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DRaT – Development of the Ravelling Test

Compendium of sites and the extent of ravelling

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CEDR Call 2014: Asset Management and Maintenance
DRaT
Development of the Ravelling Test

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Executive summary

This report is an output of the Development of the Ravelling Test (DRaT) project. The DRaT project was undertaken under CEDR Call 2014: Asset Management and Maintenance in order to investigate the use of standard ravelling tests to predict pavement durability.

The report describes a review into data on the performance of different sites with different mixtures in the Netherlands, Belgium and the United Kingdom with respect to ravelling. The findings from these studies are as follows:

The Dutch studies showed that:

- There can be a significant scatter in the extent of ravelling with the same asphalt mixture.
- Higher binder contents do reduce the tendency to ravel.
- The use of polymer-modified bitumen does not reduce the tendency to ravel.
- Slag aggregate makes asphalt more susceptible to ravelling.

The Belgian trial showed that:

- Twin-layer porous asphalt is more susceptible to ravelling than more dense asphalts.

The UK survey showed that:

- Ravelling increases with age, as would be expected.
- The ranking of the three mixture types for resistance to ravelling is SMA as best, then BBTM and then AUTL.
- Higher binder contents tend to reduce ravelling.
- Larger aggregate sizes tend to reduce ravelling.

However, the last three correlations are very weak and the findings are indicators rather than conclusive.

1 Introduction

Ravelling is a common mode of early failure for many types of asphalt pavement. The potential causes for this loss of aggregate particles include lack of sufficient binder; inappropriate aggregate grading; poor adhesion between the binder and the aggregate; errors during compacting; aggressive scuffing by the traffic; and ageing, effect of climatic conditions. The number of different causes and their interdependence make it difficult to assess the theoretical potential to ravel of an asphalt mixture in the design stage. This is contrary to the general progression towards the design of asphalt mixtures to be resistant to the other principal modes of failure.

Highway authorities need to specify against all the modes of failure that can foreseeably occur. Currently, ravelling is generally attempted to be curtailed by specifying minimum binder content, aggregate grading envelopes and aggregate/binder affinity, but these are indirect assessments that have also been used to counter other aspects of asphalt performance. Recently, several simulative laboratory tests have been developed that are claimed to give an indication of the potential to ravel. These tests use scuffing machines that repeatedly apply a scuffing action to slab or core samples to replicate in service loading. The test methods for four such scuffing machines have been written up as a draft technical specification by Comité Européen de Normalisation (CEN) as prCEN/TS 12697-50, Resistance to scuffing. However, these methods need to be culled or combined so that there is only one test method for this one property before the technical specification can be converted into a test standard.

There is need for a direct scuffing test to assess the resistance to ravelling of asphalt mixtures, but this method needs to be a single measure that is validated against site performance and has good precision. Therefore, the Conferences of European Directors of Roads (CEDR) has commissioned a project to undertake comparative tests with the four scuffing machines. However, before undertaking the physical testing required, the project includes a review of available data on the performance of various mixtures with respect to ravelling on site. This report gives the findings of that review.

2 Sites in the Netherlands

2.1 Visual condition surveys

Reports by Rijkswaterstaat Centre for Traffic and Navigation (RWS) on visual condition surveys performed on several RWS test sections on the Dutch motorway network in 2010 and 2011 have been reviewed (Groenendijk, 2012). Typically, only the inside lane was surveyed because that is the lane that bears the highest traffic loading and deteriorates fastest. A number of different distress types were assessed in the surveys with both the severity and the extent per 100 m lane length being registered for each distress type.

Each distress type has its own definitions for severity and extent. For ravelling, the most common distress type on porous surface courses these are:

- The Distress Severity is the proportion of stone loss area in the wheel track area expressed as %/m² with ravelling of less than 5 %/ m² not being recorded.
- Distress Extent is the proportion of each 100 m length of the wheel track in per cent with the severity class being the average for both wheel tracks.

Table 2.1 gives the classification of Severity and Extent for ravelling.

Table 2.1: Distress ratings for ravelling on Porous Asphalt

Distress Extent (% lane length)	Distress Severity (%/m² stone loss)		
	Light (6 – 10)	Moderate (11 – 20)	Severe (>20)
Small (<15)	1A	2A	3A
Limited (15 – 25)	1B	2B	3B
Large (>25)	1C	2C	3C

The intervention level (“end of service life”) for ravelling of Porous Asphalt in the Netherlands is the onset of severe distress, i.e. class 3. Therefore, severe distress is not acceptable in principle to any extent. Any severe distress that occurs means that maintenance should already have been executed and, therefore, the maintenance is in arrears. Such pavement sections have to be treated immediately if traffic safety is in danger or, if not, scheduled for maintenance in the following year.

Moderate distress to a large extent is a reason for scheduling maintenance in the following year or the year afterwards at the latest.

2.2 Two-layer porous asphalt

Test sections of two-layer porous asphalt (2PA) were laid at the following four different sites on Dutch motorways: A28 Staphorst in 2002, A30 Ede in 2003, A15 Leerdam in 2004 and A59 Fijnaart in 2004. Each test site consisted of the same eight nominal mixtures by eight different contractors. The gradings for the mixtures were 2/6 mm on two sections and 4/8 mm on the other six. The eight mixtures were laid in a different order at each site and the contractors were coded 1 to 8, with 1 and 3 having the 2/6 mm top layer.

Visual condition data of field performance for 2010 (i.e. at ages between 8 and 6 years) are shown in Figure 2.1. However, both sections at the A28 site with the 2/6 mm grading on the top layer had already been replaced because of ravelling, so these sections were arbitrarily rated as having 200 %/m².

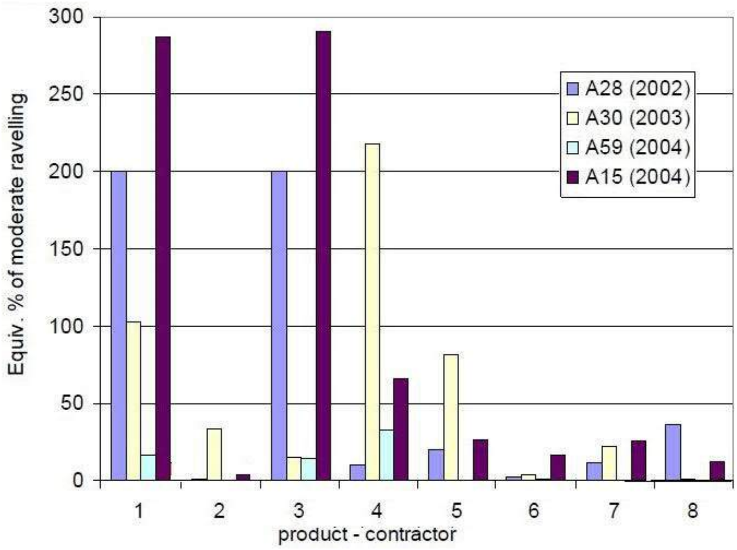


Figure 2.1: Stone loss of two-layer porous asphalt sections (Groenendijk, 2012)

The figure shows that some scatter exists between the four test sites in terms of both the relative amounts of distress for the eight products and the ranking between the products on the site. In particular, there are particularly high distress levels of Products 1 and 3 (with the 2/6 mm top layer) on the A28 and A15 together with Product 4 on the A30 (with the 4/8 mm top layer).

2.3 High binder content porous asphalt

Until 2005 in the Netherlands, the standard bitumen content for 16 mm porous asphalt was 4.5 % (by mass). Tests with higher bitumen content and/or polymer modified bitumen had indicated that polymer modification of the bitumen (at the same bitumen content) gave no improvement of service life with respect to ravelling, but that an increase of the bitumen content to 5.5 % did improve service life. However, adding drainage inhibitors or modifying the bitumen was necessary in order to prevent binder drainage at this bitumen content. In 2003, five test sections were laid on the A2 in order to test the initial wet and dry skid resistance of high binder content porous asphalt with several drainage inhibitors. The parameters used for each test section are given in Table 2.2 and the visual condition survey results from 2011 for ravelling in Figure 2.2.

Table 2.2: A2 high binder content porous asphalt sections (Groenendijk, 2012)

Test section	Bitumen		Drainage inhibitor
	Content (%)	Type	
2A	4.5	70/100	None
2B	5.5	Nypol PA	None
2C	5.5	70/100	0.2 % cellulose fibres
2D	5.5	70/100	0.15 % acrylic fibres
2E	5.5	70/100	0.2 % wax + 0.3 % cellulose fibres

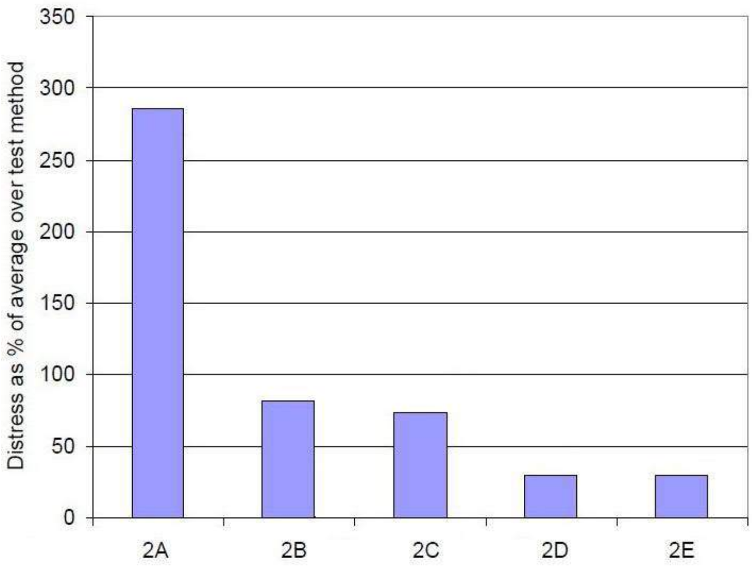


Figure 2.2: Ravelling on high binder content PA sections after 8 years in service (Groenendijk, 2012)

The results indicate that higher binder contents (Sites 2B to 2F) do reduce the tendency to ravel while the use of polymer-modified bitumen (Site 2B) is not effective.

2.4 Silent thin surfacings

Five test sections of silent thin surfacings (0/5.6 mm grading, typically 25 mm thick) were laid on the A6 in 2006. The ravelling results from the visual condition survey for 2011 are shown in Figure 2.3.

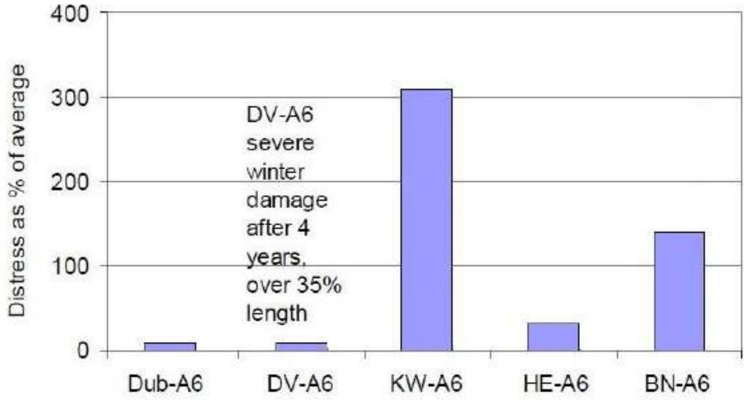


Figure 2.3: Ravelling on silent thin surfacings after five years in service (Groenendijk, 2012)

The first 350 m (out of 1000 m) of the DV-A6 section had been replaced early in 2010 after four years in service because of localised winter damage (potholing and ravelling), although no distress was detected there in 2009. This mixture contained 0/1 mm glass slag, as did the DV mixture on A15 Leerdam which also ravelled badly after 4 years. These findings indicate that the material makes asphalt more susceptible to ravelling. The winter damage on DV-A6 is indicated, but not processed quantitatively, on Figure 2.3.

2.5 Slag aggregate

In 2007, two test sections of two-layer porous asphalt were laid on A35 near Hengelo. One of the sections used natural aggregate while the other with artificial aggregate made from crushed electro-oven slags, a by-product of steel production. The higher specific heat content (because of higher bulk density) of the slag was expected to allow better compaction from the slower cooling. Informal visual condition survey in 2012 showed that the slag section was the only one of the A35 tests that showed ravelling.

3 Sites in Belgium

The Flemish Agency for Roads and Traffic arranged for the laying and monitoring of ten test sections, each section 200 m long, in 2012 in order to study the acoustical quality and other properties, including resistance to ravelling, of thin noise reducing asphalt layers (Bergiers *et al*., 2014); De Visscher and Vanelstraete, 2015). The trial was on the N19 regional road between Turnhout and Kasterlee in Belgium, where the road has two lanes in each direction. The typical daily traffic for a working day was 9,340 vehicles, of which 16 % are heavy, and, for the weekend, 7140 vehicles, of which 5 % are heavy. Section 1 was a reference section of stone mastic asphalt with a maximum aggregate size of 10 mm and Section 5 was another reference of twin-layer porous asphalt. The remaining eight sections (Section 2 to Section 4 and Section 6 to Section 10) were paved with thin asphalt layers of which Sections 8 and 9 were paved with the same asphalt mixture at a different thickness (25 mm and 30 mm).

The performance characteristics of thin layers are known to be highly sensitive to paving conditions. Adverse weather conditions, inadequate compaction temperatures or poor quality of the tack coat are some of the parameters that may seriously affect the performance of the pavement. Therefore, all critical parameters were measured during and after construction. Surface temperature measurements showed large variations over the length and width of the trial sections due to rapid cooling of the thin layers. However, the final densities, as measured with a nuclear density gauge, were fairly uniform within each section because the compactors followed the finisher closely so as to be able to compact the surface course correctly.

Visual inspections were made once or twice a year to register the locations and measure the severity of possible damage. The purpose of these inspections was primarily to study the durability of the thin layer sections. The difference in ravelling resistance was evident by the visual inspections after less than two years. Sections 2 and 3 were already showing local ravelling, especially in the wheel tracks (Figure 3.1). A 100 mm diameter pothole was also observed in Section 3. Severe ravelling was detected on Section 5 (twin-layer porous asphalt), especially at the beginning and end of this section (Figure 3.2).

Figure 3.1: Ravelling on Section 2

Figure 3.2: Ravelling on Section 5

Contamination with dirt of the trial sections was observed during the inspections that came from nearby fields with agricultural machinery often passing.

4 Sites in the United Kingdom

4.1 Durability study

In the early 1990s, asphalt for ultra-thin layers (AULT) and thin asphalt concrete (bétons bitumineux très minces, BBTM) from France and stone mastic asphalt (SMA) from Germany were introduced in the UK as proprietary asphalt products. The products were adopted by the Highways Agency (now Highways England) for use on trunk roads under a certification scheme and the amount of these types of product used on the UK trunk and local authority road networks grew dramatically. In order to justify their extensive use, the Highways Agency commissioned a nine-year study of the durability being obtained with these asphalt types from the early sites where they were laid (Nicholls *et al*., 2002; Nicholls and Carswell, 2004; Nicholls *et al*., 2007; Nicholls *et al*., 2010).

The study collected data annually on a range of properties from several sites across England and Wales. Whilst some of these sites were laid as trials, most of them were sections of larger sites that were laid under normal conditions from which laying data was available. Data was collected from 76 sites (14 with AULT, 37 with BBTM and 34 with SMA surfacing) on between one and 11 years. The data extracted for this ravelling study were the type of asphalt, the aggregate size, the binder content, the age, the visual condition and the ravelling category, as described below.

Type of asphalt — Whether the mixture is an AUTL, BBTM or SMA. However, the mixtures are of an age that the type was described just as thin surfacing systems rather than the mixture type as defined in the various parts of EN 13108. Therefore, a mixture was classified as AULT when the mixture had unmodified binder but was laid on a heavily polymer-modified bond coat so that the polymer seeped into the mixture; BBTM when the mixture had polymer-modified bitumen (PmB) and only required an unmodified binder coat; and SMA when the mixture had unmodified bitumen but incorporated fibres to carry the relatively high binder content and generally had a polymer-modified bond coat. However, there can be cases where fibres are used with PmB in the mixture and/or polymers are used in both the mixture and bond coat.

Aggregate size — The maximum nominal aggregate size in millimetres.

Binder content — The target binder content in per cent. This parameter was not always provided because of commercial sensitivity about the proprietary mixtures.

Age — The time in service when the visual condition and category of ravelling were measured in years.

Visual condition — An assessment of the overall condition by a panel of experts from across the industry in accordance with a set procedure (Nicholls, 1997). The assessment includes identifying whether several specific faults, including loss of aggregate, are present to give an overall rating as reproduced in Table 4.1.

Ravelling category — An assessment of the extent of chipping loss identified in the visual surveys. The survey results only identify whether or not there was any loss of aggregate particles, which can be equated to ravelling, but a crude ravelling category has been added by looking at the extent of that loss from photographs. The categories are “0” for no particle loss (from the survey results), “1” from limited particle loss, “2” for areas of more extensive ravelling and “3” for extensive areas of ravelling. Examples of the three degrees of actual ravelling are shown in Figure 4.1.

Table 4.1: Basic 7-point scale for visual condition

Mark		Value	Description	
E	Excellent	7	No discernible defect	Termed serviceable
G	Good	6	No significant defect	
M	Moderate	5	Some defects but insufficient for serious problem	
A	Acceptable	4	Several defects but would usually be just acceptable	
S	Suspect	3	Seriously defective but still serviceable in the short term	Termed unserviceable
P	Poor	2	Requires remedial treatment	
B	Bad	1	Requires immediate remedial treatment	

Category “1” = limited particle loss

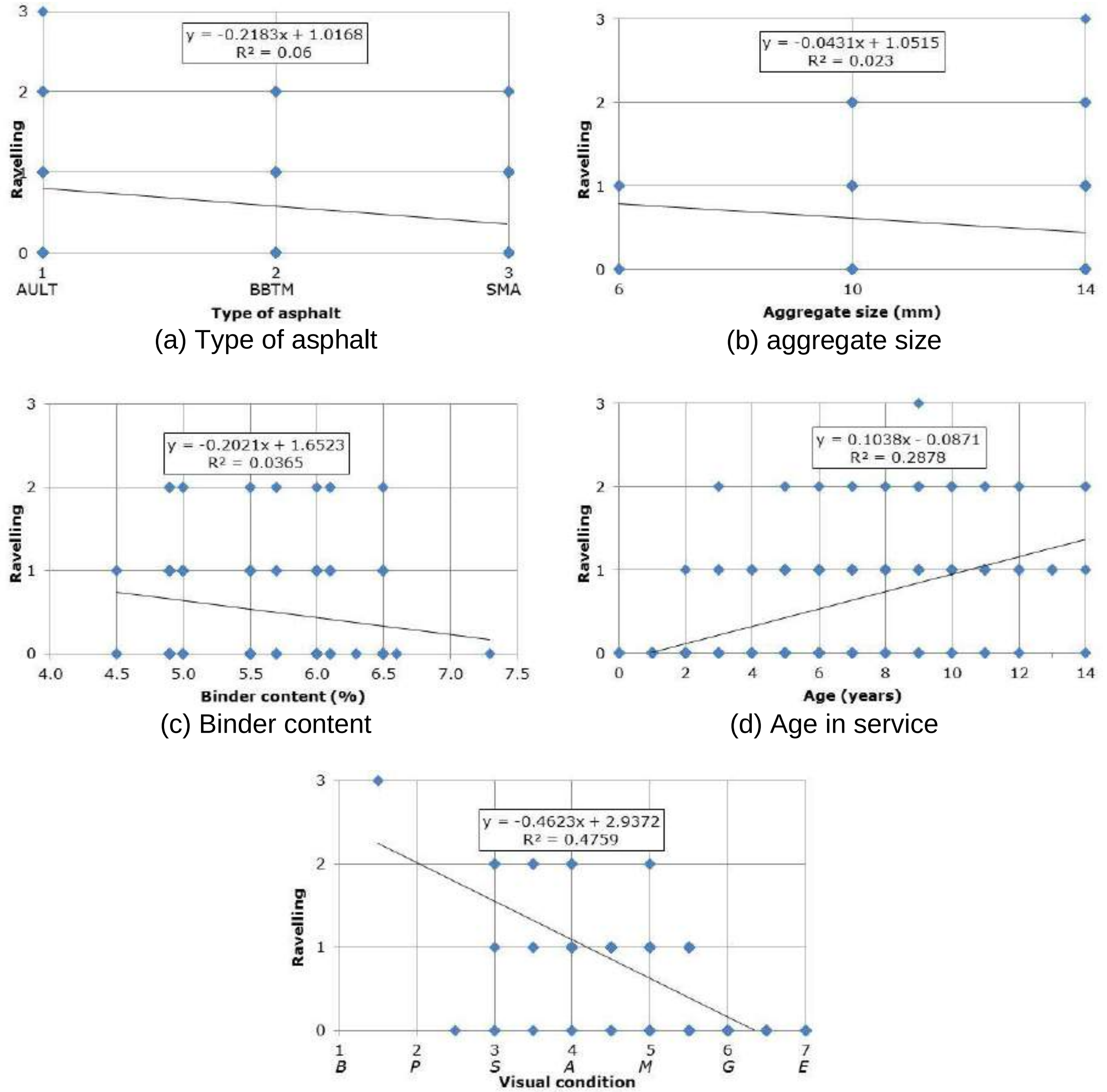
Category “2” = areas of more extensive ravelling

Category “3” = extensive areas of ravelling

Figure 4.1: Examples of ravelling categories

4.2 Analysis for ravelling

The results obtained from the 323 measuring occasions are given in Table A.1 of Annex A. Using that data, the ravelling categories are plotted against the other five parameters with linear trend lines in Figure 4.2. The trend line is more descriptive than the plots themselves because most of the parameters, including ravelling category, are discreet with only a few options so many points can be on top of each other.



(a) Type of asphalt

(b) aggregate size

(c) Binder content

(d) Age in service

(e) Visual condition

Figure 4.2: Relationship of ravelling with measured properties

The equations for the trend lines are given below:

$$Ravelling = -0.2183 \times Type + 1.0168 \qquad (R^2 = 0.060)$$

$$Ravelling = -0.0431 \times Aggregate + 1.0515 \qquad (R^2 = 0.023)$$

$$Ravelling = -0.2021 \times Binder + 1.6523 \qquad (R^2 = 0.037)$$

$$Ravelling = +0.1038 \times Age - 0.0871 \qquad (R^2 = 0.29)$$

$$Ravelling = -0.4623 \times Condition + 2.9372 \qquad (R^2 = 0.48)$$

The correlations are relatively poor, with only the visual condition having an R^2 getting close to 0.5, but this limited correlation is not surprising given the limited value range for each of the parameters, in particular the ravelling category. The observations on these findings, starting from the trend line with the highest correlation, are:

- The visual condition has the best correlation as it is not independent of the ravelling condition because particle loss is one of the properties assessed to judge the visual condition rating. The top two ratings (*Excellent* and *Good*) not being given if there was any particle loss. Therefore, this correlation is self-fulfilling and, furthermore, is not useful in that it just tells us that when a surfacing looks poor there may well be ravelling.

- Age is the other parameter that has a correlation coefficient that has any real significance. The trend line shows that ravelling increases with age, which would be expected.

- The ranking of the three mixture types for resistance to ravelling is SMA as best, then BBTM and then AUTL. The numerical value of 1, 2 or 3 for each of the three types was changed to get the best correlation, which was achieved with BBTM in the middle. It can be assumed that the generally higher binder contents with SMA was more significant than the polymer-modified binder in reducing ravelling whilst the thin layers for AULT did not allow the mixture to provide as much resistance. However, the correlation is very weak and the ranking is only an indicator rather than a conclusive finding.

- The higher binder contents tended to have reduced levels of scuffing, which is as would be expected. The extent of the correlation, however, is less than would be expected, possibly because the mixtures with the lower binder contents tended to be BBTM with PmBs, which would also be expected to reduce the tendency for ravelling. The two factors (high binder contents and the use of PmBs, tended to roughly balance each other out. This balance shows that those designing the asphalt “got it about right”.

- Larger maximum nominal aggregate sizes tended to have a reduced level of scuffing, which is contrary to what would be expected. In the UK at least, smaller aggregate sizes are generally recommended at roundabouts where there are higher ravelling stresses because of the turning. However, this correlation is very weak and the finding is only an indicator rather than conclusive and may just demonstrate that the larger aggregate sizes were generally laid in areas with lower levels of stress.

5 Conclusions

The Dutch studies showed that:

- There can be a significant scatter in the extent of ravelling with the same asphalt mixture.
- Higher binder contents do reduce the tendency to ravel.
- The use of polymer-modified bitumen does not reduce the tendency to ravel.
- Slag aggregate makes asphalt more susceptible to ravelling.

The Belgian trial showed that:

- Twin-layer porous asphalt is more susceptible to ravelling than more dense asphalts.

The UK survey showed that:

- Ravelling increases with age, as would be expected.
- The ranking of the three mixture types for resistance to ravelling is SMA as best, then BBTM and then AUTL.
- Higher binder contents tend to reduce scuffing.
- Larger aggregate sizes tend to reduce scuffing.

However, the last three correlations are very weak and the findings are indicators rather than conclusive.

6 Acknowledgement

The research presented in this deliverable was carried out as part of the CEDR Transnational Road Research Programme Call 2014. The funding for the research was provided by the national road administrations of Belgium-Flanders, Finland, Germany, Ireland, Norway, the Netherlands, Sweden, United Kingdom and Austria.

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Annex A Data collected on UK sites

Table A.1: Data collected on UK sites with AULT, BBTM and SMA

Site Number	Type of asphalt	Aggregate size (mm)	Binder content (%)	Age (years)	Visual condition	Ravelling category
PLSD1	AULT	10	4.9	1	6.5	0
				2	6.5	0
				3	6	0
				4	5.5	1
				5	5.5	1
				6	5	1
PLSD5	AULT	10	4.9	1	6	0
				2	5	0
				3	4.5	1
				4	4.5	0
				5	4.5	0
				6	3	0
PLSD6	AULT	10	4.9	10	3	0
				11	3	0
				12	2.5	0
PLSD7a	AULT	10	4.9	1	6.5	0
				2	6	0
				3	6	0
				4	5	1
				8	4.5	1
				9	4	2
PLSD7b	AULT	10	4.9	9	4.5	1
				10	4.5	1
				11	4.5	1
				12	3.5	1
				13	3.5	1
PLSD8	AULT	10	4.9	8	4	2
				9	3.5	2
				10	3	2

Table A.1: Data collected on UK sites with AULT, BBTM and SMA (Cont.)

Site Number	Type of asphalt	Aggregate size (mm)	Binder content (%)	Age (years)	Visual condition	Ravelling category
PLSD9	AULT	14	4.9	7	5.5	1
				8	5	1
				10	4.5	1
PLSD10	AULT	14	4.9	0	6.5	0
				1	6.5	0
				2	6	0
				6	6	0
				7	5	1
				8	5.5	1
				9	4.5	1
				10	4	1
				11	5	1
PLSD11	AULT	14	4.9	1	6	0
				6	5	0
				7	5	1
				8	5	0
PLSD12	AULT	14	4.9	2	6	0
				4	4	1
				5	4	2
				6	3	2
PLSD13	AULT	14	Not available	9	1.5	3
PLSD14	AULT	14	5.5	1	6.5	0
				2	5.5	1
				3	5	2
PLSD15	AULT	14	Not available	9	3.5	2
PLSD16	AULT	14	Not available	10	3.5	2
PLSD17	AULT	14	4.9	2	7	0
				14	3	0

Table A.1: Data collected on UK sites with AULT, BBTM and SMA (Cont.)

Site Number	Type of asphalt	Aggregate size (mm)	Binder content (%)	Age (years)	Visual condition	Ravelling category
TAC1a	BBTM	10	5.5	1	7	0
				2	6.5	0
				3	6	0
				4	5.5	0
				5	5	0
				9	5	0
				10	5	1
				11	4	1
				12	4	1
				13	4	1
				14	4	2
TAC1b	BBTM	10	5.5	10	4.5	1
				11	4.5	1
				12	4.5	1
				13	5	1
				14	4	1
TAC2	BBTM	10	5.5	0	6	0
				1	6.5	0
				2	5.5	0
				6	6	0
				7	5	1
				8	5.5	1
				9	4.5	1
				10	6	0
				11	4.5	1
TAC3	BBTM	14	4.5	1	6	0
				2	6	0
				6	6	0
				7	4	1
				8	5	1

Table A.1: Data collected on UK sites with AULT, BBTM and SMA (Cont.)

Site Number	Type of asphalt	Aggregate size (mm)	Binder content (%)	Age (years)	Visual condition	Ravelling category
TAC4a	BBTM	14	5.5	4	5.5	0
				5	6	0
				6	6	0
				7	6	0
				8	5.5	1
				9	5.5	0
TAC4b	BBTM	14	5.5	2	6.5	0
				4	6.5	0
TAC5a	BBTM	14	5.0	2	6.5	0
TAC5b	BBTM	14	5.0	2	6.5	0
				5	5	0
				6	5	1
				7	4.5	1
				8	4.5	1
				9	4.5	1
TAC6	BBTM	10	5.0	2	6	0
				3	6	0
				5	6.5	0
				6	5.5	1
				7	5	1
				8	4.5	1
				9	3.5	2
TAC7	BBTM	10	5.7	2	6	0
				5	5.5	1
				6	5	0
				7	5	0
				8	4.5	0
				9	5	1
				10	5	2
TAC8	BBTM	10	5.0	4	5	1
				5	5	1
				6	5	1
				7	4	2
				8	3	2

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Table A.1: Data collected on UK sites with AULT, BBTM and SMA (Cont.)

Site Number	Type of asphalt	Aggregate size (mm)	Binder content (%)	Age (years)	Visual condition	Ravelling category
TAC9	BBTM	10	5.5	4	6	0
				6	6	0
				7	5.5	0
				8	5	1
				9	5	1
TAC10a	BBTM	10	Not available	3	5	1
				4	5	1
				5	3.5	1
				6	4.5	1
				7	3	2
TAC10b	BBTM	10	Not available	3	6	0
				4	5	0
				5	5	1
				6	4.5	1
				7	4	1
TAC11	BBTM	14	Not available	0	6.5	0
				1	7	0
				2	5	0
				3	5	0
TAC12	BBTM	10	Not available	11	4.5	1
				12	4	1
				13	4	1
TAC13	BBTM	10	Not available	6	6	0
				11	6	0
				12	5	1
				13	5	1
TAC14	BBTM	10	5.0	0	6	0
				2	6.5	0
				7	5	1
				8	4	1
				9	3.5	2
TAC15	BBTM	14	Not available	4	5	1
				5	4	1
				6	3.5	1

Table A.1: Data collected on UK sites with AULT, BBTM and SMA (Cont.)

Site Number	Type of asphalt	Aggregate size (mm)	Binder content (%)	Age (years)	Visual condition	Ravelling category
TAC16	BBTM	10	Not available	10	5.5	1
				11	5	1
				12	5	1
TAC17	BBTM	10	Not available	10	4	2
				11	3	2
				12	3.5	2
TAC18	BBTM	10	Not available	2	6	0
				9	4	1
				10	4.5	1
TAC19	BBTM	6	Not available	5	5.5	1
				6	5.5	1
TAC20	BBTM	10	Not available	4	5	0
				5	6	0
				6	5	1
TAC21	BBTM	10	Not available	9	5	1
				10	5	1
				11	5	1
TAC22	BBTM	10	Not available	5	6	0
				6	6	0
				7	5.5	0
TAC23a	BBTM	10	Not available	5	6	0
				6	6	0
				7	6.5	0
TAC23b	BBTM	10	Not available	5	5	1
				6	5	1
				7	5	1
TAC24	BBTM	14	Not available	5	5	1
				6	5	1
				7	4.5	1
TAC25	BBTM	6	Not available	1	5.5	0
				2	5.5	0
				3	5	1

Table A.1: Data collected on UK sites with AULT, BBTM and SMA (Cont.)

Site Number	Type of asphalt	Aggregate size (mm)	Binder content (%)	Age (years)	Visual condition	Ravelling category
TAC26	BBTM	6	Not available	1	3.5	0
				2	5.5	0
				3	5	0
TAC27	BBTM	14	Not available	4	7	0
				5	6	0
				6	7	0
TAC28	BBTM	14	5.5	2	6.5	0
				3	6	0
TAC29	BBTM	14	5.5	1	6.5	0
				2	6.5	0
TAC30	BBTM	6	Not available	7	5	1
TAC31	BBTM	6	Not available	7	5	1
TAC32	BBTM	6	Not available	7	3.5	1
TSMA1	SMA	14	6.3	0	6.5	0
				1	7	0
				2	7	0
TSMA2	SMA	10	6.6	9	5	0
TSMA3	SMA	14	6.5	0	6	0
				1	6	0
				2	6	0
				6	4.5	0
				7	4.5	1
				8	5	0
				9	3	1
				10	4	1
				11	4	1
TSMA4	SMA	14	Not available	7	5	1
				8	5	1
				9	6	0

Table A.1: Data collected on UK sites with AULT, BBTM and SMA (Cont.)

Site Number	Type of asphalt	Aggregate size (mm)	Binder content (%)	Age (years)	Visual condition	Ravelling category
TSMA5	SMA	10	Not available	7	6	0
				8	6	0
				9	6	0
				10	6	0
				11	6	0
TSMA6	\SMA	14	6.1	1	6	0
				6	7	0
				7	6	0
				8	6	0
TSMA7	SMA	10	6.1	1	6	0
				2	6	0
				3	6	0
				6	7	0
				7	4.5	1
				8	4	1
				9	4	1
				10	3.5	2
TSMA8	SMA	14	6.0	0	5.5	0
				1	5.5	0
				2	6	0
				3	5	0
				6	6	0
				7	5	1
				8	5	0
				9	5	1
				10	5	1
				11	5	1
TSMA9	SMA	14	6.1	4	5	1
				6	4.5	1
				7	5	1
				8	4	1
				9	3.5	2

Table A.1: Data collected on UK sites with AULT, BBTM and SMA (Cont.)

Site Number	Type of asphalt	Aggregate size (mm)	Binder content (%)	Age (years)	Visual condition	Ravelling category
TSMA10	SMA	14	6.5	2	7	0
				5	6	0
				6	6	0
				7	6	0
				8	5	0
				9	6	0
				10	6	0
TSMA11	SMA	14	6.0	5	5.5	0
				6	5.5	0
				7	5.5	0
				9	5	1
				10	5	2
TSMA12	SMA	14	Not available	3	6	0
				5	5	0
				6	5	0
				7	5	0
				8	5	1
				9	5	1
				10	5	1
TSMA13	SMA	14	6.0	4	6	0
				5	6	0
				6	6	0
				7	6	0
				8	5	1
				9	6	0
TSMA14	SMA	14	6.5	1	6	0
				2	6	0
				4	5	0
				5	5	1
				6	4.5	1
				7	4.5	1
				8	4.5	1
				9	4	2

Table A.1: Data collected on UK sites with AULT, BBTM and SMA (Cont.)

Site Number	Type of asphalt	Aggregate size (mm)	Binder content (%)	Age (years)	Visual condition	Ravelling category
TSMA15	SMA	14	6.0	3	5.5	0
				4	5	0
				5	5.5	0
				6	6	0
				7	5	0
				8	4.5	0
TSMA16	SMA	14	6.0	2	6.5	0
				4	5	0
				5	5	1
				6	5	1
TSMA17	SMA	14	6.0	2	6	0
				3	6	0
				4	5.5	1
				5	5.5	1
				6	5	1
				7	5	1
				8	4.5	1
TSMA18	SMA	14	6.5	1	5.5	0
				2	5.5	0
				3	4.5	0
				4	5	0
				5	4	0
				6	4	0
TSMA19	SMA	14	Not available	0	6	0
				1	6	0
				2	6	0
TSMA20	SMA	10	Not available	5	6	0
				6	6	0
				7	6	0
TSMA21	SMA	14	Not available	5	6	0
				6	6	0
				7	6	0

Table A.1: Data collected on UK sites with AULT, BBTM and SMA (Cont.)

Site Number	Type of asphalt	Aggregate size (mm)	Binder content (%)	Age (years)	Visual condition	Ravelling category
TSMA22	SMA	14	Not available	1	6	0
				2	6	0
				3	6	0
TSMA23	SMA	14	Not available	1	6	0
				2	6	0
				3	6	0
TSMA24	SMA	14	Not available	5	6	0
				6	5.5	1
				7	6	0
TSMA28	SMA	14	Not available	1	6	0