Review of alternatives to High Friction Surfacing

Task 1-912 Review of Materials Performance & Texture Depth Policy

National Highways

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Quality information

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Executive summary

A number of sections of proprietary asphalt materials have been installed instead of High Friction Surfacing (HFS) on the Strategic Road Network (SRN) since 2011. These materials are marketed as having enhanced skid resistance performance compared to conventional asphalt materials, and as suitable alternatives to High Friction Surfacing (HFS). These materials fall into two categories:

1. asphalt materials containing calcined bauxite; and,
2. asphalt materials containing high-PSV natural aggregate coarse aggregate.

The in situ skid resistance performance of these materials are not fully understood. Therefore, National Highways commissioned the Arup AECOM consortium to investigate the in situ performance of these materials and provide recommendations for future usage of these materials.

Two different mixtures, one falling into each category, were identified as having been installed on the SRN. The skid resistance performance of the two materials was assessed across several sites over several years, comparing the characteristic skid coefficient (CSC) of the materials against the:

- site investigatory level (IL);
- performance of the prior surfacing on the site (either conventional asphalt or HFS); and,
- characteristic performance of HFS on the SRN on similar sites.

Based on the performance of two sites of very limited length, the CSC of the material containing high-PSV natural aggregate coarse aggregate appears to deteriorate after 3 to 4 years' service life. In addition, the material is unlikely to deliver the necessary CSC at locations with high traffic and high stress if an IL above 0.45 is required.

The material containing calcined bauxite offers superior performance compared with the material containing only high-PSV natural aggregate coarse aggregate. In most locations the material containing calcined bauxite achieved, or came close to achieving a CSC of 0.5. However, it is unlikely that an IL of 0.55 is achievable. The average CSC values for the material containing calcined bauxite were lower than for HFS at comparable sites, but the difference was less marked when considering the minimum values at each location. Minimum values are expected to represent the most critical lengths of pavement, such as the apex of a bend where skid resistance performance is most important.

While it is recommended that HFS is continued to be required as currently outlined in DMRB CD 236, in some scenarios, materials containing calcined bauxite could offer improved whole life cost value owing to purported enhanced surface integrity durability versus HFS. However, there should be caution in approving the use of materials containing only high-PSV natural aggregate coarse aggregate in high-traffic, high-stress applications, where HFS would otherwise be used.

1. Introduction

National Highways commissioned the Arup AECOM consortium to undertake an independent and fundamental review of pavement materials performance for a selection of materials used on the Strategic Road Network (SRN) whose performance is presently not fully understood.

The project is driven by achieving pavement efficiency savings, through the support that the National Highways Safety, Engineering and Standards (SES) Pavement Team provides to various parts of National Highways, including the Operations and Major Projects Directorates. The team also manages standards and is responsible for policy development aimed at ensuring sustainable solutions that represent best value are used on the SRN.

High Friction Surfacing (HFS) is a surface treatment used to provide the highest achievable level of skid resistance, particularly in wet conditions. HFS comprises 1 – 3 mm nominal size calcined bauxite aggregate bonded to the road surface with a thermosetting (cold applied) or thermoplastic (hot applied) binder. Cold applied materials are produced by broadcasting the calcined bauxite onto the thermosetting binder, whilst hot applied materials are premixed then screed applied. The aggregate in the finished surface is randomly orientated. Sharp edges protrude from the surface, which reduce the contact points between the tyre and surface, increasing the contact pressure and ultimately enhancing the skid resistance.

HFS is covered by Clause 924 in the Manual of Contract documents for Highway Works (MCHW) Volume 1 Specification for Highway Works (SHW). On the SRN, the use of HFS on sites is determined by Design Manual for Roads and Bridges (DMRB) CD 236 Surface course materials for construction. The requirement for HFS to be installed on a particular site is dependent on the commercial vehicle traffic, site characteristics (site category) and Investigatory Level (IL) for skid resistance (Characteristic Skid Coefficient (CSC)).

However, the use of HFS presents several technical, commercial and practical challenges:

- There are minimum and maximum surface temperature requirements for the application of HFS and the road surface must be dry.
- A time delay is often necessary between the installation of new asphalt and the application of HFS, up to 28 days depending on the HFS system used, meaning an additional road closure may be required to apply HFS.
- Relatively short lives compared with other road surfacing materials have been reported, particularly for hot applied systems.

As a result, alternative asphalt materials have been proposed for sites where HFS would traditionally be applied either due to the requirements in CD 236, or as a risk mitigation measure. These materials are proposed with statements from the material suppliers that they are more durable than HFS, and that the aggregate sources used offer performance equivalent to conventional HFS in polished stone value (PSV) tests, and therefore are a suitable alternative to HFS.

A number of sections of these materials have been installed since 2011, some under departure from standard where HFS would otherwise be required by CD 236. In order to inform future departure from standard applications and with a view to accepting or otherwise these materials and potentially others as a standard alternative to HFS, Arup AECOM have been commissioned to investigate the performance of these materials in situ and provide recommendations for future usage of these materials.

1.1 Objectives of this report

The objectives of this report are to:

1. Characterise and summarise the usage of the materials used as alternatives to HFS on the SRN.
2. Establish the skid resistance performance of these materials.
3. Compare the skid resistance performance of these materials with the performance of:
    a. the prior surfacing on the site; and,
    b. HFS on similar sites on the SRN.
4. Provide recommendations for the acceptance or otherwise of these materials as a replacement for HFS on the SRN.
5. As appropriate, provide recommendations for incorporation of these materials into standards.

1.2 Skid resistance on the SRN

The term "skid resistance" refers to the frictional properties of the road surface in wet conditions. The skid resistance of a wet or damp road surface can be substantially lower than the same surface when dry, and is more dependent on the condition of the surfacing material (National Highways, 2020).

Skid resistance is measured on the SRN to identify lengths of pavement for potential maintenance. To achieve consistency, routine (normally annual) measurements are made using specific devices, sideway-force coefficient routine investigation machines, under standardised conditions. The measurements are processed, taking into account seasonal variations dependent on the time of year of the measurements, to derive a Characteristic Skid Coefficient (CSC).

The CSC is an estimate of the underlying skid resistance once the effect of seasonal variation has been taken into account. This value is taken to represent the state of polish of the road surface. CSC measurements are used to characterise the road surface and assess the need for maintenance, but cannot be related directly to the friction available to a road user making a particular manoeuvre at a particular time (National Highways, 2015). CSC data is reported for each 10 m section length and stored in National Highways' pavement management system (known as HAPMS).

Site Categories are assigned based on broad features of the road type and geometry plus specific features of the individual site. Each site is assigned an Investigatory Level according to the perceived level of risk within each Site Category.

The Investigatory Level (IL) represents a limit, above which the skid resistance is considered to be satisfactory but at or below which the road is judged to require an investigation of the skid resistance requirements. However, it should be noted that there is no boundary at which the skid resistance passes from being "safe" to being "dangerous" (National Highways, 2020). Investigatory Levels are reviewed on a rolling programme, to ensure that changes in the network are identified, local experience is applied and consistency is achieved (National Highways, 2015).

2. Materials on the SRN used as alternatives to HFS

The asphalt materials proposed as alternatives to HFS fall into two categories:

1. asphalt mixtures incorporating calcined bauxite; and,
2. asphalt mixtures incorporating high-PSV (in this context defined as PSV 68+ or greater) natural aggregate coarse aggregate.

The two categories require separate consideration. Calcined bauxite is a manufactured aggregate that is harder wearing and more resistant to polishing than natural aggregate. Studies have shown that calcined bauxite maintains higher levels of friction for longer periods of time than natural aggregates (Friel & Woodward, 2019). The former requires consideration of whether an asphalt employing a larger nominal size (typically 10 mm) calcined bauxite, where aggregates have been orientated during compaction to produce smooth surface, offers equivalence to a HFS with a rough surface employing a 1 – 3 mm nominal size calcined bauxite. The latter has the additional consideration of the equivalency of calcined bauxite and high-PSV natural aggregates.

Two materials have been used on the SRN as an alternative for HFS:

- **Material A** – a proprietary asphalt incorporating a blend of calcined bauxite and 'high PSV' (stated in the product acceptance scheme certification, but not defined) natural aggregate, limestone filler, cellulose fibres, and a proprietary clear bitumen.
- **Material B** – a proprietary Stone Mastic Asphalt (SMA) incorporating high-PSV natural aggregate coarse aggregate and a polymer modified binder. This material has previously been used under departure from standard and has been offered with a warranty for maintaining a CSC value at or above 0.55 for 10 years.

Material A falls into the first category above, while Material B falls into the second category. The characteristics of each material and compliance with National Highways' specifications are outlined in Table 2.1.

Table 2.1 Characteristics of Material A and Material B

Property / Characteristic	Material A	Material B
National Highways specification clause	N/A [1]	N/A [2]
Standard	N/A [1]	BS EN 13108-5 Stone Mastic Asphalt (SMA)
Product acceptance scheme certification?	Yes – Thin Surfacing System	No [2]
Nominal aggregate size	10 mm	10 or 14 mm
Coarse aggregate	A blend of calcined bauxite 'high PSV' natural aggregate	Natural aggregate
Bitumen	Proprietary clear bitumen	PMB

[1] Material A uses a proprietary clear bitumen which does not comply with binder requirements in BS EN 13108-5 (does not conform to a bitumen standard (BS EN 12591 or BS EN 14023)), so does not conform to Clause 942.
[2] Material B is used under a departure from standard application. It is not intended to comply with a National Highways specification clause. It is designed to have a lower initial macrotexture depth than required by Clause 942 and does not have product acceptance scheme certification.

Table 2.2 provides a summary of the amount of each material in situ on the SRN in January 2020 according to HAPMS. Some materials may have been replaced, and additional material may have been installed since this point.

Table 2.2 Summary of materials used as alternatives to HFS on the SRN

	Material A	Material B
Number of sections	38	23
Number of sites	20	19
Date first installed	2015	2011
Total length installed	11312 m	2801 m
Maximum length installed	1234 m	235 m

3. Review of characteristic skid coefficient (CSC) offered by alternatives to HFS

In order to understand the performance of the alternatives to HFS materials used on the SRN, this report reviews the time evolution of CSC for sections of pavement utilising each material. The time evolution of CSC provides an indication of the deterioration of the skid resistance for a specific material. Then, the report compares the CSC on the sections of pavement using the alternative materials with:

- The CSC of the prior surfacing on the same section of the pavement (asphalt or HFS).
- The CSC typical of HFS on relevant (high-risk) sites on the SRN.

The former gives an understanding of performance on sections of pavement of identical geometry. The latter gives an understanding of whether sections previously surfaced with HFS are performing in a manner consistent with HFS elsewhere on the SRN. This project focuses on available CSC data (from HAPMS) for HFS for relevant sites (site category S1 and S2 only) between 2010 and 2020. Data are available for other sites (for example site category Q and K), but lower stress is expected on these sites which may otherwise skew the findings if included in the analysis.

The time evolution of the CSC is reported for each site to allow straightforward comparison between the different materials (conventional asphalt material, HFS, Material A and Material B) and the different years (pre and post-treatment). The CSC data is reported as boxplots as shown in Figure 1. The boxplot provides information about the median alongside the lower and upper quartiles. The boxplot whiskers represent 1.5 times the interquartile range (IQR). Outliers are defined as CSC values beyond the 1.5 IQR. Since lower CSC values are attributed with lower skid resistance and hence a high risk, the outliers are also plotted, as stars in Figure 1 then diamonds in subsequent figures. This is relevant since localised loss of skid resistance may occur where polishing is concentrated, for example at the apex of a bend, whereas a material may be applied along a greater length.

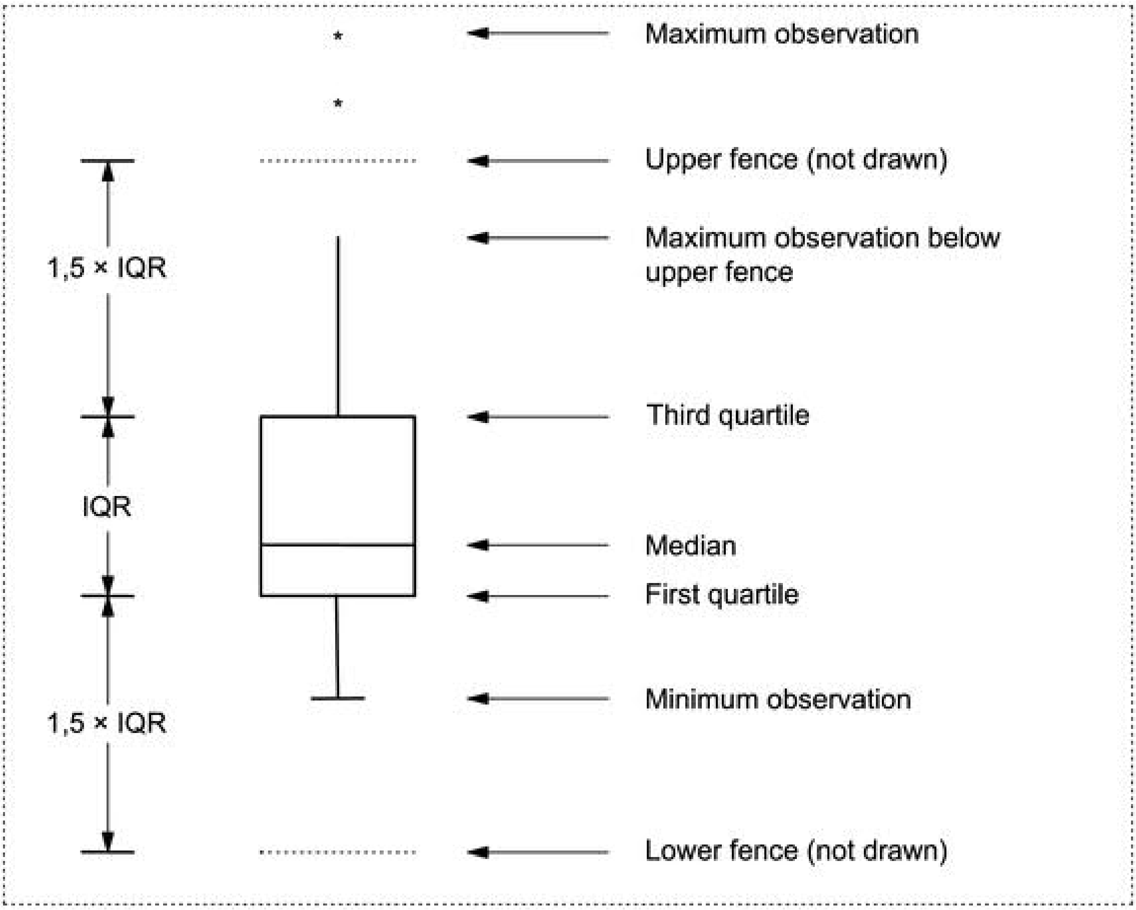

Figure 1. Boxplot (ISO, 2010)

3.1 Review of CSC offered by HFS

This section reviews the CSC typically offered by HFS on the SRN. Sites with site category S1 (bends with radius < 500 m with one-way traffic) and S2 (bends with radius < 500 m with two-way traffic) only are considered in this analysis, as these sites are considered to be the highest stress sites where HFS would offer lowest performance and deteriorate most rapidly.

Table 3.1 provides a summary of the length of HFS with a lifespan of five years or greater on sites with site category S1 and S2 in lanes CL1 and CR1 on the SRN in January 2020, according to HAPMS. According to HAPMS, approximately 40 % of sections are hot applied HFS, approximately 20 % of the sections are cold applied HFS and for approximately 40 % of sections the HFS type is unknown. Since January 2020, some materials may have been replaced. Table 3.2 outlines the number of 10 m CSC count points at each year for the different ILs.

Table 3.1 Summary of sections of HFS analysed

Number of sections analysed	Total section length (m)
216	26,295

Table 3.2 Count of 10 m CSC for different IL

IL	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10
0.4	7	6	16	16	16	14	15	18	8	8
0.45	663	729	809	982	1226	1049	743	524	535	314
0.5	469	577	733	901	910	963	717	596	471	335
0.55	0	0	3	5	5	5	5	5	1	2

3.1.1 Overall performance

Figure 2 compares the CSC on lengths of HFS following different periods of time in service (NB this does not track the same sites over time but does indicate changes in performance that may occur as materials age). The median CSC value remains consistent over the 10-years span. The spread of the boxplots is relatively high, indicating a considerable variation in CSC values. Furthermore, the lower quartile and minimum CSC values decrease for the older materials. The minimum values on a site are of importance as this corresponding area could represent the area of highest risk on a site.

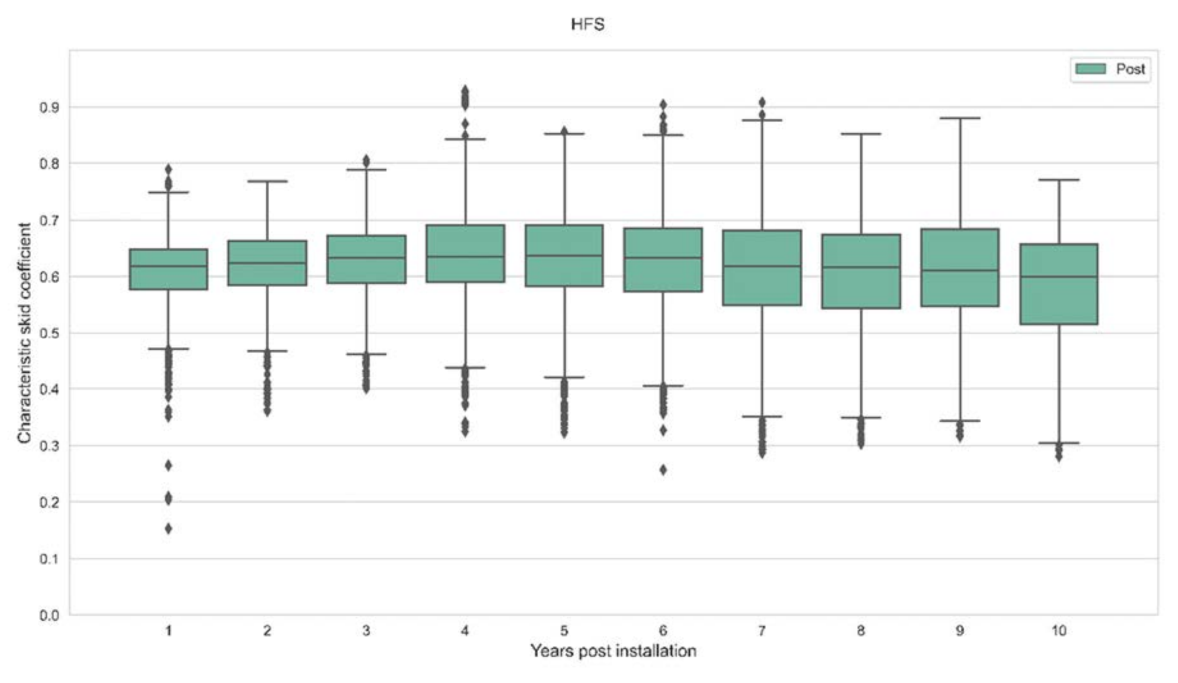

Figure 2. Time evolution of the CSC of HFS

3.1.2 Time evolution of the CSC of HFS by IL and direction

The data have been split by left and right bends for sites with 0.45 IL and 0.5 IL, respectively, so that the CSC provided versus the limit for that particular site can be understood. Only 0.45 IL and 0.5 IL sites are considered since there is limited CSC data for 0.4 IL and 0.55 IL sites as shown in Table 3.2.

IL 0.5 sites generally can be considered to present a higher risk than IL 0.45 sites. For site category S1 sites (bends with radius < 500 m with one-way traffic) an IL of 0.45 is typically required, whilst for sites with site category S2 (bends < 500 m radius with two-way traffic) an IL of 0.5 is typically required. For sites with site category S2, an IL of 0.45 can only be specified following a detailed site investigation (National Highways, 2020).

Splitting the data for left and right bends is important as the CSC is measured in the nearside wheel path of a lane, and the more highly stressed (so most heavily worn) wheel path varies depending on turning direction. For right bends, the nearside wheel path is most heavily stressed, whereas for left bends, the offside wheel path is most heavily stressed. Therefore, the CSC of right bends is generally an accurate representation of the true condition of the site, whilst the CSC of left bends may be overstated versus the true condition of the site.

3.1.2.1 Sites with an IL of 0.45

Figure 3 illustrates the CSC on left and right bends for sites with an IL of 0.45. There are substantial differences in the CSC for left bends and right bends. The median and minimum CSC values are lower from years 1 to 6 for right bends. The relative increase in CSC for right bends with service lives of years 7 through 10 can be attributed to fewer sites which perform well over an extended period, whilst lesser performing sites would have been replaced prior to reaching this service life. The right bend data is considered to be representative of the CSC performance of HFS.

Considering the right bend data presented in Figure 3, with the exception of a limited number of outliers, HFS delivers a CSC approximately at or above 0.45 on 0.45 IL sites for up to 4 years. After this point, the minimum values decrease below the 0.45 threshold and data spread increases, whilst the median values remain consistent. This indicates that at year 4, some sites will require investigation to determine whether intervention is required.

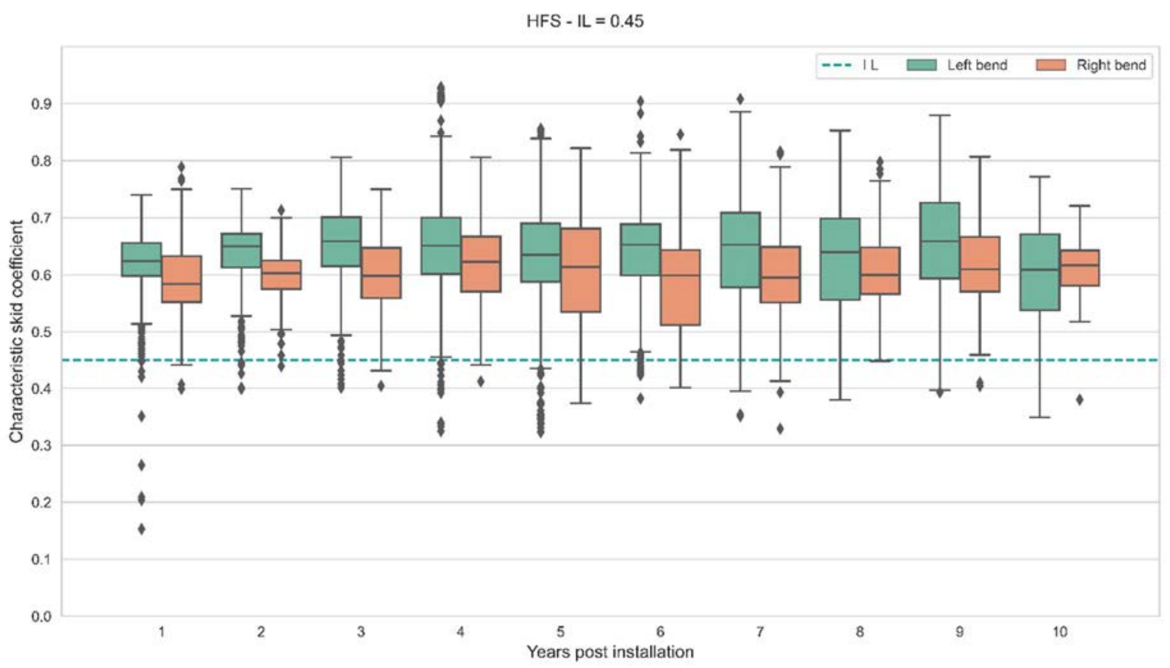

Figure 3. Time evolution of the CSC of HFS on 0.45 IL sites, sites split by left bend vs. right bend

3.1.2.2 Sites with an IL of 0.5

Figure 4 illustrates the CSC on left and right bends for sites with an IL of 0.5. There is not the clear reduction in CSC for right bends versus left bends as with sites with an IL of 0.45.

Considering the sites that are right bends, some 10 m sections on 0.5 IL sites do not meet the required 0.5 CSC at year 1; however, the minimum CSC increases after year 1 so that, with the exception of a limited number of sections, the IL is achieved in years 2 and 3. This increase suggests the reduced values in year 1 may be associated with the presence of the resin coating at the surface for some materials. From year 4, the minimum CSC deteriorates below the IL then remains broadly consistent to year 6. The reduction in CSC for the older materials (year 7 onwards) is most notable for the right bends on the IL 0.5 sites.

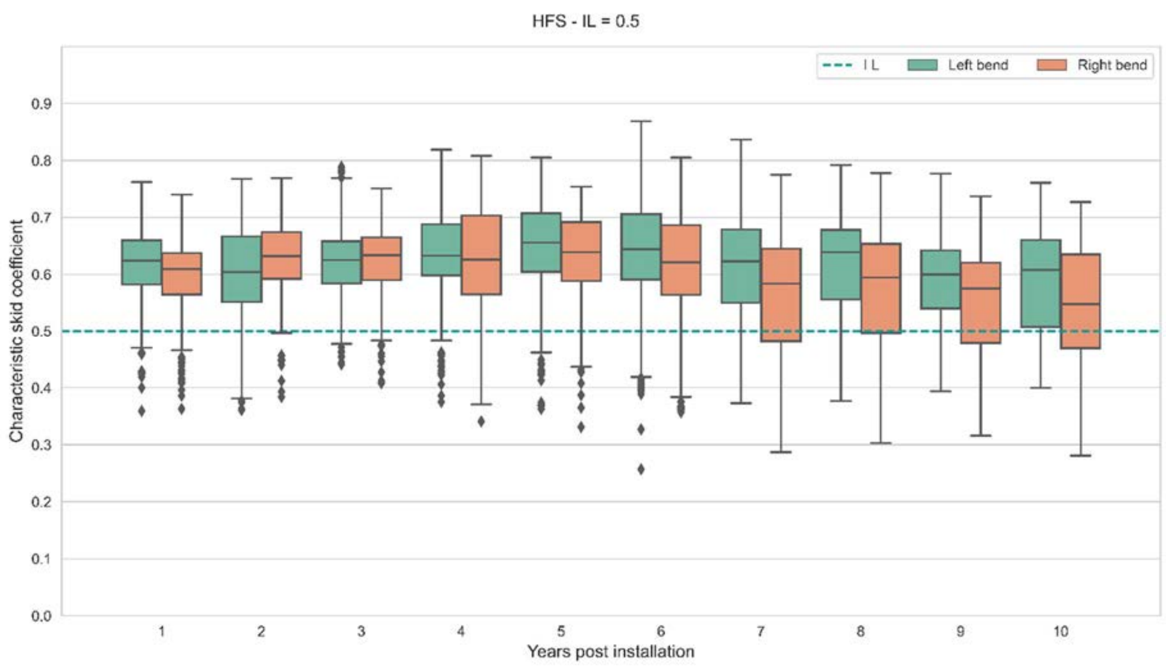

Figure 4. Time evolution of the CSC of HFS on 0.5 IL sites, sites split by left bend vs. right bend

3.1.3 Time evolution of the CSC of HFS by IL, direction and HFS type

The performance of the different types of HFS was compared. Figure 30 to Figure 33 in Appendix A outline the time evolution of CSC by turning direction for cold applied HFS and hot applied HFS for sites with an IL of 0.45 and 0.5. There is little discernible difference in the lower portion of the distribution between cold applied HFS and hot applied HFS. However, there is an apparent increase in median values for hot applied HFS compared with cold applied HFS. Comparing right bends, cold applied HFS would appear to be more consistent than hot applied HFS on sites with an IL of 0.45, but this is not the case on sites with an IL of 0.5.

Direct comparisons between cold applied HFS and hot applied HFS using this data set may not be appropriate as the site conditions including traffic and geometry may not be comparable. Further analysis is outside the scope of this task. On this basis, the entire HFS data set has been taken to characterise the performance of HFS on the network rather than attempting to distinguish between hot applied and cold applied materials.

3.1.4 Conclusions

The median CSC values for HFS are extremely high, remaining close to 0.6 for the oldest materials studied. However, the performance of the lower quartile is relevant since this is likely to contain the localised areas of greatest stress (represented by the lower whisker pole and outliers in the graphs). In this case, HFS generally maintains a CSC at or above:

- 0.45 for 4 years on sites with an IL of 0.45.
- 0.5 for 3 years on sites with an IL of 0.5.

However, some 10 m sections on 0.5 IL sites do not meet the required 0.5 CSC at year 1, and many 10 m sections maintain a CSC above the IL for longer than the values mentioned above. The median CSC for HFS on IL 0.45 and 0.5 sites is comparable for 6 years, at which point the CSC of sites with an IL of 0.5 deteriorates more rapidly.

In general, there appears to be low consistency in the performance of the HFS, but this is likely due to variations in site geometry, trafficking and materials i.e. type (hot applied HFS or cold applied HFS (see Appendix A)) and installation quality.

3.2 Sites considered in the review

Of the sites reported in Table 2.2, three sites laid with Material A, sometimes comprising numerous chart sections and several distinct lengths of surfacing, and two sites laid with Material B were carried over for the analysis.

Table 3.3 and Table 3.4 provide a summary of the sites with Material A and Material B, respectively that have been considered for the analysis. The sites were selected based on the age of the material and the length of material installed, so that the maximum amount of CSC data would be available, and whether the installation of the material could be verified in a straightforward manner i.e. using Google Street View imagery.

Material A on the reviewed sites was grey in colour, so visually distinguishable from conventional asphalt and straightforward to identify. However, Material B is indistinguishable from conventional asphalt so verification presented more of a challenge. Verification of Material B and the previous material installed on the site outlined in Table 3.3 and Table 3.4 was undertaken by reviewing historical Google Street View imagery. The identification of HFS as being hot applied was identified by the presence of visual strips from the use of a screed box during application.

Table 3.3 Summary of Material A sites analysed

Site	Type ‡	Chart Section(s)	Installation chainage (m)	Length installed (m)	Installation year	Previous material
M25 J5 CW	T1	2200M25/693	250 - 1484	1,234	2015	Asphalt
A64 Askham Bryan Entry Slip	T2 / T1	2700A64/191 CL1 / 2700A64/187	95 – 303 / 0 – 56	264	2017	HFS – hot applied
A64 Askham Bryan Exit Slip	T1 / T2	2700A64/189 / 2700A64/191 CR1	133 – 193 / 303 – 95	268	2017	HFS – hot applied
A628 Woodhead Pass Eastbound	T2	1000A628/165 CL1	1445 – 1535	90	2017	HFS – hot applied
			1630 – 1710	80	2017	
			1795 – 1883	88	2017	
	T2	1000A628/179 CL1	217 – 290	73	2017	
			940 – 1100	160	2017	
	T2	1000A628/189 CL1 / 4405A628/60 CR1	1565 – 1612 / 2483 – 2625	189	2017	
A628 Woodhead Pass Westbound	T2	4400A628/60 CL1 / 1000A628/189 CR1	2483 – 2625 / 1565 – 1612	189	2017	HFS – hot applied
	T2	1000A628/179 CR1	217 – 289	72	2017	
			940 – 1100	160	2017	
			228 – 289	61	2017	
	T2	1000A628/165 CR1	1445 – 1544	99	2017	HFS – hot applied
			1630 – 1710	80	2017	
			1795 – 1883	88	2017	

‡ T1: One-way carriageway, T2: Two-way carriageway

Source: HAPMS

Table 3.4 Summary of Material B sites analysed

Site	Type‡	Chart Section(s)	Installation chainage (m)	Length installed (m)	Installation year	Previous material
M1 J5 SB Exit Slip	T1	1900M1/89	440 - 528	88	2016	Asphalt
M4 J4 EB Exit Slip	T1	430M4/124	0 - 109	109	2016	HFS – hot applied

‡ T1: One-way carriageway

Source: HAPMS

3.3 Review of Material A sites

3.3.1 M25 J5 CW (2200M25/693)

The HAPMS section 2200M25/693, shown in Figure 5, is a slip road, located on the clockwise (W) direction of the M25 at Junction 5, to re-join the M25 (continuing on, the main line joins the A21). It is a one-way carriageway with a total length of 1,484 m. The site includes a left bend approximately between chainages 400 m and 800 m and a right bend approximately between chainages 1,000 m and 1,400 m.

Historically the site has been the location of skidding accidents and impacts to the parapet barrier adjacent to the right bend in Lane 1. This was attributed to low CSC values with the previous asphalt used. Material A was applied in 2015 between chainages 250 m and 1,484 m (see Figure 6) in both CL1 and CL2 to replace asphalt as shown in Figure 6. The traffic count and minimum PSV for the site are outlined in Table 3.5. Only CL1 has been analysed as the CSC data on CL2 is limited, as outlined in Table 3.6.

Table 3.5 Traffic count and minimum PSV for M25 J5 CW

Chart section	2200M25/693		
Traffic count (CV/L/D)	3700 [1]		
Site category ‡	B	S1	
Chainage (m) ‡	1400 - 1484	250 – 1000	1000 - 1400
Investigatory level ‡	0.35	0.45	0.5
Minimum PSV†	53	68+	HFS

[1] 2015 estimate outlined in Departure from Standard application.

‡ HAPMS

† CD 236

Table 3.6 Available CSC data

	Pre-installation						Post-installation			
Lane	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**
CL1	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
CL2			✓					✓		✓

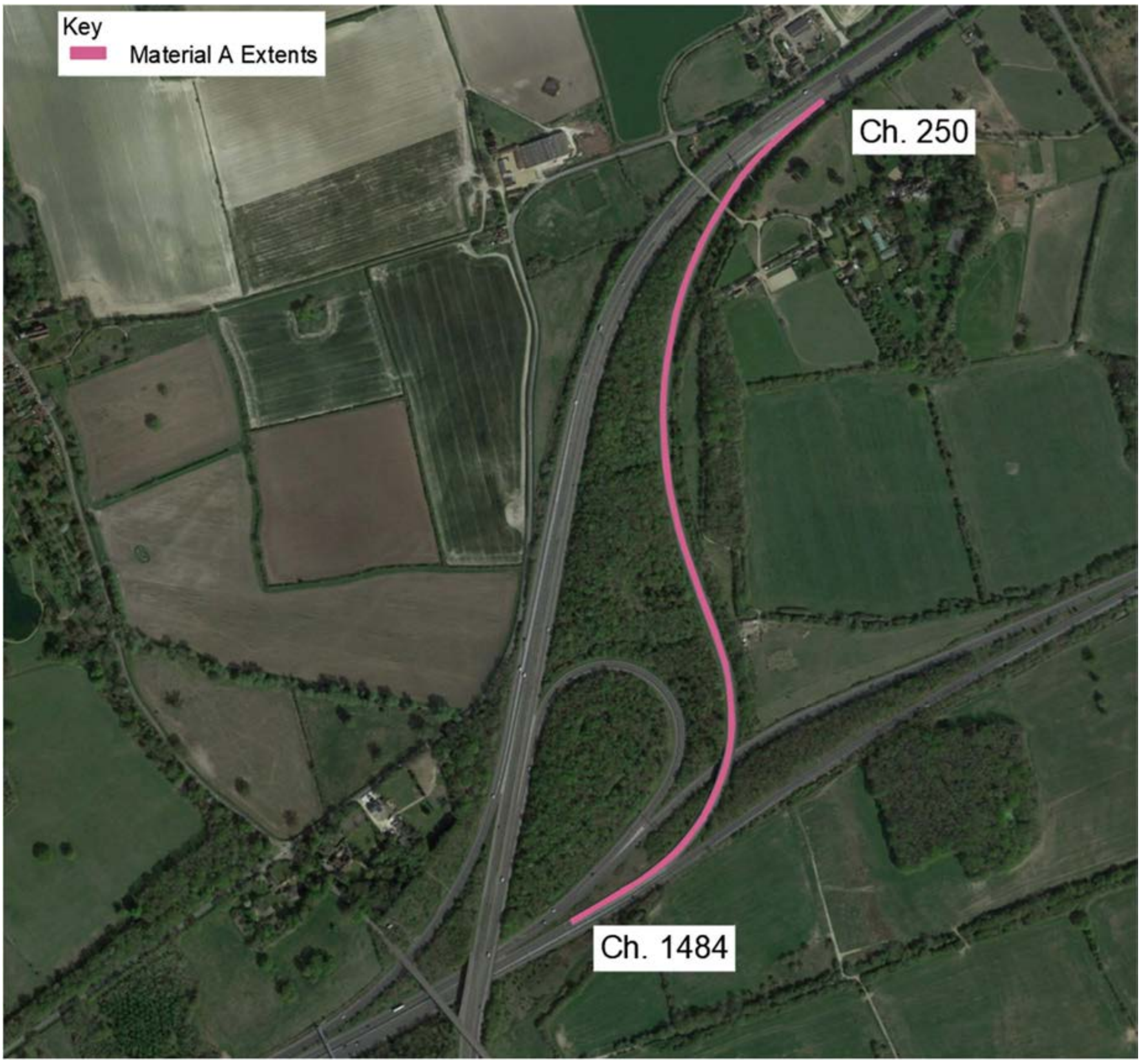

Figure 5. M25 Material A site extents

Start Joint
End Joint

Figure 6. M25 Material A start and end joint

3.3.1.1 Time evolution of CSC on the M25 J5 CW

Figure 7 illustrates the time evolution of the CSC for every 10 m length section on HAPMS section 2200M25/693 – CL1. The area highlighted in grey identifies the section where Material A has been installed. As outlined in the figure and Table 3.5, the IL ranges between 0.35, 0.40 and 0.45. From the figure, the following observations can be made:

- The pre-installation material (asphalt) generally fails to meet the required IL thresholds. There is a clear decrease in the CSC between chainages 1,000 m and 1,400 m which is associated with the sharpest part of the right bend.

- The post-installation material (Material A) increases the CSC across the section. The CSC generally meets the required IL thresholds except for the 2020 survey between chainages 1,100 m and 1,200 m. There is a clear decrease in the CSC between chainages 1,000 m and 1,400 m which is associated with the sharpest part of the right bend.

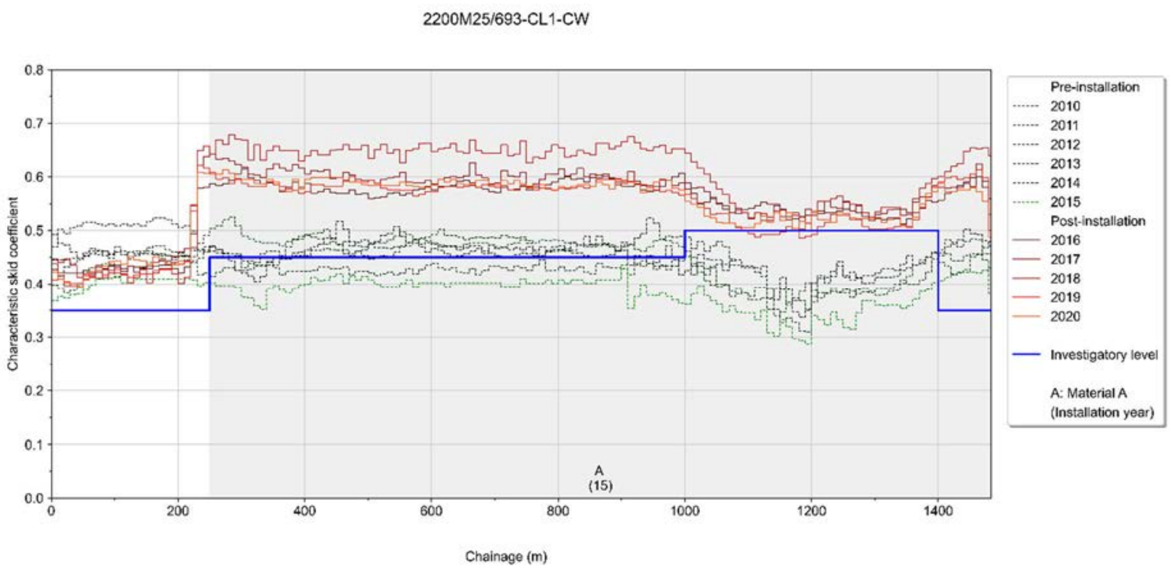

Figure 7. CSC 2200M25/693-CL1-CW

Figure 8 illustrates the time evolution of CSC for the length where Material A is installed. The average CSC pre-installation is relatively low between 0.4 and 0.45. Minimum values are generally between 0.3 and 0.4. The median CSC post-installation is considerably higher and skewed toward the upper quartile. Minimum values are also relatively high at 0.5 (or higher) in the first three years post-installation and higher than 0.45 thereafter.

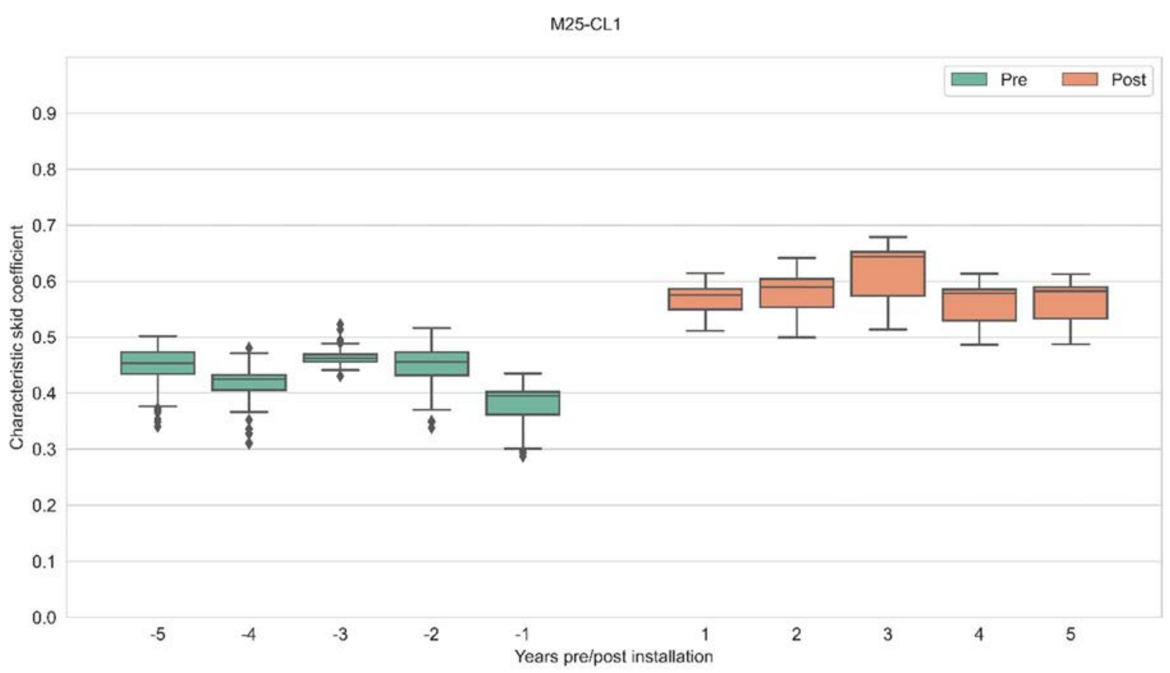

Figure 8. Time evolution of CSC for pre and post installation of Material A on 2200M25/693-CL1-CW

Figure 9 illustrates the average CSC on the left bend (Ch. 400 – 800) and right bend (Ch. 1000 – 1400). There is a consistent increase in the average CSC values post-installation in both bends. However, the right bend reports lower CSC values both pre-installation and post-installation. The spread of the right bend is relatively larger compared with the left bend indicating lower consistency.

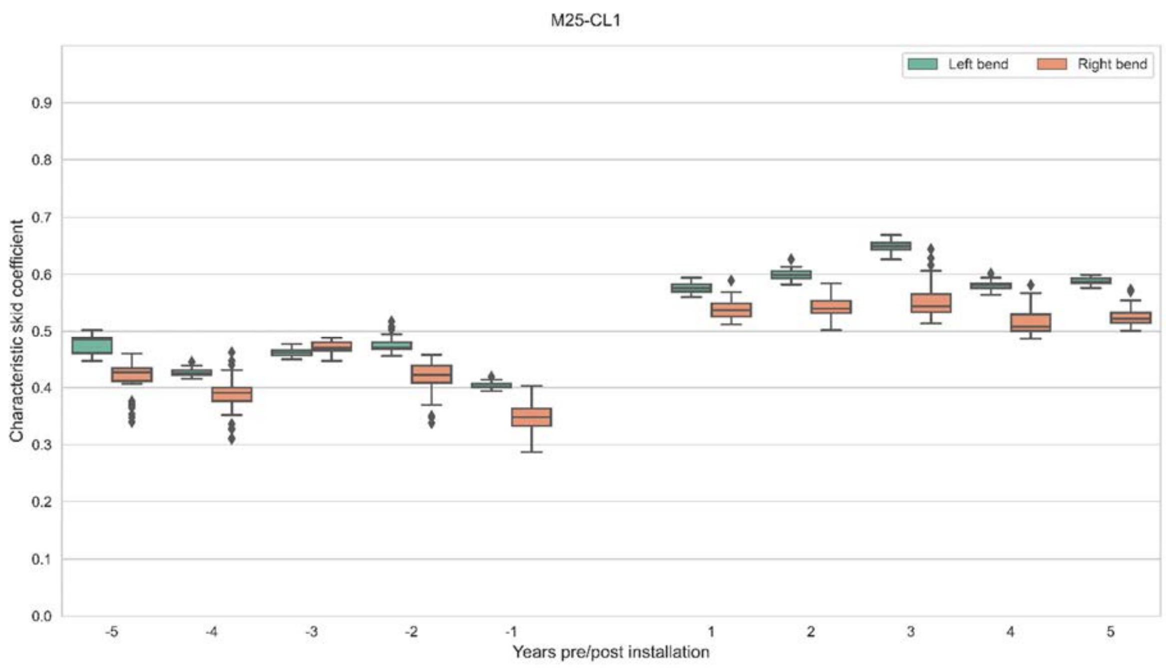

Figure 9. Time evolution of CSC for pre and post installation of Material A on 2200M25/693-CL1-CW, split by left bend and right bend

3.3.1.2 Conclusions

In summary, Material A on this site offers significantly improved performance in terms of CSC compared with the previous conventional asphalt and mostly complies with the IL requirements for the site. The performance remains broadly consistent, rather than deteriorating significantly with time, although the minimum CSC on the site falls marginally below the 0.5 IL four years post-installation. However, this value is approximately 0.2 CSC higher than the previous asphalt in this location (0.3 versus 0.5).

Comparing this with the performance of HFS on similar sites elsewhere on the SRN outlined in Section 3.1.2, the material has a lower median CSC; however, the minimum value has been maintained at a higher level and has not yet deteriorated to the same extent as is the trend for HFS with time/trafficking.

3.3.2 A64 Askham Bryan (2700A64/191, /187, /189)

The A64 at Askham Bryan is an exit slip / entry slip with a site category S1/S2. The site is shown in Figure 10 and Figure 11 and consists of three HAPMS sections.

- HAPMS section 2700A64/191 is a two-way single carriageway slip road. It has a total length of 303 m. The site includes a bend between chainages 150 m and 303 m. This is a right bend on CL1 and a left bend on CR1. Material A is applied between chainages 95 m and 303 m on both CL1 and CR1.

- HAPMS section 2700A64/189 is a one-way single carriageway slip road. It has a total length of 193 m. The site includes a left bend between chainages 60 m and 193 m. Material A is applied between chainages 133 m and 193 m.

- HAPMS section 2700A64/187 is a one-way single carriageway slip road. It has a total length of 232 m. The site includes a left bend between chainages 0 m and 90 m. Material A is applied between chainages 0 m and 56 m.

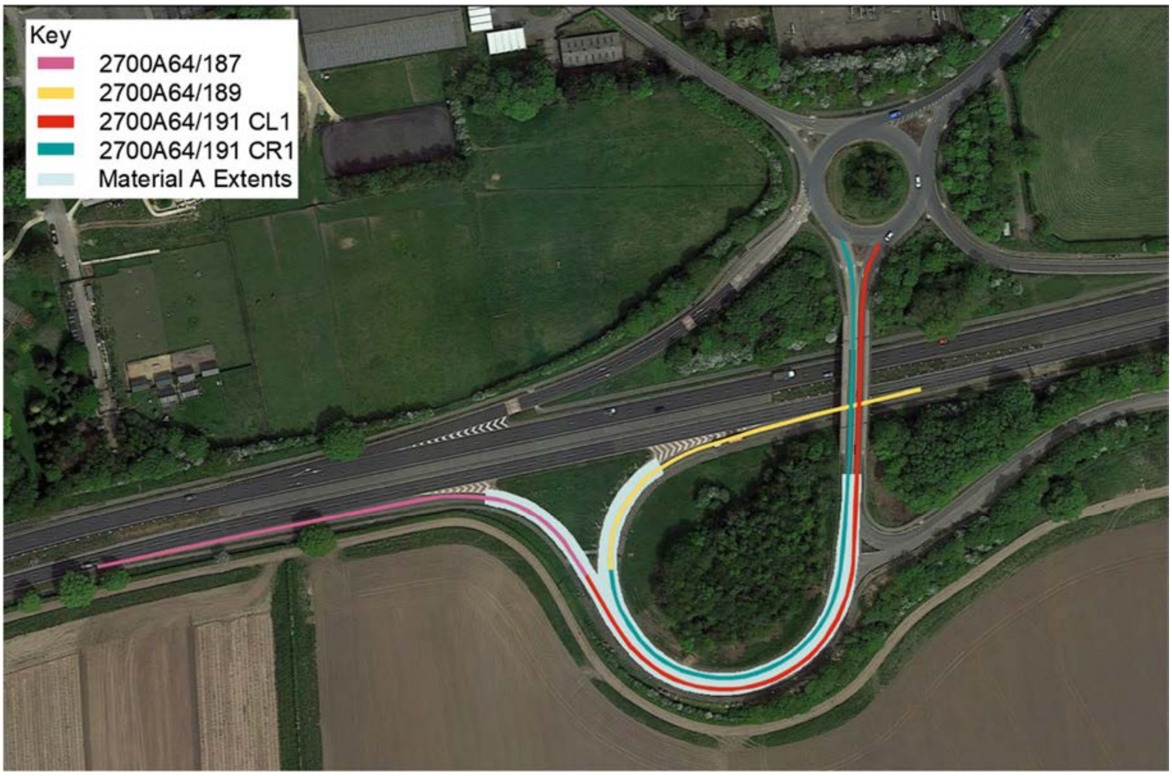

Figure 10. A64 Material A site extents and chart sections

Figure 11. A64 Material A start and end joints

Traffic count information and the minimum PSV for the A64 Askham Bryan exit slip and entry slip are outlined Table 3.7.

Table 3.7 Traffic count and minimum PSV for the A64 Askham Bryan entry and exit slips

Location Chart section	A64 Entry Slip 2700A64/191 CL1 2700A64/187			A64 Exit Slip 2700A64/189 2700A64/191 CR1		
Traffic count (CV/L/D)	511 [1]			387 [1]		
Site category ‡	Q	S2	S1	S1	S2	B
Chainage (m) ‡	95 – 140	140 - 303	0 – 56	133 - 193	303 - 140	140 – 95
Investigatory level ‡	0.5	0.5	0.45	0.45	0.5	0.35
Minimum PSV†	68+	68+	60	55	68+	50

[1] 2019 DfT manual count. Count Point 89186.
‡ HAPMS
† CD 236

3.3.2.1 A64 Askham Bryan entry slip

The A64 Askham Bryan entry slip consists of HAPMS sections 2700A64/191-CL1 and 2700A64/187. Figure 12 illustrates the time evolution of the CSC for every 10 m length section on the entry slip. The area highlighted in grey identifies the section with Material A. The IL ranges between 0.45 and 0.5. From Figure 12, the following observations can be made:

- The pre-installation material (HFS - hot applied) generally meets the required IL thresholds. There is no clear correlation between the CSC values and the required IL threshold.
- The post-installation material (Material A) does not result in an increase in the CSC, rather, the CSC values are generally lower than pre-installation.

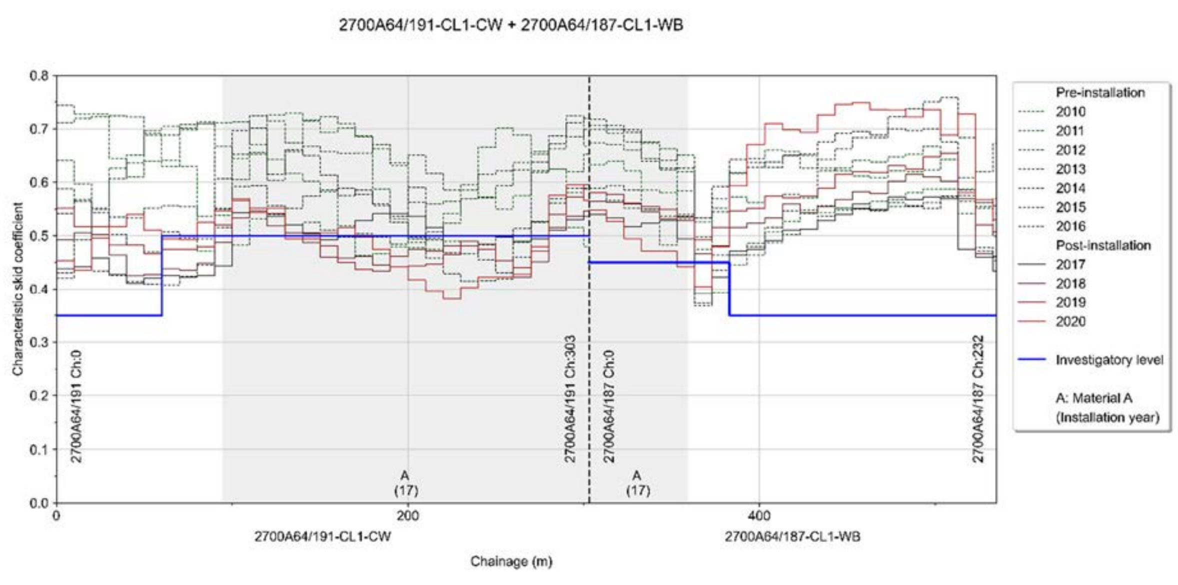

Figure 12. CSC Entry Slip 2700A64/191-187

3.3.2.2 A64 Askham Bryan exit slip

The A64 Askham Bryan exit slip consists of HAPMS sections 2700A64/189 and 2700A64/191-CR1. Figure 13 illustrates the time evolution of the CSC for every 10 m length section on the exit slip. The area highlighted in grey identifies the section with Material A. The IL ranges between 0.35, 0.45 and 0.5. From Figure 13, the following observations can be made:

- The pre-installation material (HFS - hot applied) generally meets the required IL thresholds except for 2010 and 2011 surveys between site chainages 193 m and 300 m. The site shows no clear correlation between the CSC values and the required IL threshold.

- The post-installation material (Material A) does not result in an increase in the CSC, rather, the CSC values are generally lower than pre-installation.

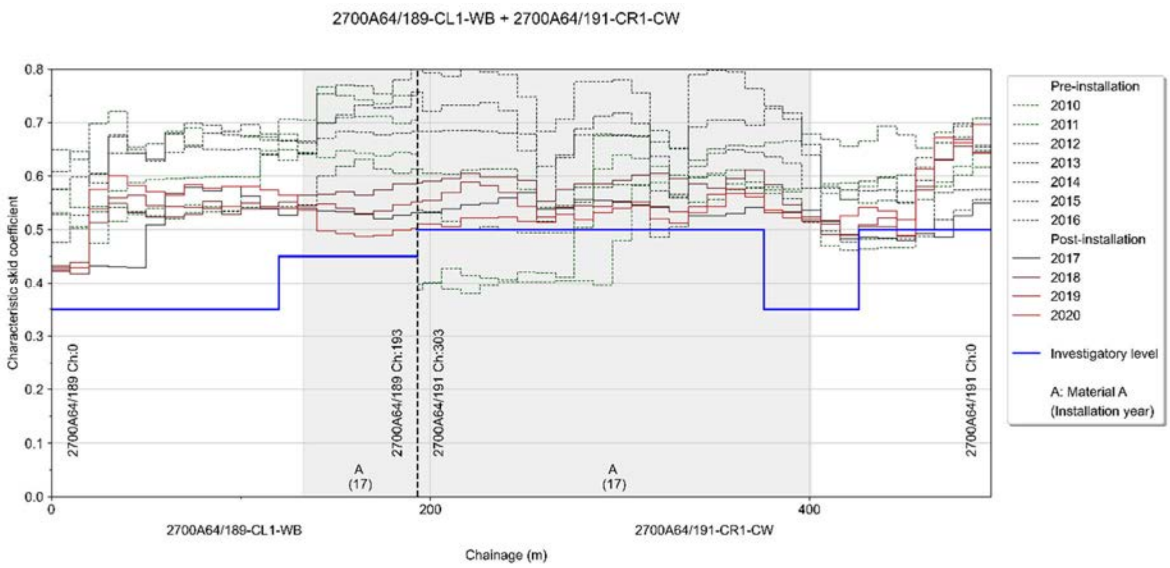

Figure 13. CSC Exit Slip 2700A64/189-191

3.3.2.3 A64 Askham Bryan CSC time evolution

Figure 14 illustrates the time evolution of CSC on the A64 site (both entry slip and exit slip) where the Material A has been installed. There is a clear decrease in the CSC values post-installation. Minimum values are also relatively lower, reaching 0.38 at some points after 4 years and remaining on a downward trend. The spread of the post-installation values is relatively smaller when compared to the pre-installation, indicating higher consistency.

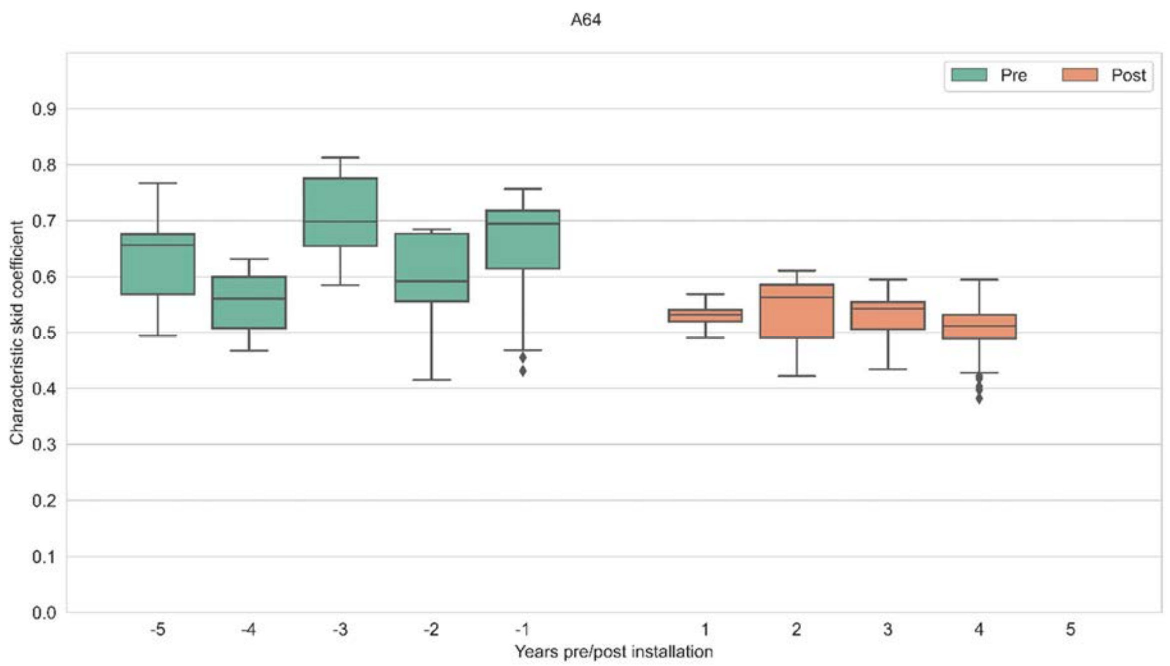

Figure 14. CSC of Material A and pre-installation material (HFS) on the A64 Askham Bryan entry and exit slips

Figure 15 illustrates the time evolution of CSC on the A64 entry slip. There is a decrease in the CSC values post-installation. Minimum CSC values are also relatively lower and appear to be on a downward trend.

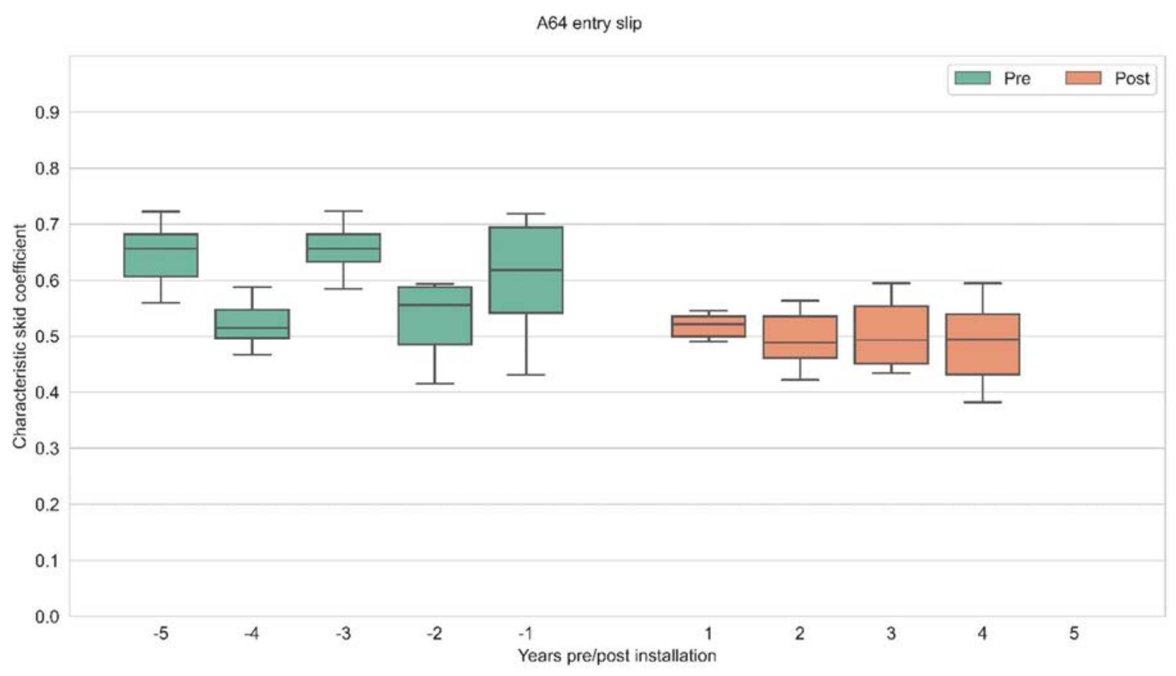

Figure 15. CSC of Material A and pre-installation material (HFS) on the A64 Askham Bryan entry slip

Figure 16 illustrates the time evolution of CSC on the A64 exit slip. There is a decrease in the CSC value post-installation. Minimum CSC values are generally comparable to pre-installation. The exit slip has relatively higher CSC values post-installation, when compared to the entry slip. This could be attributed to the fact that the exit slip has no right turns. The spread of the post-installation values is relatively small indicating higher consistency.

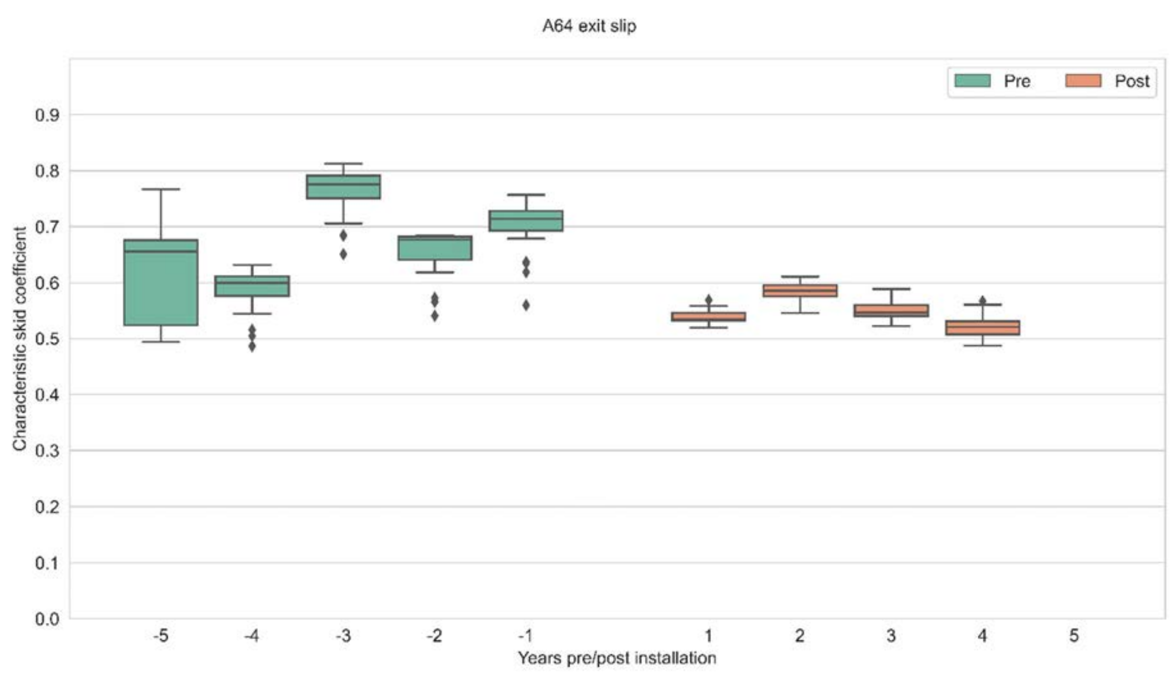

Figure 16. CSC of Material A and pre-installation material (HFS) on the A64 Askham Bryan exit slip

Figure 17 illustrates the CSC on left and right bends where the Material A has been applied. The right bend has lower CSC values both pre-installation and post-installation. Both bends report a decrease in the average CSC values post-installation. However, the lowest CSC values on right bends are initially similar to the lowest values before installation, although they appear to decline further in year 4.

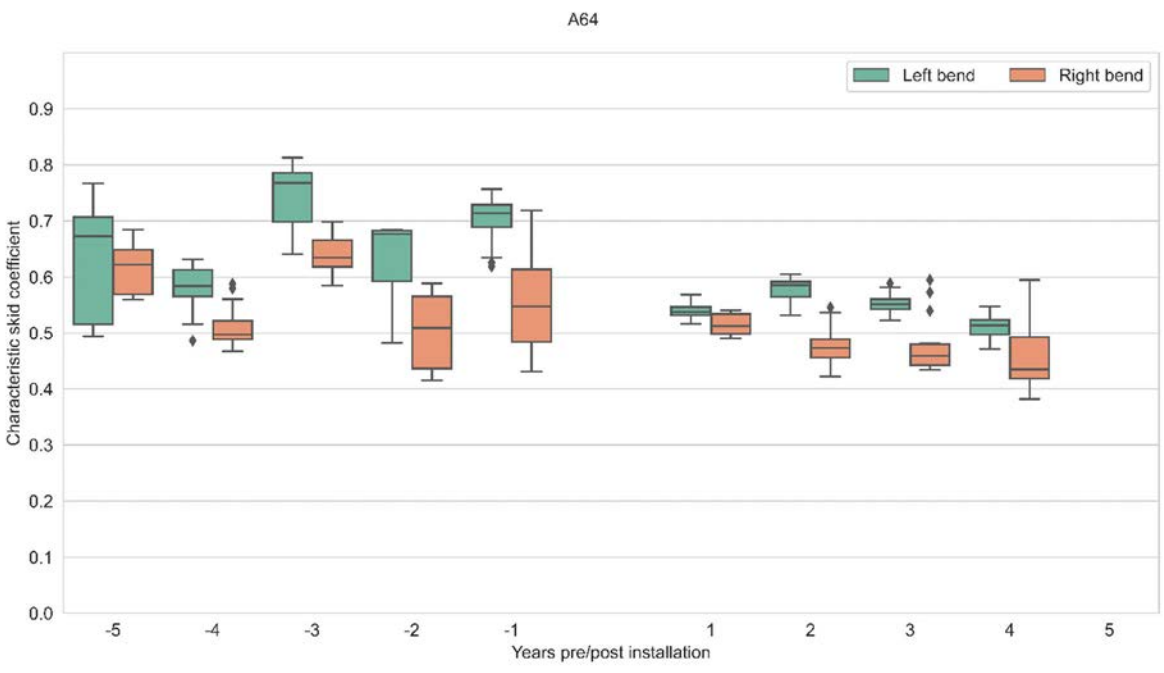

Figure 17. Time evolution of CSC for pre and post installation of Material A on the A64 at Askham Bryan, split by left bend and right bend

3.3.2.4 Conclusions

Material A appears to be performing comparatively worse in terms of CSC than the HFS previously installed on the site, with some sections falling consistently well below the 0.5 IL required on some sections of the site. The apparently satisfactory performance, above 0.5 CSC, on left bends probably does not reflect the actual condition. However, when judged on the lowest values, there is less difference between the HFS and Material A. Material A therefore provides a more consistent surface, lower overall than the HFS but with less difference between areas of high and low CSC. Should the downward trend in the CSC of Material A continue past year 4, this conclusion would no longer hold. The prior HFS performance on the site is generally comparable to the general performance of HFS as shown in Section 3.1.

3.3.3 A628 Woodhead Pass (1000A629/165, /179, /189, 4405A628/60)

Sections of Material A have been installed on several bends on the eastbound and westbound directions on the A628 Woodhead Pass. The site is shown in Figure 18. Material A has been installed on parts of four contiguous HAPMS sections:

- HAPMS section 1000A628/165 is a two-way single carriageway section of road. It has a total length of 2,110 m. Material A is applied on three locations with a total length of 258 m and 267 m in CL1 and CR1, respectively.

- HAPMS section 1000A628/179 is a two-way single carriageway section of road. It has a total length of 1,392 m. Material A is applied on two locations with a total length of 233 m and 221 m in CL1 and CR1, respectively.

- HAPMS section 1000A628/189 is a two-way single carriageway section of road. It has a total length of 1,612 m. Material A is applied between chainages 1,565 m and 1,612 m in both CL1 and CR1.

- HAPMS section 4405A628/60 is a two-way single carriageway section of road. It has a total length of 2,625 m. Material A is applied between chainages 2,483 m and 2,625 m as a continuous section with the section in 1000A628/189 in both CL1 and CR1.

Traffic count information and the minimum PSV for the eastbound and westbound carriageways is outlined in Table 3.8.

Table 3.8 Traffic count and minimum PSV for the A628

Chart section	Eastbound 1000A628/165 CL1 1000A628/179 CL1 1000A628/189 CL1 4400A628/60 CR1				Westbound 4400A628/60 CL1 1000A628/189 CR1 1000A628/179 CR1 1000A628/165 CR1			
Traffic count (CV/L/D)	750 – 1000[1]				750 – 1000[1]			
Site category ‡	S2			G1	S2			G1
Investigatory level ‡	0.45	0.5	0.55	0.45	0.45	0.5	0.55	0.45
Minimum PSV†	60	HFS	HFS	68+	60	HFS	HFS	68+

[1] 2019 DfT manual count. Count Point 73013.
‡ HAPMS
† CD 236

The chainages of Material A and the associated bends are reported in Table 3.9.

Table 3.9 A628 Site Information

HAPMS Section	Chainage (m) ‡		CL1		CR1	
	Start	End	Applied	Bend	Applied	Bend
1000A628/165	1445	1535	✓	Left	✓	Right
	1630	1710	✓	Right	✓	Left
	1795	1883	✓	Left	✓	Right
1000A628/179	215	290	✓	Right	✓	Left
	940	1110	✓	Left	✓	Right
1000A628/189	1565	1612	✓	Right	✓	Left
4405A628/60	2483	2625	✓	Right	✓	Left

‡ Reported application chainages for CL1. Application chainage on CR1 might vary up to ±10 m.
Source: HAPMS

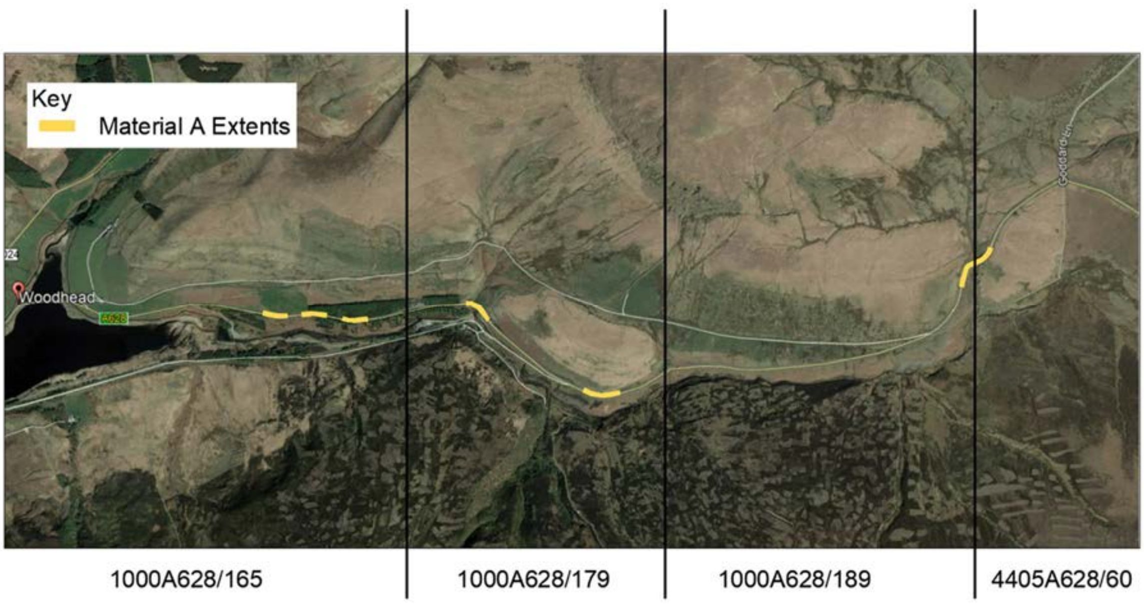

Figure 18. A628 Material A site extents

3.3.3.1 A628 eastbound

The A628 eastbound site consists of HAPMS sections 1000A628/165-CL1, 1000A628/179-CL1, 1000A628/189-CL1 and 4405A628/60-CR1. Figure 19 illustrates the time evolution of the CSC for every 10 m length section. The areas highlighted in grey identify the sections with Material A. The IL varies between 0.40, 0.5 and 0.55. From the figure, the following observations can be made:

- The pre-installation material (HFS – hot applied) generally meets the required IL thresholds. There is some type of correlation between the CSC values and the required IL threshold especially for sections on 1000A628/165 and 1000A628/179.

- The post-installation material (Material A) generally meets the required IL thresholds, with the exception of a localised length at approx. cumulative chainage 5100 m (1000A628/189 Ch. 1565 – 1612). The CSC values are generally within the range of the pre-installation material.

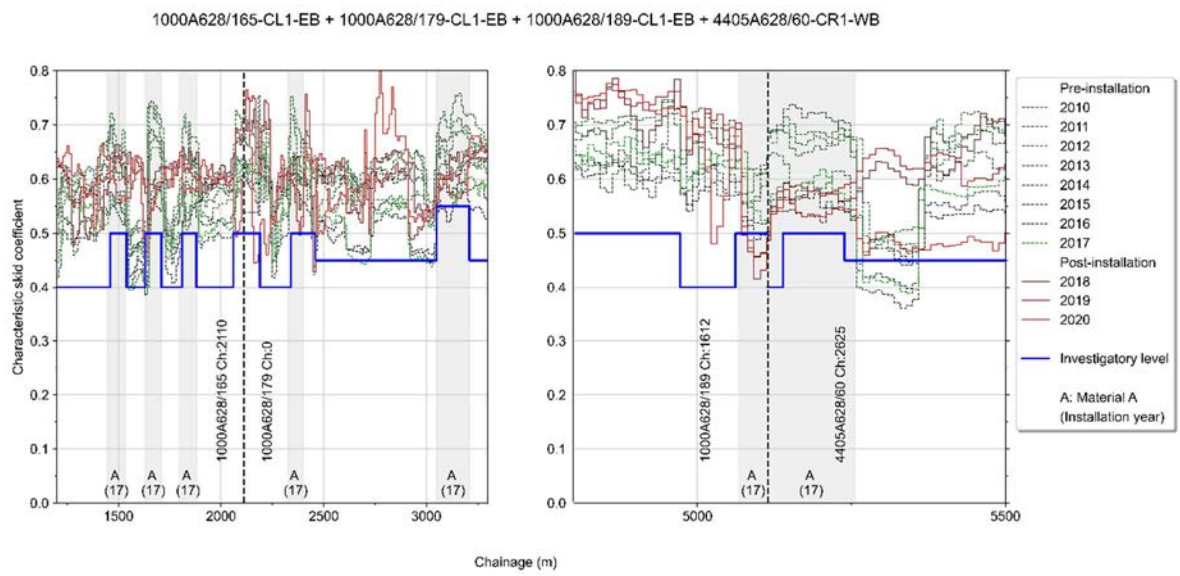

Figure 19. CSC per year 1000A628_165_CL11000A628_179_CL11000A628_189_CL14405A628_60_CR1

3.3.3.2 A628 westbound

The A628 westbound site consists of HAPMS sections 4405A628/60-CL1, 1000A628/189- CR1, 1000A628/179-CR1 and 1000A628/165-CR1. Figure 20 illustrates the time evolution of the CSC for every 10 m length section. The areas highlighted in grey identify the section with Material A. The IL ranges between 0.4, 0.5 and 0.55. From the figure, the following observations can be made:

- The pre-installation material (HFS – hot applied) generally meets the required IL thresholds. There is some type of correlation between the CSC values and the required IL threshold especially for sections on 1000A628/165 and 1000A628/179.

- The post-installation material (Material A) generally meets the required IL thresholds, with the exception of a localised length different to the eastbound direction at approx. cumulative chainage 5250 m (1000A628/179 Ch. 950 – 1000). The CSC values are generally within the range of the pre-installation material.

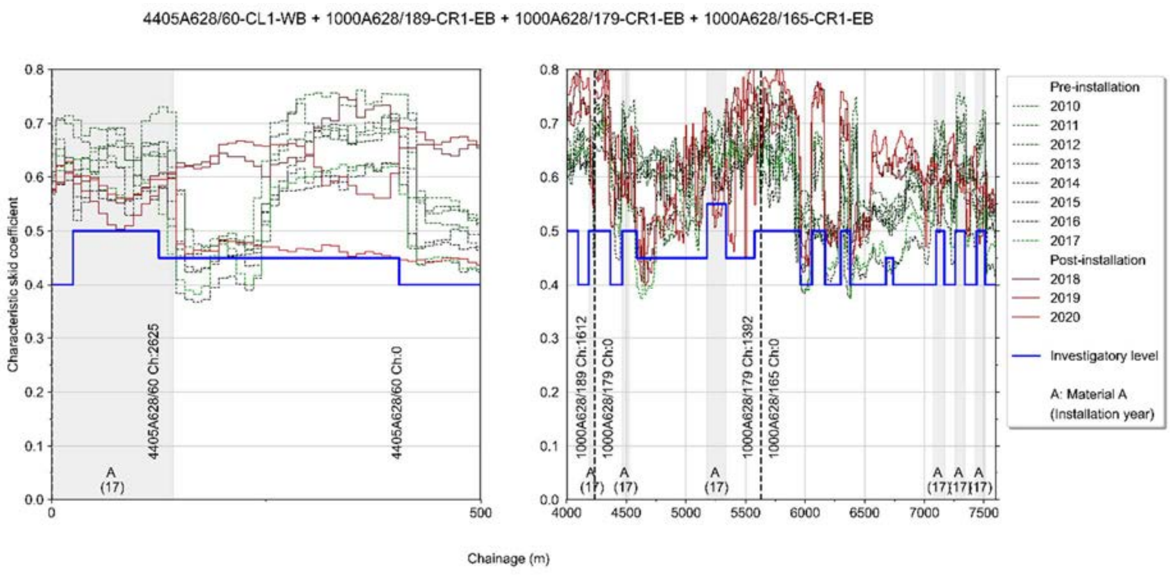

Figure 20. CSC per year 4405A628_60_CL11000A628_189_CR11000A628_179_CR11000A628_165_CR1

3.3.3.3 Time evolution of the CSC of Material A on the A628

Figure 21 illustrates the time evolution of the CSC of Material A on the A628 site. Pre-installation and post-installation materials have similar average CSC values. However, minimum CSC values are relatively lower in the pre-installation HFS.

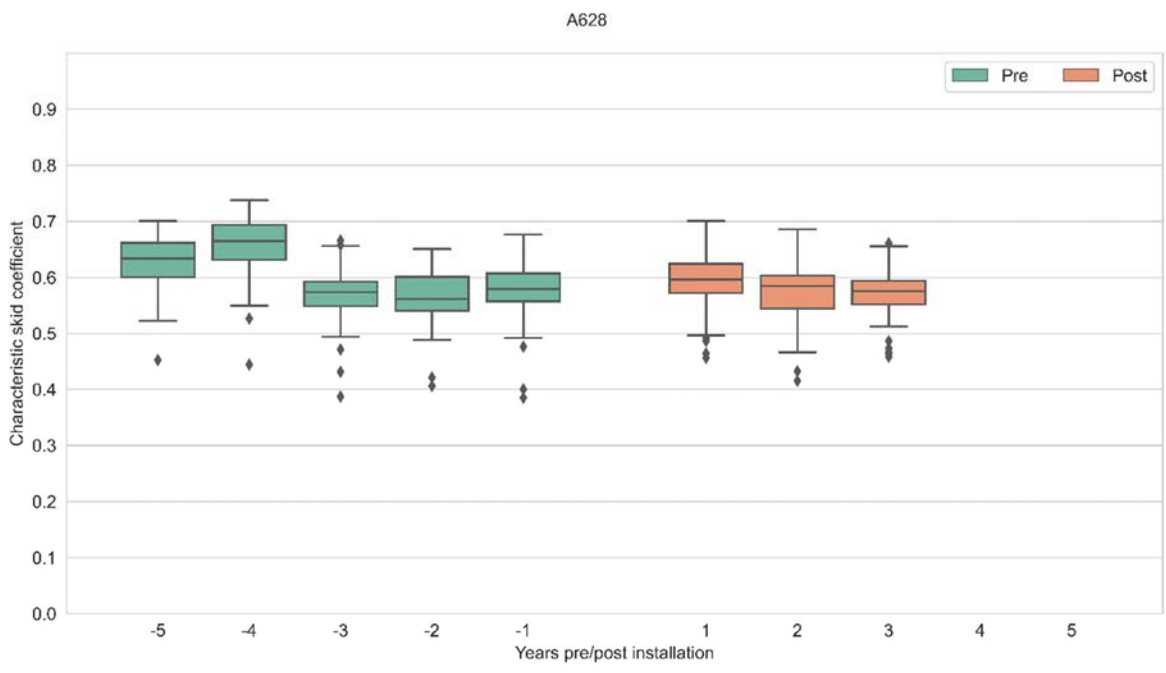

Figure 21. Time evolution of the CSC of Material A on the A628

Figure 22 illustrates the average CSC on left and right bends. There is no clear difference in the median CSC values between right and left bends. However, right bends report relatively lower minimum CSC values. Right bends have also more outliers, indicating lower consistency.

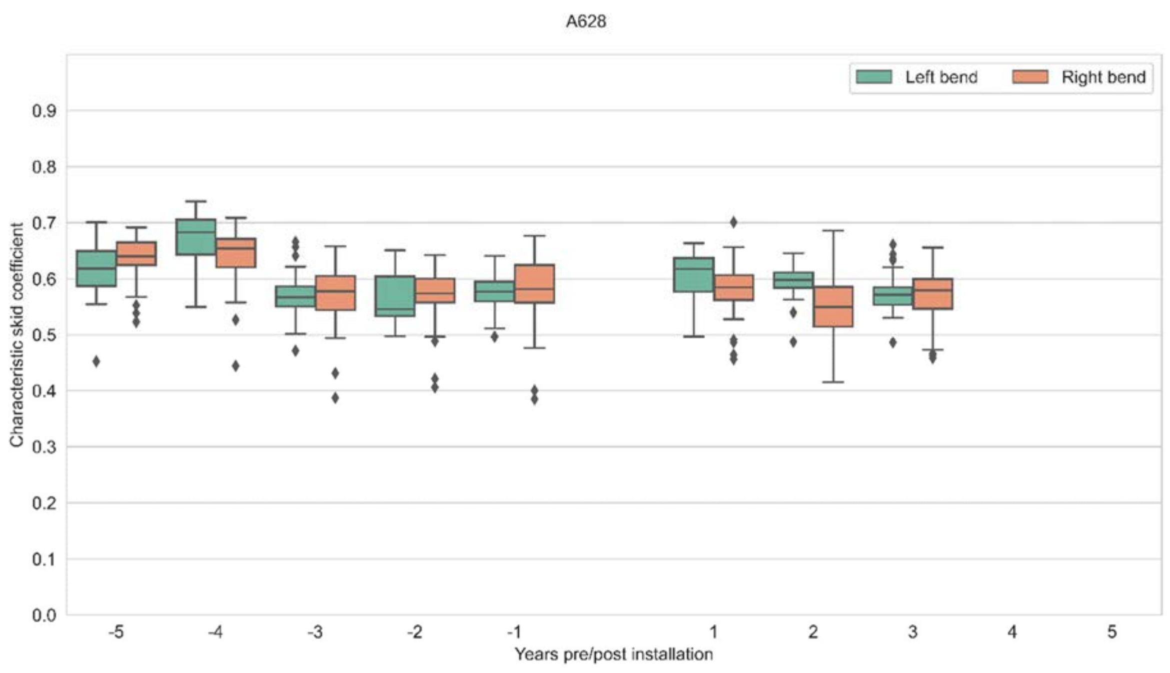

Figure 22. Time evolution of the CSC of Material A on the A628, split by left bend and right bend

3.3.3.4 Conclusions

Whilst the CSC of the Material A is generally lower than the previous HFS, the performance is mostly retained above the 0.5 IL which is assigned to the majority of Material A sections for the three years when testing has been carried out. However, minimum CSC values are lower than the pre-installation HFS, particularly on right bends where the highest stress is likely to be in the CSC measurement area.

3.3.4 Discussion and conclusions

Based on the analysis, the following conclusions can be drawn:

- The average performance of Material A is relatively good, meeting the required IL threshold.
- The spread of the CSC value is relatively high indicating low consistency across the sections.
- Localised loss of skid resistance can bring the CSC below the required IL threshold. This is more noticeable on right bends and is assumed to also occur on left bends.
- There is no clear degradation in the performance of Material A during the first three years of installation.
- Material A performs better than conventional asphalt for skid resistance.
- Material A has similar or lower performance to HFS materials.

3.4 Review of Material B sites

3.4.1 M1 J5 SB Exit Slip (1900M1/89)

The HAPMS section 1900M1/89 is a slip road located on the M1 J5 SB as shown in Figure 23. It is a one-way carriageway with a total length of 528 m. Material B is applied between chainages 440 m and 528 m on CL1 on the approach to a signalised junction. Traffic count information and the minimum PSV for the site are outlined in Table 3.10.

Figure 23. M1 J5 SB Site extents

Table 3.10 Traffic count and minimum PSV for M1 J5 SB Exit Slip

Chart section	1900M1/89	
Traffic count (CV/L/D)	750 – 1000 [1]	
Site category ‡	B	Q
Chainage (m) ‡	0 - 472	472 - 528
Investigatory level ‡	0.35	0.55
Minimum PSV†	50	HFS

[1] Estimate based on 2019 DfT manual count. Count Points 91290, 78355, 6456.
‡ HAPMS
† CD 236

Figure 24 illustrates the time evolution of the CSC for every 10 m length section for chart section 1900M1/89. The area highlighted in grey identifies the section with Material B. The IL ranges between 0.35 and 0.55. The pre-installation material is asphalt. From the figure, the following observations can be made:

- The pre-installation material (asphalt) meets the required 0.35 IL threshold but generally fails to meet the 0.55 threshold.

- Material B is not associated with an increase in the CSC across the section. The section meets the required 0.35 IL threshold but generally fails to meet the 0.55 threshold.

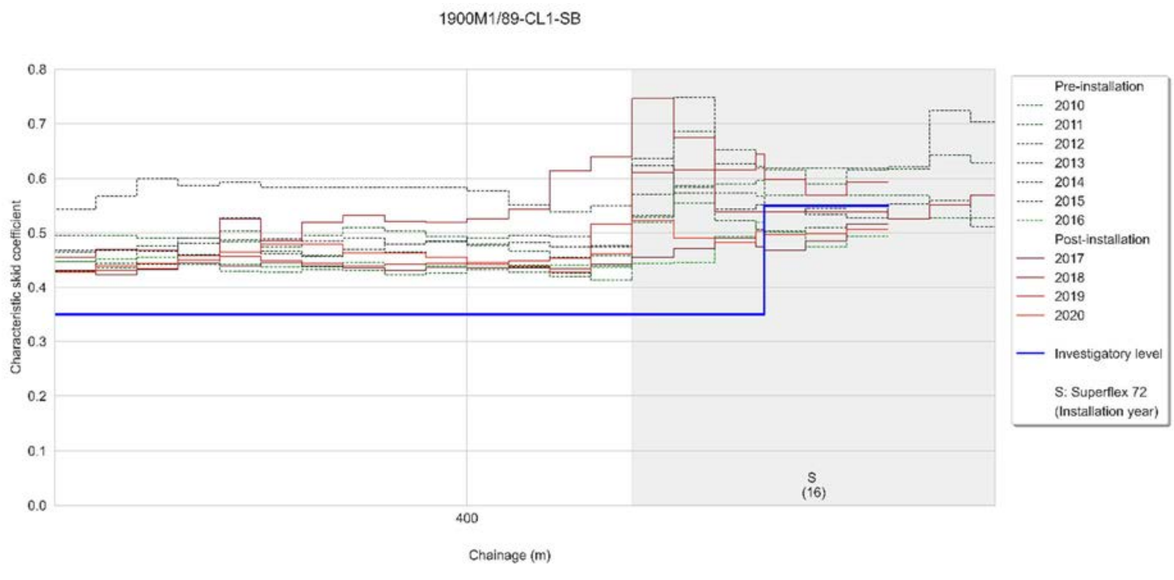

Figure 24. CSC for M1 J5 SB Exit Slip L1 Section 1900M1/89

Figure 25 illustrates the time evolution of CSC of Material B and pre-installation material on the site. The post-installation CSC is considerably lower than the IL in year 1, with most CSC values being below 0.5 IL. This could be due to the presence of the binder film on the aggregate. The post-installation material shows comparatively better performance in years 2 and 3, with all recorded CSC values being above 0.5 IL, but then reduces in year 4. This aligns with other reported studies of the skid resistance of high-PSV materials (Stephenson, Hodgson, & Premathilaka, 2014). The CSC post-installation is comparable to the values reported pre-installation. Since the pre-installation material is asphalt, Material B does not appear to provide any improvement in CSC on this section versus conventional asphalt. However, as the post-installation data is limited, it is difficult to make any meaningful judgment on the performance of the post-installation material.

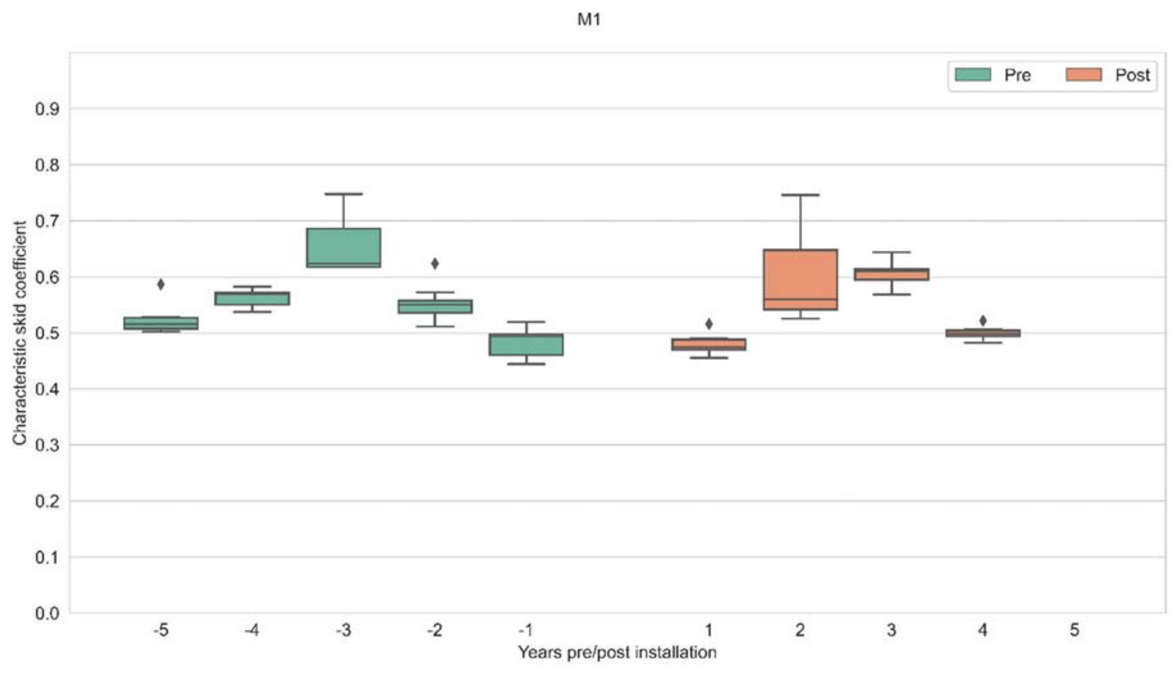

Figure 25. Time evolution of CSC for pre-installation material and Material B on the M1 J5 SB Exit Slip L1 Section 1900M1/89

3.4.2 M4 J4 EB Exit Slip (0430M4/124)

The HAPMS section 0430M4/124 is a slip road located on the M4. It is a one-way carriageway with a total length of 109 m. Material B is applied between chainages 0 m and 109 m in CL1 and CL2; however, only data for CL1 are available. Traffic count information and the minimum PSV for the site are outlined in Table 3.11.

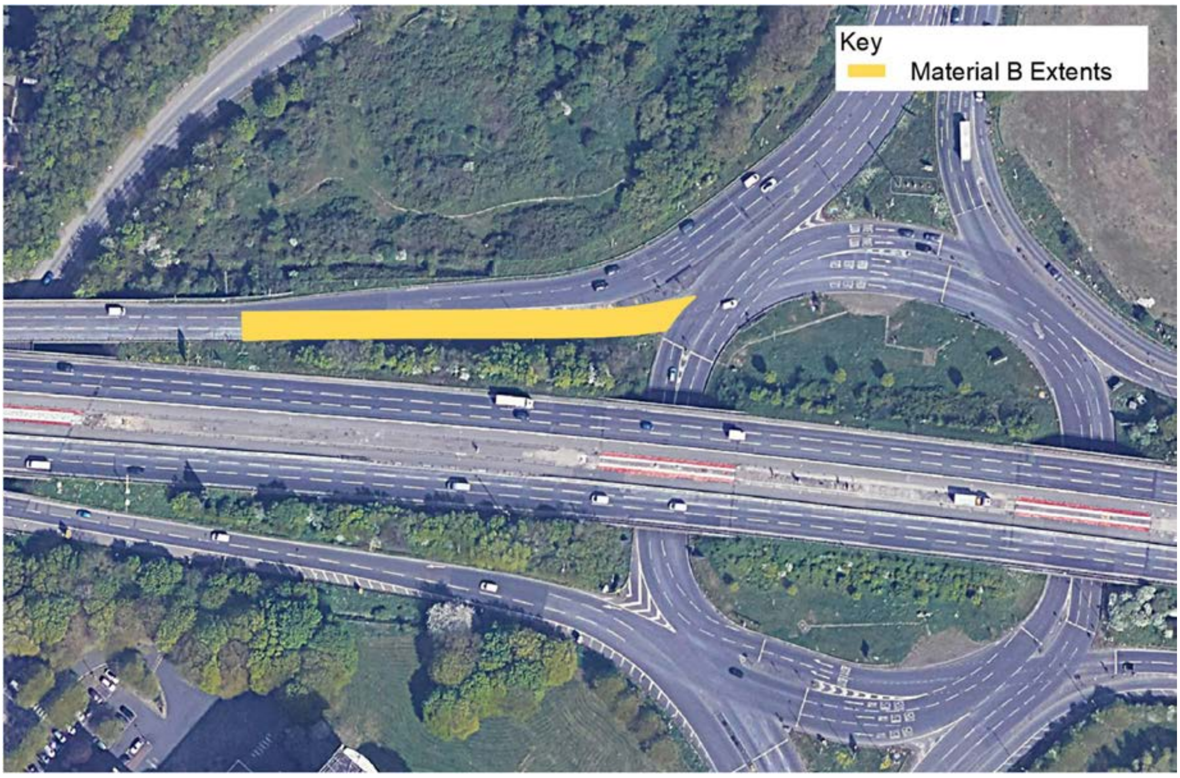

Figure 26. M4 J4 EB Exit Slip Site Extents

Table 3.11 Traffic count and minimum PSV for M4 J4 EB Exit Slip

Chart section		
Traffic count (CV/L/D)	1000 - 2000 [1]	
Site category ‡	B	Q
Chainage (m) ‡	0 - 27	27 - 109
Investigatory level ‡	0.35	0.55
Minimum PSV†	50	HFS

[1] Estimate based on 2019 DfT manual count. Count Point 36013.
‡ HAPMS
† CD 236

Figure 27 illustrates the time evolution of the CSC for every 10 m length section. The area highlighted in grey identifies the section with Material B. In this case, the entire section is surfaced with Material B. The IL ranges between 0.35 and 0.55. The pre-installation material was HFS. From the figure, the following observations can be made:

- The pre-installation material (HFS - hot applied) meets the required 0.35 IL threshold, but generally fails to meet the 0.55 IL threshold.

- Material B is not associated with an increase in the CSC across the section.

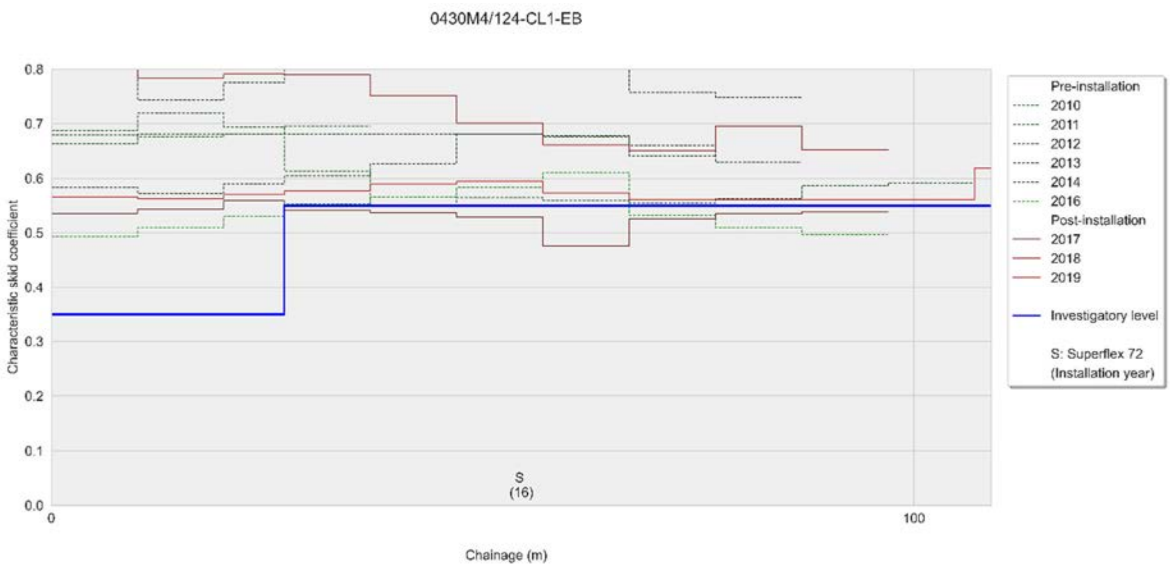

Figure 27. CSC for Material B on the M4 J4 EB Exit Slip L1 Section M40430/124

Figure 28 illustrates the time evolution of CSC of the Material B and pre-installation material on the site. The post-installation CSC is lower in year 1 when compared with year 2 and lower than the IL. Again, this could be as a result of the presence of a binder film on the aggregate. Material B shows a better performance in year 2 but in a similar manner to the material on the M1 J5 SB decreases sharply in year 3; however, the values are maintained above the 0.55 IL.

Overall, the average CSC post-installation are comparable to the values reported pre-installation. However, as the post-installation data is limited, it is difficult to make any meaningful judgment on the performance of Material B.

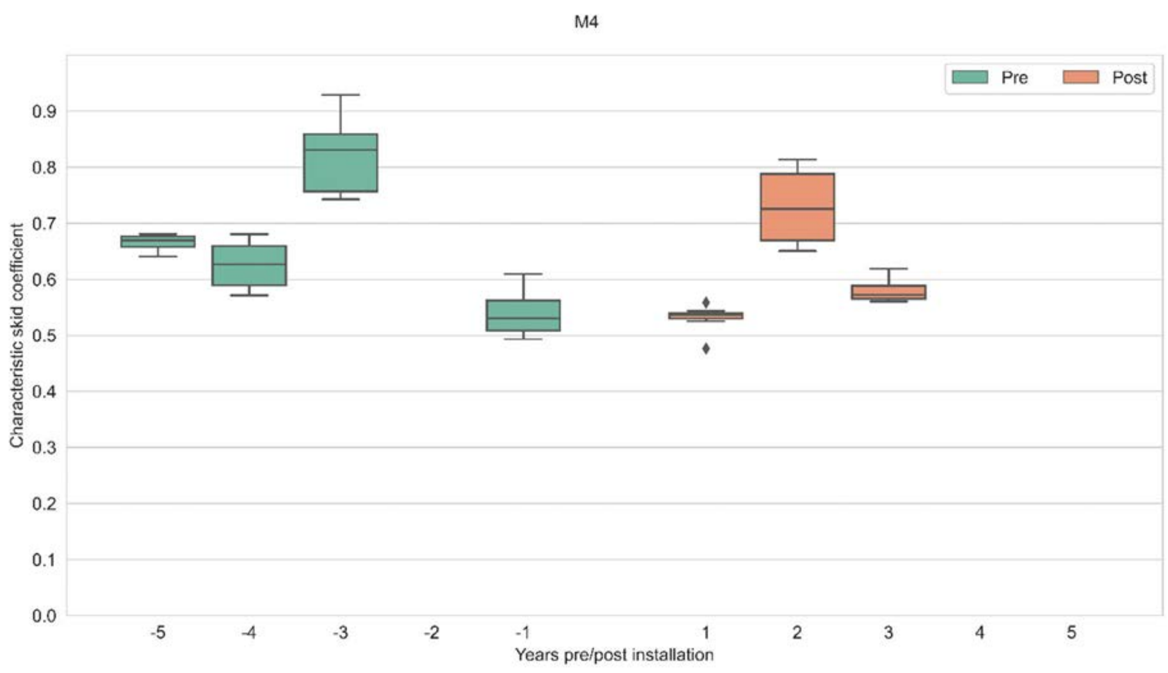

Figure 28. Time evolution of CSC for pre-installation material and Material B on the M4 J4 EB Exit Slip L1 Section M40430/124

3.4.3 Discussion and conclusions

Based on the analysis the following conclusions can be drawn:

- There are limited sites laid with Material B of sufficient length to analyse CSC performance.
- The performance of Material B is comparable to the asphalt pre-installation material on the M1 section.
- The performance of Material B is comparable to the HFS pre-installation material on the M4 section.
- The CSC of Material B appears to be initially impacted potentially by the presence of a binder film over the aggregate at the surface. Note: Material A is gritted to remove the binder film.
- The CSC of Material B appears to reduce significantly 3 to 4 years post-installation. This aligns with previous studies of high-PSV materials. However, there is limited post-installation data to make any meaningful judgment on the performance of Material B.

4. Conclusions and recommendations

An assessment has been made of the performance of the two materials at each site (Table 4.1), in which ✓ indicates the CSC is above the indicated level at all locations, ~ indicates the CSC may fall slightly below the indicated level, and ✗ indicates that the CSC was significantly below the indicated level in some locations. The lowest CSC at each location has been assessed, since the lowest CSC may coincide with the apex of a bend where the friction demand may be at its highest.

Table 4.1 Summary Table

Material	Site	AADT (CV/L/D)	CSC Achieved		
			0.45 IL	0.5 IL	0.55 IL
Material A	A64 Exit Slip	387	✓	✓	✗
	A64 Entry Slip	511	✗	✗	✗
	A628 EB	750 – 1000	✓	✓	~
	A628 WB	750 – 1000	✓	✓	✗
	M25 J5 CW	3700	✓	~	✗
Material B	M1 J5 SB Exit Slip	750 – 1000	✓	✗	✗
	M4 J4 EB Exit Slip	1000 – 2000	✓	✗	✗

4.1 Materials containing high-PSV natural aggregate

Based on the performance of a very limited length resurfaced using Material B, the CSC of these materials appears to deteriorate after 3 to 4 years' service life and will struggle to deliver at locations with high traffic and high stress if an IL above 0.45 is required. Furthermore, the initial CSC delivered by the material can be lower than the IL, potentially due to the presence of a binder film on the aggregate. This may present additional risk to the road user in early life.

4.2 Materials containing calcined bauxite

Based on the performance of several examples of Material A, materials containing calcined bauxite offer superior performance compared with materials containing only high-PSV natural aggregate. In most locations they achieved, or came close to achieving a CSC of 0.5. However, it is unlikely that an IL of 0.55 is achievable.

The average CSC values were lower than for HFS at comparable sites. However, the difference between HFS and Material A was less marked when considering the minimum values at each location, which could be expected to represent the most critical lengths. Therefore, in some scenarios, these materials could offer improved whole life cost value owing to purported enhanced surface integrity durability versus HFS.

As demonstrated by comparison between the M25 site and A64 site, it appears to be the site geometry, rather than traffic levels that has the impact on the CSC being maintained.

4.3 Left vs right bends

As expected, lower CSC values are observed on right bends than left bends. The requirement, in DMRB CS 228 Revision 2, to examine data at 10 m intervals on bends (Clause 6.3) remains sensible given the variation in CSC that is observed over short lengths.

Regarding Note 3 to CS 228 Clause 6.8.1 (reproduced below in Figure 29), the 0.05 units CSC reduction in the offside of left bends is consistent with the observations here. However, based on this analysis, a difference of this scale does not necessarily require the combination with traffic braking or acceleration. It is recommended to remove this reference, as it is potentially obscuring the issue, and introduce an assumption that the skid resistance of the sharpest point of left bends is 0.05 lower than the CSC value measured.

NOTE 3 If a site contains a sharp bend to the left in combination with traffic braking or accelerating then the offside wheel path can become more polished and the CSC can be up to 0.05 units lower than in the nearside wheel path.

Figure 29. DMRB CS 228 Clause 6.8.1 NOTE 3

4.4 Recommendations

Based on the findings of this study, the following recommendations are made:

1. At present, continue to require HFS as currently outlined in CD 236, using the results of this study in the assessment of future Departure from Standard applications. Specifically, to be cautious of approving high-PSV natural aggregate materials in high-traffic, high-stress applications. Materials containing calcined bauxite are more likely to deliver the performance needed.
2. Engage with content specialists within National Highways, namely from the Technical Assurance and Governance Group (TAGG), to understand permitted options for incorporating proprietary materials such as Material A into Standards, noting that materials conforming to a harmonised European Standard might have equivalent performance characteristics and may also need to be permitted options under a future specification clause. It is envisaged that a product approval system incorporating a type approval installation trial (TAIT), assessing CSC performance for a minimum of 5 years would be a minimum requirement. In addition product specific limitations akin to historical limitations on thin surface course systems related to site stress levels should be explored. Table 3.3a and 3.3b in DMRB CD 236 could then be amended to permit HFS or appropriate other materials subject to meeting site stress level criteria or similar.
3. CSC guarantees could be considered as a condition for Departure from Standard application acceptance. However, while this could be appropriate for established, premium products, it may reduce innovation and the uptake of alternatives to HFS.
4. Establish a whole life cost and whole life carbon calculation methodology for alternative materials for comparison with HFS, to be considered when assessing Departure from Standard applications.
5. Extend this research in successive years when additional CSC data becomes available so that CSC trends can be further understood. In addition, gather data from further verifiable sites with different characteristics and additional materials if used. Material A sites with site categories Q or K have not been reviewed as part of this study due to lack of available CSC data. Similarly, Material B sites with site categories S1 or S2 have not been reviewed as part of this study due to lack of verifiable sites. Provided sites are available and verifiable, future work could expand on this study to encompass the range of sites where these materials would be installed. This could be linked to a detailed investigation of how CSC is linked to site geometry, since it appears that geometry may be useful as well as traffic, in specifying requirements.
6. Support industry to innovate and bring forward new products, particularly those containing calcined bauxite, by facilitating laboratory (including friction after polishing) and field testing using National Highways' equipment, and by considering providing financial support for such testing. The lack of products available as alternatives to HFS gives rise to a lack of competition which may have a financial impact to National Highways.
7. Amend the DRMB to:
    a. clarify the definition of HFS in CD 236, referencing to BS 8870 when published.
    b. revise Note 3 to Clause 6.8.1 in CS 228 as noted above, at the next opportunity.

5. References

Friel, S., & Woodward, D. (2019). High Friction Surfacing Systems Using Blends of Natural Aggregate and Calcined Bauxite. *Coatings*, 1-16.

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National Highways. (2020). *Design Manual for Roads and Bridges CS 228 Skidding Resistance.* London: National Highways.

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Appendix A

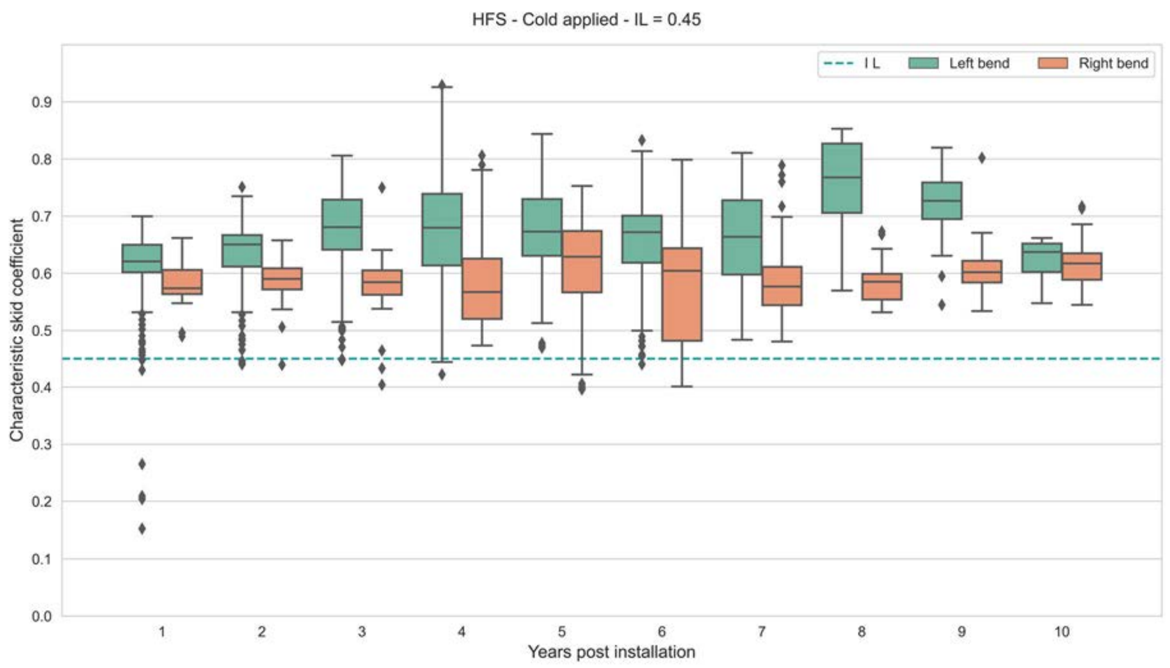

Figure 30. Time evolution of the CSC of cold applied HFS on 0.45 IL sites, sites split by left bend vs. right bend

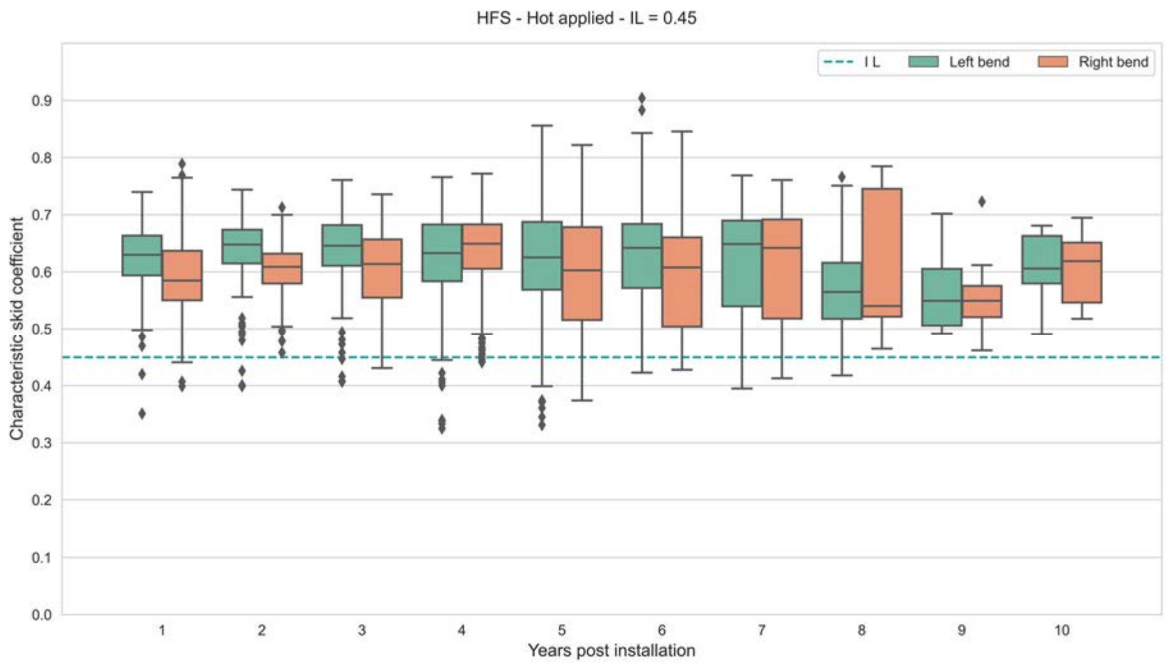

Figure 31. Time evolution of the CSC of hot applied HFS on 0.45 IL sites, sites split by left bend vs. right bend

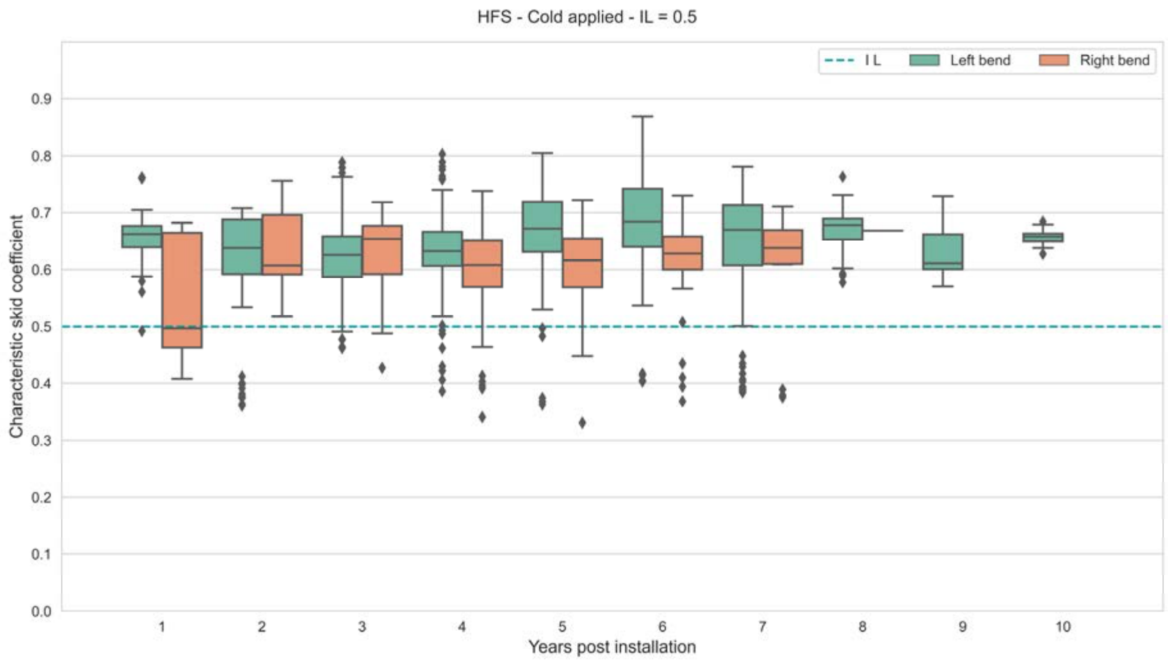

Figure 32. Time evolution of the CSC of cold applied HFS on 0.5 IL sites, sites split by left bend vs. right bend

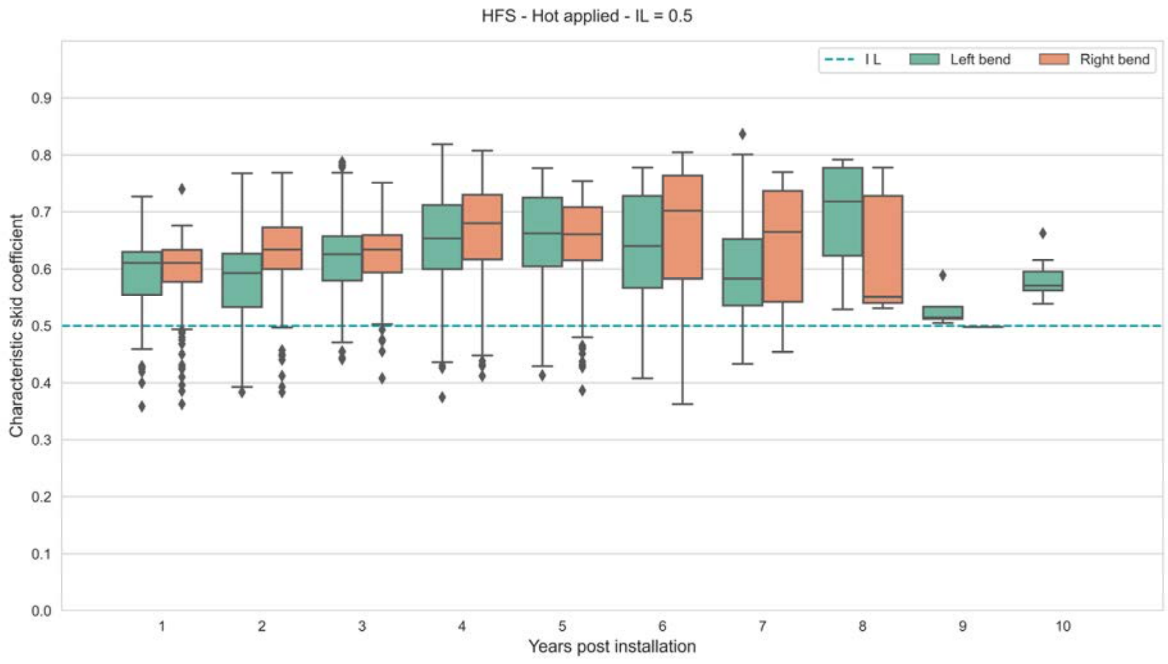

Figure 33. Time evolution of the CSC of hot applied HFS on 0.5 IL sites, sites split by left bend vs. right bend

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