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CRABforOERE

Compendium of CR performance in different climatic zones and critical review of the impact of mixture composition on performance

Deliverable D2

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Universität Kassel, Germany

Institut français des sciences et technologies des transports, de l'aménagement et des réseaux (IFSTTAR), France

Nottingham Transportation Engineering Centre (NTEC), UK

Università degli Studi di Palermo Italy

Statens väg- & transportforskningsinstitut (VTI), Sweden

Università Politecnica delle Marche (UPdM), Italy

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Deliverable D2 – Compendium of CR performance in different climatic zones and critical review of the impact of mixture composition on performance

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Authors of this deliverable:

Henrik Bjurström, Björn Kalman; Statens väg- & transportforskningsinstitut (VTI), Sweden

Konrad Mollenhauer, Marius Winter; Universität Kassel, Germany

Andrea Graziani, Chiara Mignini; Università Politecnica delle Marche (UPdM), Italy

Gaspare Giancontieri; University of Palermo, Italy

Davide Lo Presti; Università degli Studi di Palermo, Italy and Nottingham Transportation Engineering Centre (NTEC), UK

Vincent Geaudefroy, Institut français des sciences et technologies des transports, de l'aménagement et des réseaux (IFSTTAR), France

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1. Introduction

1.1. Background

The transport sector is responsible for a large part of greenhouse gas (GHG) emissions and energy consumption, where road transport represents a significant part (European Commission 2019; European Environment Agency 2019). Mitigating GHG emissions and energy consumption is now one of the primary objectives for transport administrations (TA) around Europe. In the strive of reducing emissions and energy consumption in the road construction industry, alternative material usage is an important factor. Aside from conventional hot mix asphalt (HMA), cold mix asphalt (CMA) has been increasingly employed as a more environmentally friendly pavement choice. Since CMA is mixed at ambient temperature, the energy consumption and emissions are significantly reduced. Also, because mixing of CMA is possible in mobile plants or in-situ, transports and thus CO_2-emission may be mitigated. By including reclaimed asphalt as aggregates, waste is reduced as well as the extraction of virgin materials. Using cold recycled asphalt (CRA), a large portion of the virgin aggregates, often up to 100%, can be exchanged for milled and crushed asphalt material from existing roads. Bitumen emulsion or foamed bitumen are applied as binders, often together with other mineral binders. Considering the ability for cold recycled materials (CRM) to considerably limit energy consumption and GHG emissions, and reduce waste and the extraction of virgin materials, cold recycled asphalt bases (CRAB) can thus be considered as pavement of optimal energy and resource efficiency (OERE).

However, the development of short- and long-term performance are not fully understood and need to be further studied in order to create sustainable pavement design procedures for different climatic conditions. In the project CRABforOERE, the application of reclaimed asphalt (RA) is compared between the participating member countries. It is demonstrated how the mix and structural designs generally differ between the member countries. Collected and compared information about performance are presented in as much detail as possible.

1.2. Aims of this report

The intention of this deliverable is to synthesize as much information and data as possible about existing road sections with CRM base layers. Therefore, 17 existing road sections in five countries were selected and information regarding RA content, binder content and particle size distribution were acquired and compared in order to enable a visualisation of the similarities and differences about the designs in the different member countries. Further, data about performance and evaluated test results are presented wherever it is available.

1.3. Course of action

A questionnaire was created and distributed among the project partners. The questionnaire contained questions about mix design and structural design, potential damages and details about the construction work. The questionnaire is attached in this report in Annex A2. Each partner filled in one questionnaire for each individual road section from respective country that was included in the project.

Performance of the road sections and all available test data evaluated prior to the project have been collected and are presented in this report. Each project partner has also extracted new core samples from one of its country's road section. Available tests have been performed on the core specimens by the respective project partner in order to receive new data from at least one road section in each country. All evaluated data are presented in this report.

All evaluated questionnaires for each individual road section except for one French section (data collected via e-mail) are attached in this report in Annex A3-A16. Core sample data which have been put together in laboratory reports are also attached in Annex A17-

2. Existing structures included in the project

Each country participating in the CRABforOERE project has identified two to four road sections containing a CMA base layer, most of them with recycled material. The TAs were contacted in each country in order to retrieve information about the structural design, mix design and traffic conditions. The traffic condition has been reported in the form of annual average daily traffic (AADT) and AADT for heavy commercial vehicles (HCV). For some of the roads, traffic volume has not been counted. Traffic data have been given for these roads in best possible way in Table 1. The result was 15 identified roads that have been included in this project. However, the B52 federal road was constructed with different construction methods, bitumen emulsion and foamed bitumen, and different layer thicknesses so that the B52 road section is divided into three sub-sections. The result is that 17 individual road sections have been studied. Information about construction year and traffic conditions are given in Table 1.

Table 1. Quantitative data regarding traffic.

Country	Road	Construction year	Road section length (m)	AADT	HCV
GE	B52 (1)	2009	150	26000	3900
	B52 (2)	2009	450	26000	3900
	B52 (3)	2009	725	26000	3900
	L52	2011	4590	1500	60
	L386	2007	4600	7000	240-490
IT	SP18	2008	500	5000	250
	SS38	2007	400	30000	1850
	A14	2007	42000	44000*	11000*
	SS268	2016	1000	19661	2115
UK	A21	2002	5000	47714	11700
	A46	2006	2000	19192	3664
	A38	2006	12000	37000	3700
SE	Rv95	2014	100	3136	380
	E45	2012	100	1233	333
	Lexby	2012	100	<1000**	~0**
FR	RD26	2011	200	No data	25-50
	RD44	2008	273	No data	100-150

* Traffic volume is an estimation based on measured traffic on A14 in the Ancona region. The pavement was designed for $5.0 \cdot 10^6$ 80 kN ESALs per year (Bocci et al., 2011)

** The number of vehicles has not been counted; however, it is a small and narrow municipal road used mostly by residents.

3. Materials and mixture design

A synthesis and comparison regarding constituent materials and mixture design of cold recycled materials (CRM) is presented in this chapter. It is important to recognize that both the employed materials and the mixture compositions reflect the cold recycling practice in each country. Due to the lack of harmonized terminology and specifications on CRM mixtures, the terminology and the type of data reported in the questionnaires for this project are not homogeneous. In order to overcome this limitation, a uniform terminology is introduced which is essential to allow an effective comparison of data. Summaries of the questionnaires for each road section are then presented, introducing the homogenised terminology.

The comparison of adopted mix design solutions is focused on:

- The characteristics of the aggregate blend (RA and virgin aggregates)
- The binder types and dosages (bitumen emulsion, foamed bitumen, cement).

3.1. Terminology

A uniform terminology is needed to properly identify and compare CRM mixtures obtained through different cold recycling (CR) techniques.

CR techniques are defined based on the adopted construction process and on the depth of recycling. Different techniques are associated with different production and laydown equipment and jobsite organization. Three different CR techniques are identified:

- **cold central-plant recycling (CCPR):** mixing is carried out in-plant, using selected RA aggregate. Plants may be either mobile (installed within the jobsite) or fixed. Transport and laydown are carried out using the same asphalt paving machines that are normally used for HMA, shown in Figure 1a and Figure 1d.
- **cold in-plane recycling (CIR):** recycling is carried out in-place using suitable recycling machines (recyclers) or recycling trains, see Figure 1b. CIR involves only the bituminous layers, all the RA aggregate employed for the project comes from the jobsite and may be subjected only to limited processing.
- **full-depth reclamation (FDR):** recycling is carried out in-place, using recyclers, given in Figure 1c, or recycling trains. It involves the full-depth of the pavements, including bituminous layers and the underlying granular or cemented layers.

CRM mixtures are defined based on the binders employed and on their dosages. CRM mixture families are useful to characterise the mechanical behaviour, the failure mode and thus the design criteria. Following three types of CRM mixtures are identified:

- **bitumen stabilized materials (BSM):** bitumen is the main binder while cement, other hydraulic binders or hydrated lime, are used as active fillers to improve the short-term performance.
- **cement-bitumen treated materials (CBTM):** bitumen and cement are considered co-binders and jointly affect the mechanical behaviour. Other hydraulic binders or hydrated lime may also be added to improve the shorter long-term performance.
- **cold recycled asphalt (CRA):** characterised by higher bitumen dosage in order to obtain *continuous bituminous bonding phase*, hence its mechanical behaviour is similar to that of HMA. Other hydraulic binders or hydrated lime may also be added to improve the shorter long-term performance.

The three CRM families are displayed graphically in terms of bitumen and cement content in Figure 2.

In all techniques, and thus for all CRM mixture types, bitumen can be used in the form of emulsion, either with plain or modified bitumen, or as foam. Cement normally refers to CEM I "Portland cement", but other cement types are commonly applied. Other hydraulic binders may include, for example, fly ash.

a) 

b) 

c) 

d) 

Figure 1. Application of CR techniques: a) CCPR on road A38 in the UK, b) CIR on road B52 in Germany, c) FDR on road SP 18 in Italy and d) CCPR on road Lexby in Sweden.

Additionally, pavements constructed with cold asphalt mixtures but limited or without any reclaimed asphalt were considered. For these constructions the terms Cold-mix asphalt (CMA) and Grave Emulsion are used for mixtures with continuous and non-continuous bitumen bonding phases, respectively. In both cases, usually no hydraulic binder is applied in the mixture.

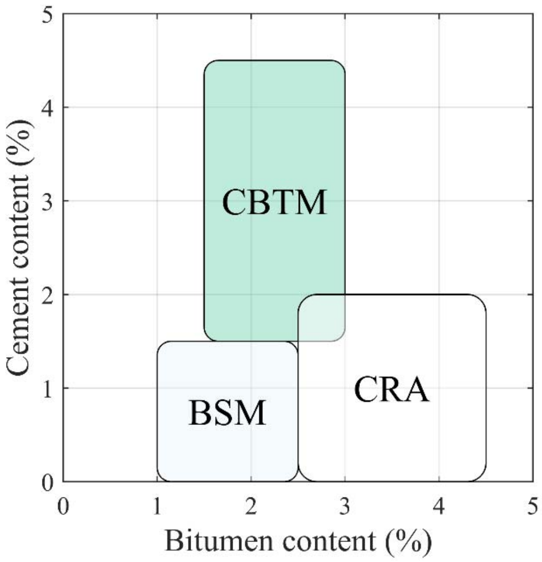

Figure 2. Qualitative identification of CRM mixtures types. (Figure adapted after Grilli et al. (2012))

3.2. Summary of collected data

Quantitative data and mixture design details are presented in Table 2. This is a summary of the answers to the question: "*Please give details on the mix design of the CRM layer. What was the composition of the mix and what were the material parameters of the constituent materials and the cold recycled mix?*".

Table 2. Reclamation types and mix design data summarised for all studied road sections.

Country	Road	CR technique	CRM mixture	% of reclaimed asphalt (RA)	Bitumen emulsion content (%)	Residual added bitumen content (%)	Bitumen type (pen.)	Cement content (%)	Cement type
GE	B52 (1)	CIR	CBTM	100	4,0	2,4	-	4,0	CEM I
	B52 (2)	CIR	CBTM	100	n/a	2,5*	70/100	3,0	
	B52 (3)	CIR	CBTM	100	4,0	2,4	-	4,0	
	L52	CIR	CBTM	100	2,5	1,5	-	4,5	CEM I
	L386	CIR	CBTM	90	3,0	1,8	-	3,5	CEM I
IT	SP18	FDR	CBTM	20	4.0**	No data	70/100	2,0	CEM I
	SS38	CIR	CBTM	34	3,0	1,8	70/100	2,0	CEM IV/B
	A14	FDR	CBTM	50	3,0	1,8	70/100	2,0	CEM IV/B
	SS268	FDR	CBTM	100	4.0**	2,4	70/100	2,0	CEM I
UK	A21	No data							
	A46	CCPR	CRA	73	n/a	3,5*	100/150	1.5***	CEM I
	A38	CCPR	CRA	88	n/a	3.0*	100/150	1.5***	CEM I
SE	Rv95	CMA/GE	CMA	30	4,8	4,6	70/100	0	n/a
	E45	CMA/GE	CMA	0	4,2	2,8	160/220	0	n/a
	Lexby	CMA/GE	CMA	30	4,8	3,0	160/220	0	n/a
FR	RD26	CMA/GE	GE	0	7,0	4,0	160/220	0	n/a
	RD44	CMA/GE	GE	0	6,7	4,1	70/100	0	n/a

* foamed bitumen
** polymer modified
*** +5% fly ash

3.2.1. Germany

The questionnaires for the three German road sections describe pavement rehabilitation works carried out in-place, and the acronym FDR was used to describe them. From the description and photos provided, it is clear that the rehabilitation involved only the bituminous layers. The applied CR technique is employed for recycling of bituminous layers containing tar, for which hot recycling is not allowed due to contamination of polycyclic aromatic hydrocarbons (PAH). In order not to increase the amount of PAH-contaminated materials, usually no, or only minor dosages, virgin aggregates are added to the mixture for adjusting the gradation. Therefore, up to 100% RA aggregate has been used, except for L386 where a correction with 10% virgin sand was applied. Therefore, applied technique can be identified as CIR.

Plain bitumen emulsion has been used in all three German sections, with dosage from 2.5 to 4.0%, corresponding to residual bitumen dosage from 1.5 to 2.5%. A sub-section with foamed bitumen (2.5%) has been also included (section B52(2)). Cement dosage varied from 3.0% in section B52(2) to 4.5% L52, and cement type is not specified.

3.2.2. Italy

The four Italian questionnaires describe pavement rehabilitation works carried out in-place with bitumen emulsion. The CIR technique has been applied in SS268 with 100% RA. The FDR technique has been applied in the other three road sections, where the RA content varied from 20% to 50% and the remaining fraction was reclaimed aggregate from the underlying layers.

A higher dosage of SBS-modified bitumen emulsion, 4.0% emulsion corresponding to 2.5% of residual bitumen, was applied in the CRM mixtures for the SP18 and SS268 base layers. On the other hand, a lower dosage of plain bitumen emulsion, 3.0% emulsion corresponding to 1.8% of residual bitumen, was used in the A14 and SS38 road sections where the CRM mixture was applied as the subbase layer with an HMA base layer on top of it. The cement dosage was 2.0% on all four Italian road sections and the cements used were CEM I and CEM IV (pozzolanic).

3.2.3. UK

Two questionnaires describe pavement rehabilitation works carried out using the CCPR technique (ex-situ recycling). No information on materials and mixture composition is available from the third questionnaire. The aggregate blend comprised mostly RA, but virgin aggregate (up to 27%) has been also used to optimise the gradation.

Foamed bitumen with dosages of 3.5% and 3.0% have been used on the two UK road sections where information was available, A46 and A38, respectively. In both of these sections, two different active fillers were applied: a cement dosage of 1.5% (CEM I) and 5.0% pulverised fuel ash (PFA), a by-product of fuel burning in power plants (similar to fly-ash) which requires lime to produce a pozzolanic reaction. However, the use of lime is not reported in the questionnaires, thus PFA is considered as a filler.

3.2.4. Sweden

Two of the Swedish questionnaires, for Rv95 and Lexby, describe rehabilitation of existing pavements carried out with CCPR technique. However, Sweden has not a long experience with high RA aggregate content and the recipes listed 30% reclaimed material for both two roads. In the third studied road section, E45, no RA aggregates were applied.

Bitumen emulsion, with dosages of 4.2% and 4.8%, has been used. The corresponding residual binder was of 2.8% and 3.0%. Neither cement nor other mineral additives were employed in the Swedish mixtures.

3.2.5. France

The questionnaires from the two French road sections describe rehabilitation of existing pavements carried out using the grave emulsion (GE) technique. This is a well-established cold mix technique commonly employed in France, with bitumen emulsion (specifically designed for the individual project) and solely virgin aggregate.

3.3. Characteristics of the aggregate blend

The RA content of the aggregate blends associated with the different CR techniques are summarised in Figure 3.

- In CIR and CCPR, a small dosage (0-30%) of *virgin aggregate* is generally added in order to obtain the requested grading curve.
- In FDR, *reclaimed aggregate* is mixed with reclaimed asphalt and virgin bitumen during the deep recycling process. Moreover, a small fraction of virgin aggregate may be added to correct the grading curve. Thus, the RA content is lower (20% to 50%).

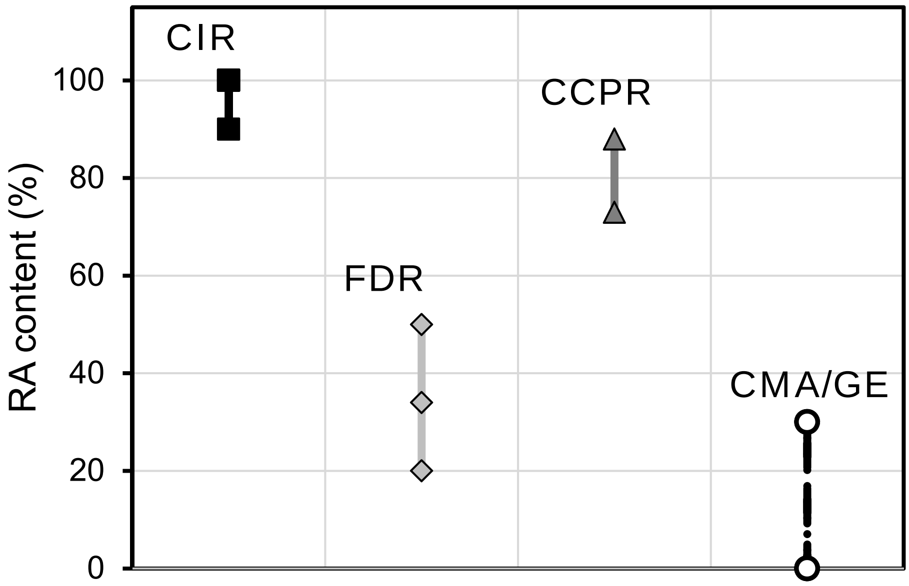

Figure 3. RA aggregate content related to different CR techniques.

In Sweden the content of RA aggregate is small (30%), which is very similar to the fraction used in hot recycling. In France, RA aggregate is not used in Grave Emulsion.

The gradation of RA grains is usually characterised by low contents (<2%) of fine particles. For adjusting the grading, it is necessary to add fine natural aggregates. The gradation curves of the aggregate blend reported in the questionnaires, or in the related reports and papers, are summarised in Table 3 and presented graphically in Figure 4. The reported curves are "black curves" showing the gradation of the RA grains as agglomerates of natural aggregates and RA binder.

The nominal maximum dimension, considering a 10% retained, varies from 12 to 32 mm. This is the same range of commonly used HMA bases and clearly reflects the local practice in each country. The lowest dimensions were applied in France and UK (12 mm) which adopted plant production. The highest dimensions (32 mm) were applied in Germany and Italy with in-place production techniques.

If the sample SE-E45 is excluded, all the remaining analysed samples have a continuously-graded curve which can be compared with the maximum density curve normally adopted as reference for HMA: $P(\%) = 100\,(d / D)^{0.45}$, where P is the cumulative passing aggregates, d is the sieve size and D the maximum sieve size. Maximum density curves with D equal to 14, 22 and 45 mm are also represented in Figure 4. Closer agreement with the maximum density curves is found in plant-produced mixtures, while in-place production clearly resulted in higher variability.

Table 3. Gradations from all road section where this information was available. All numbers are given in percent.

Sieve size (mm)	Germany		Italy			UK	Sweden		France	
	L52	L386	SP18	SS38	A14	A46	Rv95/ Lexby	E45	RD26	RD44
63	100	-	-	100	-	-	-	-	-	-
60	-	-	-	-	-	-	-	-	-	-
58	-	100	-	-	-	-	-	-	-	-
45	98.9	97.6	-	96.5	-	-	-	100	-	-
31.5	88.9	90.2	100	89.0	100	-	-	98.0	-	-
25	-	-	-	-	-	100	-	-	-	-
22.4	78.6	81.9	-	82.4	-	-	100	66.0	-	-
20	-	-	-	-	94.7	-	-	-	-	-
16	67.0	74.4	94.0	77.3	-	96.0	77.0	23.0	100	100
14	-	-	-	-	-	93.0	-	-	99.0	98.0
12.5	-	-	-	-	74.8	91.0	-	-	93.0	93.0
11.2	57.5	65.4	-	71.6	-	-	64.0	20.0	-	-
10	-	-	78.0	-	-	85.0	-	-	81.0	80.0
8	48.9	55.3	-	66.2	61.7	77.0	52.0	7.0	73.0	-
6.3	-	-	-	-	-	70.0	-	-	67.0	68.0
5.6	39.2	42.2	-	59.6	-	-	45.0	4.0	-	-
5	-	-	-	-	-	65.0	-	-	62.0	-
4	31.4	33.8	50.0	52.7	47.7	57.0	40.0	3.0	56.0	55.0
2.8	-	-	-	-	-	48.0	-	-	-	-
2.36	-	-	-	-	-	43.0	-	-	-	-
2	20.5	21.9	35.0	39.3	24.0	40.0	30.0	2.0	35.0	40.5
1	12.9	13.0	-	27.0	-	27.0	23.0	2.0	23.0	28.5
0.5	8.4	8.0	15.0	17.5	-	18.0	16.0	1.0	15.0	22.0
0.4	-	-	-	-	13.1	-	-	-	-	-
0.25	5.6	5.1	9.1	11.8	-	13.0	11.0	1.0	10.0	18.0
0.125	3.8	3.6	-	8.1	-	10.0	7.0	1.0	7.0	-
0.08	-	-	-	-	-	-	-	-	-	11.5
0.075	-	-	-	-	4.3	-	-	-	-	-
0.063	2.8	2.9	2.5	6.2	-	8.2	5.1	0.4	5.3	9.8

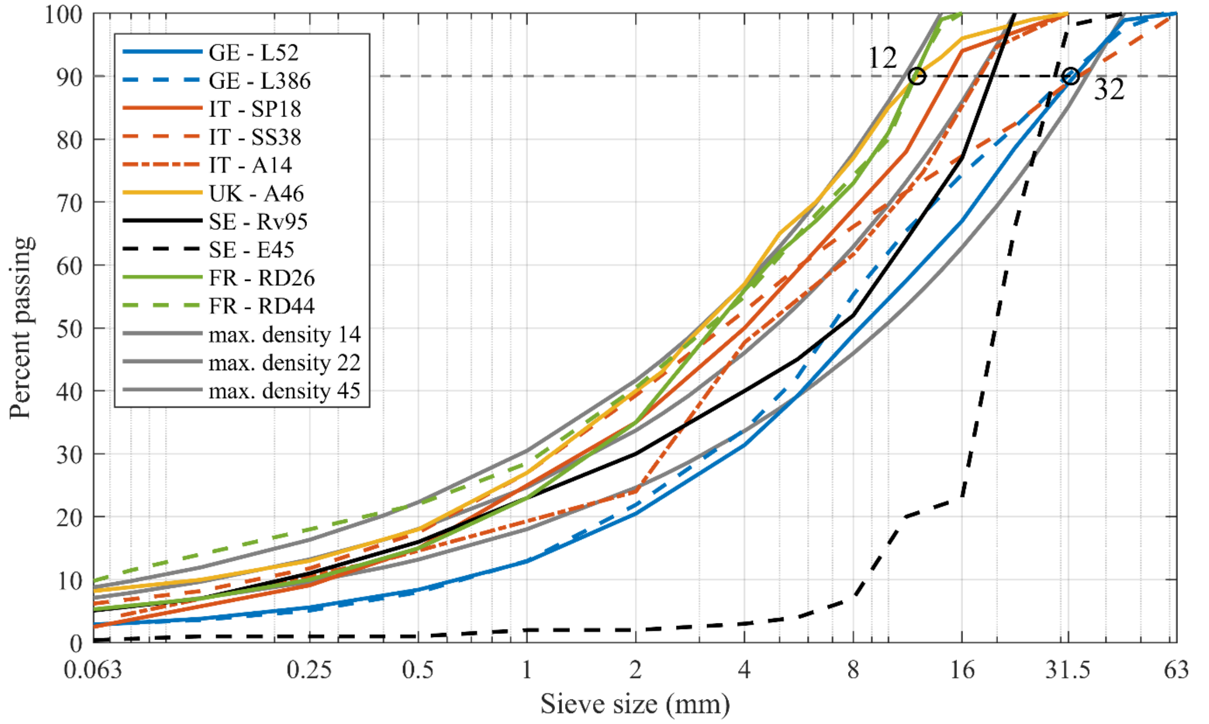

Figure 4. Particle size distribution for all roads where information was available.

In general, it is believed that a high content of fines is beneficial for CRM mixtures because, together with bitumen emulsion or foamed bitumen, and cement (if adopted) it allows the formation of a "binding mortar" phase. However, the characteristic dimension which defines the "binding mortar" is a matter of debate. Here, we compare the passing to the 0.063 mm sieve ($P_{0.063}$) and to the 2.0 mm sieve (P_2).

For the $P_{0.063}$ two ranges can be identified:

- mixtures GE-L52, GE-L386, IT-SP18, IT-A14 are characterised by lower dosages of fines, between 2.5% and 4.3%.
- mixtures IT-SS38, UK-A46, SE-Rv95 and SE-Lexby are characterised by higher values of fines, between 5.1% and 8.2%, about double with respect to the lower range.

For the P_2 two ranges can also be identified:

- mixtures GE-L52, GE-L386, IT-A14 are characterised by lower dosages of this fraction, between 20% and 24%.
- mixtures IT-SP18, IT-SS38, UK-A46, SE-Rv95 and SE-Lexby are characterised by higher dosages of material passing the 2.0 mm sieve size, between 30% and 40%. Again, this is almost double with respect to the previous range.

3.4. Binder type and dosage

In Figure 5 the CRM mixtures are categorized and compared based on the binder type (bitumen and cement) and dosages.

Along the x-axis, where no cement is included in the mixture, we find the mixtures produced in France (labelled GE) and Sweden (labelled CMA). As explained above, these projects were more focused on cold paving using bitumen emulsion rather than on RA recycling.

Mixtures from UK were produced using CCPR with foamed bitumen and are considered as CRA, because of their rather high bitumen content resulting in a bitumen to cement ratio (B/C) ≥2.0. In the TRL611 report (Merrill et al., 2012) this kind of CRM mixture is classified as quick-viscoelastic, which means its mechanical behaviour is bitumen-dominated (prone to fatigue and/or permanent deformation).

The four CRM mixtures from Italy were produced with different techniques but all fall within the CBTM family. They are characterised by similar dosages of bitumen and cement (0.75 < B/C < 1.33). The Pavement Catalogue developed by Provincia Autonoma di Bolzano - Alto Adige (Provincia Autonoma di Bolzano, 2016) was calibrated on the results obtained from SS38. The pavements included in the catalogue were calculated considering fatigue but not permanent deformation. Indeed, with those compositions, the CRM mixture is not considered prone to permanent deformation failure. In order to avoid a fragile behaviour due to an excess of cement, an upper limit is imposed on the CRM mixture stiffness.

The four CRM mixtures from Germany were produced with the CIR technique and fall within the CBTM family. The CRM mixture produced with foamed bitumen (B52(2)) has a B/C = 0.8, close to the values of the Italian mixtures. The CRM mixtures produced with bitumen emulsion are characterised by a higher dosage of cement (B/C < 0.6). Due to this high cement content they may be prone to shrinkage cracking, especially in their early life.

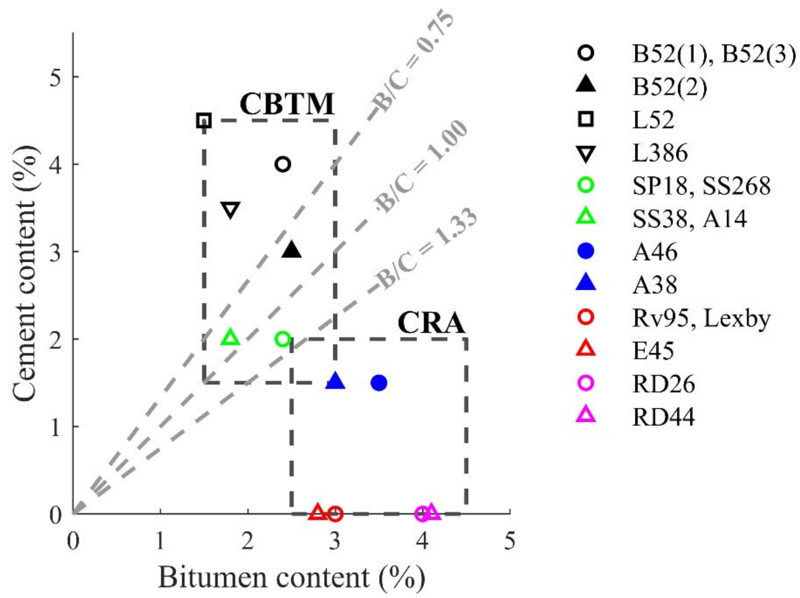

Figure 5. Identification of CRM mixtures families. Filled markers refer to foamed bitumen and empty markers to bitumen emulsion.

4. Pavement design

When pavement design procedures between the five participating countries are compared, it can be noticed that three general approaches are practiced. Germany and Italy apply an empiric catalogue system where the design is based on increased or reduced thickness depending on traffic loading conditions, subground bearing conditions and climatic conditions. In the UK a nomogram system is applied that is based on fitted functions to identify the total thickness. Sweden and France both apply mechanistic-empiric design methods where software is used to calculate the internal strains which are then compared to the maximum strains allowed.

4.1. Structural design

Structural designs for the road sections included in this project are presented from the surface layer down to the deepest bitumen/cement bound layer. This is the CMA layer for all road sections except for two of the UK sections and one Italian section where the CRAB layers rest on cement bound foundations. All these layer thicknesses are presented in Table 4 and graphically in Figure 6. Layer thicknesses evaluated from extracted core specimens are presented in Chapter 6. The last column in Table 4 indicate what is believed to lie beneath the bottom bound layer. Information on these underlying was not always available, and the right column can thus be seen as an engineering judgement.

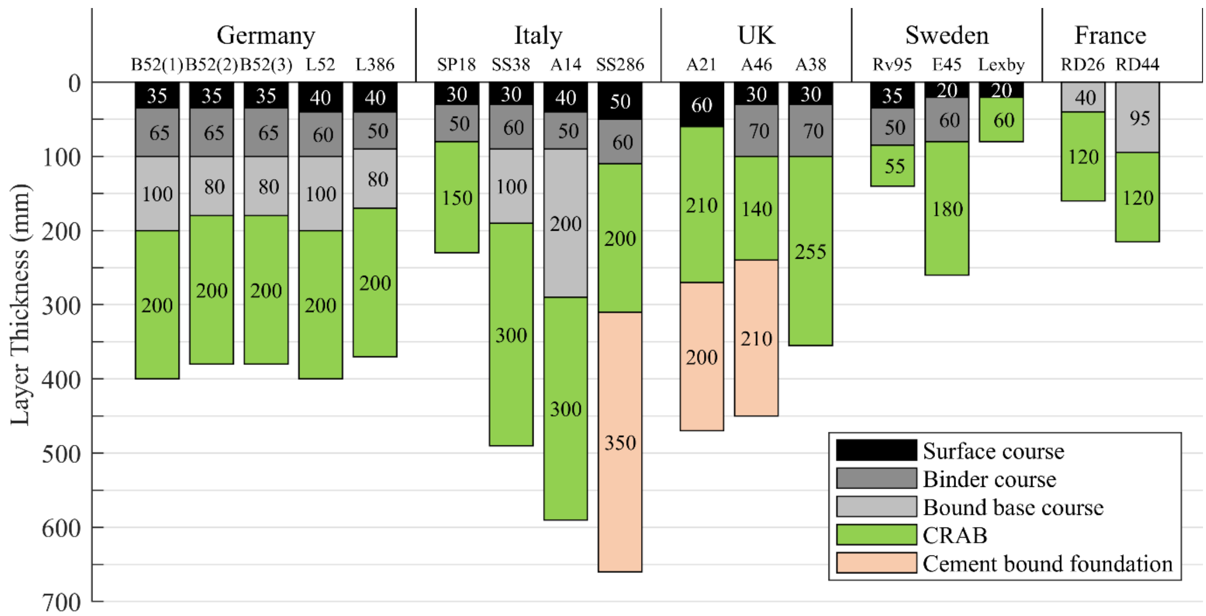

Figure 6. Layer thicknesses for the 17 studied road sections illustrated from the surface down to the deepest bound layer.

Table 4. Layer thicknesses [mm] of the studied road sections.

Country	Road section	Surface	Binder	Asphalt base	CRAB	Cement bound foundation	Underlying layers
Germany	B52(1)	35	65	100	200	-	Unbound base layer
	B52(2)	35	65	80	200	-	
	B52(3)	35	65	80	200	-	
	L52	40	60	100	200	-	30 cm unbound granular material
	L386	40	50	80	200	-	Unbound granular material
Italy	SP18	30	50	-	150	-	18 cm of granular foundation (existing foundation prior to FDR)
	SS38	30	60	100	300	-	Natural subgrade poorly graded gravel, GP (ASTM-D2488)
	A14	40	50	200	300	-	>20 cm granular foundation (existing foundation prior to FDR)
	SS268	50	60	-	200	350	Natural subgrade(E=64 MPa, from FWD on distressed pavement)
UK	A21	60	-	-	210	200	Old existing pavement. Two layers of HMA.
	A46	30	70	-	140	210	No data
	A38	30	70	-	255	-	Dense bituminous macadam
. Sweden	Rv95	35	50	-	55	-	Old penetration macadam
	E45	20	60	-	180	-	70 cm sandy gravel, silty sand subgrade
	Lexby	20	-	-	60	-	Unbound material, subground
France	RD26	-	-	40	120	-	No data available
	RD44	-	-	95	120	-	~10 cm old asphalt pavement on ~45 m unbound base layer

In total 17 road structures in five countries were assessed for this study. All sections contained a base layer constructed using cold asphalt and most of them recycled asphalt. The structures are demonstrating a large variation in traffic loading and climatic conditions (location) as well as design approach.

The total thickness of all bituminous bound layers is plotted against the average daily traffic volumes for HCV for all road sections where traffic load information was available in Figure 6**Fehler! Verweisquelle konnte nicht gefunden werden.**. The total thickness of the bound layers for the pavements indicate a common trend for the structures from France, Italy and Sweden. This trend is shown in a regression function. It should be emphasised that the trend seems to be very consistent considering that the experiences are collected from southern, central and northern Europe.

Regarding the sections from Germany, the thickness of the bound layers doesn't show an influence of the actual traffic loading. A reason for this can be, that the cold recycling procedure in Germany is applied only for recycling of tar-contaminated pavements in new road structures. Here, sometimes the aim is to recycle a high amount of reclaimed road materials even if this is not necessarily required according to the loading conditions. The pavement structure of road B52 which shows the highest traffic loading fits well to the "common" regression.

For the UK pavements, only the structure of A38 fits to the “common” pavement thicknesses function. The other structure of A46 with similar traffic load as well as A21 have a cement stabilised base layer below the CRAB layer, therefore less bituminous layer thickness is required.

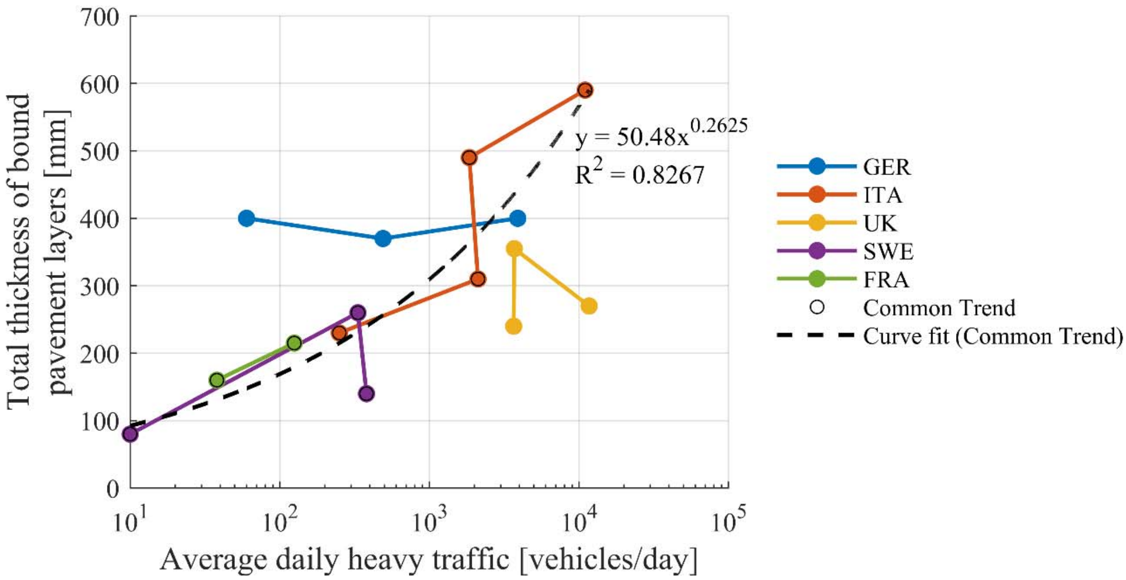

Figure 7. Total thickness of all bound layers plotted against the average number of daily heavy vehicles for all studied sections.

4.2. Mix design

The mix design differs significantly between the identified road sections. Reclaimed material content, types of additives and additive content are all parameters that vary greatly. While solely RA aggregates were used as granular material in some German and Italian roads, no reclaimed material was included in the French and one of the Swedish roads, only virgin ballast. All available information on reclaimed material content, binder content and air void content are according to mix designed is specified in Table 5.

Table 5. Mix design table for the 17 studied road sections.

Country	Road	Year of construction	% of reclaimed asphalt (RA)	Bitumen emulsion content (%)	Residual added bitumen content (%)	Cement content (%)	Void content (%)
GE	B52 (1)	2009	100	4,0	2,4	4,0	9,2
	B52 (2)	2009	100	n/a	2,5*	3,0	9,5
	B52 (3)	2009	100	4,0	2,4	4,0	9,2
	L52	2011	100	2,5	1,5	4,5	10,5
	L386	2007	90	3,0	1,8	3,5	6,8
IT	SP18	2008	20	4.0**	No data	2,0	No data
	SS38	2007	34	3,0	1,8	2,0	18
	A14	2007	50	3,0	1,8	2,0	No data
	SS268	2016	100	4.0**	2,4	2,0	No data
UK	A21	2002	No data				
	A46	2006	73	n/a	3,5*	1.5***	4,7
	A38	2006	88	n/a	3.0*	1.5***	No data
SE	Rv95	2014	30	4,8	4,6	0	No data
	E45	2012	0	4,2	2,8	0	No data
	Lexby	2012	30	4,8	3,0	0	No data
FR	RD26	2011	0	7,0	4,0	0	16,0
	RD44	2008	0	6,7	4,1	0	11,0

* foamed bitumen
** polymer modified
*** +5 % fly ash

5. Climatic conditions

The roads included in this project are located around a large part of Europe with large spreads in climatic conditions. Average annual temperature and precipitation are given in Table 6 for all locations where data could be retrieved. Along with these data are comments given about design requirements for each country.

Table 6. Average annual temperature and precipitation near the test section locations.

Country	Road	Year of const-ruction	Average annual air temp. since year of const-ruction (°C)	Average annual precipitation since year of construction (mm)	Common design requirement for each country
Germany	B52	2009	9.3	696	Empirical design against deformation of unbound bases and subground, strain in asphalt base and frost heave.
	L52	2011	8.7	626	
	L386	2007	13.1	~600	
Italy	SP18	2008	13.9	770	Frost is not explicitly considered in the Italian design. However, in many specifications, the presence of silty soils in the subground is considered dangerous “in case of frost”.
	SS38	2007	11.3	790	
	A14	2007	14.4	757	
	SS268	2016	16.1	879	
UK	A21	2002	10.1	710	Empirical design against deformation of unbound bases and subground, and against fatigue cracking in bound layers
	A46	2006	8.9	1318	
	A38	2006	9.2	1082	
Sweden	Rv95	2014	3.8	596	Mechanistic-empiric design against strains and frost heave. Limiting requirement is often strains in the south and frost heave in the north.
	E45	2012	0.0	560	
	Lexby	2012	9.5	921	
France	RD26	2011	No data		Mechanistic-empiric design against fatigue at the bottom of the asphalt layers and/or hydraulically bound layers and against permanent deformation of unbound materials and subground
	RD44	2008			

6. Structural performance

The structural performance for each studied road section has been assessed by either the partner themselves by visual inspections or by the road authorities responsible for the roads during regular condition monitoring. The performed tests are unfortunately not the same for each individual road section due to different protocols in the different countries. However, all evaluated performance and test data available are presented in its original state in this chapter. One pavement section in each country has been investigated in more detail where cores have been extracted, tested and evaluated. Additionally, an evaluation of all current pavement conditions has been implemented.

6.1. German road sections

6.1.1. B52

From an optical inspection, the B52 road showed no distress. No cracking nor excessive rutting could be detected in the summer of 2019.

Falling weight deflectometer measurements have been acquired at different times during a nine-year period. Centre deflections, i.e. deflections right beneath the load, are plotted in Figure 8 together with corresponding stiffness moduli. It can be seen that the deflections are smallest in the first sub-section (B52(1)) which corresponds to the thicker CRM layer (100 mm). The largest deflections are found in the second sub-section (B52(2)) corresponding to the CRM mixture with foamed bitumen. This is also the section with the lowest stiffness.

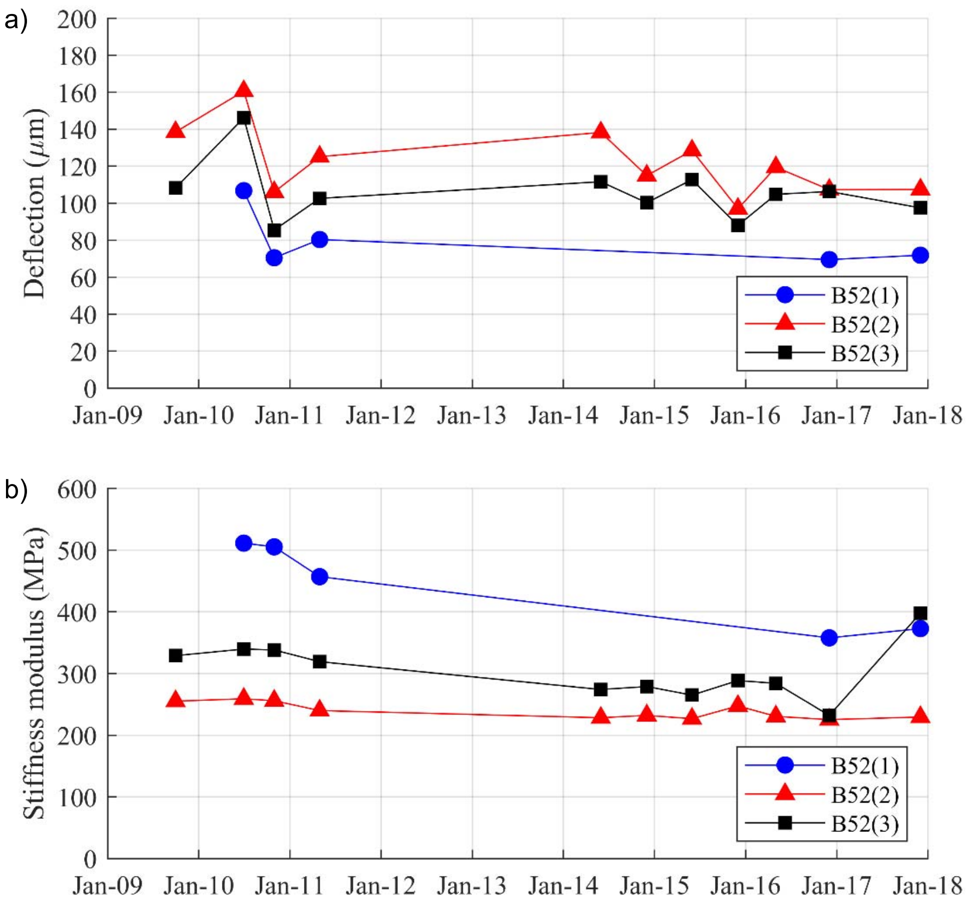

Figure 8. Falling weight deflectometer data collected from the three B52 sub-sections. The figure presents a) centre deflections beneath the load and b) corresponding stiffness moduli at different dates.

6.1.2. L52

No distress has been reported for the L52 test site.

6.1.3. L386

In its early life, the L386 road suffered from transversal cracks across the road surface. The reason for these cracks was believed to be shrinkage cracking due to a high cement content. The layers above the CRM were removed within the cracked zones and replaced with new layers. No new cracks have occurred in these areas since then. However, some new minor cracks have been identified at intersections.

Cores were extracted in seven different locations along the L386 test section. Five of the cores were extracted in areas showing no distress while the remaining two cores were obtained from distressed areas.

Cracks on the surface course were visible on these cores, named L386_6 and L386_7, which are displayed in Figure 9. These cracks are only visible withing the surface course. The CRM layer (bottom) is not deteriorated.

Furthermore, it can be mentioned that there was no interlayer bond between the CRM mixture and the HMA material on two of the extracted cores.

Figure 9. L386 cores extracted from cracked zones.

The seven cores were measured in order to determine the actual layer thicknesses on the surface, binder and base HMA layers as well as the bottom CRM layers. Measured layer thicknesses are illustrated in Figure 10. The nominal thicknesses for these layers according to the structural design were 40, 50, 80, and 200 mm, respectively. It can be concluded that the thickness of the CRM layer was higher on each core than the design.

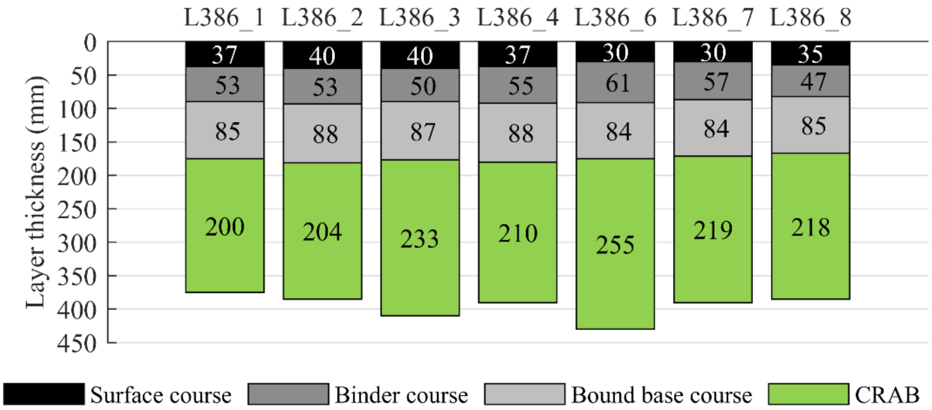

Figure 10. Layer thicknesses measured on the extracted core samples from L386.

Because the thickness of the CRM-layers was sufficient, two specimens were prepared from the CRM mixture of each core. Top and bottom specimens were marked in order to investigate if the depth had any effect on the strength and stiffness values. The cores were tested using the indirect tensile strength (ITS) test at 5°C according to EN 12697-23 and the results from these tests are presented in Figure 11. Two specimens were damaged during production and could not be tested.

Minimum and maximum strength limits for specimens 28 days after compaction according to German mix design specifications (FGSV, 2005) are identified with red dotted lines.

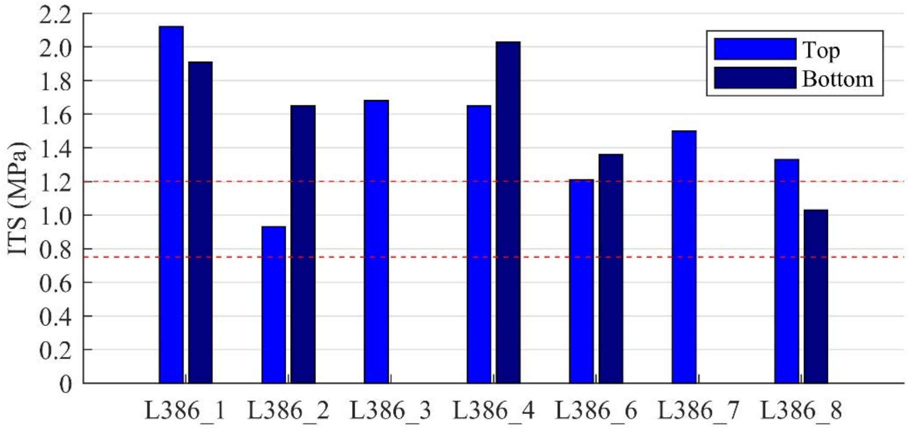

Figure 11. Indirect tensile strength values of top and bottom specimens prepared from each core. Red lines mark limit values according to German specifications.

Firstly, the measured strength values vary between 1,18 and 2,02 MPa and therefore show a high range of strength values. There is no obvious difference between the strength measured at the top specimen s to the bottom specimens from the cores. This indicates, there is no systematic difference during the height of the layer due to compaction or other effects.

The ITS obtained for the specimens from cores L386_6 and L386_7, which were taken from cracked zones of the pavement, doesn't differ from the general strength range measured.

After testing the cores, the fresh surface, displayed in Figure 12, shows more white/grey zones than black zones, indicating more cement bonds compared to bitumen bonds. This is an effect of the high cement content applied in the L386 pavement. This also refers to the comparatively high indirect tensile strength values. In nine of the twelve test results, the measured strength exceeds the maximum limit of ITS allowed during mix design. From the construction data, after 28 days originally an ITS of 1,13 MPa was obtained. This shows that the long-term strength is considerably higher than the mix design specifications limit obtained after 28 days of curing.

Figure 12. Cracked surface after ITS test on specimen obtained from L386

By measuring the horizontal deformation from some of the ITS tests, stiffness moduli, E_{SZ}, could also be calculated using:

$$E_{SZ} = \frac{F \cdot (0.274 + \mu)}{h \cdot u}$$

where ESZ is given in MPa. The variables in the equation above are defined as:

F = 45% of the maximum (failure) force (N)

h = height of the test specimen (mm)

u = horizontal deformation at 45% of the maximum (failure) force (mm)

μ = Poisson's ration, here calculated to be 0.30)

Stiffness results are presented in Figure 13. The red dotted lines mark limit values according to German specifications. Most evaluated specimens can be seen to have a stiffness higher than the German limit value of 12 000 MPa.

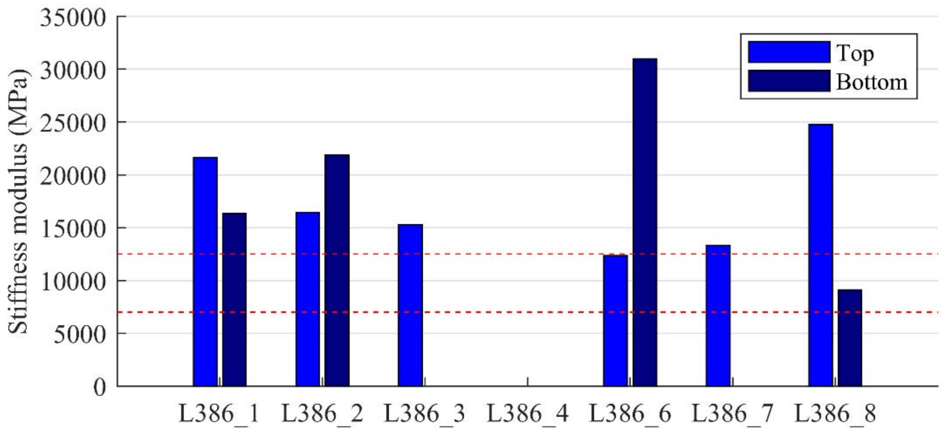

Figure 13. Stiffness modulus results.

Air void content was also determined on each core sample. It varied between 8.8% and 13.6%. therefore, all specimens were within the void content specification of minimum 8% and maximum 15%.

6.2. Italian road sections

6.2.1. SP18

Eight core samples were extracted from the SP18 road section in October 2019. These eight cores were divided into two groups, A and B, depending on where along the road the cores were collected. Point A and B, where the cores were extracted, are separated approximately 400 m. One core from the wheel path and one core from the centre lane, from both locations A and B, were dedicated for determination of bulk density. The remaining cores, the same number of cores and from the same locations, were used for material characterisation.

All the eight extracted cores were measured to determine the layer thickness of the three bound layers; HMA surface course, HMA binder course, and CRM base course. The nominal thicknesses for these layers according to the design were 30, 50, and 150 mm. Real thicknesses are depicted in Figure 14 and show that most layers are slightly thinner than the design.

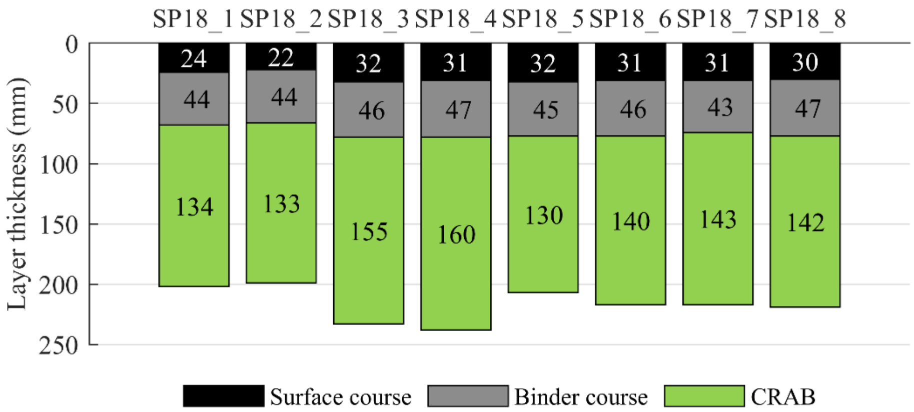

Figure 14. Layer thicknesses measured on eight individual core samples extracted from the SP18 road section.

Cores dedicated to testing bulk density showed results ranging from 2039 to 2155 kg/m3 where the two cores from point B had lower density compared to the two cores from point A.

The CRM mixture had such thickness that two specimens could be prepared from each core, a top specimen and a bottom specimen. Each specimen was tested for indirect tensile stiffness modulus (ITSM) according to EN 12697-26 and ITS according to EN 12697-23. The ITSM test was performed at 20°C with a rise time of 124 ms and a target horizontal deformation of 3 µm. During the first loading cycle, both specimens from the core named SP18_6 broke and could not be evaluated.

Results from the ITSM tests are displayed in Figure 15 and show a high variability. All evaluated moduli are lower than the stiffness measured 35 days after construction (approximately 4100 MPa).

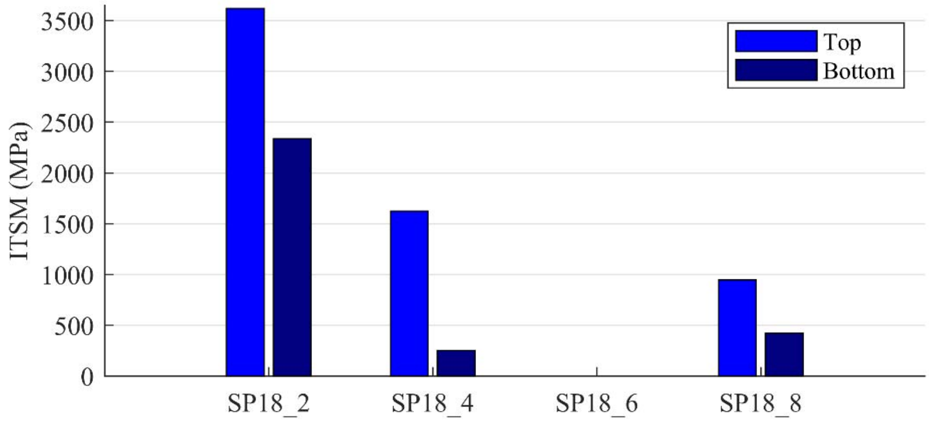

Figure 15. Evaluated ITSM results for the SP18 road section.

After the ITSM test, the same specimens were tested again to obtain the ITS. The test was performed at a temperature of 20°C and had a constant deformation rate of 50±2 mm/min. Since the specimens from core SP18_6 broke during the ITSM, ITS could neither be tested on these specimens. Evaluated ITS test results are presented in Figure 16 and display a large spread between highs and lows, ranging from 0.106 MPa to 0.391 MPa.

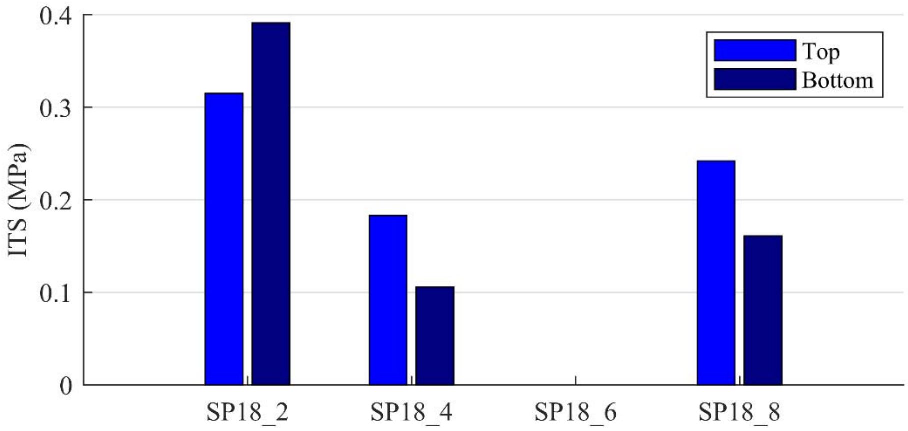

Figure 16. Evaluated ITS results for the SP18 road section.

A condition survey inspection and determination of pavement condition index (PCI) were carried out according to ASTM D6433-16. The inspection was carried out on eight representative and equally sized sample units. After the inspection, the distress information collected was processed using the Micro PAVER 5.2 computer program to obtain PCI, general rating and distress mechanism of the section.

The pavement condition survey revealed the presence of load-associated distresses such as alligator cracking (low and medium severity) and rutting (low severity). Besides, longitudinal and transversal cracking was observed as well.

The PCI obtained for the pavement section is 68, representative of fair conditions. An assessment of the causes for the distresses using the computer program mentioned above revealed that about 2/3 of the distresses were caused by traffic loading and the remaining 1/3 by climate degradation.

6.2.2. SS38

Seven years after construction, ten core samples were extracted for stiffness characterisation from the SS38 road section. The cores were tested in the laboratory at different temperatures and different frequencies to enable a master curve assembly. This way the stiffness modulus can be presented over a wide frequency range at a single reference temperature which was 20°C in this case.

Two master curves, extracted from CRM emulsion layer, display the stiffness modulus at 20°C over a wide range of frequencies in Figure 17. An FWD measurement was obtained 40 days after construction and the evaluated stiffness is plotted in Figure 17 for comparison.

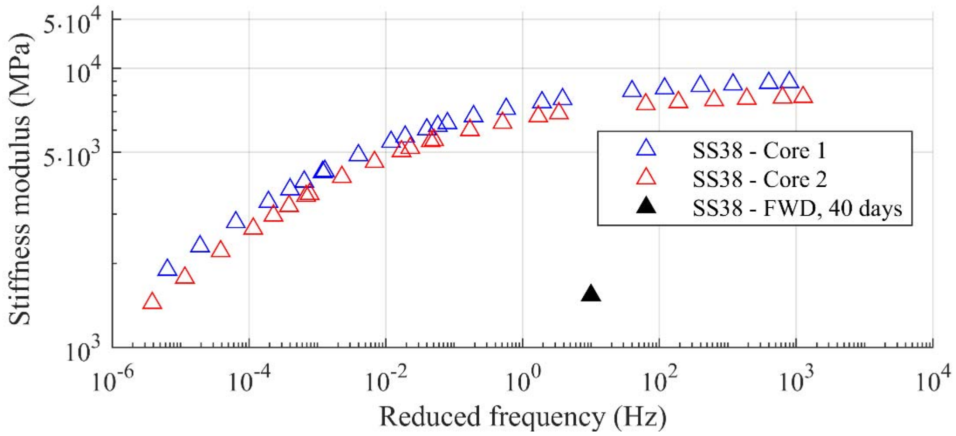

Figure 17. Master curves calculated for two cores extracted from the SS38 road section. The results are shifted to represent the stiffness over a wide frequency range at the reference temperature of 20°C. A corresponding FWD, representing the CRM mixture stiffness at the same reference temperature, is also plotted.

Falling weight deflectometer testing has been performed yearly on the SS38 road section during 2007-2015 and the modulus results are given in Figure 18. The presented values in Figure 18 are average values for multiple drops along a 400 m test section. The displayed FWD stiffnesses are transformed original values to represent the stiffness at a reference temperature of 20 °C and a reference frequency of 10 Hz. The number of drops was different from year to year, varying from 10 to 20. It can be seen in Figure 18 that the stiffness increases considerably up to six years after construction before it decreases over the following years.

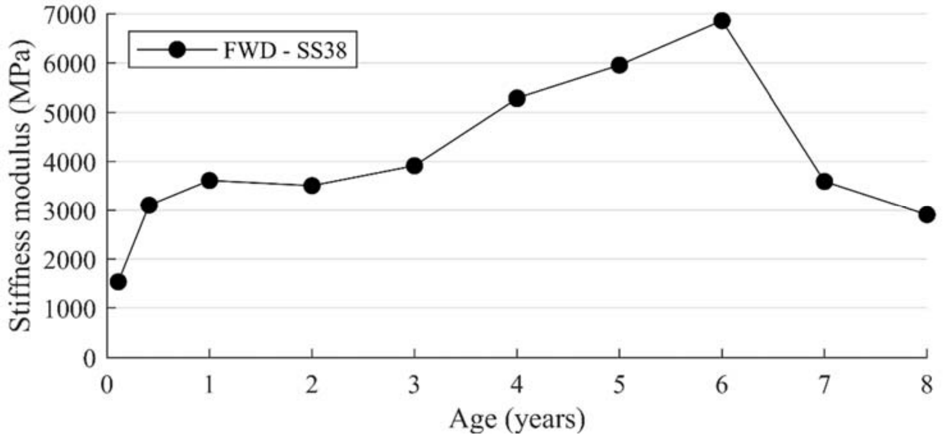

Figure 18. Stiffness development over time determined from FWD data acquired during eight years after construction. All values are transformed to represent the stiffness at a reference temperature and frequency of 20 °C and 10 Hz, respectively.

6.2.3. A14

No new testing has been performed on the A14 test section for this project. Initial testing after construction indicates normal stiffness values with an ITSM of 4245 MPa after 28 days at 25°C. No distress has been reported for the A14 test site after construction.

6.2.4. SS268

Master curves assembled from two cores specimens obtained from SS268 are presented in Figure 19 together with the falling weight deflectometer (FWD) test results 45 days after construction. The actual FWD result which is an average value from multiple drops is transformed to represent the CRM mixture stiffness at the reference temperature of 20°C with the testing frequency of 10 Hz. The FWD stiffness at these conditions gave a stiffness of 8641 MPa which is corresponding very well with the master curve data.

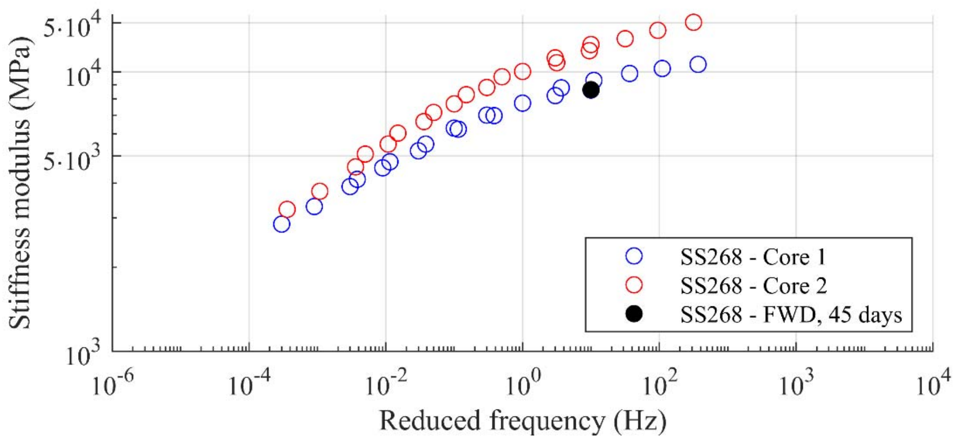

Figure 19. Master curves assembled for two cores obtained from SS268 at the reference temperature of 20°C together with a corresponding FWD measurement for the CRM mixture.

6.3. UK road sections

6.3.1. A21

No cores have been extracted from the A21 road section since no distress has been identified. However, with more than 47 000 vehicles daily and with no visible distress, the A21 road can be concluded to be in good general condition. During a traffic speed survey performed in September 2018, rut depths were measured along multiple road sections of different lengths and the results from this survey are presented in Figure 20. Rut depths are below the threshold value for category 2 roads (11 mm) for the northbound lane (Figure 20a) and category 1 roads (6 mm) for the southbound lane (Figure 20b) according to the UK guidelines (Highway Agency, 2008).

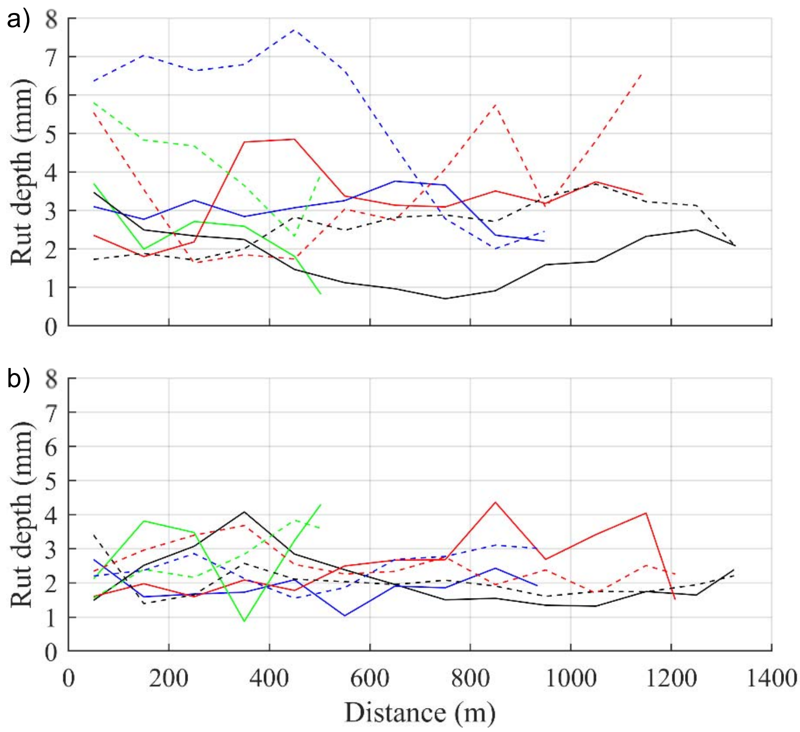

Figure 20. Rut depth measured in the a) northbound and b) southbound directions. Multiple series were measured, and they are presented with different line colours. The solid and dashed lines represent the left and right rut, respectively.

6.3.2. A46

Twelve cores were extracted from the A46 road section in April 2019 in order to determine the ITSM of the CRM. The cores were extracted as couples, two cores from each location, to receive more data and verify that the couple appeared similar. The mean layer thicknesses for these cores are presented Figure 21.

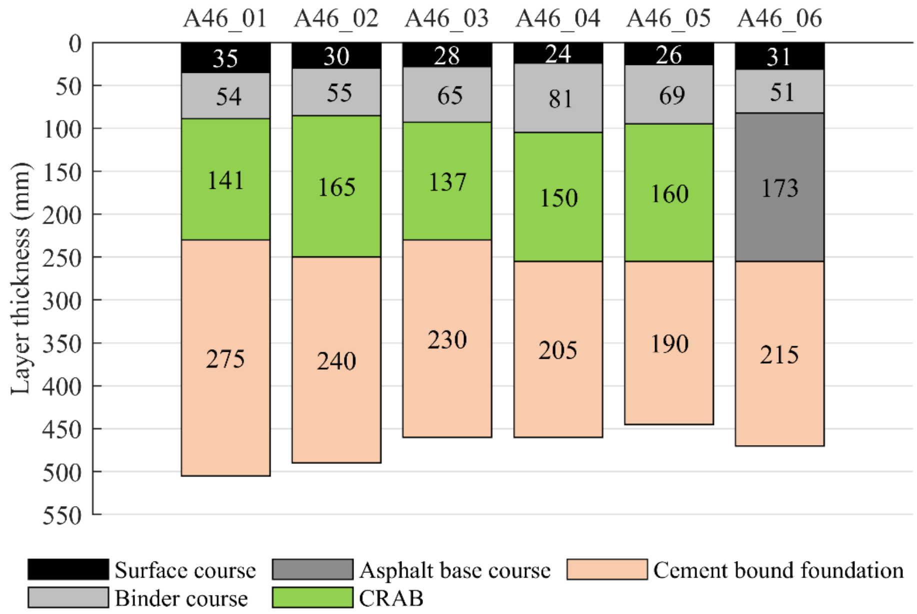

Figure 21. Layer thickness for extracted cores from the A46 test road. Each presented layer thickness is represented by the mean value of that particular layer from the two cores extracted at the same location.

As can be seen in Figure 21, the last core, named A46_06, didn't appear to have a CRM layer but rather a conventional HMA base layer. The difference between these two layers can be seen in Figure 22.

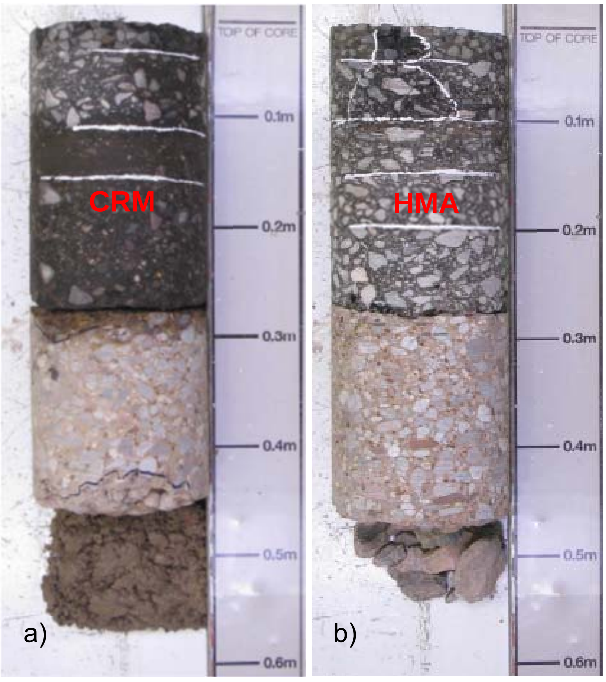

Figure 22. Extracted cores named a) A46_05 and b) A46_06.

All obtained cores were tested for ITSM at 20 °C. Unfortunately, the cores acquired in one location were too damaged to test upon arrival to the laboratory. Remaining ITSM values are presented in Table 7 and graphically in Figure 23. Within each core couple, the ITSM values were found to be very similar. Test values from A46_06 should also be disregarded since this base layer was constituted of HMA.

Table 7. Evaluated stiffness moduli of the cores extracted from the A46 road section. All moduli are given in MPa.

	1	2	3	4*	5	6**
ITSM 1	6697	5399	5102	-	5267	3736
ITSM 2	6479	5347	5197	-	4895	3625
Mean ITSM	6588	5373	5150	-	5081	3681
* The core sample was too damaged to test upon arrival to the laboratory. ** Sample appeared to be conventional HMA, the cold mix layer was not present on this core.						

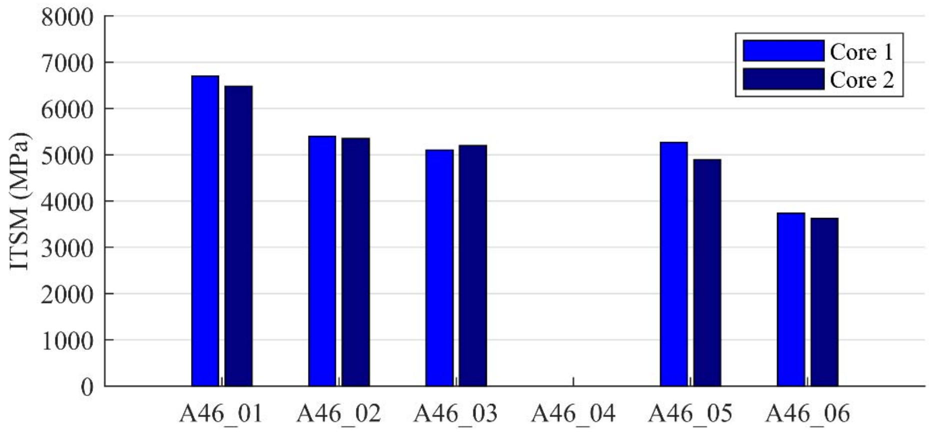

Figure 23. Evaluated ITSM values for the extracted A46 core. Cores from A46_04 were damaged upon arrival to the laboratory and therefore not possible to test.

6.3.3. A38

No distress has been reported on the A38 road section. Since the road is performing as expected, Highway England reports that the road still maintains the criteria for road category 1 or 2 and that no maintenance have been required.

6.4. Swedish road sections

6.4.1. Rv95

After construction in 2014, FWD measurements were acquired with 10 m increments along the 100 m test section and a reference section constructed with a conventional HMA base layer. Testing was performed during the fall of 2015 and the fall of 2016 and the collected data are displayed as deflection basins in Figure 24. The figure indicates that the construction containing a CRM mixture is weaker compared to the reference since the deflection difference between 0 mm (D0) and 1200 m (D1200) is larger. The deflection difference beneath the loading plate (D0) between the two years are probably due to a temperature difference when data were collected.

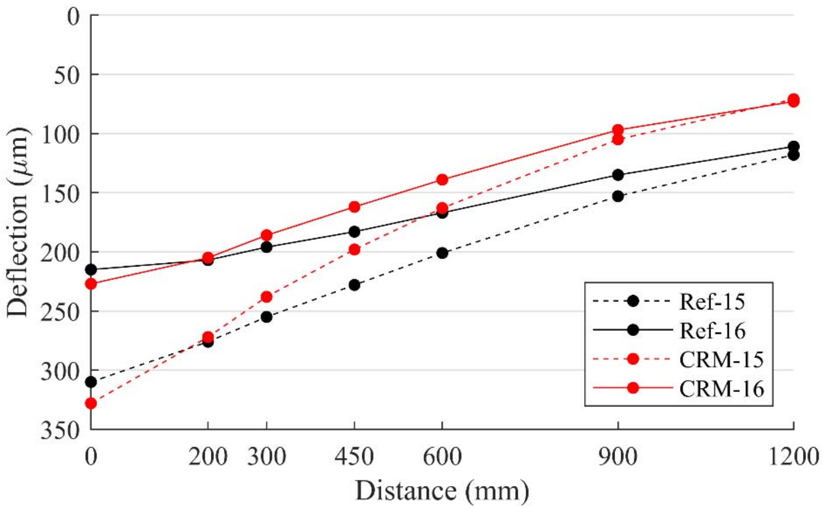

Figure 24. Deflection basins for FWD measurements acquired two consecutive years after construction.

Six cores were extracted from the Swedish road section Rv95 during September 2019. Measured thicknesses from these cores are presented in Figure 25 and corresponding ITS and ITSM in Figure 26 and Figure 27.

The extracted core samples were measured in order to determine the layer thickness of the surface, binder, and bound base layers. The nominal thicknesses for these layers were 35, 50, and 55 mm, respectively. The measured layer thicknesses are presented in Figure 25 where it is shown that the surface layer and CRAB layer thicknesses are both about 5 mm too little compared to the structure design.

An additional layer of penetration macadam was earlier placed beneath the CRM layer. Although this layer is still in place, it is believed to be uneven in thickness and not more than a few centimetres anywhere. Also, the penetration macadam is an old existing layer and its function as a bound layer is therefore considered to be outdated. The macadam is thus considered as an unbound base layer and is not depicted in Figure 25.

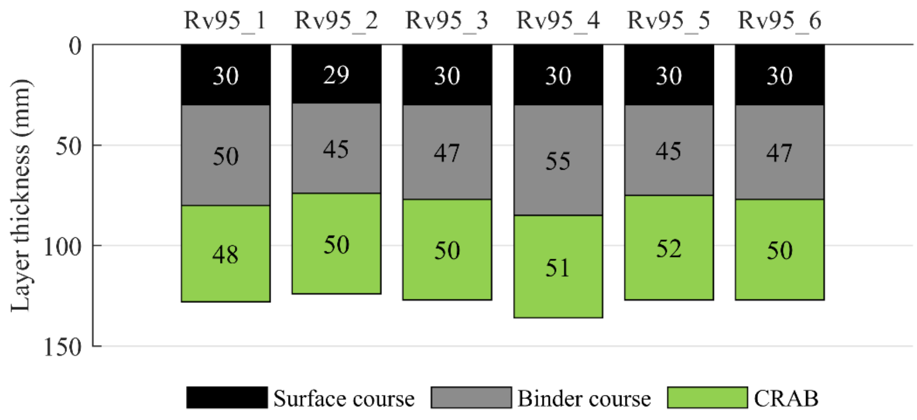

Figure 25. Layer thicknesses measured on the six Swedish core samples extracted from the Rv95 road section.

Tensile strength and stiffness of the CRM mixture were determined from the six cores samples. Figure 26 depicts the ITS results measured at 5°C and Figure 27 shows the modulus determined at 10°C. Test values are shown to be fairly even for the six individual specimens and are considered to be of normal character.

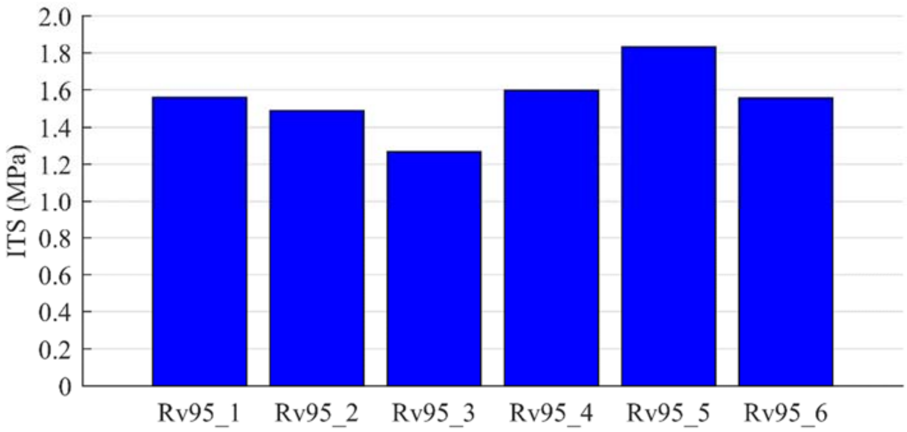

Figure 26. Indirect tensile strength test results measured at 5°C.

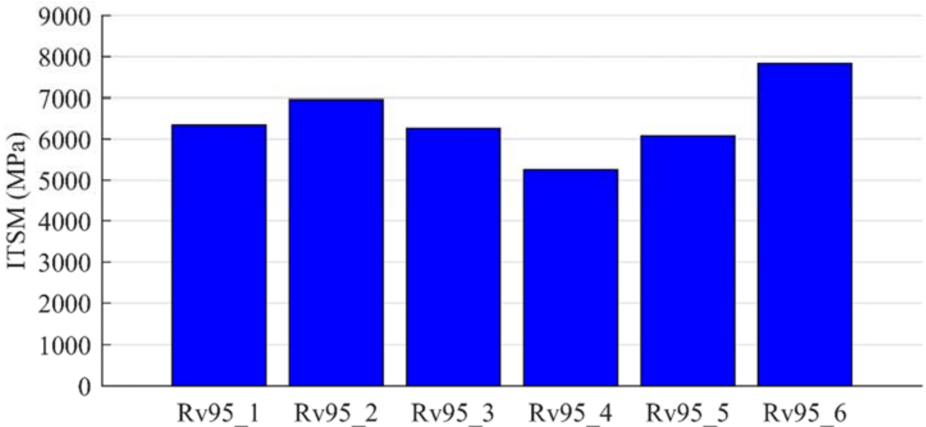

Figure 27. Indirect tensile stiffness modulus results determined at 10°C.

Air void content was also determined for the cores extracted in September 2019. The results are presented in Table 8 and can be concluded to be normal for a CRM mixture.

Table 8. Air void content determined for the six cores extracted in September 2019.

Core	Rv95_1	Rv95_2	Rv95_3	Rv95_4	Rv95_5	Rv95_6
Air voids (%)	5.6	6.2	9.4	9.1	6.6	5.2

Generally, it can be pointed out that the CRM mixture appears to be dry and tend to crumble. From the cores tested after construction, presented in Figure 28, it became clear that the CRM has less binder coverage compared to the conventional HMA.

Figure 28. Binder coverage seems to be better in the reference section (conventional HMA), shown in the bottom row compared to the CRM layer shown in the top row.

6.4.2. E45

Ten core specimens were extracted in 2013 for evaluation in the laboratory.

The average thicknesses of the surface layer, binder layer, top CRM layer and bottom CRM layer are 17, 62, 94 and 111 mm, respectively, and can thus be concluded to match the design quite well. The layer thicknesses from each individual layer are plotted in Figure 29.

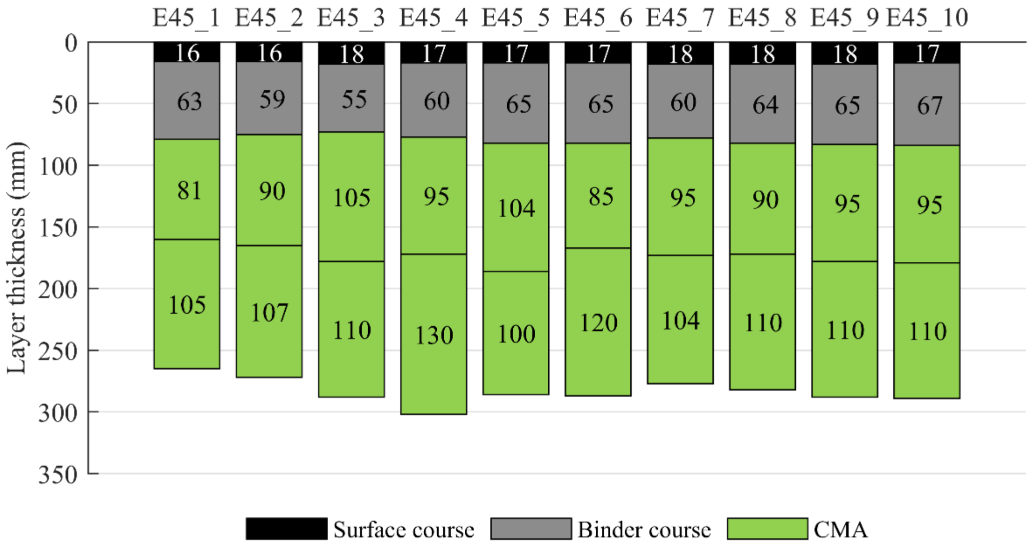

Figure 29. Measured layer thicknesses on from ten cores on E45.

Unfortunately, the stability of the large aggregate cold mix was so poor that no testing could be carried out. This is believed to be the result of the heavy rains that broke out during the night after paving the bottom CMA layer and washed away much of the bitumen emulsion.

6.4.3. Lexby

No distress has been reported for the Lexby road section. Tests performed on cores extracted after construction demonstrate a lower evaluated stiffness at different temperatures compared to a reference section containing a conventional HMA base layer.

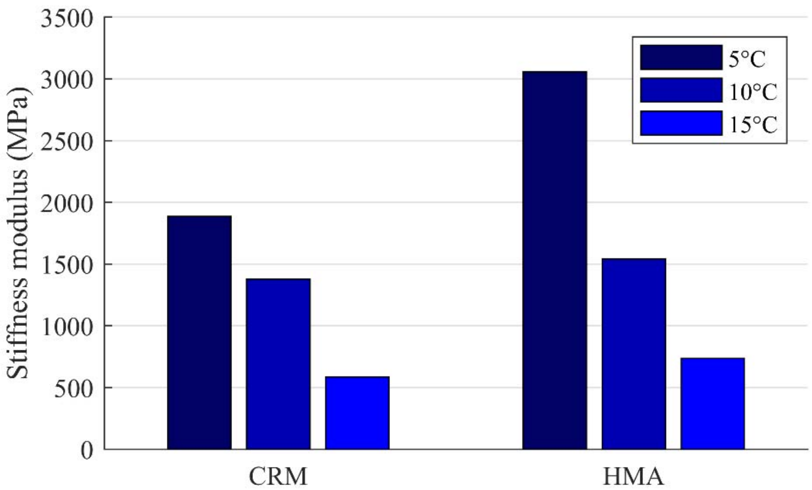

Figure 30. Stiffness moduli from cores extracted from the Lexby road after construction.

6.5. French road sections

6.5.1. RD26

A visual inspection from the RD26 road section showed no distress in 2016. Three test methods; ITSM, two-point bending test (2PBT) and direct traction (DT), have been employed to test the CRM stiffness when the road section reached different ages after construction. The results from these tests are presented in Table 9.

Table 9. Moduli for the RD26 road section determined using three test methods at different ages.

Sampling time after pavement construction	EN 12697-26		
	Annex C: ITSM (MPa)	Annex A: 2PBT (MPa) Prismatic specimen	Annex E: DT (MPa)
11 months	1500		1400
16 months	2050		1250
20 months	3250		2000
25 months	3000		
35 months	3050	2450	

6.5.2. RD44

For the RD44 road section, a visual inspection showed a few cracks on the surface. Specimens extracted from the CRM layer were tested using the same methods as for the RD26, showing results presented in Table 10.

Table 10. Moduli for the RD44 road section. Three test methods were applied at different times after construction.

Sampling time after pavement construction	EN 12697-26			
	Annex C: ITSM (MPa)	Annex A: 2PBT (MPa) Prismatic specimen	Annex A: 2PBT (MPa) Trapezoidal specimen	Annex E: DT (MPa)
5 months	3250			
14 months	3080	1964	2495	2028
24 months	3990	2656	3800	2799
31 months	3840	2528	3500	3065

6.6. Structural performance

To assess the performance of each section's structure, measurement data as well as visual assessment were used. According to the German standard for condition monitoring (FGSV, 2006), each assessed road structure was split into 10- or 100-meter sections depending on the individual total length. The proportion of cracked surface was observed by using photo documentations of the sections either by photos taken during visual inspection or Google Street View pictures. Rutting data was also collected along some test sections. For the available data, different types of nomograms were given (see Figure 31 and Figure 32). Within the rutting-nomogram, different function classes are available depending on the distribution of traffic.

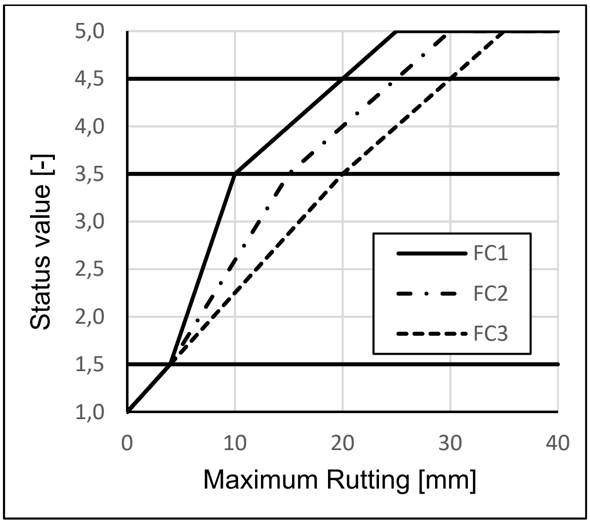

Figure 31. Nomogram for evaluate rutting

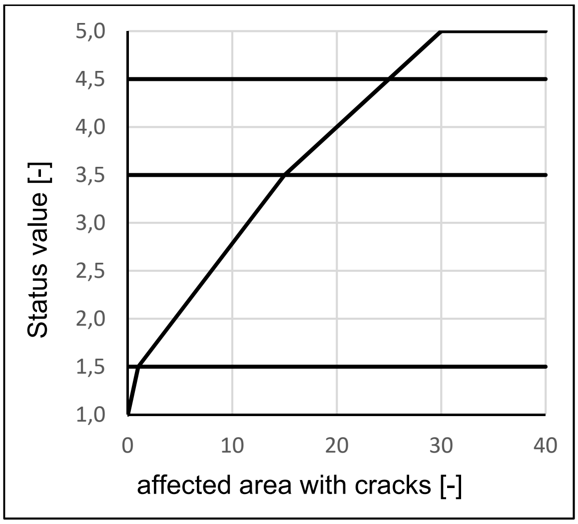

Figure 32. Nomogram for evaluate cracking

The resulting status values represent the service condition of the pavement and can be interpreted as follows:

- 1,0 – 1,49 very good / new
- 1,5 – 2,49 good
- 2,5 – 3,49 satisfactory
- 3,5 – 4,49 sufficient
- > 4,5 defective

Table 11 gives an overview on the pavement condition assessments since the rehabilitation of the roads including CRM layers. The table presents two kinds of values, the upper one in bold is the condition value of the section regarding rutting and cracking. The lower one in italic shows the 95-% quantile of the measurement series for rutting and cracking. The table only shows condition values for the last measurement period, the complete results are given in Annex A1.

For all German sections, data were available for two monitoring dates after the rehabilitation. No section has any major damage. All of them receive a rating less than 2,49. That means a good general pavement condition. However, the highest value in the 95-% quantile was reached for the proportion of cracked surface on the L386 (q_{95} = 3,45).

The Swedish sections provide a lot of data regarding rutting and cracking. A comparison between the Rv95 and the E45 shows a lower increase of rutting compared to the Rv95. Seven years after paving, the E45 shows good condition with a condition value of 1,74 for rutting and 1,54 for cracking. The scatter shows that there exist few areas with just satisfactory conditions. At nearly similar traffic load, the Rv95 shows slightly better conditions regarding cracking with a status value for cracking of 1,35 five years after construction. The corresponding value for the E45 is 1,54.

One evaluated value is available for the French section RD44. The rehabilitation of the was performed in 2008. The section has a heavy daily traffic volume of 125 vehicles per day one of the sections with the lowest traffic loads. After 11 years of traffic a condition value of cracking is 1,21 (very good condition). By a 95-% quantile of 2,07 for this section, some single areas show distresses on the surface.

The data of the Italian sections enable assessment of all assessed road structures; however, 2 out of 4 sections just provide a visual condition evaluation. The status value for the SS38 as well as the SS268 result in 1,0. None of them show any sign of damage characteristics. The SP18 provides more data. The condition value for cracking is 2,74 after 11 years of traffic which corresponds to satisfactory condition. However, due to the high value for the 95-% quantile (q_{95} = 4,50), the condition of SP18 was classified as the poorest in this survey. The condition of the A14 is quite good with a value of 1,18 for cracking as well.

Two out of three UK sections were evaluated by surface condition inspection. The A21 section provides a quite good performance with a condition value of 1,64 for rutting and 1,36 for cracking. Both quantiles are relatively low. The second section is the A46 with a traffic load of 3664 heavy vehicles per day and an age of 12 years. The condition values of this section are 1,56 for rutting and 1,0 for cracking, corresponding to a good pavement condition.

Table 11. Pavement condition of each section since rehabilitation.

Country	Section	Year of Rehabilitation	Last year of Measurement	Daily heavy traffic		status value*	
						RUT	CRA
GER	B52	2009	2015	3900	**Average** / *95%-Quantil*	**1,88**	
						2,18	
GER	L52	2011	2017	60		**1,28**	**1,00**
						2,00	1,00
GER	L386	2007	217	365		**1,50**	**1,36**
						1,79	3,45
SWE	Rv95	2014	2019	380		**2,10**	**1,35**
						2,25	2,75
SWE	E45	2012	2019	333		**1,74**	**1,54**
						1,81	2,79
FR	RD44	2008	2019	125			**1,21**
							2,07
FR	RD26	2011	-	38			
ITA	SS38	2007	2019	1850			**1,00**
							1,00
ITA	SS268	2016	2017	-			**1,00**
							1,00
ITA	SP18	2008	2019	250			**2,74**
							4,50
ITA	A14	2007	2019	-			**1,18**
							1,73
UK	A46	2006	2018	3664		**1,64**	**1,36**
						1,84	1,82
UK	A21	2002	2018	11700		**1,56**	**1,00**
						2,01	1,00

**status value written in bold and a 95-% quantile written in italic*

7. Conclusions

In total, 17 road sections in five European countries have been studied in this project in order to identify the expected service lifetime of road structures containing base layers composed out of CRM. In all these road sections, cold paving techniques have been applied. Out of these 17 road sections, 14 contains reclaimed asphalt as aggregates.

The ages of the structures vary considerably. They have been open for traffic between 3 and 18 years. Nevertheless, most structures show no sign of distress on the surface. The German section L52 experienced some transversal cracking soon after construction. However, these cracks were believed to be the results of a high cement content, causing the overlaying layers to crack due to shrinkage in the CRM layer. Also, after milling of the cracked layers and replacing them with new ones, no new cracks have developed after 9 years.

Regarding the mix design of the different CRM layers, it is shown that the content of RA differs considerably. In the French sections and one of the Swedish sections, no reclaimed material was included and in some of the German and Italian sections, up to 100% reclaimed material was used. On the other hand, a significantly higher binder content was applied in the sections with no, or little, reclaimed asphalt. A possible explanation could be that a high RA content allows a reduction of new binder since the old binder already covers the aggregates as it is. However, in the German, Italian and UK structures, cement is added as a co-binder to help the mixing of aggregates and bitumen emulsion or as an additional rigid binder. A higher cement content results in higher stiffness, see Figure 13 for the German L386 road section as an example where a high cement content was applied.

The stiffness of CRM mixtures is increasing during several years. This is demonstrated by the FWD measurements from the Italian road section SS38 in Figure 18 and the French sections RD26 and RD44 in Table 9 and Table 10. This phenomenon emphasises the importance of addressing the short-term and the long-term properties of CRM mixtures in the design phase.

The mix design differs significantly among these 17 road sections. In Germany and Italy, up to 100% of the bound base layer aggregates constitutes of RA while lower percentage RA, or none, are included in the Swedish and French road sections. Cement is included in all studied road sections from Germany, Italy and the UK. No cement was included in the Swedish or French road section; however, a higher bitumen emulsion was applied in these sections compared to the rest. The higher cement content resulted in early-life shrinkage cracking in one of the German sites which could be repaired by replacing the overlaying layers.

Although the mix design varies significantly, similarities can be observed in the design approaches regarding total thickness of bound layers versus average daily heavy traffic.

The relatively good conditions of the assessed road structures indicate, that the applied pavement and mixture designs result in durable road constructions feasible also for roads with high traffic loading.

This project demonstrates that suitable mix and pavement design procedures can be applied in different European climatic regions to design and pave roads with CRM mixtures as base layers without the disadvantages of decreased service lifetime or increased maintenance.

References

Bocci, M., Canestrari, F., Grilli, A., Pasquini, E., and Lioi, D. (2010). Recycling techniques and environmental issues relating to the widening of an high traffic volume Italian motorway. International Journal of Pavement Research and Technology, 3 (4), 171-177.

Bocci, M., Grilli, A., Cardone, F., and Graziani, A. (2011). A study on the mechanical behaviour of cement-bitumen treated materials. Construction and Building Materials, 25 (2), 773-778.

Bocci, E., Graziani, A., and Bocci M., (2020). Cold In-place Recycling for a Base Layer of an Italian High-Traffic Highway, Proceedings of the 5th ISAP International Symposium on Asphalt Pavements & Environment (APE), doi: 10.1007/978-3-030-29779-4_31

European Commission (2019). Information retrieved from https://ec.europa.eu/clima/policies/transport_en on October 10th, 2019

European Environment Agency (2019). Information retrieved from https://www.eea.europa.eu/data-and-maps/indicators/transport-final-energy-consumption-by-mode/assessment-9 on October 10th, 2019.

Forschungsgesellschaft für Straßen- und Verkehrswesen (FGSV), "Zusätzlich Technische Vertragsbedingungen und Richtlinien zur Zustandserfassung und -bewertung von Straßen," 2006, no. 489.

Forschungsgesellschaft für Straßen- und Verkehrswesen (FGSV), Arbeitsgruppe "Mineralstoffe im Straßenbau", "Merkblatt für Kaltrecycling in situ im Straßenoberbau - MKRC," 2005, no. 636.

Grilli, A., Graziani, A., and Bocci; M. (2012). Compactability and thermal sensitivity of cement-bitumen-treated materials. Road Materials and Pavement Design, 13 (4), 599-617. doi: 10.1080/14680629.2012.742624

Highways Agency. (2008). Design Manual for Roads and Bridges (DMRB), Vol.7: Pavement Design and Maintenance, Section 3, Part 3, HD29/08: Data for Pavement Assessment. London: Department of Transport.

Merrill, D., Nunn, M., and Carswell, I. A guide to the use and specification of cold recycled materials for the maintenance of road pavements - TRL Report 611, London: Department of Transport, 2012.

Provincia Autonoma di Bolzano - Alto Adige. Catalogo per il dimensionamento delle pavimentazioni stradali. Provincia Autonoma di Bolzano - Alto Adige, Bolzano, 2016.

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Annex A1. Table of pavement condition

Country	Section	Year of Rehabilitation	Daily heavy traffic	Average / 95%-Quantil	status value															
					2011		2012		2014		2015		2016		2017		2018		2019	
					RUT	CRA	RUT	CRA	RUT	CRA	RUT	CRA	RUT	CRA	RUT	CRA	RUT	CRA	RUT	CRA
GER	B52	2009	3900		**1,54**	**1,07**					**1,88**									
					2,07	*1,27*					*2,18*									
GER	L52	2011	60				**1,00**								**1,28**	**1,00**				
							1,00								*2,00*	*1,00*				
GER	L386	2007	365				**1,03**	**1,15**							**1,50**	**1,36**				
							1,00	*2,06*							*1,79*	*3,45*				
SWE	Rv95	2014	380						**1,25**		**1,40**								**2,10**	**1,35**
									1,25		1,40								2,25	2,75
SWE	E45	2012	333						**1,39**		**1,50**		**1,49**		**1,65**		**1,63**		**1,74**	**1,54**
									1,50		*1,53*		*1,51*		*1,68*		*1,68*		*1,81*	*2,79*
FR	RD44	2008	125																	**1,21**
																				2,07
FR	RD26	2011	38																	
ITA	SS38	2007	1850																	**1,00**
																				1,00
ITA	SS268	2016	-													**1,00**				
																1,00				
ITA	SP18	2008	250																	**2,74**
																				4,50
ITA	A14	2007	-																	**1,18**
																				1,73
UK	A46	2006	3664														**1,64**	**1,36**		
																	1,84	*1,82*		
UK	A21	2002	11700														**1,56**	**1,00**		
																	2,01	*1,00*		

Annex A2. Questionnaire sent out to project partners

CRABforOERE

Cold Recycled Asphalt Bases for Optimised Energy & Resource Efficient Pavements

CRAB for OERE

Questionnaire

Roads with Cold Recycled Material (CRM)

Project information

When using cold recycling of reclaimed asphalt, high recycling rates can usually be reached. Additionally, the pavement material is mixed, transported and paved at ambient temperatures and therefore no drying/heating energy is required. Therefore, using cold recycled asphalt bases can be considered as pavement of optimal energy and resource efficiency.

The project "CRABforOERE - Cold Recycled Asphalt Bases for Optimised Energy & Resource Efficient Pavements" strives to develop harmonised mix and pavement design for cold recycle materials (CRM). To this end a questionnaire for identification of existing CRM structures which could be used to assess the overall performance and the expected durability of the structures in relation to the mix and structural design, the climate and traffic loading. The full spectrum of success of CRM structures should be identified, ranging from early failures to old structures with good performance.

Fill in one questionnaire for each identified structure.

Questionnaire

Respondent:

Suggest a working name for the structure:

Early, general assessment of the success of the structure.

In your or others opinion is the structure a success, performing as expected or performing below par? Based on what criteria?

Where (coordinates) and when was the road built:

Is there a reference structure built without CRM at the same location?

Is there data already available on the performance of the road? What type of data? FWD measurements, profile? Has there been road maintenance work on the road after construction?

Is there data on the traffic volume available? How much traffic?

Please give details on the mix design of the CRM layer. What was the composition of the mix and what were the material parameters of the constituent materials and the cold recycled mix?:

What was the structural design? In what respect did it differ from a structure built with conventional hot produced asphalt?

Is there already weather data available, before, during and after the construction? In general terms was the construction built during ideal weather conditions?

Are there reports and other reference materials available? Reference list:

Selected photos of the road, if available:

Annex A3. B52 questionnaire

Project information

When using cold recycling of reclaimed asphalt, high recycling rates can usually be reached. Therefore, using cold recycled asphalt bases can be considered as pavement of optimal energy and resource efficiency.

The project strives to develop harmonised mix and pavement design for cold recycle materials (CRM). To this end a questionnaire for identification of existing CRM structures which could be used to assess the overall performance and the expected durability of the structures in relation to the mix and structural design, the climate and traffic loading. The full spectrum of success of CRM structures should be identified, ranging from early failures to old structures with good performance.

Fill in one questionnaire for each identified structure.

Questionnaire

Respondent:

Dr. Dirk Jansen

Suggest a working name for the structure:

B52 trial section, FDR of a primary federal road

Early, general assessment of the success of the structure.
In your or others opinion is the structure a success, performing as expected or performing below par? Based on what criteria?

The pavement does not show any distress after about 10 years of traffic (26.000 ADT)

Where (coordinates) and when was the road built:

2009, Position: https://goo.gl/maps/ZdjEsYBcMHo

Is there a reference structure built without CRM at the same location?

Yes, in usual hot mix asphalt.

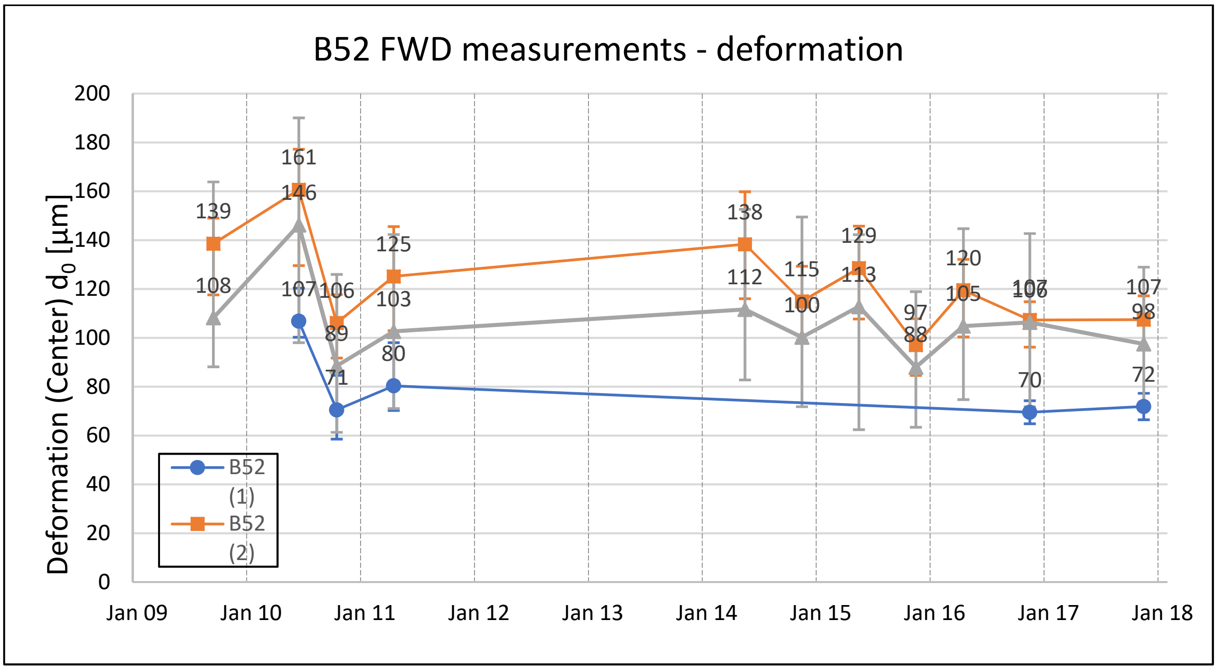
Is there data already available on the performance of the road? What type of data? FWD measurements, profile? Has there been road maintenance work on the road after construction?

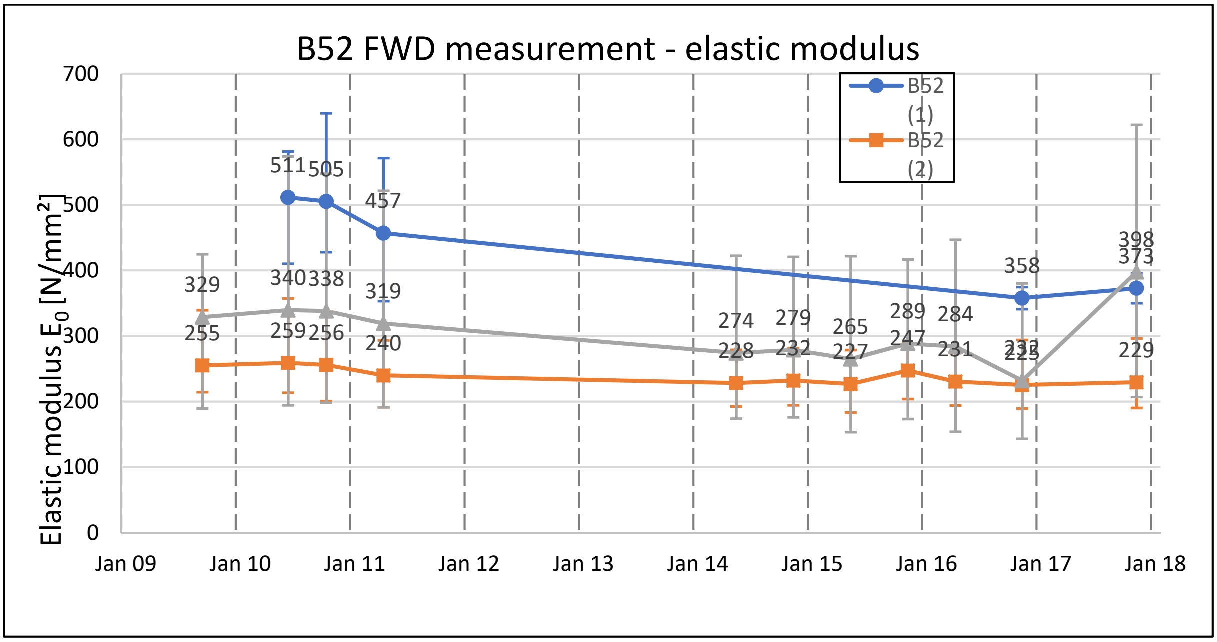
Performance data from 2007 up to 2015 is shown in the table below.

		2007 (before rehabilitation)			2011			2015		
Section	Stat.	evenness	Rutting	Cracks	evenness	Rutting	Cracks	evenness	Rutting	Cracks
B52 (1)	0	2,21	1,6	1	1,39	1,27	1,33	1,3	1,75	1
	100	1,79	1,93	1	1,5	1,3	1	1,24	1,72	1
	200	3,33	2,36	2,7	2,09	1,3	1,17	1,8	1,87	1
B52 (2)	0	1,61	1,93	2,2	1,17	1,42	1	1,1	1,85	1
	100	1,69	2,06	3,19	1,14	1,37	1	1,1	1,75	1
	200	1	2,63	5	1,21	1,47	1	1,06	1,77	1
	300	1,6	2,5	3,08	1,13	1,42	1	1,06	1,7	1
	400	2,38	1,9	5	1,2	1,37	1	1,1	1,82	1
B52 (3)	0	1,93	2,19	3,08	1,17	1,5	1	1,14	1,82	1
	100	2,24	1,86	3,21	1,16	1,52	1	1,13	1,77	1
	200	1	2,03	3,65	1,18	1,47	1	1,07	1,85	1
	300	1,91	1,7	1	1,14	1,45	1	1,08	1,82	1
	400	1	2,19	3,82	1,13	1,57	1	1,09	1,92	1
	500	2,23	1,76	2,36	1,13	1,52	1	1,09	1,82	1
	600	1,78	1,6	2,2	1,27	1,42	1	1,22	1,72	1
	700	1,53	1,73	1	1,226	1,35	1	1,17	1,92	1

Condition

- 1,0 - 1,49 (very good/ new)
- 1,5 - 2,49 (good)
- 2,5 - 3,49 (satisfactory)
- 3,5 - 4,49 (sufficient)
- 4,5 - 5,0 (defective)





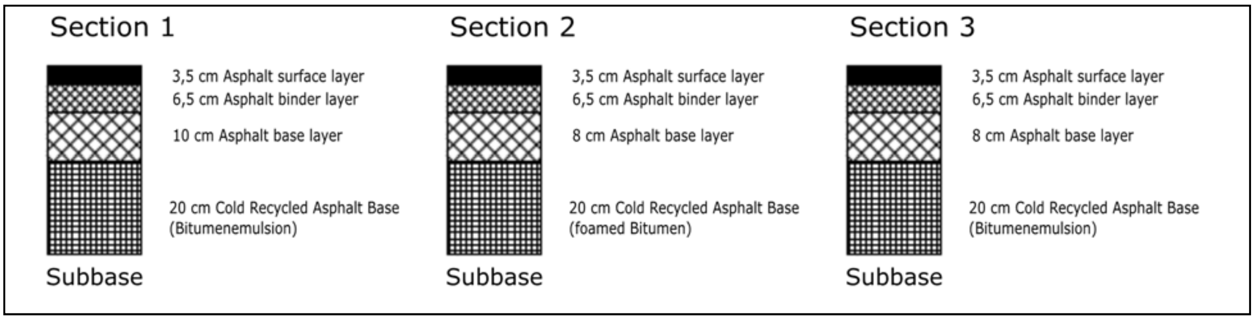
Is there data on the traffic volume available? How much traffic?

Approximate 26.000 average daily traffic (about 15% of commercial vehicles).

Please give details on the mix design of the CRM layer. What was the composition of the mix and what were the material parameters of the constituent materials and the cold recycled mix?:

There is 100% RA in use for the CRM layer. There is no gradation available. Only values for single sieve sizes ($P_{0.063mm}$ = 2.8%; P_{2mm} = ≥20%; P_{45mm} = 90 – 100 % The mix design in section 1 und 3 contain 4,0 % of cement and 4,0 % of SBS-modified bituminous emulsion. Furthermore there was 3,1 % of water adding to the mixture. In section 2 were 3,0 % of cement and 2,5 % foamed bitumen in use. The proportion of water was by 4,7 %. ITS@5°C is 0,66 and 0,93 N/mm² after curing period of 7 days or rather 28 days for B52 (1) and B52 (3). ITS@5°C is 0,5 and 0,85 N/mm² for B52 (2).

What was the structural design? In what respect did it differ from a structure built with conventional hot produced asphalt?



Is there already weather data available, before, during and after the

The construction performed from September 2008 until April 2009 with temperature ranging between – 1.6 to 12.6° C

Zeitraum	Temperatur		Niederschlag		Sonnenschein	
	Mittel	Abw.	Summe	Abw.	Summe	Abw.
2008 / 12	1,1	-1,3	43,1	59%	48,1	134%
2008 / 11	5,5	+0,2	28,8	45%	30,9	67%
2008 / 10	9,3	-0,8	62,3	84%	68,2	72%
2008 / 09	12,5	-1,7	79,5	126%	129,5	85%
2008 / 08	17,6	-0,5	54,0	86%	166,3	78%
2008 / 07	18,2	-0,5	93,2	128%	219,3	95%
2008 / 06	17,4	+1,0	61,2	90%	210,0	98%
2008 / 05	16,3	+2,7	28,2	43%	240,2	119%
2008 / 04	8,2	-1,1	49,3	91%	107,1	61%
2008 / 03	5,1	-0,7	95,5	154%	64,2	54%
2008 / 02	4,3	+2,1	74,2	137%	119,3	161%
2008 / 01	4,5	+3,1	59,7	88%	39,9	87%

Zeitraum	Temperatur		Niederschlag		Sonnenschein	
	Mittel	Abw.	Summe	Abw.	Summe	Abw.
2009 / 12	2,0	-0,4	79,6	109%	36,8	102%
2009 / 11	8,5	+3,2	124,0	194%	33,6	73%
2009 / 10	9,7	-0,4	52,0	70%	94,6	100%
2009 / 09	15,1	+0,9	36,6	58%	152,8	100%
2009 / 08	19,3	+1,2	34,1	54%	264,4	125%
2009 / 07	18,4	-0,3	115,0	158%	216,5	93%
2009 / 06	16,0	-0,4	110,8	163%	211,9	99%
2009 / 05	14,6	+1,0	53,4	82%	190,4	94%
2009 / 04	12,6	+3,3	41,8	77%	203,1	116%
2009 / 03	5,3	-0,5	57,9	93%	100,5	84%
2009 / 02	2,1	-0,1	34,1	63%	34,8	47%
2009 / 01	-1,6	-3,0	59,8	88%	83,2	181%

construction? In general terms was the construction built during ideal weather conditions?

Are there reports and other reference materials available? Reference list:

CS4.26 DIRECT_MAT – Field and laboratory case study, A. Walther; K. Mollenhauer, 2007

Selected photos of the road, if available:

Surface of the CRM-layer

Annex A4. L52 questionnaire

Project information

When using cold recycling of reclaimed asphalt, high recycling rates can usually be reached. Therefore, using cold recycled asphalt bases can be considered as pavement of optimal energy and resource efficiency.

The project strives to develop harmonised mix and pavement design for cold recycle materials (CRM). To this end a questionnaire for identification of existing CRM structures which could be used to assess the overall performance and the expected durability of the structures in relation to the mix and structural design, the climate and traffic loading. The full spectrum of success of CRM structures should be identified, ranging from early failures to old structures with good performance.

Fill in one questionnaire for each identified structure.

Questionnaire

Respondent:

Fr. Kappes (LBM Cochem-Koblenz)

Suggest a working name for the structure:

L52, Rehabilitation in section Laubach to Schöne Aussicht, FDR

Early, general assessment of the success of the structure.

In your or others opinion is the structure a success, performing as expected or performing below par? Based on what criteria?

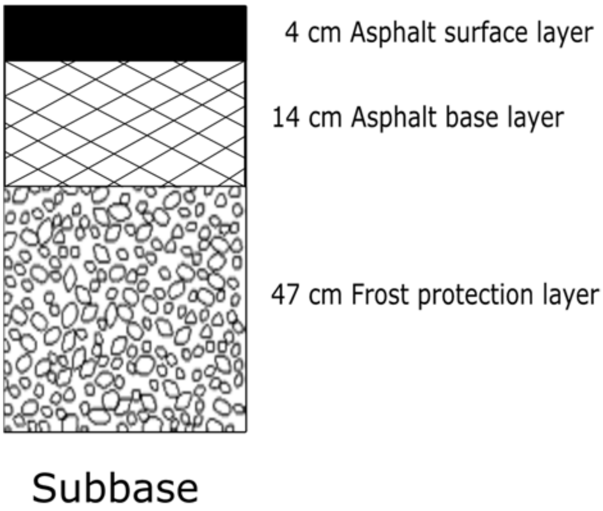
The pavement does not show any distress after about 8 years of traffic (about 1.500 ADT)

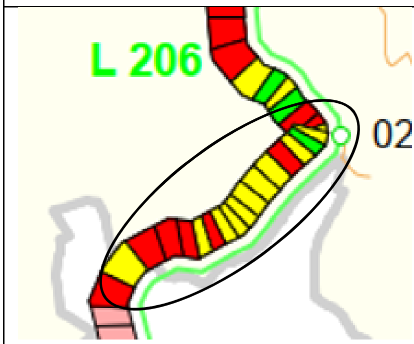
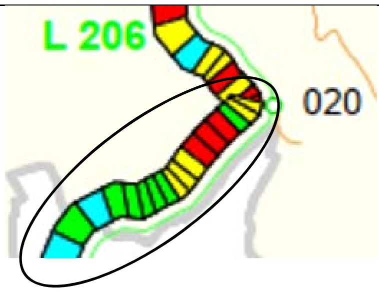
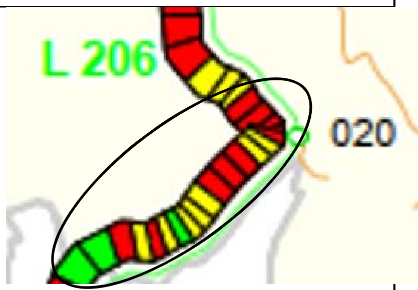
Where (coordinates) and when was the road built:

2011, Position: https://goo.gl/maps/a9pzcHCa4aG2

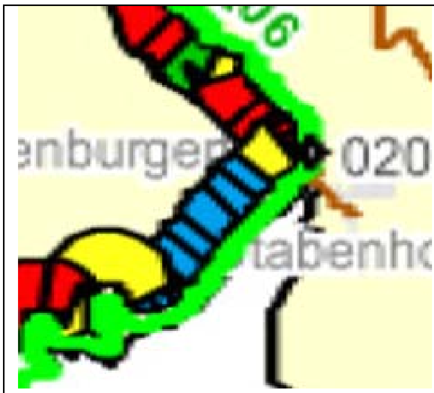
Is there a reference structure built without CRM at the same location?

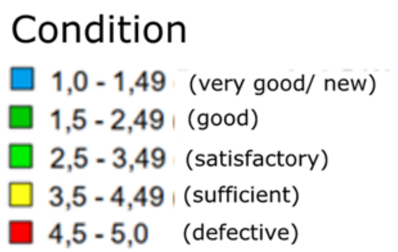
L206 with approximate 1.500 avarage daily traffic. Rehabilitation in 2011. Structurel design and performance data are shown below. Position: https://goo.gl/maps/9fgvpe4wg1S2



Performance Data 2007		
Longitudinal evenness	Cracks	Total value
		

Perfomance Data 2012 (total value)



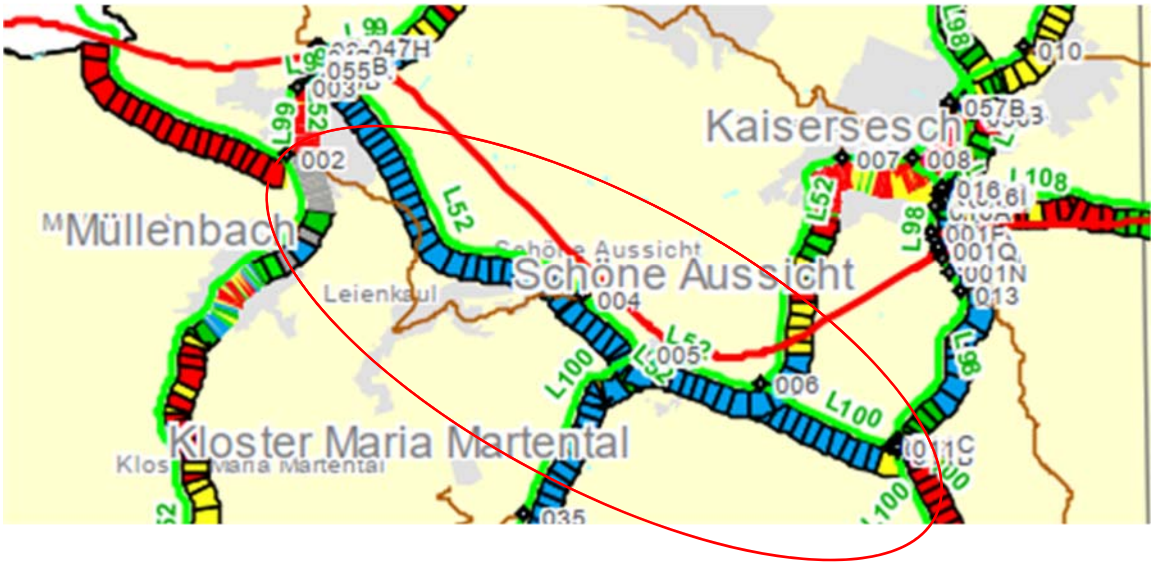


Is there data already available on the performance of the road? What

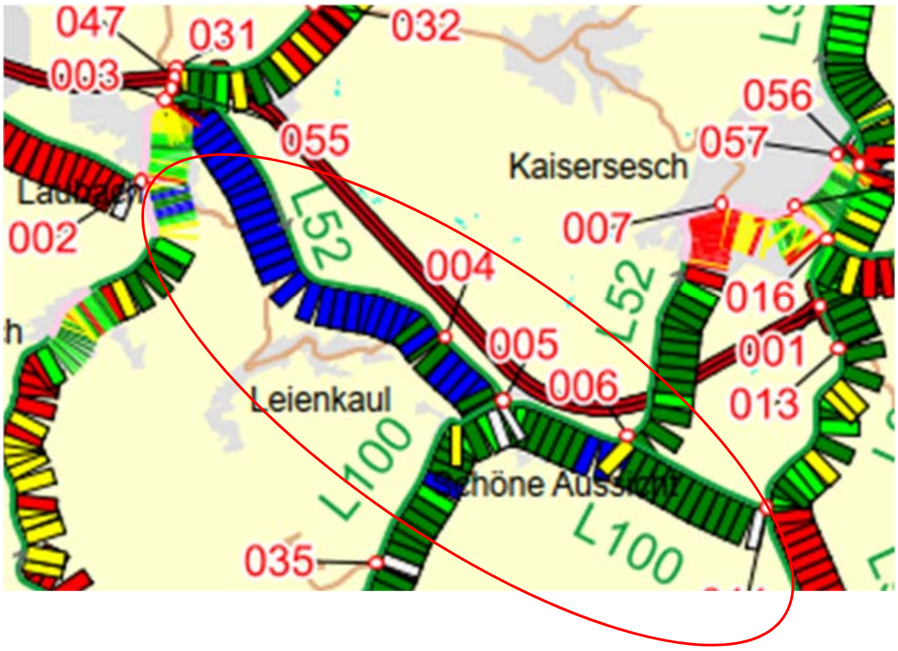
Surface performance data from 2012 & 2017.

No cracks. In 2017 longitudinal evenness problems in a short section.

Data from 2012 (total value)



Data from 2017 (total value)

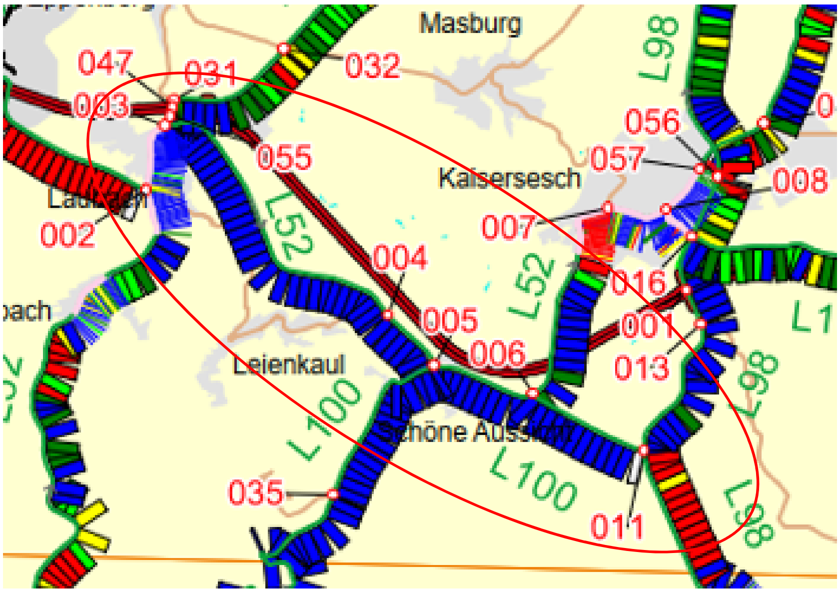


Condition

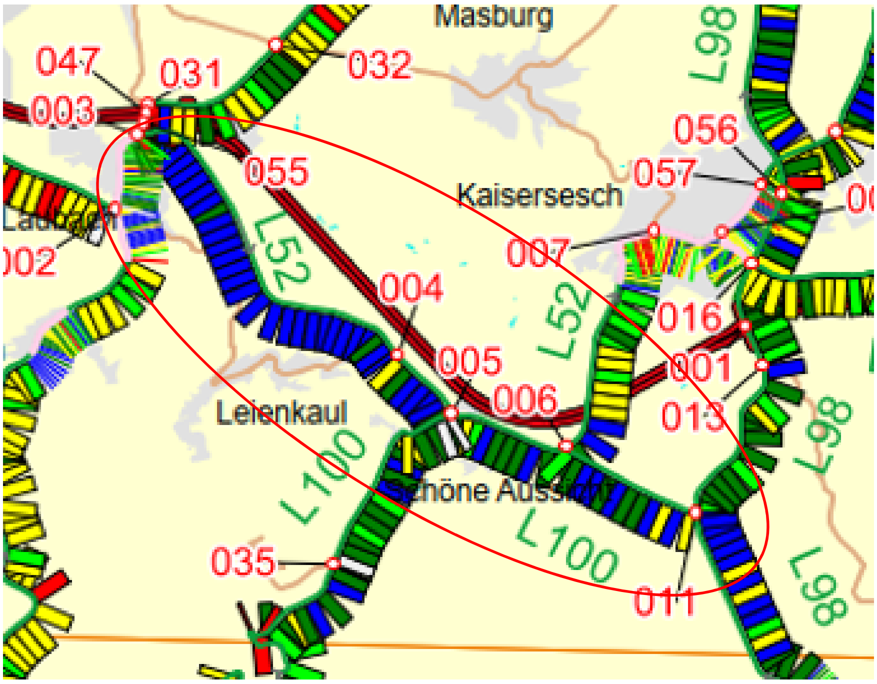
- 1,0 - 1,49 (very good/ new)
- 1,5 - 2,49 (good)
- 2,5 - 3,49 (satisfactory)
- 3,5 - 4,49 (sufficient)
- 4,5 - 5,0 (defective)

type of data? FWD measurements, profile? Has there *been road* maintenance work on the road after construction?

Data from 2017 (cracks)



Data from 2017 (longitudinal evenness)



Condition

- 1,0 - 1,49 (very good/ new)
- 1,5 - 2,49 (good)
- 2,5 - 3,49 (satisfactory)
- 3,5 - 4,49 (sufficient)
- 4,5 - 5,0 (defective)

Is there data on the traffic volume available? How much traffic?

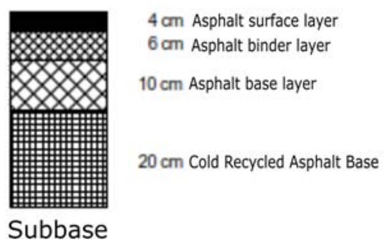
Approximate 1.500 average daily traffic (about 4 % of commercial vehicles).

Please give details on the mix design of the CRM layer. What was the composition of the mix and what were the material parameters of the constituent materials and the cold recycled mix?:

Sivesize	Sample (passing fraction)	Guidelines M-KRC
[mm]	[M.-%]	[M.-%]
63	100,0	
45	98,9	90-100
31,5	88,9	
22,4	78,6	
16	67,0	
11,2	57,5	
8	48,9	
5,6	39,2	
4	31,4	
2	20,5	≥20
1	12,9	
0,5	8,4	
0,25	5,6	
0,125	3,8	
0,063	2,8	2-10

There is 100% RA in use for the CRM layer. The gradation is shown above and was suitable for cold in-situ recycling using with cement and bituminous emulsion ($P_{0.063mm}$ = 2.8%; P_{2mm} = ≥20%; P_{45mm} = 90 – 100 %). By adding 4,5 % of cement and 2,5 % of SBS-modified bituminous emulsion suitable mechanical performance were reached. ITS@5°C ranging between 0,47 to 0,60 N/mm² after curing period of 7 days. ITS@5°C ranging between 0,73 to 0,76 N/mm² after curing period of 28 days. Moisture content by w_{opt}= 6%.

What was the structural design? In what respect did it differ from a structure built with conventional hot produced asphalt?



Is there already weather data available, before, during and after the construction? In general terms was the construction built during ideal weather conditions?

The construction performed in October 2010 to June 2011 with temperature ranging between 2 to 24°C approximately.

Are there reports and other reference materials available? Reference list:

There are no other reference materials available.

Selected photos of the road, if available:


Service

Annex A5. L386 questionnaire

Project information

When using cold recycling of reclaimed asphalt, high recycling rates can usually be reached. Therefore, using cold recycled asphalt bases can be considered as pavement of optimal energy and resource efficiency.

The project strives to develop harmonised mix and pavement design for cold recycle materials (CRM). To this end a questionnaire for identification of existing CRM structures which could be used to assess the overall performance and the expected durability of the structures in relation to the mix and structural design, the climate and traffic loading. The full spectrum of success of CRM structures should be identified, ranging from early failures to old structures with good performance.

Fill in one questionnaire for each identified structure.

Questionnaire

Respondent:

Hr. Milz (LBM Worms)

Suggest a working name for the structure:

L386, Rehabilitation in section Bischheim to Stetten, FDR

Early, general assessment of the success of the structure.

In your or others opinion is the structure a success, performing as expected or performing below par? Based on what criteria?

The pavement shows only distress (see photos) at intersections after about 12 years of traffic (between 4.000 and 7.000 ADT)

Where (coordinates) and when was the road built:

2007, Position: https://goo.gl/maps/EfTGQdtbZJG2 (Total length: 4,6 km)

Is there a reference structure built without CRM at the same location?

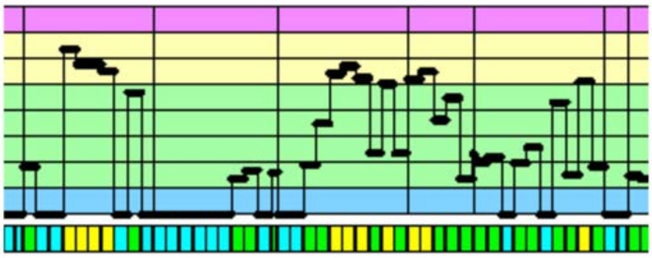
Will follow.

Is there data already available on the performance of the road? What type of data? FWD measurements, profile? Has there been road

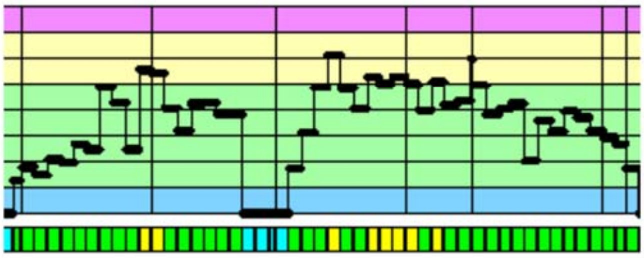
Road maintenance work in 2011 (bitumen of the surface layer was hardened - cracking). In the course of the maintenance an extra binder layer was paved in the HMA package.

Performance Data 2002:

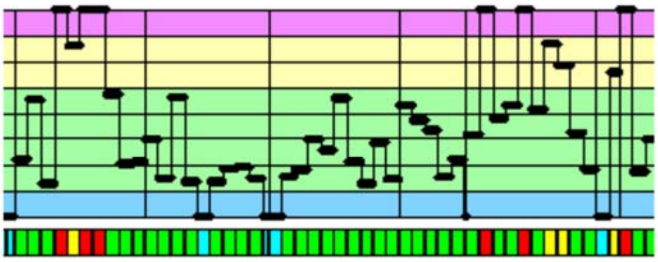
evenness



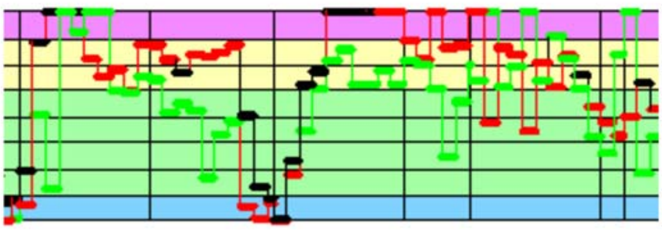
rutting



cracks



total value

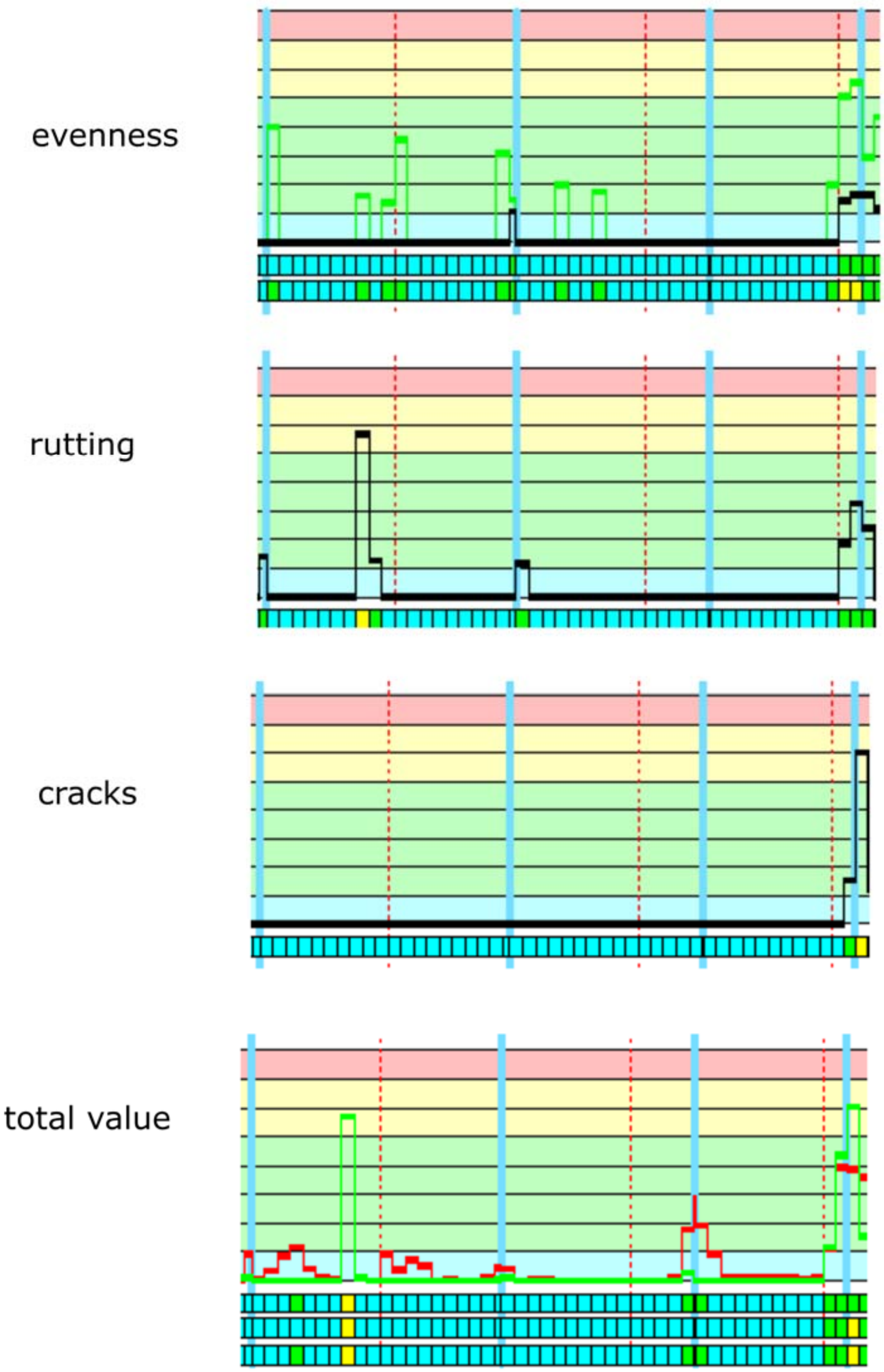


Condition

- 1,0 - 1,49 (very good/ new)
- 1,5 - 2,49 (good)
- 2,5 - 3,49 (satisfactory)
- 3,5 - 4,49 (sufficient)
- 4,5 - 5,0 (defective)

maintenance work on the road after construction?

Performance Data 2007:

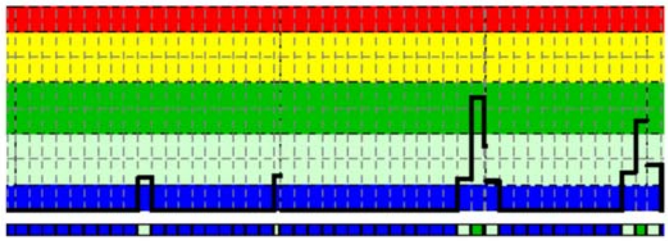


Condition

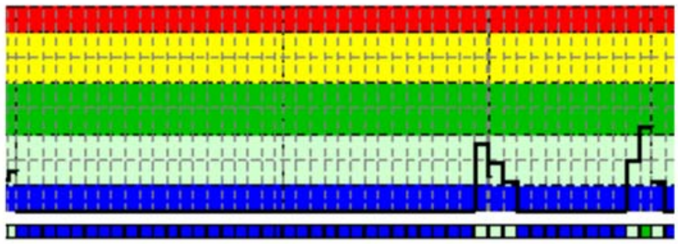
- 1,0 - 1,49 (very good/ new)
- 1,5 - 2,49 (good)
- 2,5 - 3,49 (satisfactory)
- 3,5 - 4,49 (sufficient)
- 4,5 - 5,0 (defective)

Performance Data 2012:

evenness

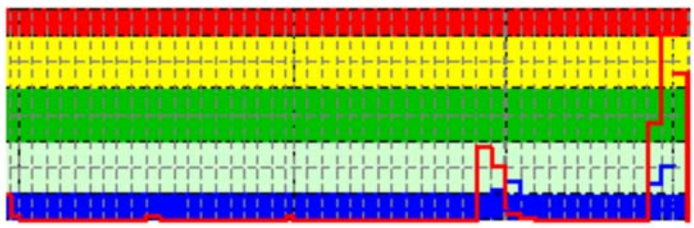


rutting



cracks

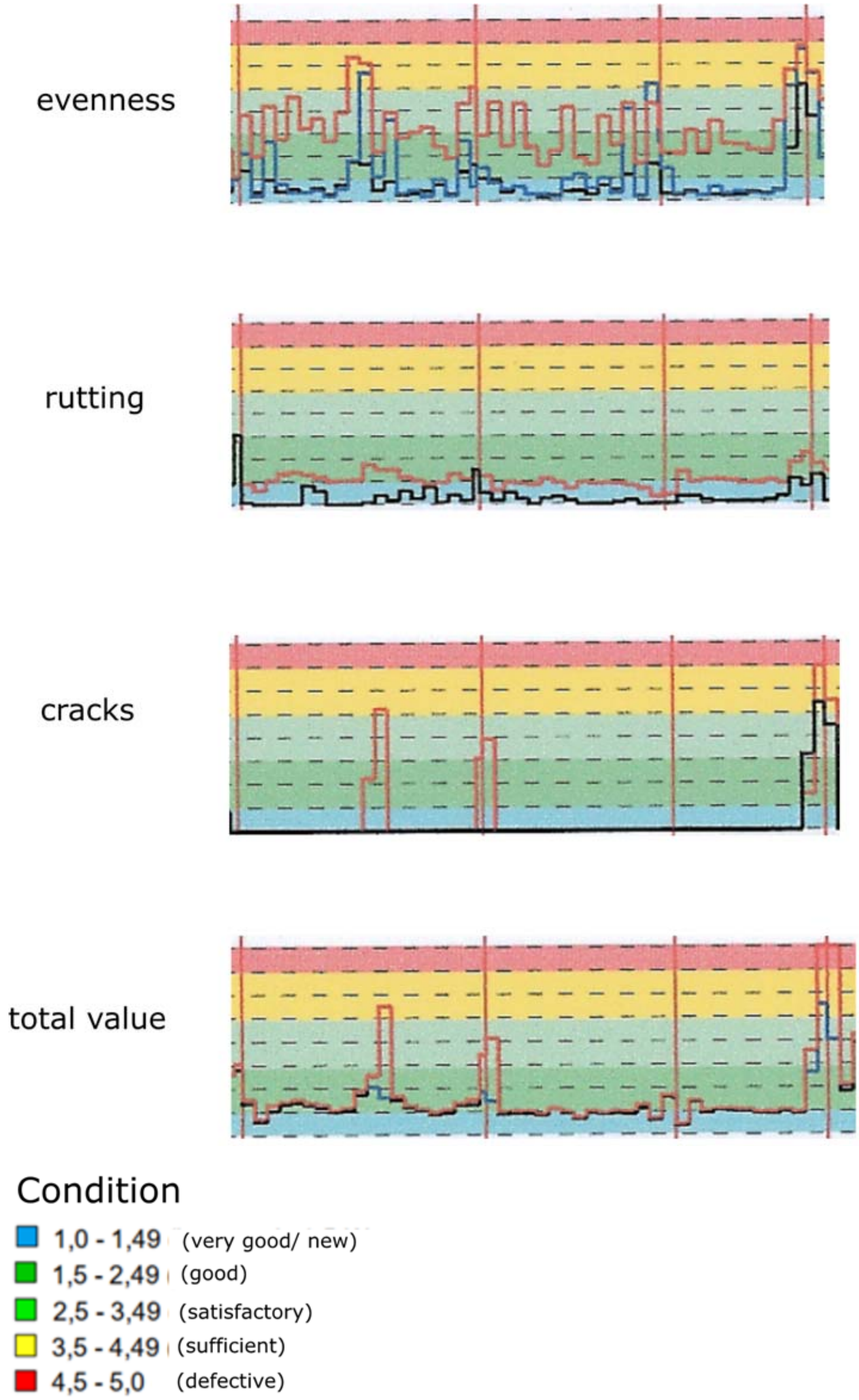
total value



Condition

- 1,0 - 1,49 (very good/ new)
- 1,5 - 2,49 (good)
- 2,5 - 3,49 (satisfactory)
- 3,5 - 4,49 (sufficient)
- 4,5 - 5,0 (defective)

Performance Data 2017:



Is there data on the traffic volume available? How much traffic?

From Stetten to Rittersheim (ca. 2,6 km) approximate 4.000 average daily traffic (about 6% of commercial vehicles).

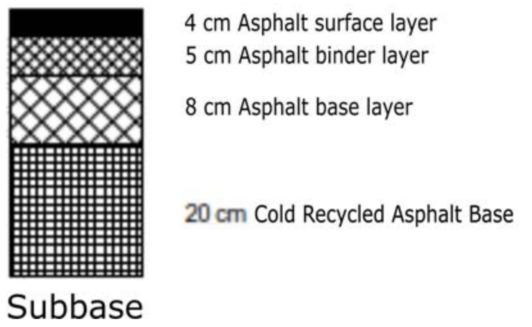
From Rittersheim to Bischheim (2,0 km) approximate 7.000 average daily traffic (about 7% of commercial vehicles).

Please give details on the mix design of the CRM layer. What was the composition of the mix and what were the material parameters of the constituent materials and the cold recycled mix?:

Sivesize	Sample (Passing fraction)	Guidelines (M-KRC)
mm	M-%	M-%
58,0	100	
45,0	97,6	90-100
31,6	90,2	
22,4	81,9	
16,0	74,4	
11,2	65,4	
8,0	55,3	
5,8	42,2	
4,0	33,8	
2,0	21,9	≥20
1,0	13,0	
0,5	8,0	
0,25	5,1	
0,125	3,6	
0,063	2,9	2-10
<0,063		

There is 90% RA in use for the CRM layer and 10% fresh sand. The gradation is shown above and was suitable for cold in-situ recycling using with cement and bituminous emulsion ($P_{0.063mm}$ = 2-10%; P_{2mm} = ≥20%; P_{45mm} = 90 – 100 %). By adding 3,5 % of cement and 3,0 % of SBS-modified bituminous emulsion suitable mechanical performance were reached. ITS@5°C ranging between 0,47 to 0,60 N/mm² after curing period of 7 days (test result: 0,67 N/mm²). ITS@5°C ranging between 1,14 to 1,12 N/mm² after curing period of 28 days (test result: 1,13 N/mm²). Moisture content by w_{opt}= 6,6 %.

What was the structural design? In what respect did it differ from a structure built with conventional hot produced asphalt?



Is there already weather data available, before, during and after the construction? In general terms was the construction built during ideal weather conditions?

There are no weather data available. Approximately temperature ranging between 5 until 18°C.

Are there reports and other reference materials available? Reference list:

There are no other reference materials available.

Selected photos of the road, if available:

Photos from 2007 before maintenance work:

Photos from 2019:

Annex A6. SP18 questionnaire

Project information

When using cold recycling of reclaimed asphalt, high recycling rates can usually be reached. Therefore, using cold recycled asphalt bases can be considered as pavement of optimal energy and resource efficiency.

The project strives to develop harmonised mix and pavement design for cold recycle materials (CRM). To this end a questionnaire for identification of existing CRM structures which could be used to assess the overall performance and the expected durability of the structures in relation to the mix and structural design, the climate and traffic loading. The full spectrum of success of CRM structures should be identified, ranging from early failures to old structures with good performance.

Fill in one questionnaire for each identified structure.

Questionnaire

Respondent:

Dr. Andrea Grilli

Suggest a working name for the structure:

Trial section: Full-depth reclaimation for a secontary road (S.P. 18 Jesi-Monterado (AN), Italy)

Early, general assessment of the success of the structure.

In your or others opinion is the structure a success, performing as expected or performing below par? Based on what criteria?

The pavement does not show any distress after about 10 years of traffici (about 5.000 ADT)

Where and when was the road built:

Provincial road S.P. 18 Jesi-Monterado, via Del Fiume from km 33+100 to km 33+ 600, Monterado (AN), Italy (https://goo.gl/maps/kTMPafdBhdQ2). The trial section was built in September 2008.

Is there a reference structure built without CRM at the same location?

No, there is not.

Is there data already available on the performance of the road? What type data? FWD measurements, profile? Has there been road maintenance work on the road after construction?

Road maintenance has not been carried out on the trial section so far.

Data on road performance were published in Maurizio Bocci, Andrea Grilli, Fabrizio Cardone and Gilda Ferrotti, " Full-depth reclamation for the rehabilitation of local roads: a case study", International Journal of Pavement Engineering, 2014, Vol. 15, No. 3, 191–201, http://dx.doi.org/10.1080/10298436.2012.657196.

Is there data on the traffic volume available? How much traffic?

About 5.000 average daily traffic (about 5% of commercial vehicles). Some data are reported in the above mentioned paper.

Is there already a mix design available? What was the composition of the mix and what were the material parameters of the constituent materials and the cold recycled mix?:

There is not a mix design. The recycled aggregates were sampled during the FDR operations and several batches were taken out immediately behind the recycler before adding binders in order to obtain a significant sample of the recycled material. The milling procedure produced a blend of about 20% reclaimed asphalt (RA) and 80% unbound material. The gradation was suitable for cold in-place recycling using cement and bituminous emulsion ($P_{0.063mm}$ = 2.5%; P_{2mm} = 35%; D_{max} = 20 mm). By adding 2% of cement and 4% of SBS-modified bituminous emulsion suitable mechanical performance were reached (ITSM@20°C>3000 MPa after curing perdiod od 7 days at 20°C).

What was the structural design? In what respect did it differ from a structure built with conventional hot produced asphalt?

The structural design was carried out by means of MePADS.

Is there already weather data available, before, during and after the construction? In general terms was the construction built during ideal weather conditions?

The construction performed in September with temperature ranging between 15 to 25°C approximately.

Is there already weather data available, before, during and after the construction? In general terms was the construction built during ideal weather conditions?

Are there reports and other reference materials available? Reference list:

Maurizio Bocci, Andrea Grilli, Fabrizio Cardone and Gilda Ferrotti, " Full-depth reclamation for the rehabilitation of local roads: a case study", International Journal of Pavement Engineering, 2014, Vol. 15, No. 3, 191–201, http://dx.doi.org/10.1080/10298436.2012.657196.

Dolciotti G., Grilli A., "Provinciale rigenerata", Le Strade, Volume 10, 2011. (in Italian)

Bocci M., Grilli A., "Il riciclaggio a freddo sulla viabilità provinciale di Ancona", Strade & Autostrade, fascicolo n° 6, Novembre/Dicembre, 2010. (in Italian)

Selected photos of the road, if available:






Annex A7. SS268 questionnaire

Project information

When using cold recycling of reclaimed asphalt, high recycling rates can usually be reached. Therefore, using cold recycled asphalt bases can be considered as pavement of optimal energy and resource efficiency.

The project strives to develop harmonised mix and pavement design for cold recycle materials (CRM). To this end a questionnaire for identification of existing CRM structures which could be used to assess the overall performance and the expected durability of the structures in relation to the mix and structural design, the climate and traffic loading. The full spectrum of success of CRM structures should be identified, ranging from early failures to old structures with good performance.

Fill in one questionnaire for each identified structure.

Questionnaire

Respondent:

Dr. Edoardo Bocci

Suggest a working name for the structure:

Trial section: Cold in-place recycled base layer for the two-lane dual carriage SS268 highway (Naples, Italy)

Early, general assessment of the success of the structure.

In your or others opinion is the structure a success, performing as expected or performing below par? Based on what criteria?

The laboratory and in-situ controls indicated a high quality of the mixtures produced. The pavement structure is performing well after two years of service.

Where and when was the road built:

Highway S.S. 268 ”Vesuvian” from km 17+300 to km 18+300, Naples, Italy. The trial section was built in October 2016.

Is there a reference structure built without CRM at the same location?

No, there is not.

Is there data already available on the performance of the road? What type data? FWD measurements, profile? Has there been road maintenance work on the road after construction?

Road maintenance has not been carried out on the trial section so far.

Data on road performance were recently submitted to ISAP APE 2019 Conference in Padua: E. Bocci, A. Graziani and M. Bocci, ”Cold in-place recycling for a base layer of an Italian high-traffic highway”, ISAP APE 2019 Conference, Padua, 11-13 September 2019. These data include FWD tests, laboratory tests on gyratory compacted specimens and on cores taken from the trial section.

Is there data on the traffic volume available? How much traffic?

The traffic volume, measured in 2011 using pneumatic tubes, was estimated equal to 17 million 80 kN ESALs in twenty years of service.

Is there already a mix design available? What was the composition of the mix and what were the material parameters of the constituent materials and the cold recycled mix?:

Before the construction, the cold recycled asphalt base (CRAB) mixture was designed in laboratory to determine the optimum content of bitumen emulsion, cement and water. The reclaimed asphalt (RA) was milled from SS268 and was characterized in terms of gradation (black curve). The particle size distribution was suitable for the use in CRAB mixture, without the addition of any virgin aggregate.

The CRAB mixture was produced in laboratory using pozzolanic cement (classified as CEM IV/B 32.5 R according to EN 197-1) and slow-setting cationic polymer-modified bitumen emulsion (classified as C60BP10 according to EN 13808). Six water contents (3-8% by aggregate weight), three cement contents (1.5, 2.0 and 2.5% by aggregate weight) and three bitumen emulsion contents (3.0, 3.5 and 4.0% by aggregate weight) were considered. Cylindrical specimens with 150-mm diameter were prepared by means of a gyratory compactor (GC) and cured at 40 °C for 72 h (accelerated curing). Then, dry bulk density and indirect tensile strength at 25 °C (EN 12697-23) were determined.

The job mix formula determined through the mix design study provided 4.0% of bitumen emulsion (2.4% of residual bitumen), 2.0% of cement and 4.0% of total water. The optimized CRAB mixture showed a dry bulk density of 2.147 Mg/m^3 after 100 gyrations and an indirect tensile strength at 25 °C of 0.40 MPa. Moreover, the indirect tensile stiffness modulus at 20 °C was measured according to EN 12697-26-Annex C and was equal to 3242 MPa.

What was the structural design? In what respect did it differ from a structure built with conventional hot produced asphalt?

The structural design of the pavement was carried out using a mechanistic-empirical approach. In particular, the pavement was modelled with a multi-layer linear elastic system, where each layer was characterized by thickness, Young’s modulus and Poisson’s ratio. FWD tests were carried out on the old pavement to estimate the stiffness of the subgrade.

With respect to a typical pavement structure, this consisted of 35 cm of in-place stabilization of the foundation material with cement (in place of an ordinary unbound granular foundation), 20 cm of CRAB containing 100% reclaimed asphalt and treated with polymer-modified bitumen emulsion and cement (in place of a hot mix asphalt base layer), 6 cm of hot mix asphalt binder course and 5 cm of porous-asphalt surfacing.

Is there already weather data available, before, during and after the construction? In general terms was the construction built during ideal weather conditions?

The construction performed in October with temperature ranging between 13 to 25 °C approximately. The weather was cloudy during the construction. As rain was expected in the next days, the CRAB layer was immediately sealed with polymer-modified bitumen emulsion to avoid the penetration of water.

Are there reports and other reference materials available? Reference list:

E. Bocci, A. Graziani and M. Bocci, "Cold in-place recycling for a base layer of an Italian high-traffic highway", submitted to ISAP APE 2019 Conference, Padua, 11-13 September 2019

Selected photos of the road, if available:







Annex A8. SS38 questionnaire

Project information

When using cold recycling of reclaimed asphalt, high recycling rates can usually be reached. Therefore, using cold recycled asphalt bases can be considered as pavement of optimal energy and resource efficiency.

The project strives to develop harmonised mix and pavement design for cold recycle materials (CRM). To this end a questionnaire for identification of existing CRM structures which could be used to assess the overall performance and the expected durability of the structures in relation to the mix and structural design, the climate and traffic loading. The full spectrum of success of CRM structures should be identified, ranging from early failures to old structures with good performance.

Fill in one questionnaire for each identified structure.

Questionnaire

Respondent:

-

Suggest a working name for the structure:

Trial section: Full-depth reclamation for a four-lane divided highway in northern Italy, connecting the cities of Bolzano and Merano.

Early, general assessment of the success of the structure.

In your or others opinion is the structure a success, performing as expected or performing below par? Based on what criteria?

The pavement does not show any distress after about 10 years of traffic.

Where and when was the road built:

National road S.S. 38 Merano-Bolzano, from km 16+000 to km 17+ 000, Italy The trial section was built in May 2007.

The project was sponsored by the Autonomous Province of Bolzano (Provincia Autonoma di Bolzano Alto Adige/Autonome Provinz Bozen Sudtirol)

The experimental pavement section was about 1 km (slow lane and shoulder). Three CRAB mixtures were produced and compared:

- CRAB with foamed bitumen and cement;
- CRAB with bitumen emulsion and cement;
- Cement treated material.

The questionnare considers only the data for the emulsion section.

Is there a reference structure built without CRM at the same location?

Yes, the pavement before and after the trial section.

Is there data already available on the performance of the road? What type data? FWD measurements, profile? Has there been road maintenance work on the road after construction?

Road maintenance has not been carried out on the trial section so far.

The performance has been monitored with annual falling weight deflectometer (FWD) surveys. Data were analysed to consider the temperature at the time of the FWD measurement and temperature susceptibility of the mixtures. In this way it was possible to compare directly the stiffness moduli from different years.Results revealed the the stiffness of the CRAB increased during the first 5-6 years under traffic.

Is there data on the traffic volume available? How much traffic?

About 30.000 average daily traffic, about 1850 of commercial vehicles.

Is there already a mix design available? What was the composition of the mix and what were the material parameters of the constituent materials and the cold recycled mix?:

For the wole project the dosages of the different binders were based on "usual practice" in the region. All CRAB mixtures complied with the specifications.

What was the structural design? In what respect did it differ from a structure built with conventional hot produced asphalt?

The structural design was based on experiece and local practice.

Is there already weather data available, before, during and after the construction? In general terms was the construction built during ideal weather conditions?

The construction performed in May with temperature ranging between 12 to 25°C approximately.

Is there already weather data available, before, during and after the construction? In general terms was the construction built during ideal weather conditions?

The weather during construction was good (sunny, no rain).

Are there reports and other reference materials available? Reference list:

Godenzoni, C., Graziani, A., Bocci, E., & Bocci, M. (2018). The evolution of the mechanical behaviour of cold recycled mixtures stabilised with cement and bitumen: field and laboratory study. Road Materials and Pavement Design, 19(4), 856-877.

Selected photos of the road, if available:

First recycler pass for mixing Reclaimed Asphalt (33%) with the underlying reclaimed aggregate (67%)

Stabilization with bitumen emulsion

Compaction by means of steel and pneumatic tire rollers

Cores taken in 2014

FWD measurements

Annex A9. A14 questionnaire

Project information

When using cold recycling of reclaimed asphalt, high recycling rates can usually be reached. Therefore, using cold recycled asphalt bases can be considered as pavement of optimal energy and resource efficiency.

The project strives to develop harmonised mix and pavement design for cold recycle materials (CRM). To this end a questionnaire for identification of existing CRM structures which could be used to assess the overall performance and the expected durability of the structures in relation to the mix and structural design, the climate and traffic loading. The full spectrum of success of CRM structures should be identified, ranging from early failures to old structures with good performance.

Fill in one questionnaire for each identified structure.

Questionnaire

Respondent:

-

Suggest a working name for the structure:

A14 motorway Full-Depth Reclamation

Early, general assessment of the success of the structure.

In your or others opinion is the structure a success, performing as expected or performing below par? Based on what criteria?

The pavement is performing very well. Only minor resurfacings were carried out due to localized problems with the porous asphalt.

Where and when was the road built:

Upgrading works for A14 Motorway (six-lane dual carriageway facility) 42 km between Ancona Sud and Civitanova Marche, in the Marche region.

Works started in 2007 (duration almost 2 years)

Is there a reference structure built without CRM at the same location?

The works were carried out on the right lane of the motorway (high percentage of heavy traffic) and on the emergency lane (almost no traffic). The right lane is performing very well. The performance is comparable with that of the middle and left lanes where the heavy traffic is much lower.

Is there data already available on the performance of the road? What type data? FWD measurements, profile? Has there been road maintenance work on the road after construction?

FWD campaign was carried out for 3 months after construction.

Is there data on the traffic volume available? How much traffic?

About 8 millions/year of 80 kN ESALS

Is there already a mix design available? What was the composition of the mix and what were the material parameters of the constituent materials and the cold recycled mix?:

The mix design was based on the results of a test section.

What was the structural design? In what respect did it differ from a structure built with conventional hot produced asphalt?

The structural design was based on the results of a test section. The existing CTM layer of 200 mm was replaced by a CRAB layer of 300 mm. The thickness of the other layers was not modified.

Is there already weather data available, before, during and after the construction? In general terms was the construction built during ideal weather conditions?

The works were carried out over more than 2 years.

Are there reports and other reference materials available? Reference list:

Bocci, M., Canestrari, F., Grilli, A., Pasquini, E., & Lioi, D. (2010). Recycling techniques and environmental issues relating to the widening of an high traffic volume Italian motorway. International Journal of Pavement Research and Technology, 3(4), 171-177.

Santagata, F.A., Bocci, M., Grilli, A., and Cardone, F., (2009). Rehabilitation of an Italian Highway by Cold In-Place Recycling Techniques, Proceedings of the 7th International RILEM Symposium ATCBM09 on Advanced Testing and Characterization of Bituminous Materials, Vol. 2, pp. 1113-1122, Rhodes, Greece

Selected photos of the road, if available:

First recycler pass for mixing Reclaimed Asphalt (33%) with the underlying reclaimed aggregate (67%)

Stabilization with bitumen emulsion

Compaction by means of steel and pneumatic tire rollers

Cores taken in 2014

FWD measurements

Annex A10. A21 questionnaire

Project information

When using cold recycling of reclaimed asphalt, high recycling rates can usually be reached. Therefore, using cold recycled asphalt bases can be considered as pavement of optimal energy and resource efficiency.

The project strives to develop harmonised mix and pavement design for cold recycle materials (CRM). To this end a questionnaire for identification of existing CRM structures which could be used to assess the overall performance and the expected durability of the structures in relation to the mix and structural design, the climate and traffic loading. The full spectrum of success of CRM structures should be identified, ranging from early failures to old structures with good performance.

Fill in one questionnaire for each identified structure.

Questionnaire

Respondent:

Matthew Wayman (Highway England) Matthew.Wayman@highwaysengland.co.uk

Suggest a working name for the structure:

Trial section: Sustainable structural maintenance of a flexible composite trunk road A21

Early, general assessment of the success of the structure.

In your or others opinion is the structure a success, performing as expected or performing below par? Based on what criteria?

Based on the pavement construction records, the latest two surface condition surveys (TRACS) and the latest structural surveys (TRASS) the trial section didn't show any distress or need of maintenance. Regarding the current conditions, recycled base is still in place which suggests good current condition.

Where and when was the road built:

The scheme consisted of approximately five kilometres of the A21 (Sevenoaks), between roundabouts with the A225 and the A25. The trial section was realised in July 2002.

https://www.google.co.uk/maps/dir/51.2406303,0.207955/51.2777405,0.1535767/51.2827063,0.1474743/@51.2628388,0.1629758,14z/data=!4m2!4m1!3e2?hl=en

Is there a reference structure built without CRM at the same location?

No

Is there data already available on the performance of the road? What type data? FWD measurements, profile? Has there been road maintenance work on the road after construction?

No road maintenance on the trial section so far.

Data on road performance available on TRL Published Project Report TRL611 and spreadsheet (See attached)

Is there data on the traffic volume available? How much traffic?

AADF - Annual average daily flow (2017, https://www.dft.gov.uk)

Motorcycles	Cars/Taxis	Buses/Coaches	Light Goods Vehicles	High Goods Vehicles	All Motor Vehicles
460	35555	80	8933	2687	47714

Is there already a mix design available? What was the composition of the mix and what were the material parameters of the constituent materials and the cold recycled mix?

There is not mix design availabe for this site.

What was the structural design? In what respect did it differ from a structure built with conventional hot produced asphalt?

A21 pavement design using bitumen bound cold recycled material and the proposed design

	Site information						Proposed design	
Site	*Design traffic (msa)*	*Road category*	*Foundation class*	*Material class*	*Recycled layer thickness (mm)*	*Surfacing (mm)*	*Cold recycled base thickness (mm)*	*Surfacing (mm)*
A21 Sevenoaks	25.6	1	3	B3	200	100	210	60

Adopted from Published Project Report RL611 more details in the TRL611 report and survey spreadsheet

Is there already weather data available, before, during and after the construction? In general terms was the construction built during ideal weather conditions?

The construction performed in February with temperature ranging between 22.3 to 13.5°C.

https://www.metoffice.gov.uk

```
Heathrow (London Airport)
Location 507800E 176700N, Lat 51.479 Lon -0.449, 25m amsl
Estimated data is marked with a * after the value.
Missing data (more than 2 days missing in month) is marked by  ---.
Sunshine data taken from an automatic Kipp & Zonen sensor marked with a #,
recorder.
```

yyyy	mm	tmax degC	tmin degC	af days	rain mm	sun hours
2002	4	15.7	6.1	0	38.4	220.5
2002	5	17.3	9.4	0	66.4	192.2
2002	6	20.1	11.6	0	74.2	191.5
2002	7	22.3	13.5	0	67.2	193.9
2002	8	23.3	14.7	0	36.3	190.4
2002	9	20.3	11.5	0	20.0	178.2
2002	10	15.3	8.4	0	61.6	109.2
2002	11	12.4	7.0	0	151.0	66.1

Are there reports and other reference materials available? Reference list:

TRL Published Project Report 611 and survey spreadsheet, see attached

Selected photos of the road, if available:

A21 Sevenoaks By-Pass heading towards Sevenoaks

Annex A11. A46 questionnaire

Project information

When using cold recycling of reclaimed asphalt, high recycling rates can usually be reached. Therefore, using cold recycled asphalt bases can be considered as pavement of optimal energy and resource efficiency.

The project strives to develop harmonised mix and pavement design for cold recycle materials (CRM). To this end a questionnaire for identification of existing CRM structures which could be used to assess the overall performance and the expected durability of the structures in relation to the mix and structural design, the climate and traffic loading. The full spectrum of success of CRM structures should be identified, ranging from early failures to old structures with good performance.

Fill in one questionnaire for each identified structure.

Questionnaire

Respondent:

Matthew Wayman (Highway England) Matthew.Wayman@highwaysengland.co.uk

Suggest a working name for the structure:

Trial section: Sustainable structural maintenance of a flexible composite trunk road A46

Early, general assessment of the success of the structure.

In your or others opinion is the structure a success, performing as expected or performing below par? Based on what criteria?

Overall, the major maintenance of the A46 was carried out successfully using a combination of crack and seat of the CBM base and cold-mix recycling. The early-life characteristics of the foamed bitumen and the FWD measurements on the cracked and seated CBM both meet the requirements of the two design methodologies employed. This would indicate that the long-term durability of the maintained pavement is likely to be satisfactory, although it is recommended that further periodic testing be carried out on the in-service pavement to quantify the anticipated increase in strength of the foamed bitumen.

Where and when was the road built:

The scheme consisted of approximately two kilometres of the A46 (the Stratford Upon AvonNorthern Bypass), between roundabouts with the A422 at Shottery and the A3400 at Bishopton. The trial section was realised in February 2006.

https://www.google.com/maps/dir/''/52.1984044,-1.7481175/''/@52.2041812,-1.7466881,15z/data=!3m1!4b1!4m11!4m10!1m3!2m2!1d-1.74876!2d52.1981645!1m0!1m3!2m2!1d-1.7271334!2d52.2102644!3e0

Is there a reference structure built without CRM at the same location?

No

Is there data already available on the performance of the road? What type data? FWD measurements, profile? Has there been road maintenance work on the road after construction?

No road maintenance on the trial section so far.

Data on road performance available on TRL Published Project Report PPR228 (See attached)

Is there data on the traffic volume available? How much traffic?

AADF - Annual average daily flow (2017, https://www.dft.gov.uk)

Motorcycles	Cars/Taxis	Buses/Coaches	Light Goods Vehicles	High Goods Vehicles	All Motor Vehicles
97	15432	41	2152	1471	19192

Is there already a mix design available? What was the composition of the mix and what were the material parameters of the constituent materials and the cold recycled mix?:

Constituent	Proportion by mass
Crushed planings (ULM+HRA+DBM)	73%
0/4 ex Wickwar crushed stone	20%
Conditioned PFA	5%
OPC ex Rugby Cement	1.5%
Viabit A ex Totalfina bitumen	3.5%

Tab. Foamed bitumen mixture proportions

Sieve Size	Mix Design (% passing)	Zone A TRL Report 611 (% passing)
40.0mm	100	100
31.5mm	100	100
25.0mm	100	
20.0mm	99	
16.0mm	96	
14.0mm	93	85-100
12.5mm	91	
10.0mm	85	68-100
8.0mm	77	
6.3mm	70	
5.0mm	65	
4.0mm	57	38-74
2.8mm	48	
2.36mm	43	
2.0mm	40	26-58
1.0mm	27	
0.500mm	18	13-38
0.250mm	13	9-28
0.125mm	10	
0.063mm	8.2	5-21

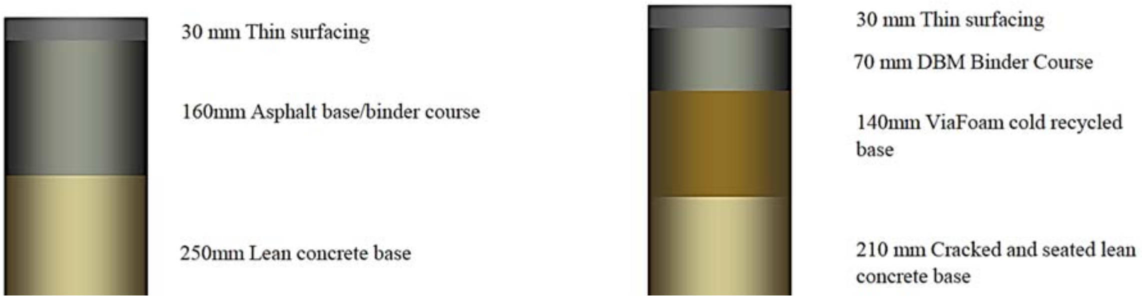
Tab. Final combined aggregate particle size distributions

Property	Value	
Binder Content for Maximum Stiffness (Dry)	3.5%	
Design Binder Content	3.5%	
Optimum Moisture Content (%)	6.5%	
	Result	TRL Report 611 Specification
Stiffness at design Binder Content (Dry)MPa	6913	>3100
Stiffness at design Binder Content (Wet)MPa	6638	-
% Stiffness (Wet) of Stiffness (Dry)	96.0	>80%
Air Voids at Design Binder Content	4.7	≤ 7

Tab. Values obtained from mixture design

Full details about the mix design can be found on the attached report, TRL611 and PPR228

What was the structural design? In what respect did it differ from a structure built with conventional hot produced asphalt?



Adopted from TRL Published Project Report PPR228

Is there already weather data available, before, during and after the construction? In general terms was the construction built during ideal weather conditions?