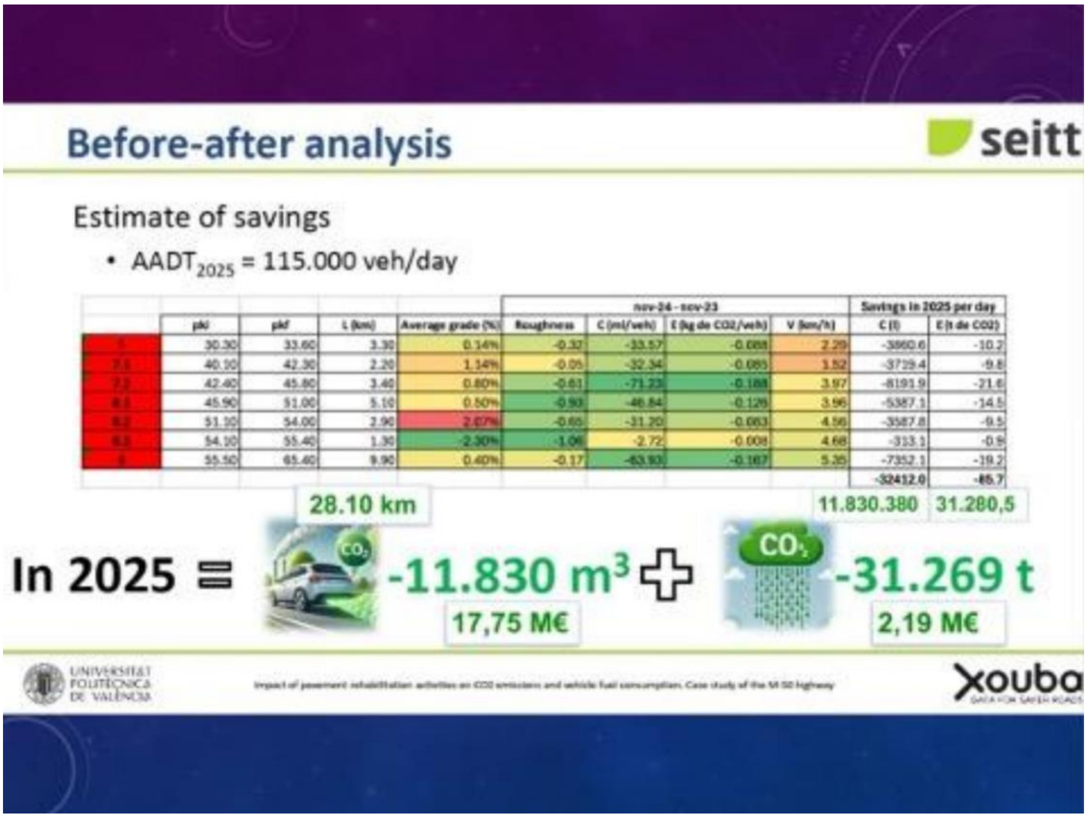


Fig. 5: Before and after analysis

6 Beyond Comfort and Safety: The CARES Philosophy

The findings of the M-50 case study underscore a critical paradigm shift in how we must think about and communicate the value of road maintenance. Traditionally, the primary arguments for road maintenance have been centered around Comfort and Safety (CS). While these remain important considerations, they represent only a partial view of the true value that well-maintained roads provide to society.

The current data and analysis capabilities now available through connected vehicle technology allow us to quantify with precision the environmental and energy benefits of road maintenance. This demands an updated framework for defending the need to properly maintain roads. The study proposes a new acronym and philosophy: CARES, which stands for Comfort and Safety, Energy and operational savings, Reduced environmental impact, Enhanced fuel and energy efficiency consumption of vehicles.

This new philosophy recognizes that road maintenance is fundamentally about sustainability and climate action. Given that more than 20% of emissions generated in the European Union come from road transport, and given that we can now accurately quantify how much energy and emissions we can save annually through proper road maintenance, it is time to reframe the conversation around road infrastructure investment.

The CARES philosophy has several important implications:

First, it aligns road maintenance with national and European decarbonization goals. The European Union has committed to achieving climate neutrality by 2050, with intermediate targets for 2030. Transportation is one of the most challenging sectors for decarbonization, as it requires coordinated action across multiple fronts. Pavement rehabilitation represents a readily available tool that can contribute meaningfully to these goals without waiting for complete fleet electrification or other long-term technological transitions.

Second, it provides a more compelling and comprehensive justification for road maintenance investments. While comfort and safety are important, they can sometimes be perceived as subjective or secondary concerns compared to other budget priorities. In contrast, quantifiable reductions in fuel consumption and emissions provide objective, measurable benefits that align with pressing societal priorities around climate change and energy security.

Third, it creates opportunities for new funding mechanisms and policy frameworks. If road rehabilitation projects can be quantified in terms of their emission reduction potential, they may become eligible for climate finance, carbon credit mechanisms, or other sustainability-focused funding sources that would not traditionally be available for road maintenance.

Fourth, it changes the conversation with citizens and taxpayers. Rather than asking for support for "road repairs," we can communicate about "projects to reduce emissions and fuel/energy consumption of vehicles." This reframing helps citizens understand that they are direct beneficiaries of these investments through reduced fuel costs, in addition to the broader societal benefits of emission reductions.

7 Implementing the CARES Strategy

The CARES philosophy provides a framework, but its true value lies in practical implementation. The study proposes several concrete actions for putting this new approach into practice:

7.1. Reframing Road Construction Projects

Project titles and descriptions should be changed to reflect their environmental benefits. Instead of generic titles like "Pavement Rehabilitation of Highway X, Section Y-Z," projects should be titled: "Projects for the reduction of emissions and fuel/energy consumption of vehicles circulating between kilometer point xxx.xx and kilometer point yyy.yy."

Each project should include in its documentation a quantification of the expected reduction in emissions and fuel consumption based on estimated traffic and the proposed rehabilitation actions. This quantification should be based on the methodology demonstrated in the M-50 study, using data from connected vehicles to establish baseline conditions and predict improvements.

Project evaluation criteria should explicitly include environmental and energy benefits alongside traditional factors like structural condition, safety, and traffic volume. This ensures that the climate benefits of road maintenance are formally recognized in decision-making processes.

7.2. Communicating with Citizens

Public communication about road maintenance must evolve to emphasize environmental benefits. The traditional messaging from organizations like ASEFMA—"reinforcing the road, consolidating the future"—should be updated to: "reducing emissions, reinforcing the roads."

We should stop talking exclusively about "road rehabilitation projects" and instead refer to them as "emission and energy reduction projects" or "climate action through road improvement." This linguistic shift is not merely semantic; it fundamentally reframes how citizens perceive and value road maintenance investments.

Road construction signage presents an opportunity for direct communication with drivers. Instead of generic messages about road works, signs could communicate: "You reduce here 6.9% of fuel consumption and we reduce XX tons of GHG emissions." This makes the benefits tangible and personal for each driver, helping build public support for road maintenance investments.

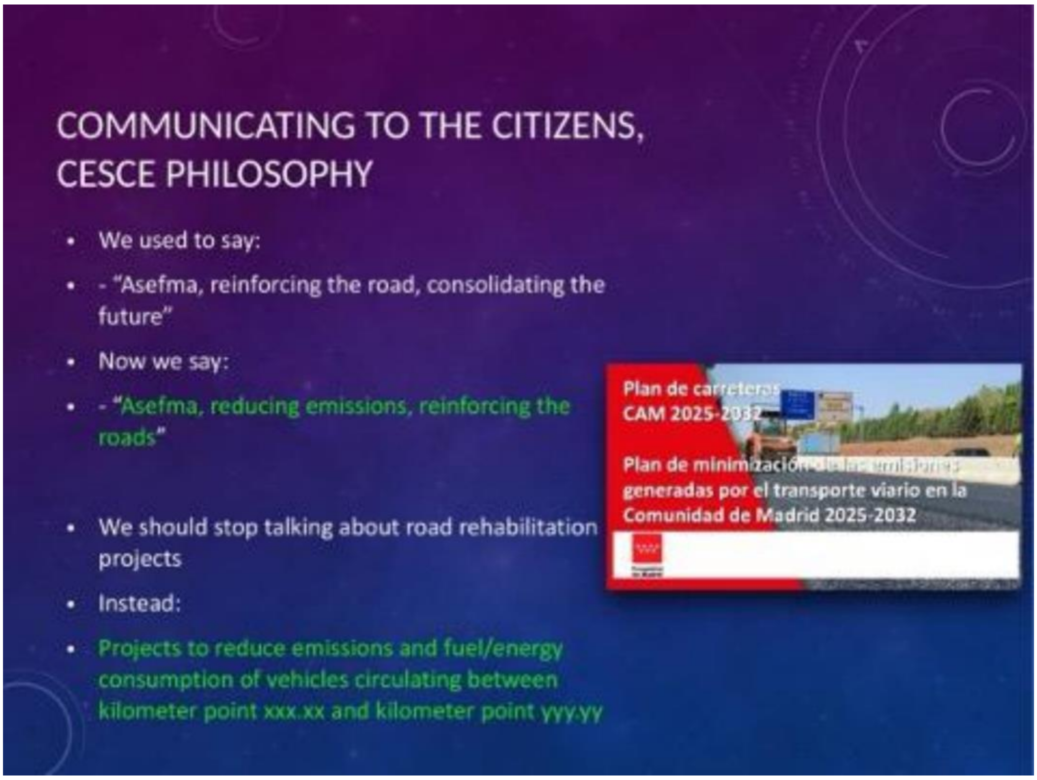


Fig. 6: Communicating to the citizens, CARES philosophy

7.3. Creating Emissions Maps

Road authorities should develop emissions maps associated with their road networks. These maps would identify not only the current emission levels associated with different road sections but also the potential emission reductions that could be achieved through rehabilitation. This would create an "emissions reduction map" that could guide investment priorities and help target resources where they can achieve the greatest environmental benefit.

Such maps would also facilitate integration with broader climate action plans and allow road authorities to demonstrate their contribution to national and regional emission reduction targets. They could be updated regularly using data from connected vehicles, providing a dynamic tool for ongoing management and prioritization.

7.4. Aligning with Decarbonization Goals

Road maintenance strategies should be explicitly aligned with national and European decarbonization and energy-saving goals. This means:

- Including road rehabilitation in national climate action plans and emission reduction strategies
- Quantifying the contribution of road maintenance to achieving climate targets
- Coordinating road maintenance planning with energy policy and transportation decarbonization initiatives
- Establishing performance metrics that track emission reductions achieved through infrastructure improvements

7.5. Developing New Funding Mechanisms

The quantifiable emission reductions from road rehabilitation could open new funding opportunities. Potential mechanisms include:

- Climate finance instruments that recognize infrastructure improvements as climate mitigation measures

- Carbon credit systems that allow road authorities to monetize emission reductions
- Green bonds specifically designated for sustainable infrastructure maintenance
- Public-private partnerships that share the economic value of fuel savings with investors

8 Conclusions and Recommendations

This study provides compelling evidence that preventative road maintenance is a powerful and cost- effective strategy for reducing emissions and energy consumption in the transportation sector. The M-50 case study demonstrates that pavement rehabilitation can achieve 9-10% reductions in fuel consumption and CO_2 emissions, translating to annual savings of approximately 6 million liters of fuel and 16,000 tonnes of CO_2 for just 28 km of rehabilitated highway.

These findings lead to several important conclusions:

Preventative road maintenance is a climate action tool. Road rehabilitation should be recognized as a legitimate and effective strategy for achieving decarbonization goals. Unlike many climate mitigation measures that require long-term technological development or behavioral change, road maintenance delivers immediate, measurable benefits using existing technology and infrastructure. The benefits are substantial and quantifiable. The M-50 study demonstrates that the environmental and economic benefits of road rehabilitation can be precisely measured using data from connected vehicles. This quantification capability transforms road maintenance from a subjective necessity into an objective investment with measurable returns.

Vertical alignment matters. The study found that sections with greater gradients showed larger absolute reductions in fuel consumption following rehabilitation. This suggests that prioritization strategies should consider not only pavement condition but also geometric characteristics when allocating maintenance resources.

Communication must evolve. The traditional framing of road maintenance around comfort and safety, while valid, is insufficient. The CESCE philosophy—emphasizing Comfort and Safety, Reducing Emissions, Reducing Consumption and Energy consumption—provides a more comprehensive and compelling framework for advocating for road maintenance investments. Based on these conclusions, the study offers the following recommendations:

1. Prioritize preventative maintenance as a key strategy for achieving national and European decarbonization and energy-saving goals. Road authorities should develop systematic preventative maintenance programs that maintain pavements in good condition rather than allowing deterioration and performing reactive repairs.
2. Adopt the CESCE philosophy as the guiding principle for defending and promoting road maintenance. All communication, project documentation, and policy frameworks should emphasize the environmental and energy benefits alongside traditional comfort and safety considerations.
3. Develop emissions reduction maps associated with road networks to identify areas where maintenance can achieve the greatest environmental impact. These maps should be integrated into climate action planning and used to guide investment prioritization.
4. Rebrand road rehabilitation projects as "emission and energy reduction projects" in all official documentation, public communication, and policy discussions. This reframing helps align road maintenance with broader societal priorities and opens new funding opportunities.
5. Implement direct communication with citizens through road signage and other channels to make the benefits of road maintenance tangible and personal. Messages like "You reduce here 6.9% of fuel consumption" help build public support for maintenance investments.

6. Establish systematic monitoring using connected vehicle data to continuously track pavement condition, fuel consumption, and emissions across road networks. This provides the data foundation for evidence-based maintenance planning and performance measurement.
7. Explore new funding mechanisms that recognize and monetize the environmental benefits of road maintenance, including climate finance, carbon credits, and green bonds.
8. Coordinate across policy domains to ensure that road maintenance strategies are integrated with energy policy, climate action plans, and transportation decarbonization initiatives.

The M-50 case study demonstrates that road condition is much more than a matter of comfort and safety—it is a critical factor in the environmental performance of the transportation system. By embracing the CESCE philosophy and implementing the recommendations outlined above, road authorities can transform road maintenance from a routine operational necessity into a powerful tool for climate action and sustainable development.

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Kaj se dogaja na slovenski prometni infrastrukturi?

How to solve the chaos on Slovenian roads?

Metod Di Batista; (Slovenija)

1. Uvodne ugotovitve

Tudi v letošnjem letu je značilnost slovenske prometne infrastrukture zelo slab nivo uslug za slovenske državljane oz. davkoplačevalce, ki se odraža v:

- zastojih na avtocestah,
- zastojih in uničenih regionalnih in lokalnih cestah,
- zamudah v železniškem prometu,
- neurejenih voznih redih na ostalem javnem transportu,
- veliki ekonomski škodi,
- nezadovoljnih uporabnikih cest in železnic,
- nezadovoljnih prebivalcih ob lokalnih cestah kamor vozniki iščejo obvoze iz
- prenatrpanih avtocest in
- ne nazadnje je vedno slabša mednarodna ocena naše prometne infrastrukture.

V zvezi s tem se postavljajo naslednja vprašanja:

Ali bodo te razmere kaj vplivale na predvolilno obdobje? S to neurejeno situacijo je posredno ali neposredno prizadetih večina Slovencev in potencialnih volivcev!

Kje so vzroki?

Kje so rešitve?

Ali še vedno velja predvolilni slogan, da v Sloveniji ne bomo več vlagali v asfalt in beton ampak le v mehke smeri razvoja?

Kako bomo reagirali na ideologijo trajnostne mobilnosti, ki prepoveduje širjenje avtocest in vlaganja v ceste?

Kaj pomeni nepregledna organiziranost prometnega resorja v sistemu državne uprave?

2. Prometna strategija v zadnjih 15 letih

Po zaključku uspešno izvedenega avtocestnega programa so se povsem spremenile strateške usmeritve in ukrepanja na slovenski prometni infrastrukturi. V ospredje so prišle Investicije na zanemarjenih železnicah in ukrepi ideologije trajnostne mobilnosti. Predvsem slednja je prepovedovala vlaganja v ceste, predvsem v širitev avtocest in poudarjala preusmeritev na javni prevoz, kolesa in peš hojo!

Na plodna tla je padla tudi usmeritev, da ne bomo več vlagali v asfalt in beton ampak le v »mehke« smeri razvoja. To je bila tudi posledica velike gospodarske krize, v kateri so nekateri odločujoči na infrastrukturnem področju poudarjali, da v Sloveniji ne bo več denarja za velike infrastrukturne projekte! Zaradi takega razmišljanja, najbolj odgovornih, tega časa, obdobja manjše gradbene aktivnosti, tudi nismo izkoristili za pripravo projektne in prostorske dokumentacije, kar nas še danes tepe!

Na zgornje ideološke in politične usmeritve je vseskozi odgovarjala prometna stroka, ki je že pred 15 leti opozarjala na nujnost širitve nekaterih odsekov avtocest v šest pasovnice.

Razlogi za te strokovne usmeritve so zelo enostavni. Promet narašča s približno enako stopnjo kot gospodarska rast. Zelo malo matematičnega znanja in enostavne logike je potrebno, da je bilo že takrat jasno, da bodo nekateri odseki avtocest kapacitetno »pregoreli« in ne bodo več zagotavljali optimalne pretočnosti, v vse daljših časovnih obdobjih v letu.

V tem času so nekateri izumljali »mehke« ukrepe s katerimi bi povečali pretočnost avtocest. To je bilo približno tako kot če bi želel s počasnim nalivanjem vode v steklenico, vanjo naliti več tekočine kot je njen volumen!?

Predvsem v zadnjih letih so se zelo povečala vlaganja v železniško infrastrukturo, kar je dobro, omejevala pa so se oz. prepovedovala vlaganja v širitev avtocest. Zelena in civilna gibanja so uporabljala neke zahodne analize iz velikih urbanih aglomeracij, kjer so s širitvijo avtocest z dodatnimi pasovi, dodatno pritegnili promet (inducirani promet), ki je ponovno zapolnil dodatne pasove. Take enostavne primerjave iz povsem drugih okolji, z milijonskimi mesti so neprimerne za majhno Slovenijo z razpršeno poselitvijo in centri, ki ne generirajo velikega prometa. Le milijonski centri upravičujejo npr. podzemne železnice, hitre vlake itd.

Ideologija trajnostne mobilnosti temelji na predpostavki, da če bodo na avtocesti dodatni pasovi, bodo pritegnili še več prometa in bodo tudi ti kmalu zapolnjeni. To ideološko predpostavko zavračam saj se ljudje ne vozijo po avtocestah zato ker je to fino in bo še bolj če bo več pasov. Ljudje uporabljajo avtoceste zaradi svojih poslovnih, znanstvenih, zdravstvenih, kulturnih, športnih, verskih, turističnih, rekreacijskih in drugih potreb. Dve zagrizeni ideologinji trajnostne mobilnosti sta me pred leti v medijih podučili, da naj vse to ljudje počnejo v svojem lokalnem okolju in naj tako ne obremenjujejo avtocest!?

3. Posledice ideologije trajnostne mobilnosti

Zelo pomembna je časovna, ekonomska in okoljska komponenta ideologije trajnostne mobilnosti. Zadnje javno izrečene ocene odgovornih govorijo, da vsaj še 20 let železnice ne bodo izpolnjevale zadostnih pogojev za prevzem velikega dela prometa iz cest. V tem času in v času vsaj 10 let, ki smo jih izgubili z ne ukrepanjem, je nastala oz. bo nastala, zaradi zastojev na avtocestah:

- Velika ekonomska škoda zaradi izgubljenega časa in potrošnje energije (pa še kaj), ki
- jo nekateri ocenjujejo na vsaj 500 mio EUR na leto – v 30 letih je to 15 mlrd EUR ali
- vrednost ene jedrske centrale. Sam ocenjujem, da je teh stroškov še več!
- Velika ekološka škoda, ki nastaja z izpusti v stoječih kolonah. Namesto, da bi uporabili kot argument zmanjšanje izpustov CO_2, z bolj tekočim prometom na šest pasovnicah, kar bi omogočilo privarčevati emisijske kupone, trajnostniki
- prepovedujejo tak ukrep!
- Prometna varnost se je poslabšala, kar je tudi posledica zastojev, živčnosti voznikov,
- iskanje obvozov po neustreznih lokalnih cestah in ne vlaganj v ureditev cest.
- Veliko je nezadovoljstvo prebivalcev (volivcev) ob neustreznih cestah, kamor se
- preusmerja promet iz »pregorelih« avtocest.

Slovenija je imela pred 15 leti veliko primerjalno prednost z zgrajenim avtocestnim sistemom, kar so nam priznavali tudi v tujini. Danes pa mednarodne inštitucije ugotavljajo, da je neustrezna prometna infrastruktura naša slabost!

Pri tako veliki škodi in slabšanju kvalitete življenja velikega dela Slovencev (da ne govorimo o vtisu na tujce) bi morali postaviti vprašanje kdo je odgovoren za vse to?

4. Odgovornost za današnje stanje na cestah

Objektivno so odgovorni vsi ministri, ki so pokrivali prometni resor v zadnjih 15 letih. Velika je tudi odgovornost na predsednikih vlad, ki so nastavljali ministre in strukturo ministrstev. Danes je odgovorno za strategijo razvoja prometa v Sloveniji Ministrstvo za okolje podnebje in energijo (MOPE). Ministrstvo za infrastrukturo ne pokriva vse infrastrukture (čeprav ima tako ime?) ampak le prometno in formalno nima nič s strateškim načrtovanjem, kar je zelo nenavadno. Imamo pa še Ministrstvo za naravne vire in prostor (MNP), ki pa skrbi za usklajevanje novih prometnic v prostoru. Verjamem, da je koordinacija med njimi, za razvoj učinkovite prometne infrastrukture, zelo težka ob večnih uradnikih, ki prej zavirajo kot pospešujejo razvoj.

V obdobju zadnjih 15 let so se zelo hitro menjavali ministri in državni sekretarji pristojni za prometno infrastrukturo. Tako niti niso mogli pustiti posebnega dolgoročnega pečata svojega dela. Izjema je sedanja ministrica za infrastrukturo, ki je v veliki meri pokrivala kontinuiteto odločanja o prometnih strategijah in dejavnostih na cestah ter železnicah. Bila je nadzornica v DRIju, predsednica vlade in večkrat ministrica, ki je pokrivala prometno infrastrukturo. V zadnjem obdobju pa se je povsem distancirala od strateških vprašanj!?

Velik vpliv na dogajanja zadnjih 15 let so imeli večni uradniki iz prometnega ministrstva, ki so se preselili na MOPE in tam skrbijo za prometne strategije.

Obstaja spisek preko 50 oseb, ki nosijo osebno odgovornost za stanje na prometni infrastrukturi v Sloveniji, v obdobju ko je le ta močno nazadovala.

Velik vpliv na ta dogajanja pa so imela v vsem obdobju tudi ekološka in civilna gibanja, ki so prepovedovala vlaganja v ceste – posebno avtoceste, z ideologijo trajnostne mobilnosti. Kakšen absurd in »blef« je bila ta ideologija, kaže podatek iz medijev, da je vodila inštitut za trajnostno mobilnost upokojena medicinska sestra!?

Močno so vplivali na razvoj prometne infrastrukture tudi akademiki iz nekaterih drugih strok kot npr, geografi. Na žalost so pri tem uporabljali diskretizacijo prometne stroke, ki naj bi po njihovem mnenju povsem napačno razmišljala. Brez ustreznega prometnega znanja, ki zajema interdisciplinarno znanje na pripravi strokovnih analiz, izračunov in načrtov, so poučevali prometnike kako morajo razmišljati in delati. Ljudje, ki verjetno v življenju niso nikoli izdelali prometne študije, tehnične zasnove prometnic, ekonomske ter ekološke analize in prometno varnostne analize, so z ideološkimi argumenti trajnostne mobilnosti, izločili prometno stroko iz odločanja o razvoju prometne infrastrukture. Na žalost so jim mediji navdušeno sledili, na drugi strani pa se škandalizirali zaradi razmer na cestah!

Resorna ministrica zelo rada poudarja, da se nikoli v Sloveniji niso vlagala v promet tako velika finančna sredstva kot danes. To je sicer dobro in pohvalno. Vprašanje pa je ali so ta sredstva racionalno porabljena in predvsem ali so za prave namene. Lepo je, da bomo Slovenijo prepredli s kolesarskimi stezami. Dobro je, da bi ljudje čim več pešačili oz. uporabljali javni transport. Toda ali so to res prve prioritete ob sedanjih velikih, težko obvladljivih in dragih zastojih na avtocestah in drugih državnih cestah? Kolesarske steze uporablja nekaj % državljanov (volivcev?!), na cestah pa so posredno ali neposredno prizadeti skoraj vsi državljani. Ali je to pravično, ne glede, da je to v skladu z globalnim reševanjem svetovne podnebne krize in po diktatu zelenega prehoda v EU?

5. Nivo uslug (Level of service) na naših avtocestah

Mejne prometne obremenitve se strokovno določajo z nivojem uslug (angl. LOS, Level Of Service). Ti nivoji so razdeljeni v razrede od A do F, po katerih je omogočen na nivoju A prost prometni tok, na nivoju F pa prisilni ali prekinjen prometni tok. Pravilnik o projektiranju cest nalaga da morajo daljinske ceste zagotavljati na koncu planskega obdobja (20 let) nivo uslug D.

Na nekaterih odsekih naših avtocest cest je pogosto nivo uslug E ali celo F. Maksimalna kapaciteta je presežena ko nivo uslug preide v D!

Nivo uslug na avtocestah je pokazatelj, ki zagotavlja udobnost in varnost vožnje po the cestah. V okviru usmeritev ideologije trajnostne mobilnosti še nisem zasledil kriterija, ki bi zagotavljal primeren nivo uslug in s tem skrb za udeležence prometa na avtocestah, ki jih posredno ali neposredno uporablja večina državljanov!

Kot kaže bomo, po dolgih letih blokade s strani okoljašev, širili nekatere najbolj obremenjene odseke avtocest, s tretjim pasom. Zaradi nerazumno dolgih postopkov in nepripravljene dokumentacije, se bo ta širitev izvedla na račun ukinjanja odstavnih pasov in z izgradnjo odstavnih niš. To je pač izhod v sili in je bolje kot nič. Ob taki ureditvi pa bi bilo dobro proučiti možnosti, da se morda na delih, kjer ni ovira ne pridobljeno zemljišče ali druge tehnične ovire, že v tej fazi zgradijo odstavni pasovi. Seveda morajo biti ureditve takšne, da je zagotovljena prometna varnost!

Odstavni pasovi so element prometne varnosti. Zagotavljajo tako ustavljanje pokvarjenih vozil, ustavljanje v izredni situaciji, boljši občutek pri vožnji zaradi večje razdalje do stranske ovire, odlaganje snega ob izrednih snežnih padavinah in ne nazadnje možnost uporabe ob zaporah pri vzdrževanju in vzpostavljanju začasnih obvozov za obe prometne smeri.

Veljavni Pravilnik o projektiranju cest določa v svojem 7. členu, da imajo Avtoceste obojestranski odstavni pas. Odstavne niše namesto odstavnih pasov so dopustne pri Hitrih cestah. Kot mi je znano veljavni pravilnik ni bil dopolnjen in tako sedanja rešitev šestpasovnic, brez odstavnega pasu in z odstavnimi nišami, na avtocestah ni skladna s tehnično regulativo.

Res pa je, da zaradi različnih, predvsem političnih, razlogov tudi nekateri drugi odseki avtocestnega križa nimajo odstavnih pasov kot npr. Hrušica – Vrba in Pomurski krak. Oba odseka sta zato v prometno varnostnem in vzdrževalnem smislu problematična. Je pa to posledica političnih varčevalnih pritiskov in ni dobro!

6. Analize velikih izvedenih projektov

Danes se dostikrat uporablja fraza, da ne bomo gledali nazaj in iskali napake ampak, da moramo biti usmerjeni le naprej v nove projekte in izzive. To se sicer lepo sliši. Se pa v tem skriva tudi prikrivanje krivcev za velike napake v upravljanju države.

Poleg tega bi morala urejena družba, na koncu velikih projektov, narediti analizo izvajanja takega projekta. Na osnovi ugotovljenih negativnih izkušenj in dobrih praks pa bi imela dobra izhodišča in usmeritve za še boljše izvajanje novih projektov. V nasprotnem primeru družba ne napreduje in se vedno znova vrača na izhodišče in na novo uči ter dela napake, ki so nepotrebne ter je neučinkovita!

Za največji uspešno zaključen projekt v zgodovini nove države Slovenije, izgradnjo slovenskih avtocest, oblastniki niso naredili tovrstne analize, čeprav so bile strokovne osnove pripravljene. Če bi bilo to narejeno bi bilo dosti manj presenečenj, neučinkovitega dela in nenormalno dolgih rokov.

7. Zaključek in rešitve

In kje so rešitve?

Rešitve bi morali razdeliti v:
- strateške,
- sistemske in
- organizacijske.

Ideologijo trajnostne mobilnosti je potrebno spremeniti v jasno strategijo urejanja prometa v Sloveniji, ki ne bo temeljila na ideologiji ampak na prometni stroki, ekonomiki in graditeljstvu.

Takoj je potrebno izdelati novo strategijo razvoja cest s poudarkom na hitrem ukrepanju za odpravo vse večjih zastojev na avtocestah. Tako strategijo lahko usposobljena, strokovna in kompetentna ekipa, z uporabo sodobnih informacijskih orodji, izdela v zelo kratkem času nekaj mesecev.

Pri tem bi morali biti bolj dolgoročno smeli in si postaviti cilj, da bomo imeli nekoč šest pasovne avtoceste, z odstavnimi pasovi, na celotnem avtocestnem križu in s tem zagotovili primerno kvaliteto življenja vsem Slovencem!

Izdelati je potrebno močan in jasen operativni plan (5 do 6 letni), ki bo temeljil na prioritetah in zagotovljenih finančnih sredstvih. Tudi ta plan lahko sposobna ekipa izdela v zelo kratkem času.

Spremeniti je treba organizacijo upravljavcev državnih cest, ki bodo poskrbeli tako za strategije in sistemske ureditve, kot za operativno izvajanje srednjeročnih in letnih programov. Naloge morajo biti združene na enem mestu in centralno vodene.

Uradniško miselnost in način dela (nič se ne da in vse je predrago) je potrebno preseči z organizacijo kot je npr. DARS, ki mora biti zadolžena in odgovorna za optimalno odvijanje celotnega investicijskega procesa.

Za velike projekte je treba določiti vodje projektov, ki bodo zadolženi za vse faze investicijskega procesa – planska faza, projektiranje, investicijska dokumentacija, usklajevanje v prostoru, javno naročanje, nadzor nad gradnjo in spremljanje izvedenih del v garancijski dobi.

Inženiringi morajo biti organizirani projektno matrično s poudarkom na kompetentnih vodjih projektov, z močnimi pooblastili in osebno odgovornostjo!

Postopek usklajevanja novih cest v prostoru morajo formalno voditi uradniki na prostorskem ministrstvu, vodje projektov pa njihovo delo spremljajo in po potrebi usmerjajo ter reagirajo na zaplete in zamude.

O največjih državnih projektih je potrebno zagotoviti stalno (tedensko) informiranje predsednika vlade s kratkimi poročili o napredovanju del.

Vse kar sem navedel ni nič novega. To so stvari ki so bile pri nas in v tujini preskušene na uspešno izvedenih velikih projektih!

Dobro bi bilo, da bi tisti, ki odločajo o slovenski prometni infrastrukturi, prebrali kakšno strokovno primerjalno analizo sedanjega delovanja na področju urejanja prometne infrastrukture in gradbeništva, v primerjavi s tovrstnim preteklim delovanjem. Takšne analize obstajajo!

Pogoj za uspešnost predlaganega pa so strokovni kadri z bogatimi izkušnjami, kompetencami in velikim strokovnim pogumom. Taki kadri so, vendar jih je potrebno najti tudi izven političnega peskovnika!

Metod Di Batista

Član prve uprave DARSa zadolžen za tehnično pripravo in izvedbo in

10 let glavni direktor DDC - največjega inženiring podjetja v Sloveniji.

Združenje asfalterjev Slovenije

REFERATI SEKCIJA 3: Projektiranje, gradnja in vzdrževanje konstrukcij asfaltnih vozišč

LECTURES SECTION 3: Design, construction, and Maintenance of Asphalt Pavement Structures

Zgoščevanje asfaltnih plasti

Compaction of the asphalt layers

Damijan Zore; (IGMAT d.d.)

Povzetek:

Človek uporablja asfalt (zmes kamnitih zrn, vezanih z bitumnom) že več kot sedem tisoč let in je eden od najpogosteje uporabljenih gradbenih materialov. Proizvodnja asfaltne zmesi je dovršena proizvodnja, ki večinoma zagotavlja ustrezne kakovostne karakteristike. Običajno povsod najdemo pomanjkljivosti in pri asfaltu je ena glavnih ta, da je proizvedena zmes podvržena ohlajevanju in temperaturni segregaciji. Plast s prenizko temperaturo pa ni več mogoče zgostiti.

Da bi se temu v čim večji možni meri izognili, je treba poznati različne pogoje pri vgrajevanju in velikost njihovih vplivov na uspešnost zgoščevanja asfaltne plasti.

Namen tega referata je:
- *predstaviti problematiko zgoščevanja asfaltne plasti,*
- *zvišati nivo razumevanja zakonitosti obnašanja asfaltne plasti med zgoščevanjem,*
- *prikazati, da se z ustreznim strokovnim pristopom in uvedbo ukrepov lahko doseže bistveno višjo učinkovitost zgoščevanja.*

Abstract:

Asphalt (a mixture of stone grains bound with bitumen) has been used by man for over seven thousand years and is one of the most commonly used building materials. The production of asphalt mixture is a sophisticated production, which mostly ensures the appropriate quality characteristics. We usually find flaws everywhere and with asphalt one of the main ones is that the manufactured mixture is subject to cooling and temperature segregation. A layer with too low a temperature can no longer be thickened.

In order to avoid this as much as possible, it is necessary to know the various installation conditions and the extent of their influence on the success of the asphalt layer compaction.

The purpose of this article is to:
- *present the problem of thickening the asphalt layer,*
- *increase the level of understanding of the legality of the behavior of the asphalt layer during compaction,*
- *demonstrate that with an appropriate professional approach and the introduction of measures, a significantly higher efficiency of densification can be achieved.*

1. Uvod

V asfaltnem obratu proizvedeno zmes običajno vzorčimo iz kamiona, kupa ali pri polžih finišerja. Lastnosti zmesi morajo biti skladne z zahtevami v standardu SIST 1038-1 (5 ali 7). Ko proizvedeno zmes vgradimo, s tem dobimo asfaltno plast. Lastnosti plasti morajo biti skladne z zahtevami v Smernicah in tehničnih pogojih za graditev asfaltnih plasti TSC 06.300/06.410:2009. Poleg debeline, ravnosti in zlepljenosti je zelo pomembna tudi zgoščenost asfaltne plasti.

Zgoščevanje je zadnji korak v procesu gradnje asfaltnega vozišča in v osnovi pomeni povečevanje prostorninske gostote materiala, oziroma zmanjševanje vsebnosti zračnih votlin v plasti.

Zgoščevanje (pri strojnem vgrajevanju) lahko razdelimo v tri osnovne faze oziroma obdobja zgoščevanja:

1. zgoščevanje z vgrajevalno desko finišerja (predzgoščevanje; doseganje približno 75 % zgoščenosti),
2. obdelava s sredstvi za zgoščevanje (doseganje končne stopnje zgoščenosti plasti z valjanjem),
3. zgoščevanje v kasnejšem obdobju, ko je plast izpostavljena prometu. Vpliv prometa do določene mere zmanjša votline v plasti, tudi če je bila plast v fazi gradnje ustrezno zgoščena.

2 Dejavniki in pogoji, ki vplivajo na zgoščevanje asfaltnih plasti

V nadaljevanju so navedeni dejavniki in pogoji, ki kakorkoli (posredno ali neposredno) vplivajo na uspešnost zgoščevanja asfaltnih plasti:

- organizacija izvedbe del (predhodno načrtovanje):
  - osebje (usposobljenost),
  - ravnovesje štirih faz asfaltiranja (proizvodnja, prevoz, vgrajevanje, zgoščevanje),
  - proizvodnji obrat (zmogljivost, kapaciteta (t/h), oddaljenost od gradbišča),
  - prevozna sredstva:
    - količina zmesi na tovornem vozilu (večja količina se počasneje ohlaja),
    - oblika kesona (kvadratni ali polkrožni prerez),
    - vrsta kesona (običajni, potisni, izoliran ali toplotni zabojnik),
    - vrsta ponjave na kesonu (odprta ali zaprta),
  - mehanizacija (ustreznost, starost, vzdrževanje, oskrba z vodo in gorivom),
  - zapora vozišča,
- asfaltna zmes:
  - vhodni materiali; bitumen, polnilo, zmes kamnitih zrn (drobljenec ali prodec),
  - lastnosti zmesi; delež zračnih votlin, zrnavostna sestava, homogenost mešanice,
- temperaturni dejavniki:
  - temperatura proizvedene asfaltne zmesi,
  - okolica (temperatura zraka in hitrost vetra),
  - podlaga (temperatura tal ali obstoječe asfaltne plasti),
  - stopnja temperaturne segregacije (nizka, srednja, visoka),
- debelina plasti (od 25 do 140 mm),
- vgrajevalni stroj (finišer):
  - vgrajevalna deska; enojni ali dvojni noži, nastavitev nožev, nastavitev vibracije,
  - hitrost napredovanja stroja (cca. od 1 do 5 m/min), kontinuiranost, časi zastojev,
  - širina vgrajevanja (cca. od 1,5 do 15 m),
- energija zgoščevanja:
  - vrsta, število in masa valjarjev,
  - hitrost valjanja, število prehodov in vrsta vibracije (vertikalna, oscilacijska),
- lastnosti podlage (so odvisne tudi od kraja vgrajevanja):
  - na avtocesti, v naselju na mostu ali viaduktu,
  - togost podlage (visoka, srednja, nizka).

3 Primeri slabe prakse

V zadnjem obdobju se na terenu vse več soočamo z neustrezno zgoščenostjo. Predstavljeni so trije primeri, kjer rezultati zgoščenosti (odvzetih asfaltnih jeder) niso dosegali zahteve.

3.1 Plato za kamione

Zap. št.	Lab. št.	Mesto odvzema / Lokacija	Prostorninska gostota (Mg/m³)	Stopnja zgoščenosti (%)	Delež zračnih votlin % (prost.)
AC 22 bin PmB 45/80-65 A2					
Metoda preiskave SIST EN			12697-6 /20 2)	12697-9 /04 3)	12697-8 /19
1	1243-A-23	Plato (parkirišča) H132	2,365	**97,4**	7,5
2	1251-A-23	P10 (krožna cesta)	2,330	**96,0**	8,9
3	1276-A-23	Plato (dovozna cesta) H72	2,370	**97,7**	7,3
4	1276-A-23	Plato (parkirišča) H106	2,370	**97,7**	7,3
5	1277-A-23	P27 (krožna cesta) DS	2,423	99,8	5,2
6	1277-A-23	P33+2m (krožna cesta) DS	2,343	**96,5**	8,4

ZAHTEVE ZA SKUPINO TEŽKE IN ZELO TEŽKE PROMETNE OBREMENITVE
TSC 06.300 / 06.410 : 2009 **min. 98%** 4 do 9

Zap. št.	Lab. št.	Mesto odvzema / Lokacija	Prostorninska gostota (Mg/m³)	Stopnja zgoščenosti (%)	Vsebnost zračnih votlin % (prost.)
AC 11 surf PmB 25/55-65 A2 Z3					
Metoda preiskave SIST EN			12697-6 /20 2)	12697-9 /04 3)	12697-8 /19
1	1243-A-23	Plato (parkirišča) H132	2,238	**94,8**	**10,3**
2	1276-A-23	Plato (dovozna cesta) H72	2,374	100,6	4,8

ZAHTEVE ZA SKUPINO TEŽKE IN ZELO TEŽKE PROMETNE OBREMENITVE
TSC 06.30 / 06.410 : 2009 **min. 98%** **2 do 8,5**

Preglednica 1: *Prikaz rezultatov preiskav zgoščenosti (levo vezna plast in desno obrabno zaporna asfaltna plast)*

3.2 Kolesarska povezava

Zap. št.	Lab. št.	Mesto odvzema / Lokacija	Prostorninska gostota (Mg/m³)	Stopnja zgoščenosti (%)	Vsebnost zračnih votlin % (prost)
AC 16 base B 50/70 A4					
	Metoda preiskave SIST EN		12697-6 /20 2)	12697-9 /04 3)	12697-8 /19
1	1265-A-23	Pododsek 11; 1,2 m od L roba	2,303	**95,8**	**10,1**
2	1267-A-23	Pododsek 3; 0,9 m od L roba	2,334	**96,2**	**9,0**

ZAHTEVE ZA SKUPINO LAHKE IN ZELO LAHKE PROMETNE OBREMENITVE
TSC 06.300 / 06.410 : 2009 **min. 97%** **2 do 8,5**
skraina meina vrednost **10.5**

Zap. št.	Lab. št.	Mesto odvzema / Lokacija	Prostorninska gostota (Mg/m³)	Stopnja zgoščenosti (%)	Vsebnost zračnih votlin % (prost)
AC 8 surf B 50/70 A4					
	Metoda preiskave SIST EN		12697-6 /20 2)	12697-9 /04 3)	12697-8 /19
1	1265-A-23	Pododsek 11; 1,2 m od L roba	2,229	**91,8**	**10,9**
2	1267-A-23	Pododsek 3; 0,9 m od L roba	2,266	**93,3**	**9,4**

ZAHTEVE ZA SKUPINO HODNIKOV ZA PEŠCE, KOLESARSIH **min. 96%** **1 do 6,5**
TSC 06.300 / 06.410 : 2009 skrajna mejna vrednost **8,5**

Preglednica 2: *Prikaz rezultatov preiskav zgoščenosti plasti (levo nosilna plast, desno obrabno–zaporna asfaltna plast)*

3.3 Rekonstrukcija priključka na hitro cesto

Zap. št.	Lab. št.	Mesto odvzema / Lokacija	Debelina plasti (mm)	Prostorninska gostota (Mg/m³)	Stopnja zgoščenosti (%)	Vsebnost zračnih votlin (% (prost))
SMA 11 PmB 45/80-65 A1, A2						
Metoda preiskave SIST EN			12697-36 /04 1)	12697-6 /20 2)	12697-9 /04 3)	12697-8 /19
1	1226-A-22	krak E, P4 sredina	40	2,456	99,6	3,3
2	1237-A-22	xy jug, P8 D	40	2,359	**95,7**	7,2
3	1306-A-22	xy jug, P6 L	40	2,345	**95,1**	**7,7**
4	1306-A-22	xy zahod, P7 DD	35	2,313	**93,8**	**9,0**
5	391-A-23	krak D P5 sredina	41	2,414	97,9	5,0

ZAHTEVE ZA SKUPINO IZREDNO TEŽKE, ZELO TEŽKE IN TEŽKE PROMETNE OBREMENITVE
TSC 06.300 / 06.410 : 2009 25 do 50 min. **97** % 1,5 do **7,5**

Preglednica 3: *Prikaz rezultatov preiskav zgoščenosti obrabno–zaporne asfaltne plasti*

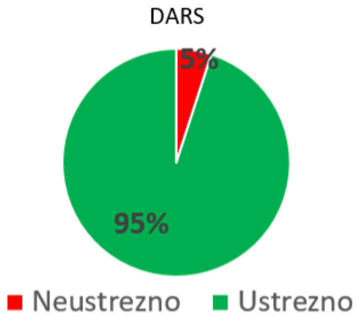
Pri vseh primerih rezultati (ali celo povprečna vrednost rezultatov) niso skladni z zahtevo. Nekatere vrednosti odstopajo celo od skrajne mejne zahteve.

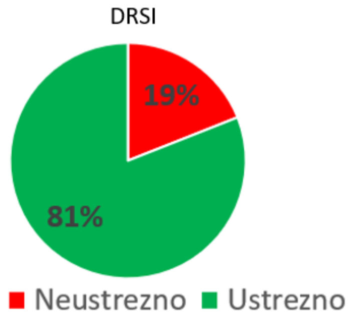
4. Delež neustrezno zgoščenih asfaltnih jeder v letu 2024 (Igmat d.d.)

V inštitutu Igmat izvajamo kontrolo kakovosti za različna podjetja, dva največja sta DARS in DRSI. Običajno je na vsakem gradbišču predvideno vzorčenje asfaltnih plasti. Namen tovrstnega vzorčenja je ugotavljanje debeline bitumenskega vozišča in ugotavljanje gostote bitumenskih preizkušancev.

Rezultati (statistike) so pokazali, da je bilo na programu DARS (v letu 2024) vzorčenih skupno 247 asfaltnih jeder, pri čemer 5 % jeder ni dosegalo zahtevane zgoščenosti. Na programu DRSI je bilo vzorčenih skupno

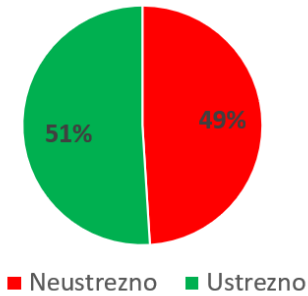
215 jeder in 19 % jeder ni dosegalo ustrezne zgoščenosti. Vzrok za slabši rezultat je tudi v načinu izvedbe del, kajti dolžina obnov odsekov regionalnih in glavnih cest je običajno zelo kratka (cca. 1 do 2 km) in dela se večinoma izvajajo pri polovični zapori vozišča, kar predstavlja povečano verjetnost za slabšo izvedbo del.





Slika 1 in Slika 2: Delež neustrezno zgoščenih asfaltnih jeder na programu DARS in DRSI.

Delež gradbišč z vsaj enim neustrezno zgoščenim jedrom (oziroma območjem) na programu DRSI znaša 49 %. To pomeni, da je skoraj na vsakem drugem gradbišču plast vsaj na enem območju neustrezno zgoščena. Vzorčenje se je izvajalo izven območja spojev, jaškov, muld in koritnic, kjer je že tako povečana verjetnost za slabšo zgoščenost.



Slika 3: Delež gradbišč z vsaj enim neustrezno zgoščenim območjem na programu DRSI.

5 Zgostitev asfaltne plasti

Ustrezno zgoščena asfaltna plast zagotavlja odpornost plasti proti obremenitvam prometa, preprečuje vdor vode in zraka, oziroma poveča odpornost na vremenske vplive in je trajnejša. Neustrezno zgoščena plast lahko povzroči zmanjšanje življenjske dobe tudi za 50 % in več (Bode, 2012).

Na doseganje ustreznih pogojev zgoščevanja vpliva zelo veliko dejavnikov (glej poglavje 2), vendar so za ustrezno zgostitev plasti potrebni le trije osnovni pogoji:

- temperatura plasti, pri katri se zmes zgošča (poglavje 5.1),
- ustrezno zgoščevanje, (poglavje 5.2),
- dovolj toga podlaga, ki zagotavlja, da se večina zgoščevalne energije prenese v asfaltno plast in ne v spodnje plasti (Evd > 45 Mpa).

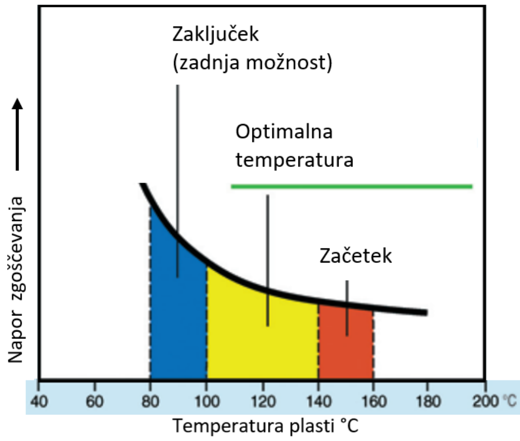
5.1 Temperatura asfaltne plasti

Visoka temperatura plasti (med 160 °C in 140 °C) pomeni, da ima bitumen zelo nizko viskoznost. Notranje trenje je zelo nizko in to omogoča najmanjši napor zgoščevanja, zato lahko pride do prekomerne zgostitve plasti. V ekstremnem primeru (odvisno tudi od lastnosti zmesi) se bitumen iztisne na površino in pojavijo se črni madeži bitumna. Plast z visoko temperaturo ne smemo intenzivno zgoščevati, lahko se izvede en ali dva prehoda brez vibracije (predzgoščevanje). Če se pojavi narivanje zmesi pred bandažo valja, je treba valjanje za nekaj časa prekiniti, drugače bo prišlo do prečnih razpok ali tako imenovane pomarančne površine. V primeru več prehodov po isti liniji ali ostrih zavojev se običajno pojavi precejšen ugrez valja z bočnim izrivanjem zmesi. Valjar lahko tako močno zareže v svežo (prevročo) plast, da sled ostane tudi po koncu glajenja, kar je ena nedopustnih napak zgoščevanja. V primeru, če ni bočne opore (robnik), bo na robu plasti prišlo do precejšnjega izrivanja zmesi, kar si nikakor ne želimo. Na vroči površini se mora valjar ves čas gibati, ob (daljšem) zastoju se lahko pojavi vdolbina (odtis) valja, kar predstavlja neravnino.

Ustrezna temperatura plasti (med 140 °C in 100 °C) zagotavlja uspešno zgoščevanje. Viskoznost bitumna oziroma ustrezno notranje trenje omogoča kamnitim zrnjem v asfaltni zmesi, da med seboj lažje zdrsijo in se namestijo v čim bolj homogeno in zgoščeno strukturo plasti. V tej fazi se izvaja glavno zgoščevanje, to pomeni, da je treba izvesti ustrezno število prehodov glede na debelino plasti in maso valjarja. Pomembna je ustrezna izbira valjarja glede na debelino plasti. Ne sme biti prelahek ali pretežak. Debelejše plasti se zgošča z večjo amplitudo in nižjo frekvenco, tanjše plasti z nižjo amplitudo in večjo frekvenco. Nižja hitrost valjarja dosega boljšo zgostitev plasti in obratno. Zmes z visokim deležem drobirja se težje zgošča, kot zmes z okroglimi zrni. Če je bila s finišerjem dosežena visoka stopnja predzgostitve, z valjarji hitreje in lažje dosežemo ustrezno zgoščenost.

Manj ustrezna temperatura plasti (med 100 °C in 80 °C) se običajno pojavi ob temperaturni segregaciji ali krajšem zastoju finišerja. Notranje trenje zmesi se bistveno poveča, za zgostitev je potrebno več energije, kar pomeni večjo intenziteto zgoščevanja, več prehodov ali/in večjo masa valjarja. Časovno okno zgoščevanja je bistveno zmanjšano, zato je treba prehode z valjarjem čimprej izvesti. V tej fazi je treba zaključiti z zgoščevanjem.

Ko pade temperatura plasti pod 80 °C, plast ni več primerna za zgoščevanje. Izvaja se glajenje oziroma zaglajevanje robov (sledov) valjarja. Bitumen preide iz funkcije maziva v svojo primarno funkcijo veziva, kar bistveno poveča togost plasti. Ob nadaljnjem zgoščevanju se lahko pojavi drobljenje zrn in rahljanje povezane strukture plasti.



Slika 4: Vpliv temperature plasti na napor zgoščevanja (Bomag, 2009)

5.2 Zgoščevanje asfaltnih plasti

Za optimalno zgoščevanje so najbolj primerni valjarji z dvema amplitudama in dvema frekvencama. Valjarji novejše generacije zaznavajo togost in temperaturo plasti ter samodejno uravnavajo potrebno energijo zgoščevanja. Programska oprema zbira in vrednoti podatke ter prilagaja efektivno amplitudo vibracije.

Preglednica 4: Tipične vrednosti za število vibracijskih prehodov (Bomag, 2009)

Debelina asfaltne plasti (cm)	Število prehodov z vibracijo (tandem valjar)			Vrsta vibracije
	4 tone	7 ton	10 ton	
2	2 – 4	1 – 2 N	1 – 2 N	N – nizka amplituda
4	4 – 6	2 – 4 N	2 – 4 N	
6	4 – 8	4 – 6 N	2 – 4 N	
10	6 – 8	4 – 8 NV	4 – 6 NV	V – visoka amplituda
14		6 – 8 V	4 – 6 V	
Temperatura plasti > 100 °C. Hitrost valjarja od 3 do 6 km/h (od 50 do 100 m/min)				

Preglednica 5: Priporočene hitrosti valjanja (Bomag, 2009)

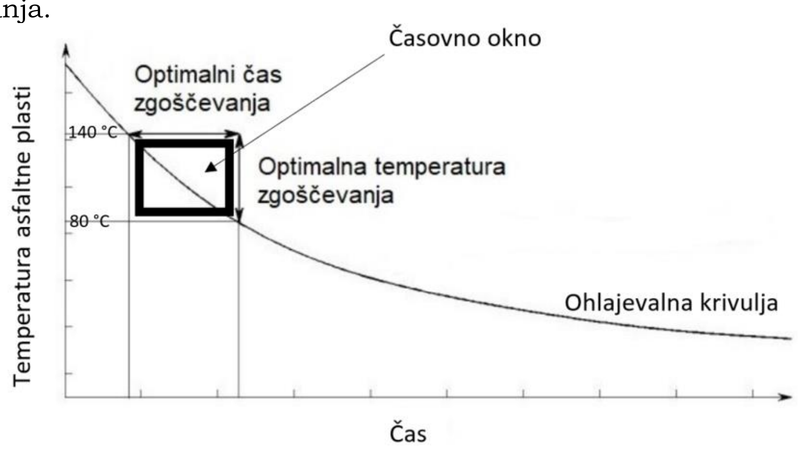
Priporočene povprečne hitrosti valjanja (km/h)		
Predzgoščevanje	4 - 6	Statično, tandem
Glavno zgoščevanje	3 - 5	Z vibracijo, tandem
Glajenje	6 - 8	Statično, tandem
Glavno zgoščevanje	4 - 8	Valjar s pnevmatikami
Kasnejše valjanje	10 - 12	Valjar s pnevmatikami

V zgornjih preglednicah so navedeni podatki kolikšno maso mora imeti valjar, koliko prehodov s kolikšno hitrostjo mora opraviti, pri kateri temperaturi plasti, da bo plast ustrezno zgoščena.

Dokaj pogosta oskrba valjarja z vodo prekine dinamiko zgoščevanja. V tem času ga mora nadomestiti predhodno določen valjar, ki nam pride prav tudi v primeru morebitne okvare. Stari asfalterski rek pravi: ˝En valjar ni noben valjar˝. V primeru večjega števila valjarjev mora odgovorna oseba določiti razporeditev in vloge valjarjev ter sosledje zamenjav (zaradi oskrbe z vodo, …), kar je treba spoštovati ves čas vgrajevanja.

6. Ohlajevalna krivulja asfaltne plasti in časovno okno zgoščevanja

Glede na lastnosti zmesi in temperaturne pogoje okolja se da določiti ohlajevalno krivuljo plasti. Zgoščevanje je treba izvajati v t. i. časovnem oknu, glede na ohlajevalno krivuljo. Stalno spreminjajoča se temperatura je glavni dejavnik, zaradi katerega je težko napovedati, kdaj začeti z valjanjem in kdaj mora biti valjanje končano.



Slika 5: Ohlajevalna krivulja plasti in časovno okno

6.1 Izračun časovnega okna s programom PaveCool

Programsko orodje PaveCool (MnDOT, 2024) je bilo razvito za pomoč izvajalcem asfaltnih del, nadzornim organom in tehnologom pri sprejemanju odločitev pri izvajanja del. Uporabnik vnese uro, datum, vrsto zmesi in podlage, hitrost vetra, temperaturo asfaltne zmesi, podlage, zraka, količino oblačnosti in debelino plasti. Model toplotnega toka se uporablja za izračun, v kolikšnem času se temperatura površine plasti zniža do kritične vrednosti 80 °C. Če uporabnik meni, da je na voljo premalo časa za zgoščevanje, lahko ta čas podaljša (na primer: povečanje debeline plasti ali temperature zmesi bo povečalo časovno okno).

V nadaljevanju so izračunani časi zgoščevanja (časovno okno) različnih debelin plasti pri različnih pogojih. Za izračun sta navedeni dve različni temperaturi plasti za finišerjem. Vrednost 140 °C je najbolj (pogosta) primerna temperatura za začetek zgoščevanja in 100 °C, ki je še zadnja možnost, da plast lahko ustrezno zgostimo. Najnižja dovoljena temperatura plasti za vgrajevalnim strojem za B 50/70 je 130 °C (RS MZI, 2009).

Primer:

<u>Vroče obdobje</u>: temperatura zraka 30 °C, temperatura podlage 40 °C, hitrost vetra 5 km/h.

<u>Hladno obdobje</u>: temperatura zraka 3 °C, temperatura podlage 1 °C, hitrost vetra 5 km/h.

Preglednica 6: Maksimalni časi zgoščevanja, v katerih je treba doseči končno stopnjo zgoščenosti plasti

AC 22 base B50/70 A3 **60** mm	Čas zgoščevanja (min)	
Temperatura plasti (°C)	Vroče obdobje	Hladno obdobje
140	61	29
100	19	8

AC 11 surf B50/70 A3 **40** mm	Čas zgoščevanja (min)	
Temperatura plasti (°C)	Vroče obdobje	Hladno obdobje
140	30	13
100	8	3

Čas za doseganje končne zgoščenosti plasti (z valjarji) v levi preglednici je lahko 61 min ali samo 8 min. Čas za doseganje končne zgoščenosti plasti v desni preglednici je lahko 30 min ali samo 3 min.

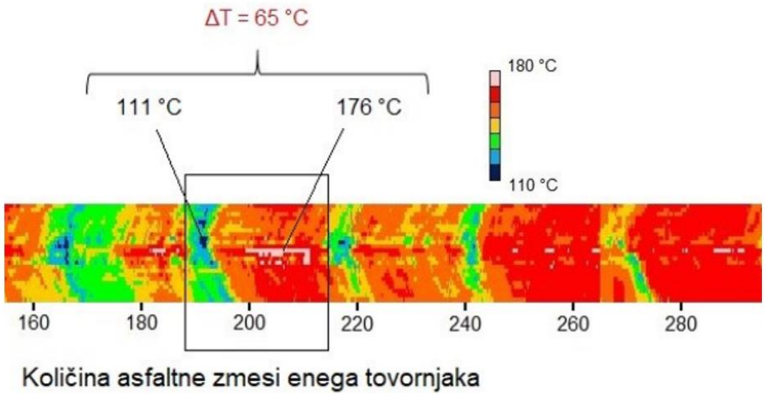
To pomeni, da je treba glede na dane pogoje, plast zgoščevati s popolnoma različnim pristopom, kar pa v praksi ni v navadi, oziroma kader ni usposobljen.

7. Vzroki za neustrezno zgoščeno asfaltno plast

Razumevanje vplivov na zgoščevanje je pomemben korak pri doseganju uspešnega cilja. V poglavju 2 so navedeni dejavniki, ki kakorkoli vplivajo na uspešnost zgoščevanja plasti. Obravnavanje vseh je preobsežno, zato so v nadaljevanju predstavljeni le štirje.

7.1 Temperaturna segregacija

Proizvedena zmes se takoj po izpustu iz mešalnega bobna na tovorno vozilo začne ohlajati. Poleg ohlajanja je med transportom podvržena tudi temperaturni segregaciji, kajti na površini se bistveno hitreje ohlaja kot v sredici. Magistrska naloga iz leta 2020 (Rošer, 2020) obravnava meritve temperature površine asfaltne zmesi na kamionu s termovizijsko kamero in meritve temperature asfaltne plasti s termoskenerjem. Predstavljen je primer izvedbe asfalterskih del (poleti 2019) v času najbolj ugodnih temperaturnih pogojev. Temperatura zraka je bila nad 30 °C ter podlage med 40 °C in 50 °C. Transportna razdalja zmesi je znašala 21 km, čas vožnje 18 minut in vsi tovornjaki so imeli ponjave. Ugotovljena temperatura površine zmesi SMA 11 PmB 45/80-65 A1 na kamionu (na gradbišču) je znašala **104** °C, kar predstavlja presenetljivo visoko stopnjo temperaturne segregacije in to se je posledično odražalo tudi v plasti za finišerjem. Debelina plasti je znašala 40 mm.



Slika 6: Temperatura asfaltne plasti za finišerjem

(levo rezultati, desno meritve s termoskenerjem); (Rošer, 2020)

Kljub zelo ugodnim vremenskim pogojem so se ob menjavah tovornjakov (na medsebojni razdalji od 20 do 30 m) pojavljala območja z visoko stopnjo temperaturne segregacije (do 65 °C). Za lokacijo s temperaturo plasti 176 °C je bilo za zgoščevanje na voljo 46 minut (izračunan s programom PaveCool). Za lokacijo s temperaturo plasti 111 °C pa je znašal čas le 13 minut, kar predstavlja veliko verjetnost za neustrezno zgoščeno območje.

7.2 Čas ustavitve finišerja

Poleg segregiranih območij, ki so se pojavila ob menjavah tovornjakov, je termoskener zaznal izgubo temperature plasti ob vsaki ustavitvi finišerja (Rošer, 2020). Ob ustavitvi za 2 min, je zabeležil izgubo temperature za 10 °C. Ob čakanju na dostavo asfaltne zmesi ali drugih razlogov je bilo znižanje temperatur še večje. Čas ustavitve finišerja za 11 min in 8 s, je povzročil znižanje temperature plasti za finišerjem za 37,6 °C.

V nadaljevanju je predstavljen primer dveh neugodnih vplivov hkrati. Temperaturna segregacija, ki je večinoma prisotna pri prvem kipanju vsakega kamiona (ugotovljena temp. plasti 111 °C) in nato še zastoj finišerja za 11 min (padec temperature za cca. 37 °C). V takšnem primeru znaša temperatura plasti približno **74** °C (111 °C - 37 °C), kar je manj od 80 °C in to pomeni, da se plast takoj za finišerjem sploh ne da več zgostiti.

7.3 Ravnovesje štirih faz asfaltiranja

V obdobju načrtovanja izvedbe del je treba teoretično določiti in dejansko zagotoviti ravnovesje štirih faz asfaltiranja (proizvodnja, prevoz, vgrajevanje in zgoščevanje). Uspešno ravnovesje zagotavlja neprekinjeno vgrajevanje, pri čemer naj ne bi prišlo do visokih izgub temperatur v plasti za vgrajevalnim strojem. S tem je zagotovljen osnovni pogoj za uspešno zgoščevanje in ravnost plasti.

V primeru, da bo asfaltni obrat za posamezno gradbišče vsako uro proizvedel 100 ton zmesi, je treba glede na razdaljo in značilnosti prometa zagotoviti dovolj prevoznih sredstev, da bo vsako uro na gradbišče prispelo 100 ton zmesi. Finišer mora glede na debelino in širino vgrajevanja zmes vgrajevati z ustrezno hitrostjo, da bo na uro vgradil 100 ton. Za zgoščevanje pa mora biti na voljo dovolj ustreznih valjarjev, da bodo na uro zgostili 100 ton zmesi oziroma plasti. **Ravnovesje je treba zagotavljati ves čas vgrajevanja**. Ko pride do spremembe v eni fazi, je treba korigirati tudi ostale faze, v nasprotnem primeru lahko pride do zastojev in drastičnih izgub temperature zmesi in/ali plasti.

7.4 Zamujeno časovno okno

Stalna dilema operaterja (ali operaterke) na valjarju je naslednja:
- če prekmalu začnem z zgoščevanjem, obstaja precejšnja verjetnost za nastanek razpok in neravnin,
- če prepozno začnem z zgoščevanjem, se bo plast preveč ohladila in je ne bom moral zgostiti.

Vzrok za neustrezno zgoščeno asfaltno plast se velikokrat pojavi zaradi zamude pri zgoščevanju, oziroma se zgošča plast s prenizko temperaturo. Običajno operaterji nekoliko kasneje pričnejo z zgoščevanjem, da se izognejo razpokam v primeru prevroče zmesi, kar je v določenem primeru (pri debelejši plasti in vročih pogojih) pravilno. Vendar tanjša plast in hladni pogoji povzročijo nenaden padec temperature plasti in težava je tu. Operater na stroju mora poznati vpliv temperaturnih pogojev in biti pozoren na obnašanje zgoščevane plasti ter glede na izkušnje (ažurno) prilagoditi dinamiko ali/in intenziteto zgoščevanja.

Trije najbolj pomembni pogoji zgoščevanja so: temperatura, temperatura in temperatura.

8. Ukrepi za izboljšanje

Ker je temperatura asfaltne plasti eden ključnih kazalnikov kakovosti pri vgrajevanju, je pomembno, da se ta lastnost stalno spremlja po celotni površini plasti, za finišerjem. Podobno kot kažejo prakse v tujini, bi morali tudi pri nas vpeljati meritve temperaturne segregacije, kar bi prispevalo k boljšemu poznavanju tovrstnega problema in spodbudilo uporabo rešitev za njeno preprečevanje. Veljavna tehnična regulativa sploh ne predvideva ugotavljanja in vrednotenja temperaturne segregacije, zato jo je treba dopolniti.

Za oddaljena gradbišča je nujna uvedba uporabe vsaj treh ukrepov: zaprte ponjave, kesona s potisno tehnologijo in podajalnika, ki dokazano zmanjšujejo stopnjo temperaturne segregacije.

Slika 7: Ukrepi za preprečevanje temperaturne segregacije (Rošer, 2020)

Globalno, po celi državi, se mora zagotoviti prevoz asfaltne zmesi na gradbišče iz najbližjega (primernega) asfaltnega obrata. Vsa podjetja bi morala podpisati skupno pogodbo o dobavi zmesi z najkrajšim transportnim časom. Ta korak bi bistveno doprinesel k zmanjšanju ali celo odpravi temperaturne segregacije. Zaradi krajše razdalje se zmanjša število prevoznih sredstev, ogljični odtis, obremenjenost cest …

Ravnotežje štirih faz asfaltiranja je treba organizirati in po najboljših močeh izvesti tako, da ima finišer stalno svežo dobavo zmesi in se cel delovni potez ne ustavlja. S čimer se izboljša tudi vzdolžno ravnost plasti.

Kar se tiče zgoščevanja asfaltne plasti, je marsikaj odvisno od znanja, marljivosti in skrbnosti vodje izvedbe asfalterskih del in delovodje, največ pa od operaterja na stroju. Operater na stroju se mora zanesti na svoje oči, občutek in izkušnje ter v časovnem oknu ali še prej zgostiti plast.

V primeru, da plast za finišerjem ne dosega dovolj visoke temperature (kar ni redek pojav), tudi najboljši valjar in najbolj usposobljen operater na stroju ne moreta zgostiti plasti.

Na žalost je tudi v asfalterstvu tako kot povsod v življenju. Obstajajo sposobni operaterji na valjarjih, ki obvladajo zadeve in obstajajo vozniki valjarjev, ki pri vožnji komaj sledijo liniji roba asfalta.

9. Zaključek

Študije in izkušnje v asfalterstvu so pokazale, da „klasično“ asfaltiranje ne omogoča preprečevanja temperaturne segregacije. Razumevanje časovnega okna zgoščevanja je pri večini vpletenih akterjev na zelo nizkem nivoju, zato je neustrezno zgoščena asfaltna plast prepogost pojav. Večinoma so predhodne faze relativno uspešno izvedene, napake pa se pojavljajo pri zgoščevanju.

Dokler ne bo doseženo večje spoštovanje do temperature asfalta in večja strokovnost pri zgoščevanju, se bomo še naprej soočali z neustrezno zgoščenimi asfaltnimi plastmi. To povzroča pogostejše obnove in zapore cest, kar vodi v nezadovoljstvo uporabnikov, višje stroške in večje obremenitve okolja.

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Površinske prevleke kot del krajinskih in okoljskih ureditev

Surface coatings as part of landscape and environmental arrangements

Franc Pungerčič; Samo Gaberšek; (VIANOVA)

1. UVOD

Površinske prevleke, o katerih govori ta prispevek, so v splošnem definirane v SIST EN 12271:2007 – „Površinske prevleke – zahteve“, in naših tehničnih specifikacijah TSC 06.417:2001 – „Vezane obrabne in zaporne plasti – Površinske prevleke“ (Direkcija republike Slovenije za ceste 2001).

Površinske prevleke se (v večini primerov) uporabljajo kot zaključni/obrabni sloj povozne / pohodne površine in s tem same po sebi lahko delno nadomeščajo ali pa dopolnjujejo plasti iz vročih asfaltnih zmesi.

Pred njimi ima ta tehnologija v okolijskem pogledu kar nekaj prednosti:
- je nizkotemperaturna,
- manjše debeline slojev – manjše porabe materialov in transportov,
- vezivo in drobir se dostavita na gradbišče – ni vmesnega mešanja,
- vzdrževanje je enostavno,
- manjši gradbeni odpadek,
- manjša obremenitev delovne sile (plini, vročina).

Govorimo torej o tehnologiji s precej manjšim ogljičnim odtisom od vročih, pa tudi toplih asfaltnih zmesi, lahko bi jo imenovali kar »zelena tehnologija«. Zato je to tehnologijo možno uporabiti tudi kot ukrep v skladu z Uredbo o zelenem javnem naročanju.

Njena značilnost je, da po vgradnji dobimo vidno površino, ki jo sestavljajo zgolj kamnita zrna izbrane granulacije in barvnega odtenka naravnega kamna, kar daje površini naraven izgled.

Zato in zaradi svoje »zelenosti« je vedno bolj prepoznana kot primerna za uporabo v parkih, kolesarskih in peš poteh, torej kot del okolijskih ureditev.

Po kratki splošni predstavitvi površinskih prevlek bomo posebej poudarili ta poseben segment, ki ima svoje zahteve in značilnosti.

2. SPLOŠNO O POVRŠINSKIH PREVLEKAH

V splošnem gre za tanko plast, narejeno z enim ali več zaporednimi pobrizgi bitumenskega veziva in posipom ter uvaljanjem plasti neovitega ali delno ovitega drobirja na asfaltni, betonski ali nevezani nosilni podlagi. Površinska prevleka je primerna za zagotovitev potrebnih lastnosti voznih - pohodnih površin na novozgrajenih in obstoječih površinah ali kot vzdrževalni ukrep na asfaltnih ali betonskih krovnih plasteh.

S površinsko prevleko:
- zaščitimo vozišćno konstrukcijo pred prepuščanjem vode
- zagotovimo ustrezne torne sposobnosti vozne površine
- zatesnimo in zaščitimo krovno ali nosilno plast
- utrdimo nevezano nosilno plast

3. MATERIAL

V tem prispevku zgolj povzemamo splošne lastnosti materialov s poudarkom na specifični uporabi. V celoti so navedene v regulativi iz točke 1.

3.1 Kamniti material

Kamniti material v površinski prevleki prenaša obremenitev na spodnje, nosilne plasti, služi kot obrabna plast, ali, v primeru nosilne plasti iz drobljenca, utrjuje površino. Da bi zadovoljivo opravljal vse naštete funkcije mora biti drobir trd, primerne oblike, odporen na zmrzal in imeti dobro afiniteto-adhezijo z bitumensko emulzijo.

Slika 1: primera kamnitega agregata

Kako se bo površinska prevleka obnašala pod prometno obtežbo je zelo povezano s kakovostjo kamnitega materiala. Ker je debelina plasti površinske prevleke majhna (1-3 cm), so zahtevani kvalitetni kamniti materiali. Material mora prenesti vse fizikalno-mehanske in kemične vplive.

Uporabljajo se kamnita zrna zgolj popolnoma drobljenih frakcij 2/4 mm, 4/8 mm, 8/11 mm, 11/16 mm.

Najbolj zaželjena oblika zrn je kubična ali tetraedrična, izogibati pa se je potrebno ploščatosti zrn. Pomembno je, da imamo čim manj nadmernih in podmernih zrn.

Škodljiva je prisotnost prašnih finih delcev, ki onemogočajo dobro omočenje oziroma ovitost zrna z vezivom. Zaradi tega se priporoča odpraševanje oz. pranje drobirja. Izbira materiala je odvisna od namena uporabe, torej zahtevane kvalitete in (želene) frakcije. V primeru okolijskih ureditev, kjer obremenitve načeloma niso odločilne, pa večjo vlogo dobijo vizualne lastnosti.

3.2 Vezivo

Namen bitumenskega veziva pri površinski prevleki je, da poveže plasti drobirja med seboj in podlago, ter vodotesno zapre vozišče. Izbira ustreznega veziva je odvisna od vrste in namena površinske prevleke, profila vozišča, vrste podlage, okolja, klimatskih razmer, prometne obremenitve, itd..

Možna je uporaba vročega bitumna ali pa bitumenske emulzije. Uporaba bitumenske emulzije ima več prednosti:

- manjša poraba energije pri proizvodnji, skladiščenju in pobrizgu in s tem povezanimi škodljivimi izpusti
- enostavnejša in bolj dostopna oprema za pobrizg, tudi zato bistveno cenejša izvedba
- ni nevarnosti eksplozije, opeklin ali vdihavanja nevarnih snovi med nanosom (pobrizgom)

Zato se v praksi vroč bitumen uporablja le, ko uporaba emulzije ni dovoljena (vodovarstvena področja – primer SAMI na Severni obvoznici v Ljubljani) ali ni praktična ali mogoča (prepočasen razpad, velik naklon površine).

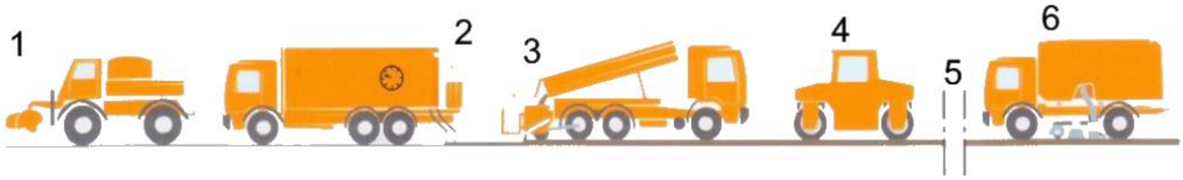
Običajno se uporablja s polimeri modificirana 70% kationska bitumenska emulzija (C 69 BP3), ki se z aditivi (lateks) lahko prilagodi specifični uporabi (večja viskoznost pri uporabi v naklonu…).

Skladno z navedenimi TSC 06.417:2001 je poraba kamnitega drobirja v odvisnosti od sistema in velikosti frakcije cca 10-20 kg/m2, poraba veziva pa 1,2 – 2,2 kg/m2. V praksi je poraba predvsem pri nevezani plasti kot podlagi večja, kar je tudi eden od razlogov, da smo Tehničnemu odboru predlagali postopek novelacije zastarele TSC.

4 IZVEDBA

V točki 4 v uvodu navedenih TSC so definirani tipi površinskih prevlek. V grobem se razlikujejo v številu plasti drobljenca in pobrizgov veziva, te bomo podrobneje omenili kasneje, pri primerih uporabe. Sama izvedba pa je v osnovi vsem enaka.

V kolikor to dopušča objekt (dolžina, minimalna širina, ovire, drevje) površinsko prevleko v celoti ali vsaj delno izvedemo strojno.



1 Čiščenje površine 2 pobrizg z emulzijo 3 posip drobljenca 4 Valjanje 5 Pavza vsaj teden dni 6 Sesanje viška zrn

Slika 2: strojna izvedba površinske prevleke - shema

Faza 1 je potrebna pred prvim slojem, faza 6 opcijsko po zadnjem sloju.

Kjer ni možna strojna izvedba, posamezne faze nadomestimo z ročnim delom (pobrizg z lanceto, ročni razvoz in razgrinjanje drobirja…).

Površina se dokončno uvalja s prometom, če le-tega ni (pešpoti) jo bolj uvaljamo pri vgradnji.

Po izvedbi in utrditvi na površini ostanejo nevezana in izločena zrna, ki se jih lahko po tednu ali več strojno pomete. To je nujno potrebno pri voziščih zaradi izletavanja izpod koles in poškodb vozil, pri okoljskih ureditvah pa se lahko tudi pustijo zaradi vizualnega učinka.

Slika 3: strojna izvedba površinske prevleke – pobrizg, posip, valjanje

Hitrost razpada bitumenske emulzije je predvsem odvisna od temperature in vlage, kar pri relativno velikih količinah, potrebnih pri površinskih prevlekah (tudi do 3 kg/m2 ene plasti), pomeni, da je izvedba del v praksi možna med mesecem majem in septembrom, v daljšem obdobju stabilnega vremena s temperaturami podlage in zraka praviloma nad 20 ° C ter, ko ni padavin. Pri pobrizgih emulzije kot vezivo med sloji asfalta je količina tipično le 0,3 -0,5 kg/m2, zato tu vremenski pogoji niso tako omejujoči.

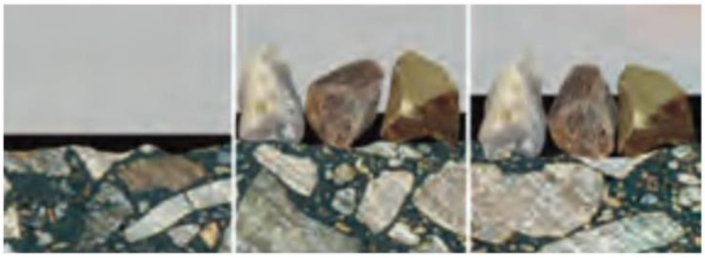
5 UPORABA

5.1 Obrabni sloj vozišč

S površinsko prevleko je možno nadomestiti obrabni sloj asfalta. Pri nas se v praksi ukrep uporablja predvsem na odsekih vozišč, kjer se ugotovi neustrezna odpornost površine proti zdrsu. Zaradi tankosti plasti (tipično cca 1 cm) niso potrebne višinske prilagoditve ostalih elementov cestišča, kot so jaški, ograje, robniki… S površinsko prevleko lahko tudi podaljšamo življenjsko dobo vozišču s »postaranim« asfaltom, če je le-to drugače v dobrem stanju.

Pod določenimi pogoji je možna tudi uporaba na betonskem vozišču.

V ta namen uporabljamo enoplastno površinsko prevleko.



Slika 4: Enoplastna površinska prevleka – pobrizg, posip, uvaljanje

Slika 5: Enoplastna površinska prevleka 4/8 mm; R2-403/1076 Češnjica -Škofja Loka

Slika 6: Nahrapavljeno in sanirano betonsko vozišče pred izvedbo protizdrsne prevleke; G1-11/1062 Koper-Dragonja

5.2 Zatesnitev veznega sloja asfalta – SAMI

Gre za enoslojno površinsko prevleko, vgrajeno med vezni in obrabni sloj asfalta, poimenovano tudi SAMI (Stress Absorbing Membrane Interlayer

Uporablja se:
- pred vgradnjo drenažnega asfalta PA
- kot zaščita podtalnice na vodovarstvenih območjih pred vgradnjo sloja SMA. V tem primeru se načeloma uporabi kot vezivo vroč bitumen.

Slika 7: zaščita podtalnice na AC A1 odsek 0655 Unec – Postojna (vroč bitumen)

5.3 Utrditev nevezane nosilne površine

Površinska prevleka se lahko izvede na nevezano nosilno podlago – tamponski sloj. Tako obdelane vozne površine zagotavljajo primerne lastnosti za prevzem predvidenih obremenitev na novozgrajenih, kot tudi na obstoječih makadamskih površinah.

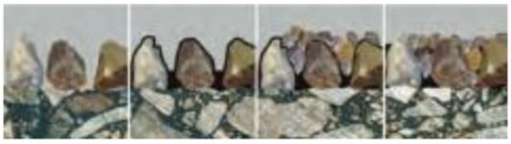
Zaradi majhne debeline površinske prevleke (1-3 cm, odvisno od izbrane vrste), je potrebno fini planum izvesti čim bolj ravno (odstopanje pod 4 m merilno letvijo +-1cm), ter homogeno (brez segregacije tamponskega sloja!). Robne elemente (robniki, granitne kocke, fasade objektov, ipd.), ter pokrove jaškov, ki bodo v stiku s površinsko prevleko, se pred izvedbo zaščiti.

Namen uporabe:
- lažje in srednje obremenjene poti
- kolesarske in pešpoti
- zunanje ureditve ob objektih
- izjemoma tudi manjša manj obremenjena parkirišča za osebna vozila

5.3.1 Vrste najpogosteje uporabljenih površinskih prevlek na nevezani podlagi

<u>»Sendvič« površinska prevleka</u>

V sestavi:
1 - posip drobirja 8/11 mm (4/8 mm)
1a - valjanje za vtis drobirja v nevezano površino
2 - pobrizg veziva
3 - zaključni posip drobirja 4/8 mm (2/4 mm)
4 - valjanje



1 2 3 4

<u>Dvoplastna površinska prevleka</u>

V sestavi:
1 - pobrizg veziva
2 - posip drobirja 8/11 mm (4/8 mm)
3 - valjanje
4 - pobrizg veziva
5 - zaključni posip drobirja 4/8 mm (2/4 mm)
6 - valjanje

1 2 3 4 5 6

<u>Dvoplastna površinska prevleka s predhodnim posipom</u>

1 2 3 4 5 6 7 8

V sestavi:
1 - posip drobirja 11/16 mm
2 - valjanje za vtis drobirja v nevezano površino
3 - pobrizg veziva
4 - posip drobirja 8/11 mm
5 - valjanje
6 - pobrizg veziva
7 - zaključni posip drobirja 4/8 mm
8 - valjanje

5.3.2 Izbor vrste površinske prevleke in količina materialov

Voziščne konstrukcije za motorna vozila

- za zelo lahko prometno obremenitev se predvidi dvoplastno površinsko prevleko in vgrajuje frakcije drobirja od 8/11 mm do 4/8 mm za zaključno vrhnjo plast.

- za lahko in srednjo prometno obremenitev se predvidi dvoplastno površinsko prevleko s predhodnim posipom s zaporednimi sloji frakcij drobirja 11/16 mm, 8/11 mm ter 4/8 mm. Zaradi obrabe se tipično uporablja silikatni kamniti drobir.

Slika 8 – dvoplastna površinska prevleka s predhodnim posipom;
R3-746, odsek 2407 Stari trg – Loški potok od km 2.020 do km 7.500

Kolesarske, peš poti in zunanje ureditve

Najpogosteje se uporabi dvoplastno površinsko prevleko s frakcijo drobirja od 4/8 mm do 2/4 mm za zaključno vrhnjo plast. Pri tem namenu je izbor odvisen tudi od preferenc glede videza ali narave uporabe.

Vrste in postopki s potrebnimi količinami materialov so v TSC navedeni z informativnimi mejnimi vrednostmi. Skozi izkušnje se je pokazalo, da so potrebne količine materialov pri izvedbi na nevezan nosilni sloj (poroznost, nevezanost) večje od v TSC navedenih splošnih. To je tudi eden od razlogov za predlagano novelacijo TSC.

Vrsta površinske prevleke	TSC 06.417:2001			IZKUSTVENA SPOZNANJA		
	zmes kamnitih zrn		Bitumensko vezivo	zmes kamnitih zrn		Bitumensko vezivo
	frakcija mm	količina kg/m2	C 69 BP 3 kg/m2	frakcija mm	količina kg/m2	C 69 BP 3 kg/m2
sendvič	8/11 4/8	11-16 4-8	1,8-2,2	8/11 4/8	13-17 15-20	2,5-3,2
dvoplastna	8/11 4/8 2/4	12-18 10-15 8-12	1,4-2,1 1,2-1,8 1,0-1,4	8/11 4/8 2/4	13-17 15-20 15-20	2,3-3,0 2,5-3,3 2,1-2,8
dvoplastna s predhodnim posipom	11/16 8/11 4/8			11/16 8/11 4/8	11-16 13-17 15-20	2,6-3,2 2,7-3,4

Vezivo

Kot že navedeno, se kot vezivo uporablja kationska polimerna bitumenska emulzija C 69 BP 3-OB. Gre pa pri uporabi na nevezani nosilni plasti za določene specifike glede viskoznosti. Biti mora dovolj tekoča da penetrira v podlago NNP in se zrna drobirja dovolj omočijo, obenem pa mora biti toliko viskozna, da ne steče s površine v določenem prečnem in vzdolžnem padcu. To se z dodatki (lateks) prilagaja v procesu proizvodnje.

6 Površinska prevleka v sklopu krajinske in okolijske ureditve

Zaradi svoje lastnosti, da so na površini vidna zgolj kamnita zrna, je površinska prevleka zelo primerna za utrditve tam, kjer je potreben naraven videz utrjene pohodne površine. Zato, in pa tudi zaradi prilagodljive izvedbe ter nizkega ogljičnega odtisa, se vedno bolj uveljavlja kot izbira v parkovnih ureditvah, na kolesarskih poteh, v naravnih parkih, spomeniških ureditvah. Tu bomo podali nekaj primerov uporabe.

Izvedba prevleke je možna na asfaltni podlagi, če želi naročnik zgolj poudariti videz površine, ali pa na tamponskem sloju, če želimo uporabiti vse prednosti površinskih prevlek. V tem primeru je izbira sistema odvisna predvsem od pričakovanih obremenitev, običajna je uporaba dvoplastne površinske prevleke, lahko s predhodnim posipom. Debelina je tako odvisna od izbire števila slojev in debeline zrn, in je med 1 in 3 cm.

Pogosto gre v teh primerih za manjše, omejene površine nepravilnih oblik oziroma ožje poti, zato se temu prilagajamo z ročno izvedbo posamezne faze del, ki je ni moč izvesti strojno (slika 9).

Ker gre v teh primerih običajno le za lahke obremenitve, in zato določene kvalitativne lastnosti niso tako pomembne, imamo več možnosti, da se z izbiro vira in granulacije materiala prilagodimo konkretnemu namenu uporabe ali želji naročnika. Za zaključni sloj je običajna uporaba frakcij 4/8 za bolj hrapavo, ali 2/4 za bolj gladko površino. Z izbiro ustreznega vira kamnitega materiala lahko v okviru naravnih možnosti tudi vplivamo na odtenek površine.

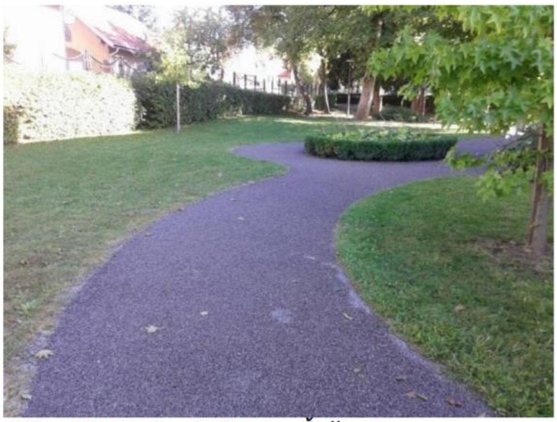
Tako je na primer naročnik v Slovenski Bistrici s površinsko prevleko s svetlejšim drobirjem na večjem asfaltnem parkirišču zmanjšal segrevanje površine (slika 10).

Na slikah 11 in 12 lepo vidimo primerjavo uporabe drobirja različnih odtenkov sive

Slika 11: Pot ob Težki vodi v Novem mestu (vir Senožeče)

Slika 12: Pot ob Dravi v Mariboru (vir Poljčane)

Površinske prevleke se zelo dobro vklopijo v parkovne ureditve. So manj toge od asfaltov, zato so manj občutljive na deformacije zaradi korenin ali posedkov.



Slika 13: Park vila Mayer Šoštanj

Slika 14: Magdalenski park Maribor

Uporabljajo se tudi za utrditev poti tam, kjer uporaba asfaltov ni dovoljena ali zaželena, kot na primer v krajinskem parku Sečoveljske soline.

Slika 15: Pot Lepa vida – Sečoveljske soline

Slika 16: Parenzana – Seča

Krajinski arhitekti jo izberejo tudi za ureditev okolice spomenikov.

Slika 17: Spomenik NOB Šentjur pri Celju

Slika 18: Spomenik vojakom Rdeče armade - Žale

Je pa pri projektiranju in pričakovani izvedbi potrebno upoštevati, da je gradnja zaradi potrebnega razpada veziva – emulzije v praksi časovno omejena na mesece, kjer je pričakovati temperature vsaj 20°C in suhe dneve. V praksi je tako v celinski Sloveniji izvedba možna v obdobju med majem in septembrom, v Istri tudi dlje.

7 ZAKLJUČEK

Tehnologija površinskih prevlek se razvija že desetletja, v nekaterih državah je tudi precej bolj zastopana, predvsem kot ukrep pri gradnji in vzdrževanju vozišč. Zaradi svojih lastnosti je pa tudi primerna za utrditve tam, kjer je želen ali potreben naraven videz pohodne površine. Krajinski arhitekti jo tako prepoznavajo kot rešitev v parkovnih ureditvah, na kolesarskih poteh, v naravnih parkih, spomeniških ureditvah.

Zaradi naravnega videza je površinska prevleka za krajinsko ureditev sprejemljivejša od klasičnega asfaltiranja, površine obdelane s tem postopkom, lažje umestimo v naravno okolje.

Zaradi bistveno manjših temperatur pri gradnji in količine ter načina uporabe potrebnih gradbenih materialov obremenjuje okolje bistveno manj kot klasični, in nizkotemperaturni asfalti.

Tehnologijo je zato tudi moč uporabiti kot ukrep skladno z Uredbo o zelenem javnem naročanju.

Ne gre za tehnologijo, ki je uporabna vedno in povsod, ima svoje slabosti, a s svojimi prednostmi je optimalna rešitev za marsikateri problem in bi si zaslužila več pozornosti.

8 VIRI IN LITERATURA

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- Productblatt Oberflachen, Vialit Austria GmbH, 2022
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Odklepanje celotnega potenciala RAP

Unlocking the full potential of RAP

Samir Irzayev (Rettenmaier & Söhne GmbH + CO KG); **Boris Kalčič** (INTERKABO HMBH)

In times of rising cost pressure paired with a growing concern for the environment, the high- quality recycling of reclaimed asphalt (RAP) provides an ideal opportunity for combining these two aspects without any compromises in terms ofquality or durability of asphalt pavements. In order to achieve the highest possible level of added value, ideally, a higher percentage of RAP derived from asphalt surface layer material with high-grade mineral aggregates and binders should be re-used in new asphalt pavement.

Asphalt recycling: recovery, treatment and addition of RAP

Whereas „recycling“ stands for the preparation and treatment of materials or products to something new, „reuse“ is defined as a repeated use of materials or products for the same application purpose.

So, for its further reuse RAP can be recovered by breaking and lifting up layer packages of asphalt in slabs (demolition asphalt) or by milling off layerwise to a certain thickness (milled asphalt). The treatment of RAP at mixing plants takes place in form of crushing, granulating and sieving. Different RAP types are stored separately from each other and should be covered with foil. The addition of cold RAP can be fulfilled batchwise or continuously, RAP can also be added hot after pre-heating in parallel drums. The portion of added cold or hot RAP depends on local regulation.

In Germany, in order to analyse the RAP content, a defined number of samples is taken from stockpiles, usually 5 samples from every 500 tons. The homogeneity is then determined by bitumen content (% by weight), softening point ring and ball (°C) and particle fractions of filler, sand and coarse aggregates of >2mm (% by weight).

Table 1: RAP content analysis

Characteristic	Softening point Ring-and-ball ($T_{R\&B}$) [°C]	Binder content [M.-%]	Particle fraction < 0,063 mm	Particle fraction 0,063 mm bis 2 mm	Particle fraction > 2 mm
Sample no. 1	68,6	5,8	9,8	27,7	62,4
Sample no. 2	64,0	5,8	11,3	25,2	63,5
Sample no. 3	64,8	5,2	9,2	19,8	70,9
Sample no. 4	68,0	4,7	6,7	21,5	71,8
Sample no. 5	66,4	5,1	12,1	23,8	64,1
Mean value	66,4	5,3	9,8	23,6	66,5
Range	4,6	1,1	5,4	7,9	9,4

The maximum amount of RAP is based on its homogeneity and the technical setup of the mixing plant. However, the lowest value out of these 5 parameters determines the maximum RAP content (see Figure 1).

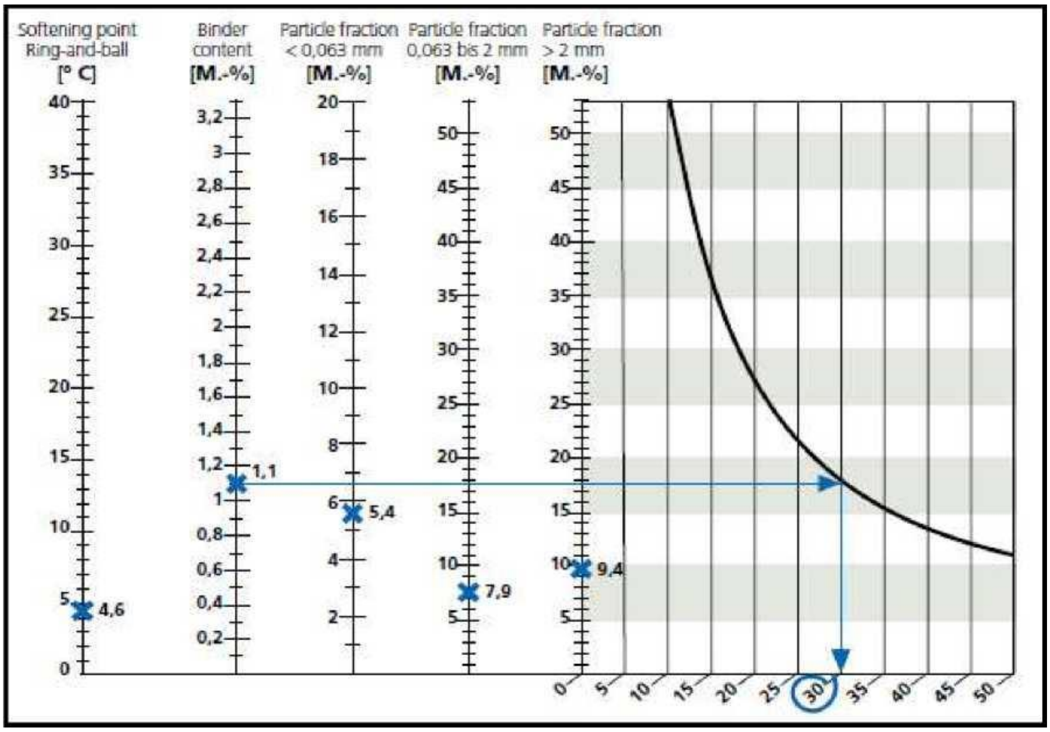


Figure 1: Determination of maximum RAP content

Problem of bitumen aging

Bitumen aging is primarily caused by heat, UV and oxidation, which all lead to increased stiffness and loss of adhesion, resulting in ravelling and thermal cracking in winter periods and, therefore, shortening the total service life of the asphalt pavement.

The exposure to heat, air oxygen and UV changes the chemical composition of the bitumen, that is reducing its oily maltenes phase with remaining greater ratio of stiffer asphaltenes. The bitumen becomes over its lifetime brittle, less ductile and more susceptible to temperature variations.

Figure 3: Cracking

Figure 2: Ravelling

Asphalt aging occur in two stages: short-term and long-term. Short-term aging is mainly caused by volatilization, oxidation, and/or absorption of oily components and happens during mixing, transport and paving. Long-term aging occurs during service life and depends mainly on the composition of asphalt as well as on external influence such as oxygen from the atmosphere.

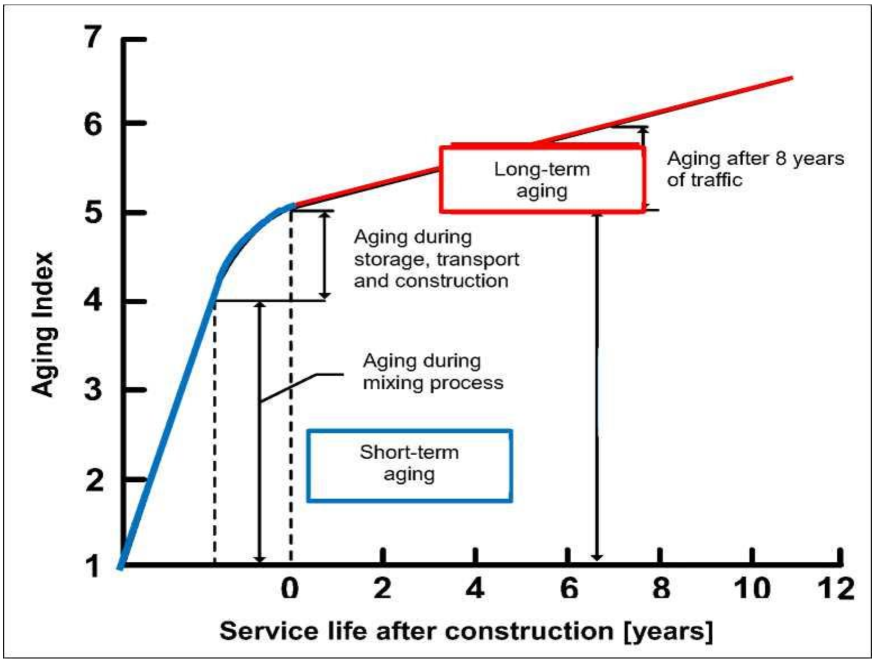


Figure 4: Short-term and long-term aging of bitumen

The bitumen aging can be simulated in lab conditions: in Pressure-Aging-Vessel (PAV) for a long-term aging and during Rolling-Thin-Film-Oven-Test (RTFOT) for a short-term aging.

Overcoming bitumen aging: real rejuvenator vs. softening agents

The usage of a sustainable and effective rejuvenator allows to solve the issue of bitumen aging. A real rejuvenator restores physical and rheological (viscoelastic) properties of an aged bitumen, reduces its overall viscosity, improves its relaxation, ductility, cohesive and adhesive properties and should not lead to the accelerated aging of a rejuvenated bitumen.

Softening agents such as flux oil, which are frequently positioned as rejuvenators, can only lower the viscosity of an aged bitumen. They are unable to re-activate it, to eliminate or reduce its exposure to cracking and to maintain or improve its rutting resistance. Softening agents only soften, dilute or plasticize the aged bitumen.

Search for a new kind of real rejuvenator led us to the development of a new product **VIATOP® *plus* *RC***, an effective combination of cellulose fibers and rejuvenator. By using **VIATOP® *plus RC***, a higher dosage of RAP is possible at mixing plants with adequate technical setup without major investments.

Comparative study on effect of various additives

In course of a comparative study performed by an independent laboratory, a total of six different additives, including the additive used in **VIATOP® *plus RC***, were examined with regard to their rejuvenation effect. The additives studied are shown in Figure 5.

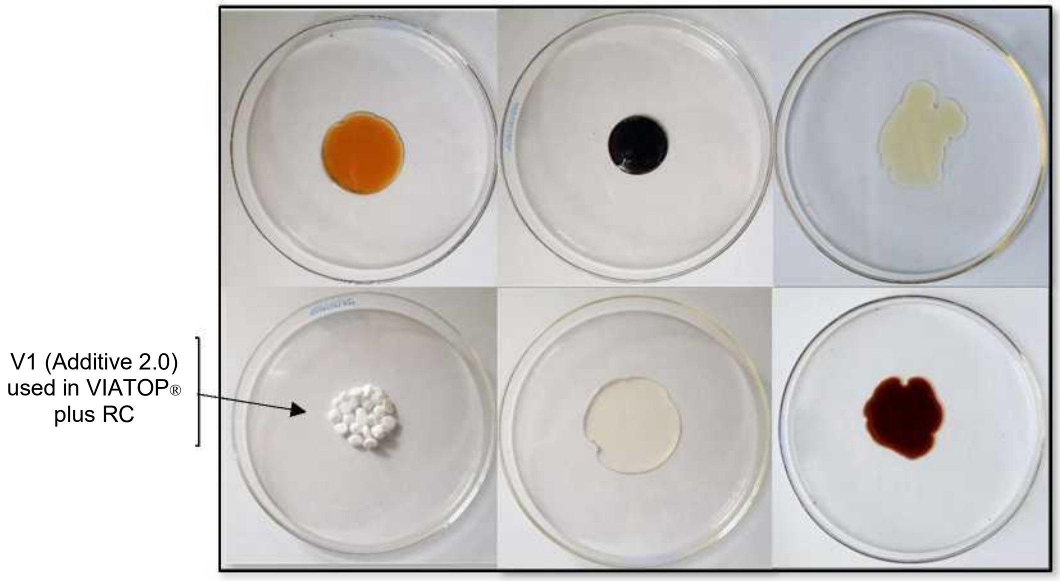


Figure 5: Additives for study

In order to obtain a comparative basis for assessment of their individual effect, the same road construction bitumen 50/70 was used for all variants and a constant quantity of 3% by weight of each additive was applied.

Rapeseed oil at the quantity of 3% by weight and soft road construction bitumen 160/220 at a rate of 30% by weight were also used for direct comparison to six additives.

Firstly, a testing of the physical (*softening point ring and ball*, *needle penetration*) and rheological properties (*complex shear modulus* and *phase angle* on Dynamic Shear Rheometer as well as *behavior at low temperatures* on Bending Beam Rheometer) was performed on a bitumen 50/70 in the "virgin" and aged (short-term aging RTFOT and long-term aging PAV) condition.

Afterwards, the above-mentioned additives, rapeseed oil and bitumen 160/220 were added to the aged bitumen samples. In order to test the effectiveness of each additive on aged bitumen, physical and rheological properties of the samples were examined again. Then, the rejuvenated samples underwent repeated aging and testing to check the long-term effectiveness of each additive.

The following indications were used to identify the aging stages:

- A0: fresh / "virgin" condition, also after rejuvenation
- AI: after short-term aging (RTFOT)
- AII: after short-term (RTFOT) and long-term aging (PAV)
- AIII: after short-term (RTFOT) and twice long-term aging (PAV)

The testing procedure is shown as a flow chart in Figure 6:

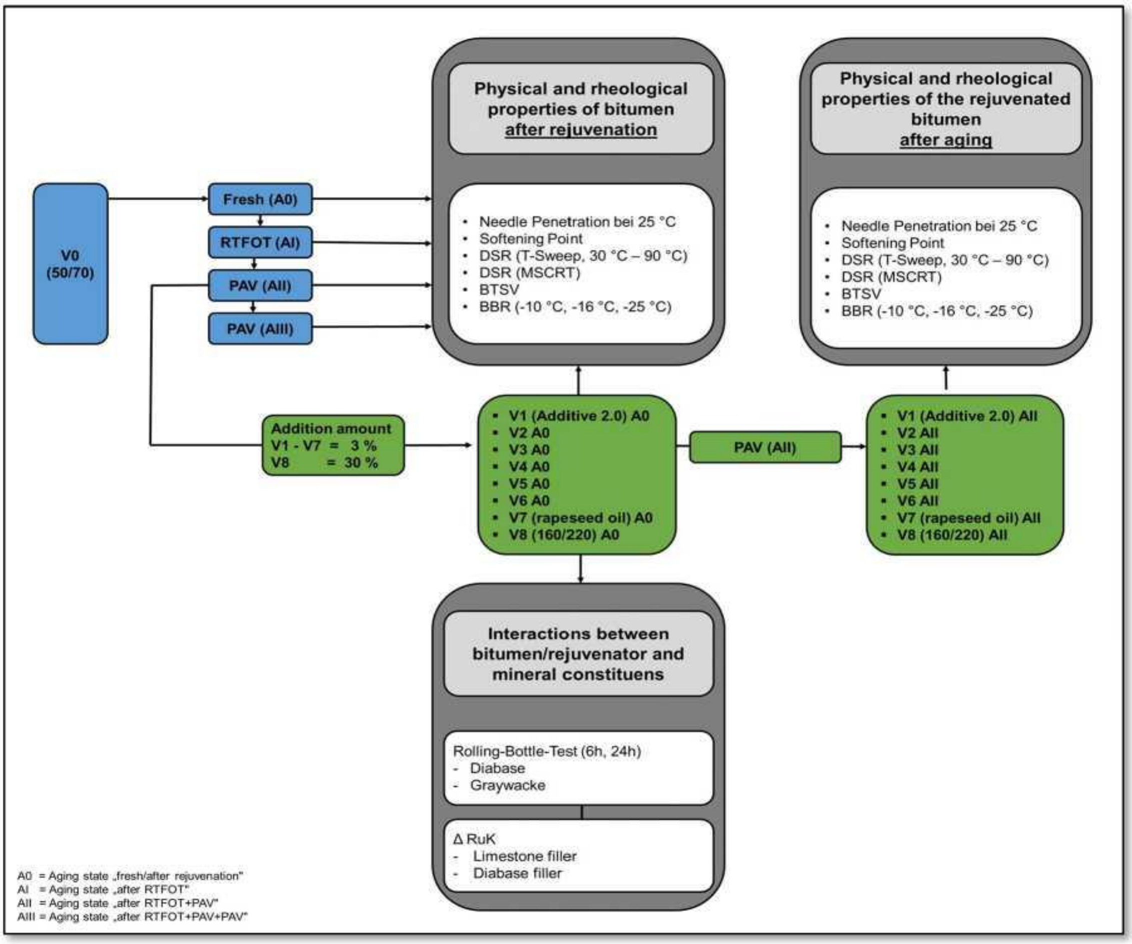


Figure 6: Testing program

For a better visualization and comparability of the results, the parameters were plotted on spider diagrams. The bitumen parameters were subdivided into three basic temperature ranges: high (60°C), medium (20°C to 30°C) and low (-10°C to -25°C).

The results show the percentage, to which the physical and rheological properties of the aged base bitumen were restored after rejuvenation in relation to base bitumen 50/70 in the „virgin" condition. They also indicate the effectiveness of an individual product within the specific temperature range based on the size of the colored area (larger colored area = higher effectiveness).

100% stands for a complete restoration of the value or even its improvement by the rejuvenating agent.

The following Figure 7 provides an example of the spider diagram for a fresh base bitumen 50/70 (A0) compared to its aged state (AII). Figure 8 compares the values achieved by all rejuvenating additives, including the one used in **VIATOP® *plus RC*** (V1).

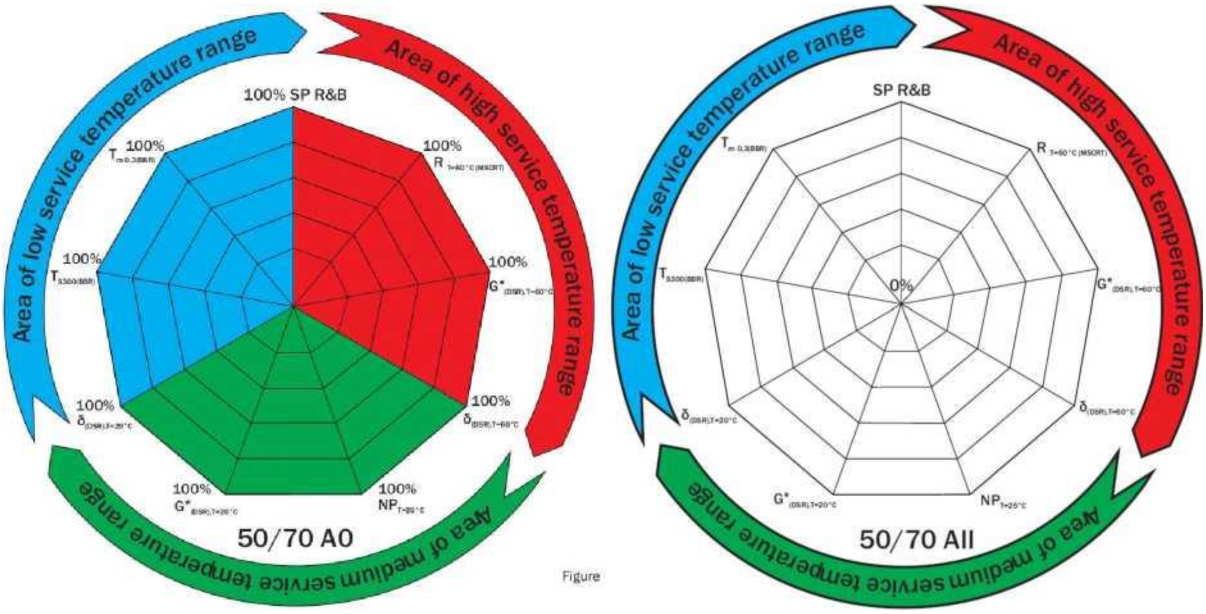


Figure 7: Fresh base bitumen 50/70 (A0) vs. aged base bitumen 50/70 (AII)

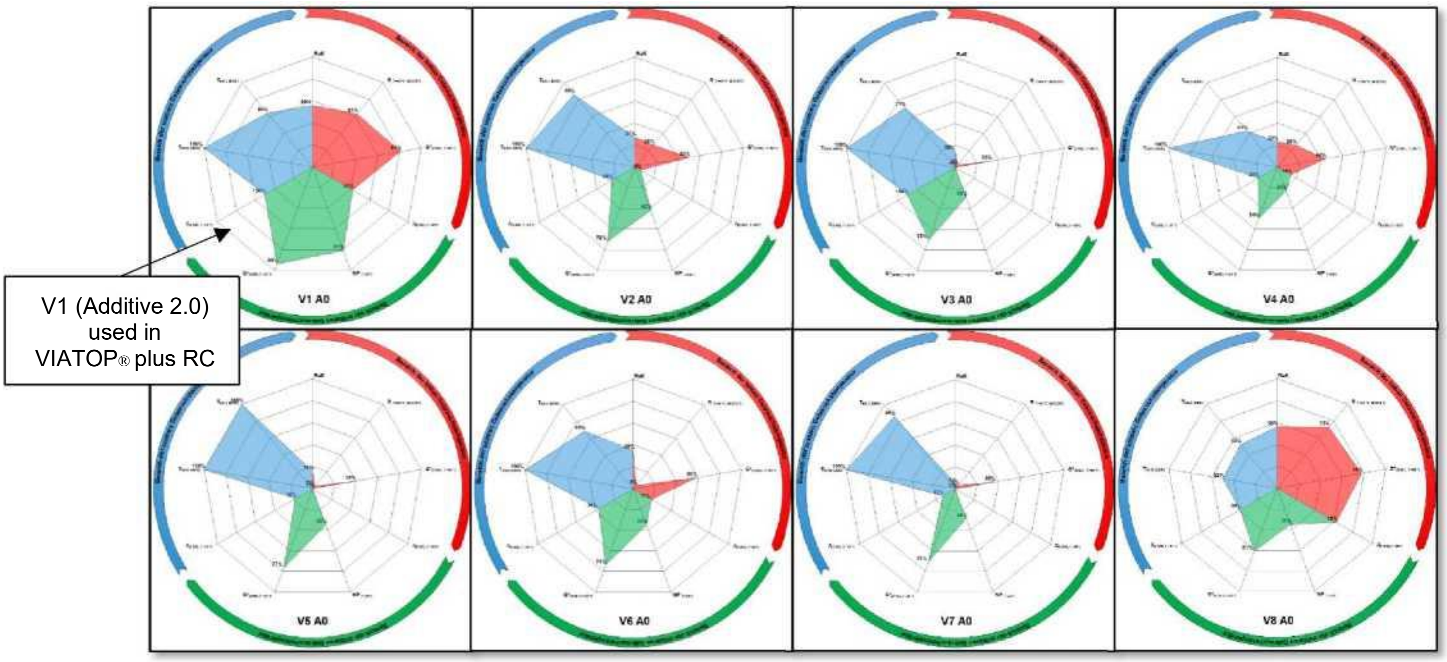


Figure 8: Restoration of properties after rejuvenation 50/70 (AII)

In order for a rejuvenator to be classified as effective, it must restore the characteristic values of the fresh bitumen over the entire temperature range. The rejuvenator V1 from **VIATOP® *plus RC*** and soft road construction bitumen 160/220 (V8), which is added at a rate of 30% by weight, both lead to the highest restoration of the physical and rheological properties with the most uniform results over all three temperature ranges.

Conclusion

The results of the study make it clear that it is not enough to simply assess the bitumen parameters directly after the addition of a rejuvenator. Rather it is necessary to also assess the properties of the rejuvenated bitumen after repeated aging as well. A rejuvenator can be considered as sustainable and effective only if it exhibits significantly better values than the base bitumen at the comparable aging level.

By any means, a rejuvenator must not accelerate the aging process of the bitumen in a way, so that the original bitumen (without rejuvenator) shows similar or better results after aging, compared to a rejuvenated bitumen of the same „aging status“. In this context, the terms sustainability and effectiveness of a rejuvenator play a major role.

The study demonstrated that the additive used in our product **VIATOP® *plus RC*** provides a real rejuvenation effect on aged bitumen. It significantly improves its physical and rheological properties. The additive does not simply soften or plasticize the aged bitumen, but re-activates it. In addition to the apparent rejuvenating effect, the study has proven that the rejuvenator is able to prevent further aging of the binder to a certain extent.

Using rejuvenators to improve the performance of asphalt pavement is an effective and economic way of hot asphalt recycling. **VIATOP® *plus RC*** contains a real rejuvenator, allowing a higher dosage of RAP at mixing plants with adequate technical setup. In the pelletized form it is easy to handle with the available dosing technology and it contains no hazardous substances.

VIATOP® *plus RC* is the solution, which combines economic and environmental aspects of asphalt production.

Sources:

[1] „Effectiveness and Performance of Rejuvenators, Part 3: Laboratory Tests“ by Dr.-Ing. Daniel Gogolin and Tim Lümkemann, B.Sc. (asphalt, Volume 2/2019)

REFERATI SEKCIJA 4: Proizvodnja asfaltnih zmesi, testiranje in oprema

LECTURES SECTION 4: Manufacture of Asphalt mixtures, testing, and equipment

Poskusna polja s toplimi asflati po postopku penjenega bitumna na odsekih AC 0043 in AC 0067 (Vransko – Blagovica): Način do boljše trajnosti in zmanjšanja ogljičnega odtisa

Full-scale test of warm asphal tusing the foamed bitumen process on sections AC 0043 and AC 0067 (Vransko – Blagovica): Toward improved durability and reduced carbon footprint

Dejan Hribar, Boris Ronkalj (STRABAG laboratorij TPA) **; Lidija Ržek** (ZAG)

Povzetek

Na odsekih AC 0043 in AC 0067 (Vransko – Blagovica) se je oktobra 2024 izvedlo primerjalno preskusno polje asfaltne zmesi AC 22 bin PmB 45/80-65 A1, A2, po klasičnem vročem postopku (oznaka vzorca HMA) ter po sodobnem toplem postopku z uporabo penjenega bitumna (oznaka vzorca WMA). Analize so pokazale, da topla asfaltna zmes (WMA) po postopku penjenega bitumna (z cca 30 °C nižjo temperaturo pri vgradnji) dosega enakovredne mehanske-fizikalne lastnosti kot klasična (HMA), pri čemer ključno razliko izkazuje WMA z manjšo otrdelostjo ekstrahiranega veziva. To potrjuje, da nižja temperatura vgradnje pozitivno vpliva na zmanjšanje staranja bitumenskega veziva ter prispeva k večji trajnosti vozišČne konstrukcije in zmanjšanju ogličnega odtisa.

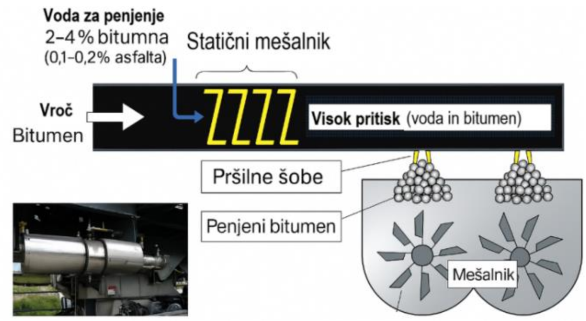
Abstract

In October 2024, on sections AC 0043 and AC 0067 (Vransko – Blagovica), a comparative trial was carried out using the AC 22 bin PmB 45/80-65 A1, A2 asphalt mixture. The mixture was applied both using the conventional hot process (HMA) and the modern warm process with foamed bitumen (WMA). The analyses showed that the warm asphalt mixture (WMA), applied at approximately 30 °C lower than the hot mix, achieves mechanical and physical properties equivalent to the conventional HMA. The main difference is that WMA exhibits lower stiffness of the extracted binder, indicating that the lower placement temperature helps reduce bitumen aging. This contributes to longer pavement life and a smaller carbon footprint.

Uvod

V zadnjih desetletjih se cestogradnja sooča z naraščajočimi okoljskimi zahtevami, ki jih narekujejo evropske in nacionalne politike. Evropski zeleni dogovor in strategija Fit for 55 predvidevata zmanjšanje emisij toplogrednih plinov za 55 % do leta 2030 ter dosego podnebne nevtralnosti do leta 2050 [1]. V tem kontekstu imajo tehnologije toplih asfaltov (*ang. Warm Mix Asphalt, WMA*) pomembno vlogo, saj omogočajo znižanje proizvodne in vgradne temperature asfaltnih zmesi za približno 20–40 °C v primerjavi s konvencionalnimi vročimi asfaltmi (*ang. Hot Mix Asphalt, HMA*) [2]. Takšen pristop neposredno prispeva k nižji porabi energije, zmanjšanju emisij CO_2 ter izboljšanju delovnih pogojev zaradi manjše emisije hlapov in dima med vgradnjo [3]. Poleg tega nižje temperature upočasnijo staranje veziva, kar lahko pozitivno vpliva na dolgoročno trajnost vozišČne konstrukcije.

Tehnologije WMA vključujejo več pristopov, med katerimi so najpogostejši uporaba organskih dodatkov (npr. voski), kemičnih dodatkov ter penjenega bitumna. Organski dodatki znižujejo viskoznost veziva pri nižjih temperaturah, kemični dodatki pa poleg izboljšane obdelovalnosti povečajo adhezijo med bitumnom in agregatom. Penjeni bitumen, ki nastane z vbrizgavanjem majhne količine vode v segreti bitumen, povzroči njegovo hitro prostorninsko razširitev in začasno zmanjšanje viskoznosti. S tem se olajša mešanje in omogoči enakomerno obdajanje agregatnih zrn, tudi pri nižjih temperaturah [4]. V Evropi je prav tehnologija penjenega bitumna ena najpogosteje uporabljanih metod za dosego ciljev WMA, saj ne zahteva nujno dodatnih kemičnih sredstev in se lahko izvaja z ustrezno prilagoditvijo obstoječe opreme v asfaltnih bazah.



Slika 1: Koncept proizvodnje toplega asfalta z penjenem bitumna [2]

Številne raziskave in testna polja so pokazali, da WMA, izdelan s penjenim bitumnom, dosega mehanske lastnosti, primerljive ali celo boljše od HMA. Med ključne prednosti sodijo lažja vgradnja pri nižjih temperaturah, možnost daljših transportnih ter možnost vgradnje v hladnejših vremenskih pogojih, kar povečuje operativno prilagodljivost gradbenih del [4], [5], [6].

V Sloveniji je uporaba WMA s penjenim bitumnom še vedno omejena. Doslej so se topli asfalti vgrajevali predvsem v okviru testnih polj, zato obstaja potreba po sistematičnem spremljanju in oceni njihovega dolgoročnega obnašanja v realnih prometnih in klimatskih razmerah. V tem prispevku so predstavljene praktične izkušnje s poskusnim poljem na slovenski avtocesti, kjer so bile izvedene asfaltne zmesi s penjenim bitumnom.

1. Materiali in metode

Na avtocestnih odsekih AC 0043 in AC 0067 med Vranskim in Blagovico je bilo izvedeno testno polje, kjer so se v vezni plasti vgrajevali topli asfalti proizvedeni s tehnologijo penjenega bitumna. Na asfaltni bazi Andraž sta bili proizvedeni dve asfaltni zmesi tipa AC 22 bin PmB 45/80-65 A1, A2:

- referenčna vroče pripravljena asfaltna zmes AC 22 bin PmB 45/80-65 A1, A2 (HMA) ter
- topla asfaltna zmes AC 22 bin PmB 45/80-65 A1, A2 NT (WMA), pri kateri je bil uporabljen penjeni bitumen.

Transport in vgradnja tople asfaltne zmesi na poskusnem polju je potekala na enak način kot pri klasičnih vročih asfaltnih zmeseh (slika 2). Uporabljena je bila mehanizacija finišer Vogele 1800-3i in valjarji HAMM HD 80i k, HAMM 75 HD, HAMM 13 HD. Vezna asfaltna zmes se je na testnem polju vgrajevala na voznem pasu v širini 4 m in dolžini 430 m (200 m HMA in 230 m WMA). Projektirana debelina asfaltne zmesi je bila 90 mm.

Slika 2: Vgradnja toplega asfalta po postopku penjenega bitumna [TPA, 2024]

Obe proizvedeni zmesi in vgrajene asfaltne plasti so bile preiskane v laboratorijih ZAG in TPA. Vhodni s polimeri modificiran bitumen (PmB 45/580-65) in ponovno pridobljena bitumna iz tople in vroče asfaltne zmesi so bili preiskani po postopkih standardnih empiričnih preiskav (temperatura zmehčišča po prstanu in kroglici, penetracija, pretrgališče po Fraassu, duktilnost) v laboratoriju ZAG in TPA. Z omenenimi preiskavami smo ugotavljali osnovne fizikalno-mehanske lastnosti bitumnov. Dodatno je bila z dinamičnim strižnim reometrom preiskana reologija bitumnov v laboratoriju ZAG.

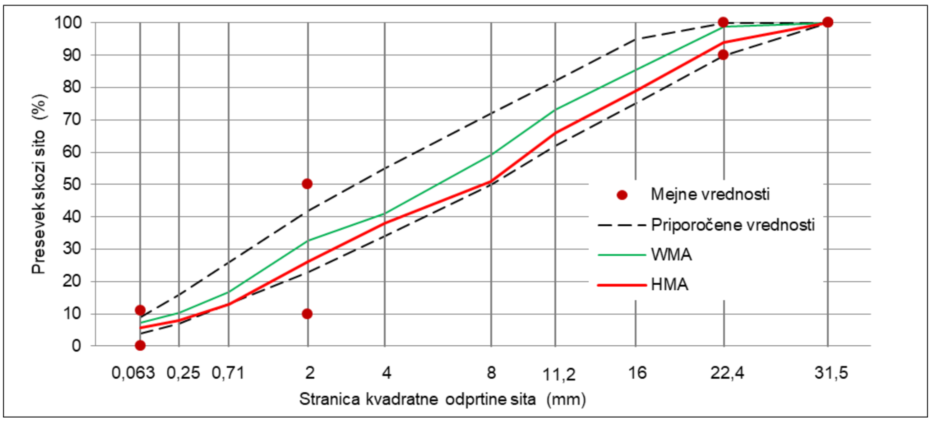
Asfaltni zmesi (WMA in HMA) sta bili preiskani po zahtevah serije standardov SIST EN 12697. Določene so bile sejalne krivulje, gostote asfaltnih zmesi (prostorninska in največja gostota asfalta), vsebnost zračnih votlin v zmesi in stopnja zapolnjenosti votlin v kameni zmesi z vezivom. Za določitev mehanskih lastnosti je bila asfaltnima mešanicama določena odpornost na utrujanje.

Na gradbišču je bilo med vgradnjo izvedeno spremljanje temperature asfaltne zmesi. Po vgradnji so bila iz obeh testnih odsekov odvzeta jedra, na katerih je bila določena zgoščenost in vsebnost zračnih votlin v plasti. Preiskana je bila tudi zlepljenost asfaltnih plasti po TSC 06.753:2006.

2. Rezultati preiskav

3.1 Rezultati preiskav asfaltne zmesi

Topni delež veziva je bil pri WMA nekoliko višji kot pri HMA, kar lahko kaže na učinkovitejše obvijanje agregata ali enakomernejšo porazdelitev veziva. Največja gostota obeh zmesi je bila praktično enaka, kar pomeni, da je skelet agregata primerljivo sestavljen. Večja razlika se kaže pri prostorninski gostoti in vsebnosti zračnih votlin. WMA je imela višjo prostorninsko gostoto in nižjo vsebnost zračnih votlin, kar nakazuje boljšo zgostljivost zmesi in potencialno manjšo prepustnost. Zapolnjenost votlin z vezivom (VFB) je bila pri WMA prav tako višja, kar pomeni, da je notranja struktura zmesi gostejša, kar lahko prispeva k večji odpornosti proti vplivom vode in zraka. Sejalni krivulji obeh zmesi sta med seboj primerjlivi. Vse preiskane vrednosti so bile znotraj zahtev standarda SIST 1038-1:2009/AC103:2022 za vezno asfaltno zmes.

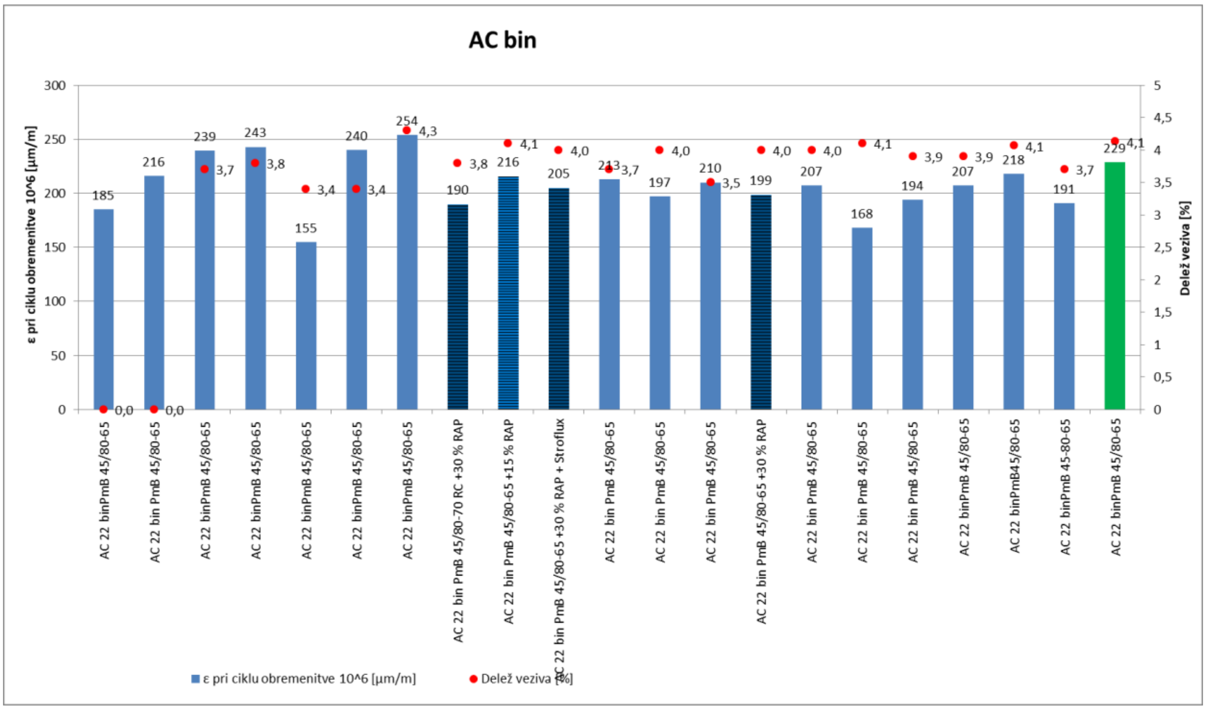


Slika 3: Sejalni krivulji asfaltnih zmesi WMA in HMA

Preglednica 1: Rezultati preiskav asfaltnih zmesi

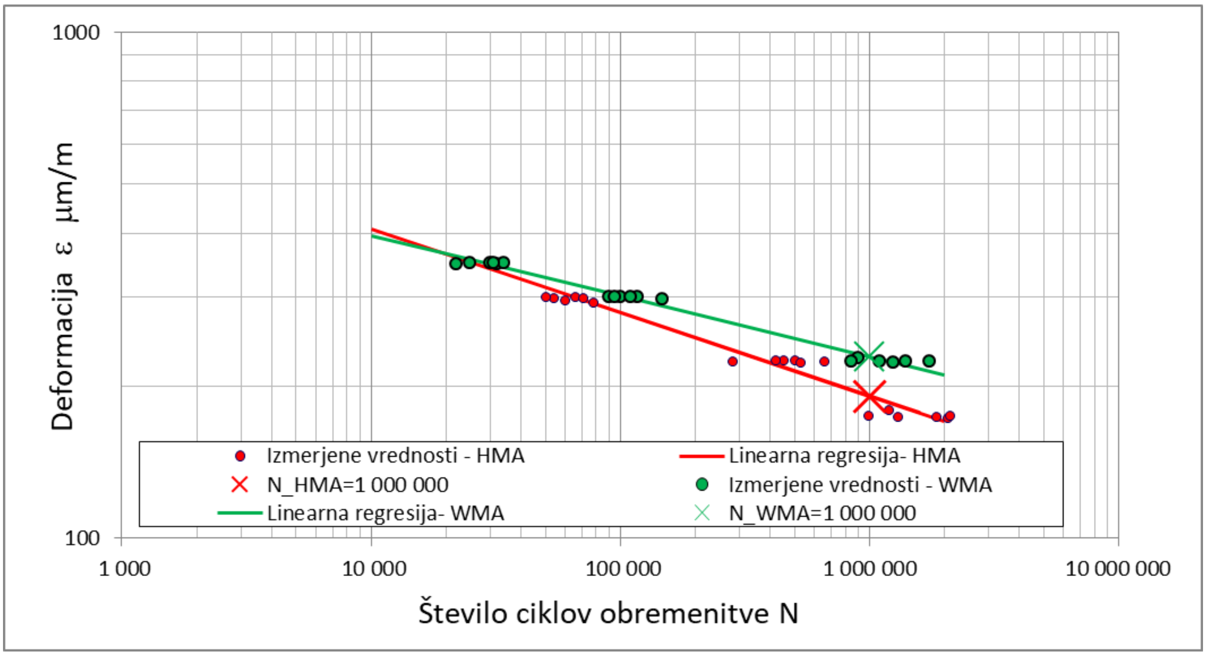
Lastnost	Metoda preiskave	Enota	HMA TPA	WMA TPA	WMA ZAG	Zahteva SIST 1038-1:2022
Topni delež veziva	SIST EN 12697-1: 2020	% (m/m)	3,7	3,9	4,1	
Največja gostota asfalta	SIST EN 12697-5: 2019, tč.9.2	Mg/m3	2,558	2,561	2,560	
Prostorninska gostota asfalta	SIST EN 12697-6: 2020, tč.9.3	Mg/m3	2,414	2,434	2,450	
Vsebnost zračnih votlin (Va)	SIST EN 12697-8: 2019	% (V/V)	5,6	5,0	4,3	4,0-7,0
Zapolnjenost votlin v KZ z vezivom (VFB)	SIST EN 12697-8: 2019	% (V/V)	60,8	65,1	69,8	55,0-77,0

Za oceno odpornosti asfaltne zmesi na ponavljajoče se obremenitve smo izvedli teste utrujanja po standardu SIST EN 12697-24:2018, dodatek D (4-točkovni upogibni test – 4PB-PR). Pri vsaki stopnji obremenjevanja (deformacija ε) se meri število ciklov, potrebnih, da začetni modul togosti asfaltne zmesi pade na polovico. Eden izmed rezultatov preiskave je izračunana vrednost deformacije ε_6, ki jo asfaltna zmes prenese pri milijon ciklih obremenitve. Na podlagi arhivskih podatkov ZAG, ki vključujejo 21 vzorcev zmesi AC 22 bin PmB 45/80-65 (nekateri vsebujejo tudi delež asfaltnega granulata RA) znaša povprečna vrednost deformacije ε_6 208 µm/m. Ugotovimo lahko, da rezultati obeh testiranih zmesi (zadnja dva rezultata na sliki 4: HMA 191 µm/m in WMA 229 µm/m) niso bistveno odstopali od povprečja.



Slika 4: Primerjava rezultatov utrujanja ε_6 in deleža veziva v zmeseh AC 22 bin PmB 45/80-65 testiranih na ZAG

Na spodnji sliki je grafični prikaz izmerjenih vrednosti ciklov obremenitve in premica linearne regresije, določena na osnovi eksperimentalnih podatkov za vsako testirano zmes (HMA in WMA). Iz naklonov premice linearne regresije lahko vidimo, da pri enakem številu ciklov obremenitve WMA prenese večje deformacije. Pri enaki stopnji deformacije (224 µm/m) WMA zmes prenese precej več ciklov obremenitve (cca 1,2 milijona) v primerjavi s HMA (cca 474000)



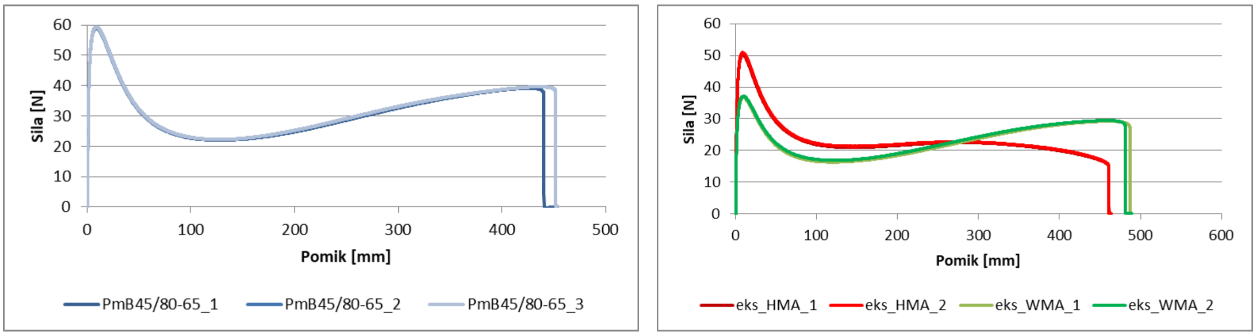
Slika 5: Rezultati preiskave utrujanja

3.2 Rezultati preiskav bitumna

Rezultati osnvovnih preiskav bitumnov so podani v preglednici 2. Vrednosti penetracije ponovno pridobljenih bitumnov sta pričakovano nižji v primerjavi z vhodnim bitumnom, kar kaže na njuno otrdelost kot posledico staranja (proizvodnja in transport zmesi). Manjšo otrdelost izkazuje bitumen, pridobljen iz tople asfaltne zmesi (WMA), kar potrjuje, da lahko nižja temperatura vgradnje zmanjša stopnjo staranja veziva. Rezultati zmehčišča po PK se precej razlikujejo. Vsi rezultati pretrgališča po Fraassu izkazujejo podobno vrednost, ki kažejo na dobro odpornost bitumna proti krhkosti pri nizkih temperaturah. Rezultati preiskave elastičnosti vhodnega bitumna so visoki in medsebojno primerljivi ter nakazujejo na dobro elastičnost bitumna.

Preglednica 2 Rezultati preiskav vhodnih in ponovno pridobljenih bitumnov

Lastnost	Metoda preiskave	Enota	PmB 45/80-65 TPA	PmB45/80-65 ZAG	eks HMA	eks WMA
Penetracija pri 25 °C	SIST EN 1426:2015	1/10 mm	59	58	36	44
Zmehčišče po PK	SIST EN 1427:2015	°C	83,5	70	70,8	80
Pretrgališče po Fraassu	SIST EN 12593:2015	°C	-19	-18	-17	-18
Elastična povratna deformacija	SIST EN 13389:2018	%	95	92	/	/
Celoten raztezek (duktilnost) s∞	SIST EN 13589:2018	mm	/	444,89	462,28	485,33
Maksimalna sila F∞, max	SIST EN 13589:2018	N	/	59,18	50,58	36,96
Celotna energija E'∞	SIST EN 13589:2018	J/cm2	/	14,23	10,86	11,34
Referenčna energija E's = E'0,4-E'0,2	SIST EN 13589:2018	J/cm2	/	6,58	4,40	4,78



Slika 6: Odvisnost sile od pomika pri preiskavi duktilnosti vhodnega (T = 5°C) in ponovno pridobljenih bitumnov (T = 10°C)

Pri duktilnosti je imel vhodni PmB 45/80-65 pri 5 °C raztezek približno 445 mm, pri 10 °C pa sta bila rezultata za ponovno pridobljen bitumen iz HMA 462 mm in iz WMA 485 mm. Vsi vzorci so pokazali visoko sposobnost raztezanja brez pretrga, pri čemer je WMA dosegel nekoliko boljše vrednosti, kar je smiselno zaradi nižjega staranja pri nižjih temperaturah vgradnje. Maksimalna sila je bila nižja pri WMA, kar nakazuje na mehkejši material, medtem ko so bile vrednosti celotne energije in referenčne energije nekoliko višje pri WMA kot pri HMA, kar potrjuje manjšo otrdelost in boljšo elastičnost. Svež polimerno modificirani bitumen (PmB 45/80-65) je pričakovano izkazal najvišje vrednosti trdnosti in energije.

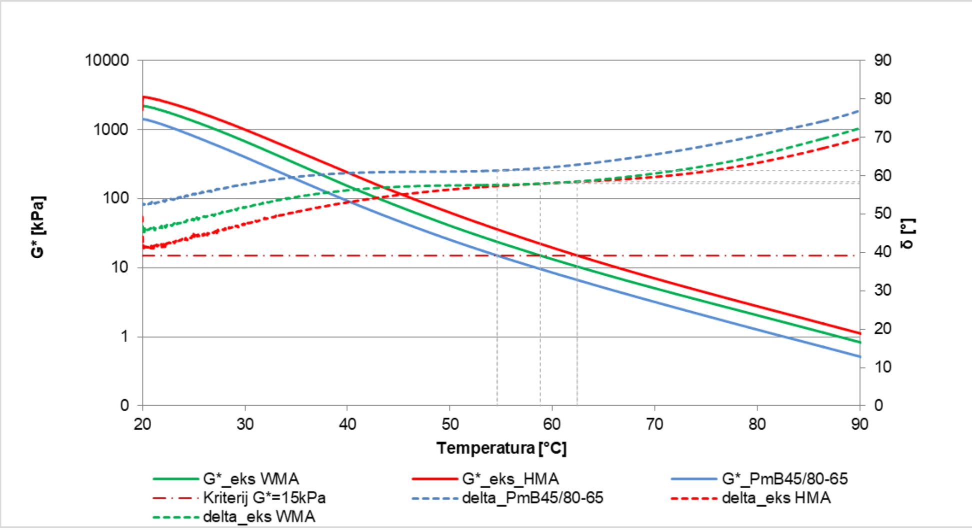
Preiskava zmehčišča je zanesljiva pri običajnih bitumnih, pri polimerno modificiranih pa pogosto ne daje konsistentnih rezultatov [7]. Pri preiskavah duktilnosti pri 5 °C je težava visoka občutljivost na odstopanja temperature vodne kopeli, kar zmanjšuje ponovljivost. Poleg tega metoda ocenjuje obnašanje pri velikih deformacijah, ki so v praksi redke, medtem ko so lastnosti pri manjših deformacijah slabše raziskane.

Zaradi navedenih omejitev v laboratoriju ZAG izvajamo tudi reološke preiskave z dinamičnim strižnim reometrom (DSR), ki omogočajo natančnejšo in ponovljivo oceno elastično-viskoznega obnašanja bitumna ter boljše razumevanje njegovega odziva pri realnih obremenitvah in temperaturah.

Za karakterizacijo bitumna pri višjih temperaturah je primerna metoda BTSV (nem. *Bitumen-Typisierungs-Schnell-Verfahren* oz. ″hitri tipizacijski test za bitumne″ SIST EN 17643:2022), ki so jo razvili v Nemčiji [8]. Dobljena temperatura T_{BTSV} je pokazatelj zmehčanja, medtem ko fazni kot δ_{BTSV} dodatno opiše viskoelastičnost bitumna. Ponovno pridobljena bitumna imata višje vrednosti kompleksnega modula G* kot vhodni bitumen, saj sta že bila podvržena staranju. Najvišje vrednosti ima ponovno pridobljen bitumen iz vroče asfaltne zmesi. Najnižje vrednosti faznega kota skozi celo temperaturno področje izkazuje ponovno pridobljen bitumen iz HMA, kar potrjuje največjo stopnjo oksidacije pri tem bitumnu.

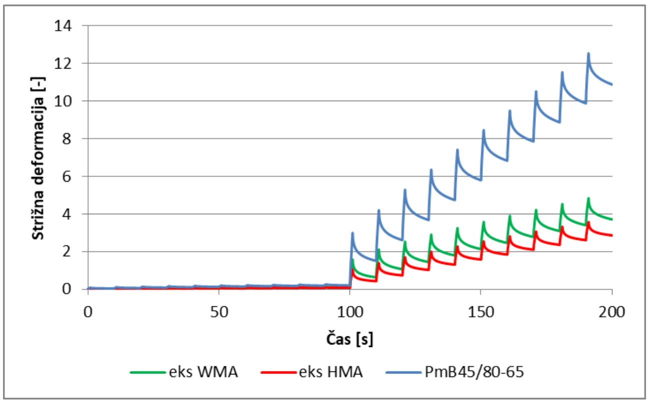
Preglednica 3: Rezultati preiskave BTSV vhodnega in ponovno pridobljenih bitumnov

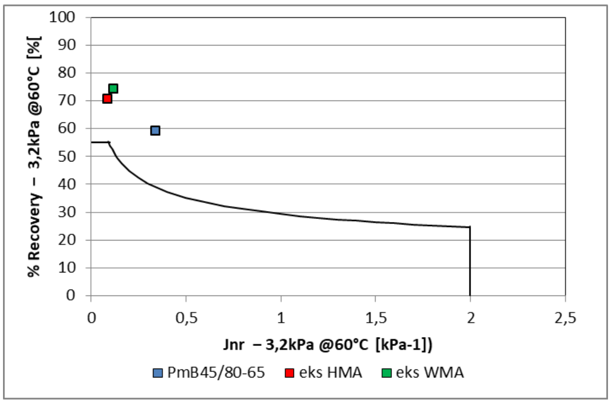
Lastnost	Metoda preiskave	Enota	PmB 45/80-65 ZAG	eks HMA	eks WMA
T pri G*=15 kPa	SIST EN 17643:2022	°C	54,6	62,4	58,8
δ pri TG*=15 kPa	SIST EN 17643:2022	°	61,4	58,4	58
T pri G*/sinδ > 1000 kPa	SIST EN 17643:2022	°C	83,2	/	88,6
δ pri G*/sinδ > 1000 kPa	SIST EN 17643:2022	°	72,3	/	71,3
T pri G*/sinδ > 2200 kPa	SIST EN 17643:2022	°C	74,8	83,6	80,3
δ pri G*/sinδ > 2200 kPa	SIST EN 17643:2022	°	67,7	65,4	65,4



Slika 7: Določanje temperature in faznega kota pri enakovrednem strižnem modulu – preskus BTSV (SIST EN 17643:2022)

Za oceno elastičnosti bitumna in ugotavljanje potenciala tvorjenja kolesnic pri visokih temperaturah smo izvedli preskus lezenja (angl. *Multiple-Stress Creep-Recovery Test – MSCRT*). Preiskava se skladno s standardom SIST EN 16659:2016 izvaja pri temperaturi 60 °C, tako da bitumen strižno obremenimo z različnimi strižnimi obremenitvami in merimo elastični povratek 'R_N' vzorca v neobremenjenem stanju oziroma delež nepovratne deformacije oziroma vrednost 'neobnovljive voljnosti' J_{nr}, ki predstavlja lezenje oziroma nepovratno deformacijo. Zaželeno je, da ima bitumen čim večji delež povratka in da je hkrati nepovratna voljnost manjša od 0,5 kPa^{-1}. Če je nepovratna voljnost večja od 0,5 kPa^{-1} in je delež povratka majhen (pod mejno črto – določena za kratkotrajno starane bitumne v ameriškem standardu AASHTO [9], [10]), je bitumen pri 60 °C bolj podvržen nastajanju kolesnic pri cestah z veliko prometno obremenitvijo. Rezultati nad mejno črto nakazujejo zadosten elastičen odziv za bitumne modificirane z elastomeri. Parameter $J_{nr\text{-}diff}$, ki opredeljuje občutljivost bitumna na spremembo obremenitve, naj ne bi bil večji kot 75 % [10].





Slika 8: Rezultati preiskave MSCRT po SIST EN 16659:2016 (levo) in mejne vrednosti po AASHTO (desno)

Ugotovimo lahko, da se vsi preiskani bitumni (vhodni PmB in ponovno pridobljena bitumna) izkazujejo dobre rezultate. Ponovno pridobljena bitumna izkazujeta večjo vrednost deleža obnove, predvsem pri višji obremenitvi (3,2 kPa), kar lahko kaže na boljšo aktivacijo elastičnih polimerov. Manjša razlika R_{diff} pri ponovno pridobljenih bitumnih nakazuje na njihovo večjo stabilnost.

Ponovno pridobljena bitumna (iz HMA in WMA) izkazujeta pri večjih obremenitvah (3,2 kPa) boljše rezultate kot vhodni PmB, kar kaže na večjo elastičnost oziroma manjše trajne deformacije. Ponovno pridobljeni bitumen iz HMA ima boljše lastnosti (nižji $J_{nr\text{-}diff}$, manj občutljiv spremembo obremenitve) kot bitumen iz WMA.

Preglednica 4: Rezultati preiskave MSCRT vhodnega in ponovno pridobljenih bitumnov

Lastnost	Metoda preiskave	Enota	PmB 45/80-65 ZAG	eks HMA	eks WMA
$R_{0,1\ kPa}$	SIST EN 16659:2016	%	74,4	74,6	80,7
$R_{3,2\ kPa}$	SIST EN 16659:2016	%	59,3	70,8	74,1
R_{diff}	SIST EN 16659:2016	%	20,4	5,1	8,2
$J_{nr\ 0,1\ kPa}$	SIST EN 16659:2016	kPa^{-1}	0,197	0,074	0,082
$J_{nr\ 3,2\ kPa}$	SIST EN 16659:2016	kPa^{-1}	0,340	0,088	0,118
$J_{nr\text{-}diff}$	SIST EN 16659:2016	%	72,5	19,6	43,3

3.3 Rezultati laboratorijskih in terenskih preiskav asfaltnih plasti

Med vgrajevanjem asfaltnih plasti smo izvajali meritve temperature v finišerju (preglednica 5). Na obeh testnih poljih so bila odvzeta jedra, ki so bila nato preiskana v laboratoriju. Kljub občutno nižjim temperaturam vgradnje pri WMA sta obe zmesi dosegli ustrezno stopnjo zgoščenosti. Povprečna stopnja zgoščenosti je bila nekoliko višja pri HMA, medtem ko je WMA izkazovala bolj enotne rezultate z nižjim standardnim odklonom.

Povprečna vsebnost votlin je bila med vgrajenima plastema primerljiva, pri čemer je imela WMA manjše razpršitve rezultatov, kar kaže na enakomerno zgostitev po celotni površini. Povprečna debelina vgrajenega sloja je bila pri WMA večja kot pri HMA, hkrati pa je bila tudi variabilnost debeline manjša, kar nakazuje na boljši nadzor v procesu vgradnje (preglednica 6). Na preiskanem mestu je bila pri WMA ugotovljena višja zlepljenost med plastmi.

Preglednica 5: Rezultati meritev temperature v finišerju

Lastnost	Enota	HMA	WMA
Število meritev	–	8	11
Povprečna temperatura	°C	170,3	143,4
Najnižja temperatura	°C	162	136
Najvišja temperatura	°C	185	160
Razpon temperature	°C	23	24

Preglednica 6: Rezultati meritev na jedrih

Lastnost	Metoda preiskave	Enota	HMA	WMA
Število jeder		/	5	6
Povprečna zgoščenost	SIST EN 12697-9:2004	%	101,3	100,4
Najmanjša zgoščenost	SIST EN 12697-9:2004	%	100,6	99,5
Največja zgoščenost	SIST EN 12697-9:2004	%	102,5	101,0
Standardna deviacija zgoščenosti	SIST EN 12697-9:2004	%	0,76	0,53
Delež votlin	SIST EN 12697-8:2019	%	4,4	4,3
Najmanjši delež votlin	SIST EN 12697-8:2019	%	3,3	3,4
Največji delež votlin	SIST EN 12697-8:2019	%	5,1	4,9
Standardna deviacija deleža votlin	SIST EN 12697-8:2019	%	0,68	0,57
Projektirana debelina		mm	90	90
Povprečna debelina	SIST EN 12697-36:2022	mm	93,2	95,5
Minimalna debelina	SIST EN 12697-36:2022	mm	86	92
Največja debelina	SIST EN 12697-36:2022	mm	99	100
Standardna deviacija debeline	SIST EN 12697-36:2022	mm	5,02	2,81
Specifična zljepljenost plasti (1 jedro)	TSC 06.753:2006	N/mm2	0,81	0,98

4 Zaključek

Rezultati izvedenih laboratorijskih in terenskih preiskav so pokazali, da tople asfaltne zmesi s penjenim bitumnom dosegajo primerljive ali celo nekoliko boljše lastnosti v primerjavi s klasično vroče pripravljeno zmesjo.

Pri laboratorijskih preiskavah asfaltnih zmesi so bili rezulatati preiskav znotraj zahtev za proizvedeno asfaltno zmes. Bitumen, pridobljen iz WMA, je izkazal nekoliko boljšo duktilnost in manjšo otrdelost, kar je skladno z nižjo stopnjo staranja zaradi nižjih temperatur vgradnje. Reološke preiskave so potrdile večjo elastičnost in manjšo otrdelost veziva v WMA.

Rezultati preiskav na jedrih potrjujejo ustrezno kakovost obeh izvedenih plasti. Povprečna stopnja zgoščenosti je bila pri obeh zmesih ustrezna, pri čemer je WMA pokazala manjšo variabilnost rezultatov, enakomernejšo zgostitev in večjo povprečno debelino sloja. Na preiskanem mestu je bila pri WMA ugotovljena tudi nekoliko boljša zlepljenost med plastmi. Spremljanje vgradnje je pokazalo, da so bile temperature pri WMA v povprečju za približno 25–30 °C nižje kot pri HMA, kar predstavlja pomemben potencial za zmanjšanje porabe energije in emisij pri proizvodnji in vgradnji asfaltnih zmesi.

Rezultati kažejo, da je uporaba penjenega bitumna za proizvodnjo toplih asfaltov zanesljiva alternativa klasičnemu vročemu postopku, saj zagotavlja enakovredno kakovost zmesi in plasti ter prinaša okoljske in energetske koristi v skladu s trajnostnimi smernicami cestogradnje.

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Dodatki za WMA in/ali izboljšanje vgradnje asfalta: tehnika za trajna asfaltna vozišča

WMA and/or asphalt workability aid additives: a technique for durable asphalt pavement

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Abstract

When introduced for the first time, Warm Mix Asphalt (WMA) technology was mainly a tool for reducing the paving cost due to less energy consumption. However, as time went by, a variety of advantages were recognized with each different type of WMA technology driven by the analyses and actions required by the European Green Deal. Reducing the emission of CO2eq (during production and laying phase) and the air contaminants, enhancing the workability and/or final compaction of the asphalt paving materials, and allowing longer paving seasons in cold climate regions (ensuring the physical-mechanical performance of road pavements) are some of the practiced goals. In fact, in some cases, the chemical WMA additives are used without any production temperature changes and are considered as workability/compaction aid additives. These previously known as adjacent technical benefits, have become the main target of some projects. This paper focuses on chemical additives and represents some case projects laid in Serbia and Italy. In these projects, in addition to temperature reduction, the main target of using the additive was to enhance the workability/compactibility of the asphalt and consequently the volumetric properties of the asphalt, allowing to comply with the technical requirements of the projects. Regardless of the defined technical goals, the in-situ workability observations and laboratory tests' results showed promising results on using chemical WMA additives for the defined technical targets. The results showed that the mixtures containing the WMA additive complied with the technical specifications' requirements. The presence of the additive allowed good workability/compactibility for the case study, where the material hauling distance was too far. In addition, during both the production and laying phase, significantly less fumes were observed for the WMA materials.

Keywords

Warm Mix Asphalt (WMA); Workability; Compaction; Chemical additives; Case projects

1. Introduction

The ever-increasing environmental challenges have encouraged engineers to focus on techniques that support sustainability. Within the field of road pavements, which is known to be one of the largest consumers of materials, sustainability has become a crucial criterion for their design and selection. As far as materials for asphalt pavements are concerned, several technologies and additives have recently gained attention, aiming at enhancing environmental performance and sustainability of the final flexible pavements. Asphalt re-using/recycling, recycled-based additives, and Warm Mix Asphalt (WMA) technologies are the most applied and investigated solutions. Each of the introduced techniques allow different benefits within the tripartite principles of sustainability, incorporating environmental, social, and economic aspects. Although among the introduced techniques asphalt recycling has been the most applied one, recently WMA showed promising multiaspect results.

WMA production enables several technical, functional, and environmental advantages, such as reducing fuel consumption, fumes and air pollutants, which result in a safer workplace. According to the literature, although the release of Polycyclic Aromatic Hydrocarbon (PAH) in the asphalt fumes and emissions increases proportionally in the material (especially when using Reclaimed Asphalt- RA), the high temperature is still the main factor in the quantity of emissions [1]. Accordingly, technologies that allow to reduce the temperature of asphalt production and laying have been considered as a sustainable alternative for traditional Hot Mix Asphalt (HMA).

In addition to the common understanding on WMA technology, thanks to recent investigations, other aspects of WMA have been highlighted. Increasing the durability of asphalt due to less aging during the asphalt production and hauling [2, 3], enhancing the workability and compactibility of asphalt materials with high viscosity, and extension of the asphalt paving seasons [4,5] are some of the proven advantages. In fact, in this case, the so-called WMA chemical additives can also be used for Hot Mix Asphalt (HMA) production, enhancing the workability of the asphalt and consequently obtaining higher density. According to the literature, even a 1% increase in the density of an asphalt mixture will result in circa 10% higher durability [6]. As far as durability is concerned, WMA mixtures generally exhibit excellent low-temperature performance and resistance to cracking [7]. In this context, research work showed superior crack resistance performance for the WMA compared to its HMA counterpart. The performance investigated via IDEAL-CT test showed higher CT index values for the mixtures produced and laid containing a WMA chemical additive [8].

Various technologies can be categorized as WMA technologies based on their approach. These techniques fall into three major classifications: organic additives, chemical additives, and foaming technologies. The latter can be further divided into water-based technologies and water-bearing additives approach. Among all these technologies, WMA chemical additives have gained increased attention from both academia and industry.

There is a wide range of chemical agents available to be used as WMA chemical additives. These additives are added to the asphalt binder to enhance aggregate coating, improve the adhesion of the binder, and increase the workability of the asphalt mixture. In general, chemical additives do not significantly affect the asphalt binder rheological properties and accordingly the overall performance of the asphalt mixture [9-11]. In fact, the main target is to facilitate the workability and compactibility of asphalt mixture, and therefore they are often called asphalt workability aid additives.

The main objective of this paper was to present knowledge obtained through real-scale WMA projects that could provide insights for future WMA projects. This paper deals with several projects where, instead of reducing the production and compaction temperatures, the WMA chemical additives were mainly used for enhancing the workability and compactibility of the traditional HMA. In some cases, thanks to the presence of the additive, the asphalt laying continued even at low ambient temperatures that are not normally possible.

2. Materials

The WMA and/or workability aid chemical additives used in the projects introduced in this paper were of amino derivatives and mixture of vegetal derivatives. Depending on the target production and compaction temperatures, the dosage is determined according to the type of mixture and to the presence and quantity of reclaimed asphalt. Table 1 summarizes some of the properties provided in the Technical Data Sheet (TDS) of the two additives.

Table 1. Some of the given properties of the additives

Property	Unit	Amino-based additive	Vegetal derivative-base additive
Physical state and colour	—	Yellow - dark brown Liquid	Yellow - dark brown Liquid
Density @25°c	gr/cm³	0.95 - 1.05	0.85 - 0.95
Viscosity @25°C	c.P.	150 - 250	20 - 70
Flash point	°C	> 105	> 190
Pour point	°C	< -5	< 5
Recommended dosage	%	0.2 - 0.5% on the weight of total bitumen	0.07 - 0.11% on the weight of RA

3. Case studies

3.1 Case I: Serbia

The project illustrated in Figure 1 involved the use of a chemical Warm Mix Asphalt (WMA) additive to produce a durable asphalt surfacing material incorporating a highly modified bitumen binder. The primary objective was to achieve optimal compaction levels while significantly reducing both production and compaction temperatures. This was particularly challenging due to the use of a hard, SBS polymer-modified bitumen (PmB) binder and the low ambient temperatures during paving. The application of the WMA technology aimed to enhance workability and performance under these demanding conditions.

Figure 1. Compaction of the laid asphalt at circa 0°C ambient temperature.

The project profile is summarized as follows:

- Location: Serbia, Pozarevac, Danube Corridor
- Construction date: 19/11/2024
- Type of road: Expressway
- Type of asphalt: SMA 11 mm
- Type and grade of the bitumen: 45-80/65
- Bitumen content: 5.9%
- Layer type: Surface course
- Layer thickness: 40 mm
- Additive: ITERLOW T - Amino-based additive
- Additive dosage: 0.3% (on the weight of the bitumen)
- WMA Production temperature: 140 ± 3°C
- HMA Production temperature: 165 ± 3°C
- Compaction temperature: Min avg. temperature 111,6°C after 6 passes
- Ambient temperature: Min. avg. temperature -1°C

Before the trial section construction, the bitumen properties with and without the chemical WMA additive were investigated. According to the results summarized in Table 2, it can be seen that the use of the chemical WMA additive did not significantly impact the original properties of the bitumen. Technically, as a surfactant this was expected to be recorded.

Table 2. Binder-scale analysis of bitumen with and without the WMA chemical additive

Test	Unit	Standard	Control bitumen PmB 45-80/65	PmB 45-80/65 + WMA additive
Penetration	dmm	SRPS EN 1426	58	60
Softening point	°C	SRPS EN 1427	71.5	70.2
Elastic recovery	%	SRPS EN 13398	88.2	88.9
Breaking point (Fraaß)	°C	SRPS EN 12593	-20	-20
Retain penetration (after RTFOT)	dmm	SRPS EN 12607-1	63.3	64.2
Mass change (after RTFOT)	%	SRPS EN 12607-1	-0.03	-0.03

The quality of the produced asphalt mixture was investigated via both in-situ and laboratory analysis. As for the mixture properties, the tests included volumetric and mechanical properties of the mixtures collected form the job site and recompacted by means of a Marshall hammer to manufacture the test specimens.

Table 3 presents the obtained results compared with the requirements of the technical specification of the project. By comparing the obtained results with the requirements of the technical specification, it can be said that the reheated and compacted mixture containing the chemical WMA additive complied with the defined thresholds and that the additive did not impact adversely the mixtures' final volumetric and performance properties.

Table 3. Binder-scale analysis of bitumen with and without the WMA chemical additive

Test	Standard	Unit	Test result	Specification
Bitumen content	12697-1	%	6.0	5.9 ± 0.3
VA	12697-8	%	4.8	-
VMA		%	19	17 - 19
VFB		%	74.6	70 - 88
Bulk density	12697-6	Kg/m^3	2.409	-
Maximum density	12697-5	Kg/m^3	2.532	-
Marshall Stability	12697-34	KN	11.7	Min. 8.0
Marshall Flow		mm	3.2	-

In addition to laboratory testing, in-situ measurements were performed using a portable digital device, which recorded the volumetric properties of the asphalt after each roller pass. The average production temperature for the HMA was 167°C, while the WMA was produced at a reduced temperature of 138°C. As shown in Figure 2, the average compaction levels indicate that the use of the chemical WMA additive not only maintained compaction performance but actually led to a slight improvement, despite the lower production temperature.

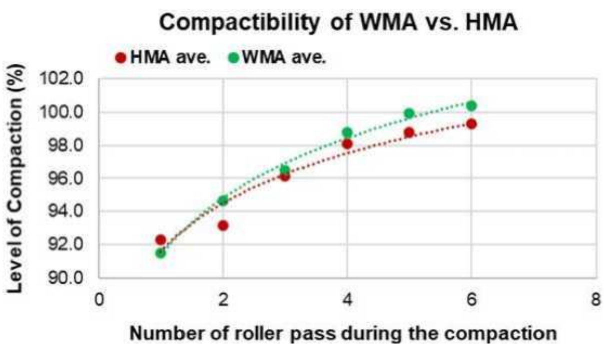

Figure 2. In-situ compactibility of WMA (containing additive) vs. HMA

In addition to the level of compaction, to control the resistance to permanent deformation, Wheel Tracking Device (WTD) according to SRPS EN 12697-22 was carried out. For this purpose, 200 mm (diameter) cores were extracted from the WMA section. The 40 mm (thickness) cores were then subjected to the 10000 load cycles at 60°C. Figure 3 shows the deformation plot for the specimen (ID: core II) and Table 4 represents the obtained results compared with the technical specification's threshold. The recorded results show that the introduction of the additive improved the workability and level of compaction of the mixture without compromising its resistance to permanent deformation, as the results of the cores from the site complied with the project's specification.

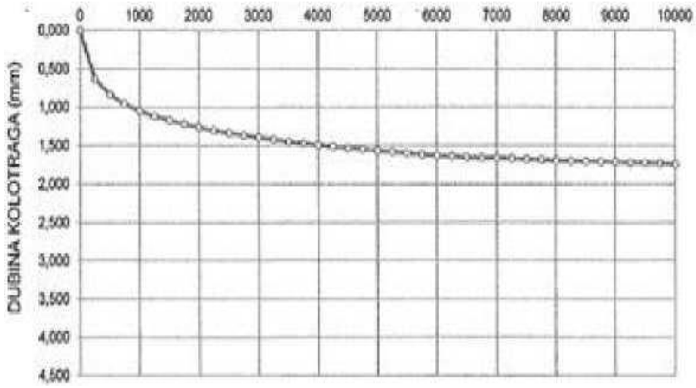

Figure 3. Rut depth vs. Number of load cycles for specimen (core III)

Table 4. WTD test rutting resistance results

Test parameter	Unit	Specimen			Specification threshold
		I	II	III	
Rut Depth	mm	1.74	1.54	1.64	-
Proportional Rut Depth (PRDair)	%	4.24	3.88	4.06	Max. 5.0
Wheel Tracking Slope (WTSair)	mm/103	0.034	0.030	0.032	-

3.2. Case II: Slovenia

The project focused on developing a low-temperature asphalt surfacing material with a high reclaimed asphalt (RA) content by simultaneously applying a chemical warm mix asphalt (WMA) additive and a rejuvenator. Since the pavement was intended for use in a tunnel roadway, the project not only aimed to enhance workability at reduced temperatures but also prioritized minimizing fumes and emissions to ensure a safer and more environmentally friendly working environment. Figure 4 shows the laying and construction of the asphalt pavement. As can be seen, the application of the WMA technique significantly reduced the emission of fumes and ultrafine particles compared to traditional hot mix asphalt (HMA) laying and compaction.

Figure 4. Produced WMA during laying and compaction in the tunnel

This resulted in a safer and healthier working environment for the construction team. The project's profile and the materials used are elaborated in the following list:

- Location: AC Karavanke-tunnel
- Construction date: 02/2025
- Type of road: Highway tunnel
- Type of asphalt: AC 16 surf
- Type and grade of the bitumen: 70/100
- Optimum design bitumen content: 5.2%
- Layer type: Surface course
- Reclaimed Asphalt - RA content: 50%
- Layer thickness: 50 mm
- Additive: ITERLOW T - Amino-based additive
- WMA additive dosage: 0.3% (on the wt. of total binder)
- Rejuvenator dosage: 3.5% (on the wt. of total binder)
- Production temperature: 140 °C
- Compaction temperature: 120 - 130 °C

To ensure the quality of the produced material and its compliance with specification requirements, post-production analysis was conducted at both the binder and mixture levels. In the first phase, the bituminous binder was extracted from the installed asphalt mixture and tested. Table 5 presents the results, which are compared with the EN standard specifications for control 50/70 bitumen.

Table 5. Extracted binder analysis results

Test	Unit	SIST EN Standard	Extracted bitumen*	Control Bitumen 50/70 range
Penetration	dmm	1426	54.6	50 - 70
Softening point	°C	1427	50.0	46 - 54
*the values are the average of minimum 3 samples				

In addition to binder analysis, asphalt mixture testing was performed on both site-collected materials and specimens cored from the completed pavement. Table 6 summarizes the results in comparison with the project specifications. For laboratory analysis, the collected asphalt was reheated at 145°C and compacted using a 2x50 Marshall hammer blow. The results indicate that both the site and lab- compacted samples meet the specified requirements. Despite the high reclaimed asphalt (RA) content and the use of lower production temperatures, the volumetric analysis confirms adequate compaction, an essential factor for ensuring pavement durability.

Table 6. Extracted binder analysis results

Test	Unit	SIST EN Standard	Lab results	Specs: SIST 1038-1	Core results*	Specs: TSC 03.310/410:2009
Bulk density	kg/m^3	12697-6	2475	-	2445	-
Maximum density	kg/m^3	12697-5	2559	-	-	-
Level of compaction	%	-	-	-	98.8	> 96
Air voids (V)	%	12698	3.3	1.5 - 5.0	4.0	1 - 9
Voids in Mineral Aggregate (VMA)	%		15.7	-		-
Voids filled with bitumen (VFA)	%		79.1	75 - 89		-
Thickness	mm	-	-	-	61	50 - 80

*the values are the average of 4 cores

3.2 **Case III: Italy**

As it was mentioned, chemical additives are often used in HMA mixtures to enhance the workability and compactibility of mixtures containing high-viscosity asphalt binders or to allow traditional asphalt mixtures to be laid and compacted efficiently after long-distance transportation. Consequently, these additives are technically known as workability aid additives. In the project shown in Figure 5, the chemical additive was used for enabling the required level of compaction after circa 4 hours. In this project, considering the distance between the asphalt plant and the job site, the HMA materials arrived with reduced temperatures at 130°C.

Figure 5. The material during discharging and laying

The project's profile is detailed in the following list.

- Location: Santu Lussurgiu (OR), Sardinia, Italy
- Construction date: 14/03/2025
- Type of road: intercity collector roads
- Type of asphalt: dense-graded asphalt concrete
- Type and grade of the bitumen: paving grade PEN 50-70
- Bitumen content: 5.4% (by the wight of the mix)
- Layer type: surface course (type A; ANAS specifications)
- Reclaimed Asphalt - RA content: 30%
- Layer thickness: 4 cm
- Additive: ITERWARM RAP - Vegetal derivative-base additive
- Additive dosage: 0.11% on the weight of the RA
- Production temperature: 170 °C
- Compaction temperature: 130 °C

Prior to the construction of the project, the produced material was tested in the laboratory and the results were compared with the requirements of the technical specifications of the project, namely the Italian Anas specification [12]. The test plan included both volumetric and mechanical properties summarized in Table 7. Based on the obtained results, it can be seen that the added workability aid additive did not compromise the volumetric and performance properties, and the obtained results complied with the requirements of the technical specifications of the project. As an important parameter, it can be observed that the additive did not affect the modulus of the mixture, ensuring that it is not subject to permanent deformation. This was expected, as previously mentioned, according to the literature and the mechanism of action of the chemical additives. The chemical additives, as surfactant, shall amend the workability during laying and improve compaction during the process.

Table 7. Summary of material laboratory analysis

Test parameter	Standard	Unit	Test result	Specification
Theoretical Maximum Specific Gravity (Gmm)	EN 12697-5	kg/m^3	2414	—
Bulk Specific Gravity (Gmb)	EN 12697-6	kg/m^3	2342	—
Air void @ N1	EN 12697-8	%	12.3	11 - 15
Air void @ N2	EN 12697-8	%	3.0	3.0 - 6.0
Air void @ N3	EN 12697-8	%	1.7	> 2.0
Indirect Tensile Strength (ITS) @25°C	EN 12697-23	MPa	1.70	0.71 - 1.95
Indirect Tensile Stiffness Modulus (ITSM) @20°C	EN 12697-26	MPa	7460	—

4. Conclusion

This study explores the different functions for chemical workability aid additives producing both Warm Mix Asphalt (WMA) and Hot Mix Asphalt (HMA) paving projects. Laboratory and field findings from these test sections revealed several key benefits of using chemical WMA. Some of the main functions and benefits are detailed as follows:

- Lowering the production temperature: the chemical additives allowed for a significant reduction in the asphalt production temperature, leading to energy savings and reduced environmental impact. Furthermore, they reduce the impacts on the workforce due to heat and fumes.
- Enhancing the workability of the asphalt mixtures: WMA mixtures with the chemical additive showed improved workability during construction. In one test section, the additive facilitated better compaction, resulting in higher pavement performance even at lower compaction temperatures.
- Improving the durability of the asphalt mixtures: as lowering the production temperature leads to less oxidative aging of asphalt mixtures during the production phase, it has been shown in the literature that WMA can enable durable asphalt pavement.
- Sustainable construction: combining WMA technology with the chemical additive offers a sustainable approach to road construction, environmental preservation, and pavement performance.

In summary, according to the literature and the results obtained in the presented projects, incorporating chemical additives into either WMA or HMA is a promising solution for achieving both technical and environmental objectives in asphalt pavement construction.

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Uporaba bitumna »PMB 45/80-65 LE« v proizvodnji toplih asfaltnih zmesi

Use of bitumen »PMB 45/8-65 LE« in the production of hot mix asphalt

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Povzetek

V zadnjem času topli asfalti vse bolj pridobivajo na pomenu tudi v slovenski gradbeni praksi. Številna podjetja so že zagnala roizvodnjo toplih asfaltnih zmesi in izvedla poskusna vgrajevanja, nekatera pa so tehnologijo že vključila v redno proizvodnjo. Pri tem uporabljajo različne pristope, najpogosteje postopke s kemijskimi dodatki ali postopke penjenja z vbrizgavanjem vode.
Kot tehnološko zanimiva novost se v zadnjem času na trgu uveljavlja posebna vrsta polimerno modificiranega bitumna z oznako LE (PmB 45/80-65 LE). Gre za predpripravljen bitumen z dodatkom, ki omogoča proizvodnjo asfaltov pri nižjih temperaturah. Bitumen je certificiran skladno s standardom SIST EN 14023:2010 in se uporablja enako kot klasična veziva, brez potrebe po spremembah proizvodnega procesa. Tako proizvedene tople asfaltne zmesi je mogoče certificirati v okviru harmoniziranega področja.
Raziskave so pokazale, da dodatek v bitumnu PmB 45/80-65 LE ne vpliva na viskoznost in torej ne gre za bitumen z znižano viskoznostjo. Omogoča pa proizvodnjo pri nižjih temperaturah ter zagotavlja kakovost zmesi, ki je povsem primerljiva z vročimi asfaltmi.
V prispevku so predstavljene lastnosti asfaltne zmesi in vgrajene plasti SMA 11, ki jo je podjetje TRGOGRAD proizvedlo z uporabo bitumna PmB 45/80-65 LE, ter primerjava z vročo asfaltno zmesjo SMA 11 45/80-65 A2 (pripravljene z uporabo »običajnega« PmB45/80-65), vgrajeno na istem odseku.

Abstract:

In recent times, warm mix asphalt has become increasingly important in Slovenian construction practise. Many companies have already started producing warm mix asphalt and have prepared trial sections, while some have already incorporated warm mix technology into their regular production. Slovenian manufacturers are pursuing various approaches in the production of warm mix, whereby chemical additives or foaming processes with water injection are predominant.
A special type of polymer-modified bitumen with the LE label (PmB 45/80-65 LE) is being launched on the market as a technologically interesting innovation. This is a prefabricated bitumen with an additive that enables asphalt to be produced at lower temperatures. The bitumen is certified in accordance with the SIST EN 14023:2010 standard and is used in the same way as a traditional binder, without the need for any changes to the production process. The warm asphalt mixtures produced in this way can be certified within the harmonised scope.
Research has shown that the additive in the bitumen PmB 45/80-65 LE has no influence on the viscosity and is therefore not a bitumen with reduced viscosity. However, it enables production at lower temperatures and ensures the quality of the mixture, which is comparable to hot asphalts.
The paper presents the properties of the produced warm asphalt mix and constructed layer of SMA 11 using bitumen PmB 45/80-65 LE, by the company TRGOGRAD, and a comparison with the properties of the hot asphalt mix SMA 11 45/80-65 A2 (prepared with "regular" PmB45/80-65), installed on the same road section.

1. UVOD

V zadnjem času topli asfalti vse bolj pridobivajo na pomenu tudi v slovenski gradbeni praksi. Številna podjetja so že zagnala proizvodnjo toplih asfaltnih zmesi in izvedla poskusna vgrajevanja, nekatera pa so tehnologijo že vključila v redno proizvodnjo. Pri tem uporabljajo različne pristope, najpogosteje postopke s kemijskimi dodatki ali postopke penjenja z vbrizgavanjem vode. Čeprav je v Sloveniji zgodovinsko gledano največ izkušenj z uporabo organskih dodatkov - voskov za proizvodnjo toplih asfaltov, pa se ti v redni proizvodnji uveljavljajo počasneje. Delno je manjša uporaba voskov v redni proizvodnji toplih asfaltov lahko tudi posledica postopkov certificiranja, saj je v primeru uporabe dodatkov, ki znižujejo viskoznost oziroma uporabe pred-pripravljenih bitumnov z znižano viskoznostjo certificiranje kontrole proizvodnje potrebno izvesti po drugačni certifikacijski shemi, izvesti dodatne preiskave in pridobiti drug certifikat, kot je to v primeru harmoniziranega področja certificiranja. V večini primerov proizvodnje toplih asfaltov je potrebna tudi modifikacija proizvodne opreme, ali s sistemi za dodajanje trdnih ali tekočih dodatkov, ali pa s sistemom za penjenje. Nekateri asfaltni obrati so sicer že od same postavitve opremljeni z vsaj enim dodatnim sistemom, vendar pa jih večina potrebuje nadgradnjo.

Proizvodnja toplih asfaltov poteka pri nižjih temperaturah kot klasične vroče asfaltne zmesi, pri čemer se za znižanje proizvodne temperature uporablja različne dodatke in tehnike, ki spremenijo viskoznostne karakteristike veziva, izboljšajo obvijanje kamenega agregat z vezivom oziroma spremenijo mehanizme zgoščanja takšnih asfaltnih zmesi (Pavšič, 2022; Wang in dr., 2022; Šobak in dr., 2024). V primeru uporabe kemijskih dodatkov, ki delujejo kot površinsko aktivne snovi, se zmanjša površinska napetost na stiku agregata in veziva, s čimer je možna ustrezna obvitost agregata in zgoščanje asfaltne zmesi že pri nižjih temperaturah, sam kemijski dodatek pa praviloma ne vpliva na spremembo temperaturne odvisnosti viskoznosti veziva (Periera in dr., 2018; Pavšič, 2022; Šobak in dr., 2024).

Kot tehnološko zanimiva novost se v zadnjem času na trgu uveljavlja posebna vrsta polimerno modificiranega bitumna z oznako LE (PmB 45/80-65 LE). Gre za pred-pripravljen bitumen z dodatkom, ki omogoča proizvodnjo asfaltov pri nižjih temperaturah. Po podatkih proizvajalca je takšen bitumen dodatno modificiran z organskim dodatkom, ki omogoča proizvodnjo asfaltnih zmesi pri nižjih temperaturah. Iz navedenega bi sicer lahko sklepali, da gre za bitumen z znižano viskoznostjo, pri čemer pa je ta bitumen tudi certificiran skladno s standardom SIST EN 14023:2010 in se lahko uporablja v okviru harmoniziranega področja certificiranja kontrole proizvodnje asfaltnih zmesi. Po navedbah proizvajalca v bitumnih z oznako LE niso uporabljeni dodatki za znižanje viskoznosti, temveč naj bi dodatek deloval kot površinsko aktivno sredstvo za zmanjšanje površinske napetosti na stiku agregata in veziva, točna vrsta dodatka pa ni znana in predstavlja poslovno skrivnost proizvajalca (A. Pocek, osebna komunikacija, 27.9.2024). Uporaba takšnega bitumna je povsem enaka uporabi klasičnih bitumenskih veziv pri proizvodnji vročih asfaltnih zmesi in za proizvodnjo toplih asfaltov ne zahteva posebnih prilagoditev na asfaltnem obratu, razen nižje proizvodne temperature.

V primeru, da dobavitelj dodatkov ali pred-pripravljenih bitumnov z dodatkom poda le generalno navedbo, da gre za organski dodatek, ne navede pa načina delovanja dodatka, se lahko kaj kmalu znajdemo v dvoumni situaciji, saj je iz splošne razdelitve dodatkov razumeti, da le ta vpliva na znižanje viskoznosti veziva, kar pa ni nujno res. Zavedati se moramo, da gre pri nekaterih kemijskih dodatkih tudi za organske spojine (npr. fosfatni estri, derivati maščobnih alkoholov, organski amini, …), torej neke vrste organske dodatke, ki pa večinoma ne vplivajo na spremembo viskoznosti veziva (Caputo, et al., 2020; HS Chemie, 2022; CECA, 2025; KAO1, 2025; KAO2, 2025), zaradi česar tudi asfaltnih zmesi proizvedenih z uporabo teh dodatkov ne smemo obravnavati kot tople asfalte, pri katerih je bilo uporabljeno vezivo z znižano viskoznostjo. Vsekakor je ob pomanjkanju točnih podatkov o uporabljenem dodatku nujno preveriti tudi vpliv spremembe temperature na viskoznost takšnega veziva oziroma preveriti ali v temperaturnem območju 70 – 150 °C zaznamo fazni prehod in na podlagi tega ustrezno opredeliti proizvedeni topli asfalt, kot NT – oznaka asfalta, ki pomeni nizko temperaturo in/ali kot NV - oznaka veziva z znižano viskoznostjo (TSPI-PGV.06.460, 2021).

Še bolj kot sama opredelitev vrste toplega asfalta, pa so pomembne njegove lastnosti v primerjavi z istovrstno vročo asfaltno zmesjo, kot tudi lastnosti vgrajene asfaltne plasti, kar nam lahko da vpogled tudi v samo trajnost takšnega toplega asfalta.

2. Raziskave in razprava

2.1 Metodologija

Vhodnemu bitumnu (PmB 45/80-65 LE za topli in PmB 45/80-65 za vroči asfalt) so bile določene osnovne mehanske lastnosti, in sicer, penetracija (SIST EN 1426, 2015), točka zmehčišča (SIST EN 1427, 2015), pretrgališče po Fraassu (SIST EN 12593, 2015) in elastični povratek (SIST EN 13398, 2018), kot tudi reološke lastnosti z dinamičnim strižnim reometrom, določanje faznega kota pri enakovrednem strižnem modulu - DSR (SIST EN 17643, 2022). Za opredelitev ali gre pri uporabi veziva PmB 45/80-65 LE za vezivo z znižano viskoznostjo, pa je bila izvedena tudi določitev faznega prehoda v območju 70 – 150 °C, skladno s postopkom podanim v TSPI-PGV.06.460:2021.

Za opredelitev lastnosti toplih asfaltnih zmesi z uporabo bitumna PmB 45/80-65 LE je bila pripravljena asfaltna zmes SMA 11 PmB 45/80-65 A2 NT, pri kateri je bil uporabljen bitumen PmB 45/80-65 LE in je bila vgrajena na avtocestnem priključku Dragomer na AC A1 Šentilj-Srmin, odsek 0052/0652 Brezovica-Vrhnika. Za primerjavo lastnosti je bila preiskana in vgrajena na istem delovišču tudi istovrstna vroča asfaltna zmes SMA 11 PmB 45/80-65 A2. Pri obeh asfaltnih zmeseh so bile uporabljene iste frakcije kamenih zmesi, polnila in dodatka celuloznih vlaken, v enakih količinah, prav tako pa je enak tudi delež uporabljenega bitumna, tako da bi bila zagotovljena čim bolj enaka sestava obeh asfaltnih zmesi in s tem čim boljša primerljivost. Proizvodnja vroče asfaltne zmesi je potekala pri temperaturi 170 °C, tople zmesi pa pri temperaturi 150 °C.

Priprava preskušancev je potekala z udarnim zgoščevalnikom (po Marshallu) skladno s SIST EN 12697-30:2019. Vročo asfaltno zmes smo zgoščali pri temperaturi 165 °C, za toplo asfaltno zmes pa smo temperaturo zgoščanja določili po metodi analogije na osnovi vsebnosti votlin (Silva in dr., 2010; Oliveira in dr., 2012; Oliveira in dr., 2013; Liu in dr., 2023; Šobak in dr., 2024) in je znašala 150 °C.

Obema asfaltnima zmesema so bile določene osnovne lastnosti, in sicer zrnavostna sestava (SIST EN 12697-2, 2025), vsebnost topnega bitumna (SIST EN 12697-1, 2020), gostota preskušancev (SIST EN 12697-6, 2020), največja gostota asfaltne zmesi (SIST EN 12697-5, 2019) in vsebnost prostih votlin ter votlin zapolnjenih z bitumnom (SIST EN 12697-8, 2019).

Poleg osnovnih lastnosti je smo proizvedenima asfaltnima zmesema določili tudi odtekanje veziva (SIST EN 12697-18, 2017), občutljivost na vodo (SIST EN 12697-12, 2018) in odpornost proti trajnemu preoblikovanju (SIST EN 12697-22, 2024).

Po vgradnji obeh asfaltnih plasti na območju priključka Dragomer (Slika 1 in 2), je bila določena gostota, zgoščenost in vsebnost votlin vgrajenih plasti z elektromagnetno sondo (Pavšič et al., 2012) in z odvzemom vzorcev vrtin (SIST EN 12697-27, 2017), pri čemer je bila določena tudi debelina vgrajene plasti (SIST EN 12697-36, 2022). Na slikah 1 in 2 je opazna vizualna razlika v emisijah plinov ob vgradnji, kjer so ob vgradnji vroče zmesi SMA 11 PmB 45/80-65 A2 (HMA – hot mix asphalt) opazne meglice dimnih plinov, ki jih pri vgradnji tople zmesi SMA 11 PmB 45/80-65 A2, NT (WMA – warm mix asphalt) ni videti.

Slika 8: Vgradnja SMA 11 PmB 45/80-65 A2 (HMA)

Slika 2: Vgradnja SMA 11 PmB 45/80-65 A2, NT (WMA)

2.2 Rezultati in razprava

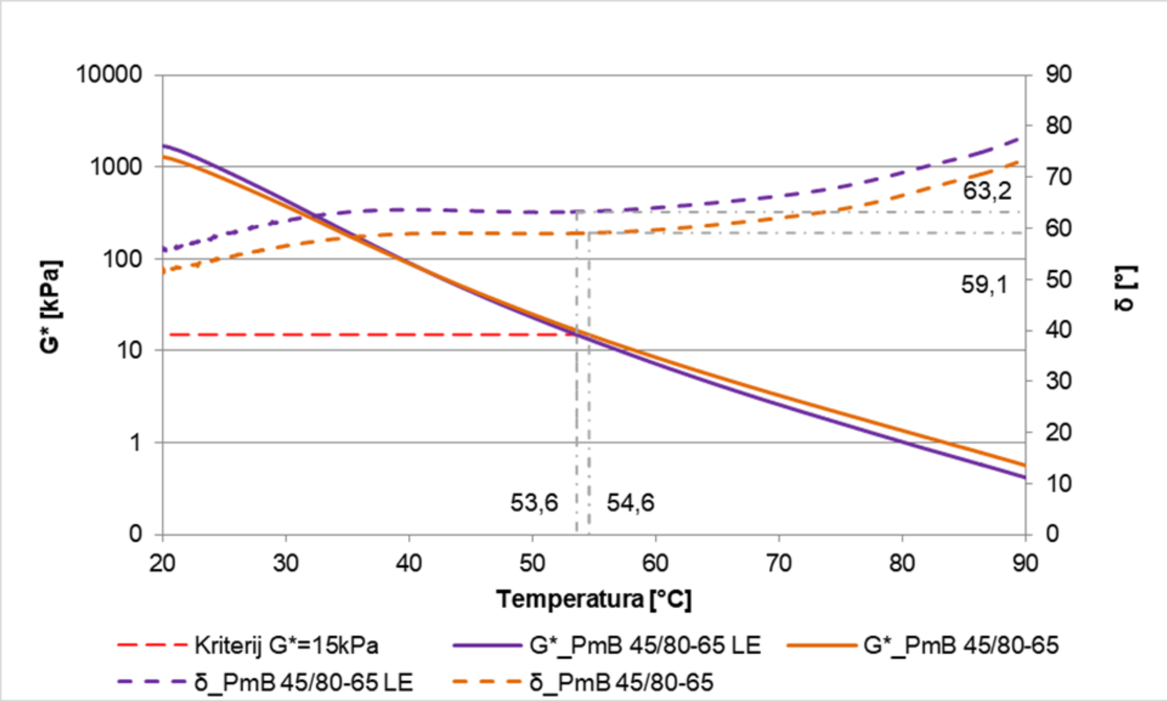
2.2.1 Bitumensko vezivo

Za pripravo tople asfaltne zmesi SMA 11 PmB 45/80-65 A2, NT je bil uporabljen bitumen PmB 45/80-65 LE Starfalt OMV Hungaria Asvanyolaj Kft., za pripravo primerjalne vroče asfaltne zmesi SMA 11 PmB 45/80-65 A2, pa bitumen PmB 45/80-65 Starfalt OMV Hungaria Asvanyolaj Kft. Preiskane lastnosti uporabljenih vhodnih bitumnov so podane v preglednici 1 in na sliki 3, določitev faznega prehoda skladno s TSPI-PGV.06.460:2021, pa je prikazana na sliki 4.

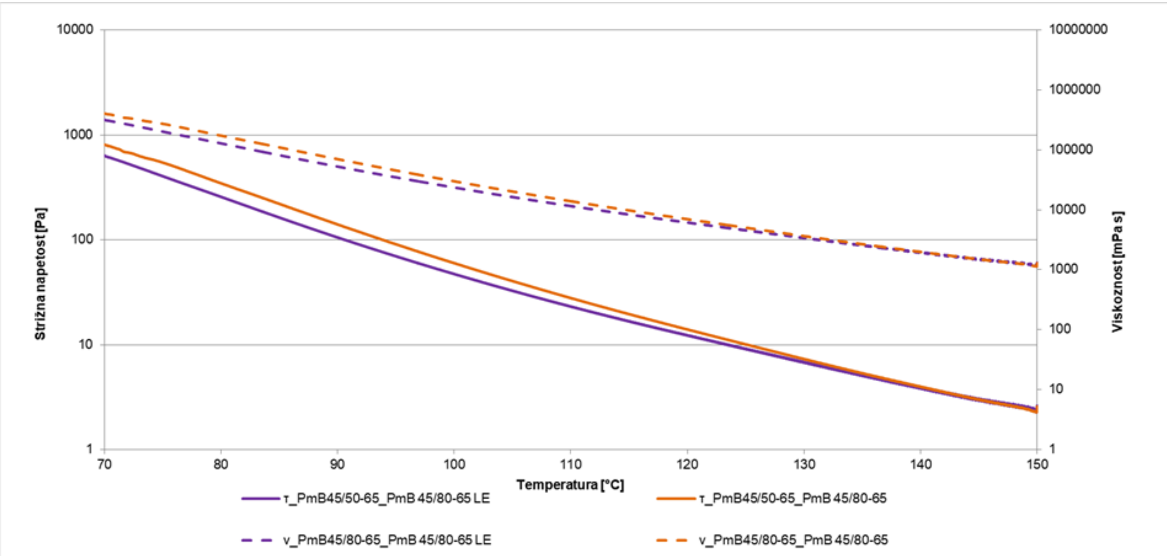
Preglednica 1: Lastnosti vhodnih bitumnov

Lastnost	Metoda	Enota	Rezultat		Zahteve (SIST 1035, 2008)
			PmB 45/80-65 LE	PmB 45/80-65	
Penetracija pri 25 °C	SIST EN 1426	1/10 mm	60	60	45 - 80
Zmehčišče po PK	SIST EN 1427	°C	78,0	79,8	≥ 65
Pretrgališče po Fraassu	SIST EN 12593	°C	-18	-18	≤-18
Elastični povratek pri 25 °C	SIST EN 13398	%	92	95	≥80
DSR - T pri G*=15 kPa - δ pri $T_{G^*=15\ kPa}$	SIST EN 17643	°C °	53,6 63,2	54,6 59,1	

Rezultati preiskav mehanskih lastnosti kažejo, da se bitumen PmB 45/80-65 LE v svojih lastnostih ne razlikuje bistveno od osnovnega bitumna PmB 45/80-65 in ustreza zahtevam podanim v SIST 1035.



Slika 3: Odvisnost kompleksnega strižnega modula in faznega kota od temperature pri preiskavi DSR



Slika 4: Določitev temperature faznega prehoda

Analiza rezultatov DSR je pokazala, da sta temperaturi, pri katerih je G* = 15 kPa, za obe vezivi zelo podobni (53,6 °C pri LE in 54,6 °C pri osnovnem PmB). Pri teh temperaturah pa je fazni kot nekoliko višji za LE (63,2° proti 59,1°), kar kaže, da ima vezivo LE v tem območju nekoliko večji delež viskoznega odziva znotraj kompleksnega strižnega modula, kar pomeni nekoliko manj elastično obnašanje. Skupno to potrjuje, da PmB 45/80-65 LE ohranja primerljive reološke lastnosti kot osnovni PmB 45/80-65, brez bistvenih razlik, ki bi vplivale na njegovo praktično uporabnost. Pri preiskavi faznega prehoda v območju 70 – 150 °C, skladno s postopkom TSPI-PGV.06.460:2021, značilnega faznega prehoda ni bilo zaznati. Obe vezivi sta izkazali podobno temperaturno odvisnost viskoznosti in strižne napetosti, brez nagle spremembe, ki bi nakazovala na uporabo dodatka za znižanje viskoznosti.

Rezultat tako potrjuje navedbe proizvajalca, da pri pripravi bitumna PmB 45/80-65 LE ni uporabljen dodatek, ki bi vplival na znižanje viskoznosti in torej ne gre za vezivo, ki bi ga morali označiti z oznako NV (TSPI-PGV.06.460, 2021).

2.2.2 *Lastnosti proizvedenih asfaltnih zmesi*

Da bi lahko primerjali lastnosti proizveden vroče in tople asfaltne zmesi, je bila za obe asfaltni zmesi pripravljena enaka proizvodna receptura, z razliko v uporabljenem bitumnu in temperaturi proizvodnje. Topla asfaltna zmes je bila pripravljena z uporabo bitumna PmB 45/80-65 LE, primerjalna vroča pa z bitumnom PmB 45/80-65 iz istega vira. Proizvodnja tople asfaltne zmesi je potekala pri temperaturi 150 °C medtem, ko je bila proizvodna temperatura primerjalne vroče zmesi 170 °C.

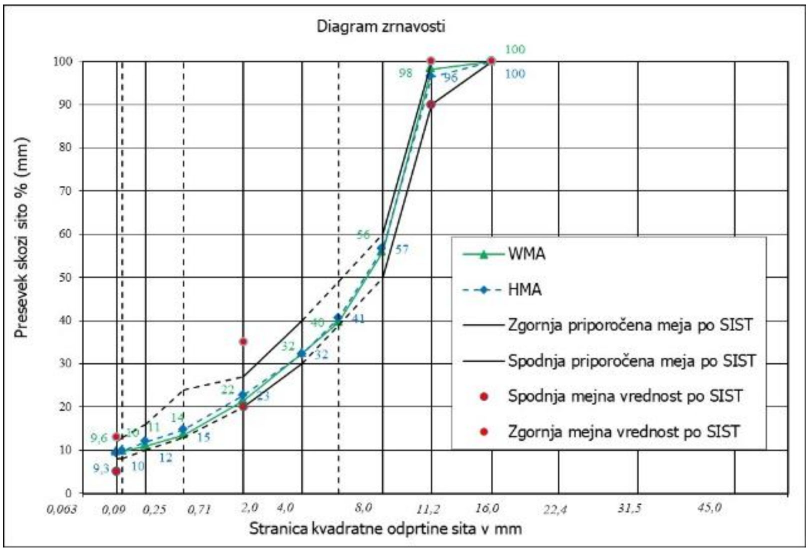
Za obe proizvedeni zmesi so bile opravljene osnove preiskave kakovosti in odpornost na trajne deformacije oziroma odpornost na nastanek kolesnic.

Rezultati preiskav, ki podajajo karakteristike primerjanih asfaltnih zmesi, so podani v preglednici 2 in na sliki 5.

Glede na osnovne lastnosti sta preiskovani asfaltni zmesi primerljivi. Obe zmesi ustrezata zahtevam podanim v SIST 1038-5 (SIST 1038-5, 2008) za ceste s težko in zelo težko prometno obremenitvijo. Topla zmes je nekoliko bolj grobo zrnata, z malenkostno višjo vsebnostjo prostih votlin. Vsebnost veziva je pri obeh zmeseh enaka. Pri topli zmesi je opaženo nekoliko nižje odtekanje veziva, občutljivost na vodo pa je pri obeh zmeseh enaka. Kot nekoliko boljša se pri topli asfaltni zmesi s PmB 45/80-65 LE kaže odpornost na trajno problikovanje oziroma tvorjenje kolesnic, kar kaže na primerljivo ali pa celo lahko nakazuje večjo trajnost takšnih zmesi (Caputo et al., 2020; Liu et al., 2023).

Preglednica 2: Lastnosti obravnavanih asfaltnih zmesi

Parameter	Metoda	Enota	SMA 11 PmB 45/80-65 A2, NT (WMA)	SMA 11 PmB 45/80-65 A2 (HMA)
Delež topnega veziva	SIST EN 12697-1	%	6,0	6,0
Največja gostota asfaltne zmesi	SIST EN 12697-5	Mg/m^3	2,638	2,636
Gostota kamenega materiala	računsko	Mg/m^3	2,931	2,928
Gostota asfaltne zmesi	SIST EN 12697-6	Mg/m^3	2,538	2,546
Vsebnost prostih votlin	SIST EN 12697-8	%	3,8	3,4
Zapolnjenost votlin z bitumnom	SIST EN 12697-8	%	79,8	81,3
Odtekanje veziva	SIST EN 12697-18	%	0,2	0,4
Občutljivost na vodo	SIST EN 12697-12	%	97,6	97,6
Odpornost proti trajnemu preoblikovanju - PRD_{air} - WTS_{air}	SIST EN 12697-22	 % mm/1000	 4,0 0,040	 5,1 0,070



Slika 5: Zrnavostna sestava preiskovanih asfaltnih zmesi

2.2.3 Lastnosti vgrajenih asfaltnih plasti

Vgrajevanje obeh asfaltnih zmesi je potekalo pri izgradnji priključka Dragomer na AC A1, odsek 0052/0652 Brezovica-Vrhnika, pri čemer je bila za obe asfaltni zmesi uporabljena enaka mehanizacija. Vgradnja vroče asfaltne zmesi je potekala pri temperaturi 165 - 170 °C, medtem ko je bila temperatura vgradnje pri topli asfaltni zmesi 145 - 150 °C. Režim vgradnje (nastavitve na asfaltnem razdelilniku, vzorec valjanja in število prehodov) je bil pri obeh asfaltnih plasteh enak.

Po vgradnji so bile preverjene osnovne lastnosti vgrajenih plasti, in sicer gostota plasti, zgoščenost plasti in vsebnost prostih votlin v zmesi z elektromagnetno sondo in s preiskavami odvzetih vzorcev vrtin. Na odvzetih vzorcih vrtin je bila določena tudi debelina vgrajene plasti. Za določitve gostote asfaltnih plasti z elektromagnetno sondo, je bila za vsako asfaltno plast uporabljena umeritvena premica, določena na osnovi meritev in rezultatov odvzetih vzorcev vrtin na obravnavanem odseku, za vsako asfaltno plast ločeno.

Rezultati izvedeni preiskav so v obliki statističnih podatkov podani v preglednicah 3 in 4.

Preglednica 3: Lastnosti vgrajenih plasti z meritvami z elektromagnetno sondo

Statistični parameter		SMA 11 PmB 45/80-65 A2, NT			SMA 11 PmB 45/80-65 A2		
		Gostota (Mg/m^3)	Zgoščenost (%)	Vseb.votlin (%)	Gostota (Mg/m^3)	Zgoščenost (%)	Vseb.votlin (%)
Število preiskav	n	20	20	20	52	52	52
Povprečna vrednost	X	2513,7	99,0	4,71	2542,5	99,9	3,55
Standardni odklon	s	22,54	0,89	0,854	26,76	1,05	1,015
Največja vrednost	X_{max}	2551,5	100,5	6,05	2596,9	102,0	5,24
Najmanjša vrednost	X_{min}	2478,4	97,7	3,28	2497,8	98,1	1,48
Razpon	R	73,08	2,88	2,770	99,08	3,89	3,759

Preglednica 4: Lastnosti vgrajenih plasti s preiskavami vzorcev vrtin

Statistični parameter		SMA 11 PmB 45/80-65 A2, NT				SMA 11 PmB 45/80-65 A2			
		Deb. (mm)	Gostota (Mg/m^3)	Zgošč. (%)	Vseb.vot. (%)	Deb. (mm)	Gostota (Mg/m^3)	Zgošč. (%)	Vseb.vot. (%)
Št. preiskav	n	6	6	6	6	9	9	9	9
Povp. vred.	X	40,0	2500,3	98,5	5,22	41,4	2515,8	98,8	4,56
Stand. odklon	s	0,97	19,31	0,76	0,732	3,16	24,07	0,95	0,913
Najv. vred.	X_{max}	41,0	2522,0	99,4	6,22	48,0	2551,0	100,2	6,15
Najm. vred.	X_{min}	38,5	2474,0	97,5	4,40	38,7	2474,0	97,2	3,22
Razpon	R	2,5	48,00	1,89	1,820	9,30	77,00	3,02	2,921

Rezultati izvedenih preiskav kažejo, da je vsebnost votlin (zahteva 1,5 – 7,5 %) in zgoščenost (zahteva ≥ 97 %) v povprečju pri obeh plasteh v mejah, ki jih predpisuje tehnična specifikacija za vgrajevanje asfaltnih plasti (TSC 06.300/06.410, 2009). Pri obeh plasteh so ustrezne tudi minimalne izmerjene vrednosti zgoščenosti in vsebnosti votlin. Povprečna debelina pri obeh plasteh ustreza projektni zahtevi 4 cm, opaženo pa je minimalno odstopanje najmanjše vrednosti izmerjene debeline pri obeh vgrajenih plasteh.

Osnovne lastnosti obeh vgrajenih plasti so tako primerljive, je pa homogenost vgrajene plasti SMA 11 PmB 45/80-65 A2, NT nekoliko boljša, saj sta tako standardni odklon, kot tudi razpon izvedenih meritev pri vgrajeni plasti tople zmesi manjša. To lahko nakazuje na nekoliko lažje vgrajevanje in zmanjšane vplive temperaturne segregacije pri vgradnji tople asfaltne zmesi proizvedene z bitumnom PmB 45/80-65 LE.

3 Zaključek

Bitumensko vezivo z oznako PmB 45/80-65 LE, je polimerno modificirano vezivo certificirano v skladu s SIST EN 14023:2010, z dodatkom, ki omogoča proizvodnjo asfaltnih zmesi pri nižjih proizvodnih temperaturah. Lastnosti veziva PmB 45/80-65 LE so skladne z zahtevami SIST 1035:2008. Lastnosti, določene v okviru reoloških preiskav in v okviru določitve faznega prehoda, so pokazale, da PmB 45/80-65 LE ne vsebuje organskih dodatkov za znižanje viskoznosti, saj pričakovani fazni prehod ni bil zaznan. Dodatek v takšnem pred-pripravljenem bitumnu lahko obravnavamo kot kemijski dodatek, toplo asfaltno zmes proizvedeno z njegovo uporabo, pa označujemo z dodatno oznako NT (TSPI-PGV.06.460, 2021). Vsekakor je ob pomanjkanju točnih podatkov o uporabljenem dodatku v pred-pripravljenem bitumenskem vezivu nujno preveriti tudi vpliv spremembe temperature na viskoznost takšnega veziva oziroma preveriti ali v temperaturnem območju 70 – 150 °C zaznamo fazni prehod in na podlagi tega ustrezno opredeliti proizvedeni topli asfalt, kot NT in/ali NV (TSPI-PGV.06.460, 2021).

Primerjava lastnosti proizvedene in vgrajene asfaltne zmesi SMA 11 PmB 45/80-65 A2, NT pripravljene z uporabo pred-pripravljenega veziva PmB 45/80-65 LE z istovrstno vročo asfaltno zmesjo SMA 11 PmB 45/80-65 A2 je pokazala, da so lastnosti asfaltnih zmesi in plasti primerljive. Asfaltna zmes z uporabo PmB 45/80-65 LE izkazuje celo nekoliko boljšo odpornost na tvorjenje kolesnic, v vgrajeni plasti pa nekoliko boljšo homogenost.

Rezultati izvedenih raziskav kažejo, da bitumensko vezivo PmB 45/80-65 LE lahko učinkovito uporabimo pri proizvodnji toplih asfaltnih zmesi, pri čemer na asfaltnem obratu niso potrebne tehnične prilagoditve proizvodnje. Tako proizvedene in vgrajene tople asfaltne zmesi izkazujejo primerljive lastnosti z istovrstnimi vročimi asfaltnimi zmesmi, pri čemer nekateri rezultati nakazujejo celo možnost za izboljšano trajnost asfaltne plasti pripravljene z vezivom PmB 45/80-65 LE, kar pa bi bilo v nadaljevanju potrebno preveriti in potrditi z dodatnimi raziskavami in dolgoročnim spremljanjem v realnih pogojih, pod vplivi vremenskih in prometnih obremenitev.

__Zahvala:__ ***Prispevek je bil pripravljen v okviru projekta ARRS – I0-0032 in pogodbe o skupnem raziskovalnem sodelovanju št. 9484/23.***

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