



Optimization of Thin Asphalt Layers – State-of-the-Art Review

By Ulf Sandberg* (ed.), Jørgen Kragh, Luc Goubert***, Hans Bendtsen**, Anneleen Bergiers***, Krishna P. Biligiri*, Robert Karlsson*, Erik Nielsen**, Erik Olesen**, Stefan Vansteenkiste*****

*Swedish National Road and Transport Research Institute (VTI)

** Danish Road Institute (DRI)

*** Belgian Road Research Centre (BRRC)



Photo by Hans Bendtsen

PREFACE

ERA-NET ROAD is a consortium comprising national European road administrations. Its purpose is to strengthen European road research by coordinating national and regional research programmes and policies.

In 2009 ERA-NET ROAD issued a call for tenders on a transnational research project titled “Optimization of thin asphalt layers”. The project is coordinated by a Project Executive Board with representatives of six European road administrations:

- **Mats Wendel** (chair), Swedish Transport Administration, **Sweden**
- **Thomas Asp** (secretary), Swedish Transport Administration, **Sweden**
- **Tony K. Andersen**, Ministry of Transport, Danish Road Directorate, **Denmark**
- **Jostein Aksnes**, Norwegian Public Roads Administration, **Norway**
- **David Lee**, Department for Transport, Highways Agency, **United Kingdom**
- **Christian Pecharda**, FSV; Austrian Association for Research on Road - Rail – Transport, Federal Ministry of Transport, Innovation and Technology, **Austria**
- **Christiane Raab**, Empa, Swiss Federal Laboratories for Materials Testing and Research, Swiss Federal Roads Authority, **Switzerland**

The Project Consortium consisting of the Danish Road Institute, the Belgian Road Research Centre and the Swedish National Road and Transport Research Institute won the tender and the project was initiated 1 July 2009. The researchers carrying out the project are the authors of the present report with support from colleagues with special expertise.

The project acronym has been "OPHTHINAL", derived from the project title “Optimization of thin asphalt layers”.

The present report documents the results of a State-of-the-Art Review which is the first project deliverable. This is the second edition of the report, the first edition was delivered in May 2010.

The Final Report of this project was delivered 2010-12-17, and updated (edited) 2011-03-15. Authors: Jørgen Kragh (ed.), Erik Nielsen, Erik Olesen (DRI), Luc Goubert, Stefan Vansteenkiste, Joëlle De Visscher (BRRC) and Ulf Sandberg, Robert Karlsson (VTI). Title: Optimization of Thin Asphalt Layers - Final Report It will be published by ERA-NET Road.

CONTENTS

ABSTRACT	IX
ABBREVIATIONS AND ACRONYMS	X
EXECUTIVE SUMMARY	XIII
1. INTRODUCTION	1
2. PURPOSE AND LIMITATIONS	2
2.1 Purpose	2
2.2 Limitations	2
3. BASICS AND HISTORY OF THIN ASPHALT LAYERS	3
3.1 What characterizes a thin asphalt layer?	3
3.2 Terminology and standards	7
3.2.1 General	7
3.2.2 TAL in this project	7
3.2.3 Terminology and standardization in CEN	8
3.2.4 Terminology in PIARC	10
3.3 Historical review	10
4. METHODS AND SOURCES OF DATA COLLECTION	12
4.1 Overview	12
4.2 Questionnaire and interviews	12
4.3 Literature searches and databases	12
4.3.1 Transportation research database	12
4.3.2 Personal networking and contacts with colleagues	13
4.3.3 Essential conferences	13
4.3.4 Work with TAL within the consortium	14
5. SUMMARY OF THE INVENTORY	15
5.1 Overview of responses	15
5.2 TAL usage according to the inventory	16
6. THE USE OF THIN ASPHALT LAYERS	20
6.1 Time trends	20
6.2 The drivers for the use of thin asphalt layers	21
6.3 Where thin asphalt layers may not be the optimum choice	24
6.3.1 Words of caution related to wear resistance and bearing capacity	24
6.3.2 Words of caution related to grooved rumble strips	24
6.4 Types of roads and traffic where thin asphalt layers are useful and popular	25
6.5 Families and categories of thin asphalt layers	26
6.5.1 Introduction	26
6.5.2 Product families according to the CEN 13108 series of standards	27
6.5.3 Proprietary pavements	28
6.5.4 Asphalt rubber thin layers	28
6.5.5 Remixing and other recycling into thin layers	31
6.6 Effect of climate on the preference for thin asphalt layers	32
6.6.1 Dry versus wet climate	32
6.6.2 Hot versus cold climate	33
6.6.3 Thin asphalt layer performance in cold region – Example from Japan	35
6.6.4 Interaction with studded tyres	36
6.7 Countries or regions with policy-driven use of TAL	38
6.8 Use in ERA-NET ROAD countries compared to other countries	40

7.	PERFORMANCE: SPECIAL KEY PROPERTIES	42
7.1	Macrotexture	42
7.2	Skid resistance	42
7.2.1	International survey	42
7.2.2	French experience	42
7.2.3	Danish measurements	43
7.2.4	Experience in the United Kingdom	44
7.2.5	Experience in the Netherlands	45
7.3	Influence on road traffic noise	45
7.3.2	Noise optimization of thin layers	46
7.3.3	The Kastrupvej example	47
7.3.4	French experience	49
7.4	Influence on rolling resistance	50
7.5	Thickness and weight advantages	52
7.6	Economy	53
7.7	The special properties of asphalt rubber thin layers	55
7.7.1	Cost Considerations	55
7.7.2	Energy Savings Considerations	57
7.7.3	Reduced Thickness Design Considerations	57
7.7.4	Life Cycle Cost Considerations	58
7.7.5	Main conclusions from Swedish seminar in 2010	58
7.8	Overall assessment of TAL performance in the U.K.	59
7.9	Other performance properties	60
8.	SUMMARY OF PERFORMANCE	61
9.	SYSTEMS FOR CHECKING OR VERIFYING TAL PERFORMANCE	63
10.	MIX DESIGN AND OPTIMIZATION OF TAL	63
11.	CONCLUSIONS	64
12.	ACKNOWLEDGEMENTS	67
13.	REFERENCES	68
	APPENDIX A: QUESTIONNAIRE AND INTERVIEWS	76
A.1	Questionnaire	76
A.2	List of addressees for questionnaires	78
A.3	Results of the interviews	79
A.3.1	Summary of interview with an expert from the Netherlands	79
A.3.2	Summary of the interview with a Norwegian panel of specialists	79
A.3.3	Summary of the interview with a Swiss specialist	83
A.3.4	Summary of the interview with a panel of Austrian specialists	86
A.3.5	Summary of the interview with an Italian specialist	89
A.3.6	Summary of interviews with Danish specialists	90
	APPENDIX B: OTHER ASPECTS OF PERFORMANCE	94
B.1	DURABILITY	94
B.1.1	Ageing	94
B.1.2	Acoustical durability	95
B.1.2.1	Danish long time experiment on acoustical durability	95
B.1.2.2	Norwegian long time experiment on acoustical durability	98
B.1.2.3	Acoustical durability of Dutch thin layers	99
B.1.3	Wear by traffic	100
B.1.3.1	General	100
B.1.3.2	Danish project HOLDA	100

B.1.4	Typical lifetimes.....	101
B.1.5	Possibilities of restoring a deteriorated TAL	102
B.2	MISCELLANEOUS PERFORMANCE PROPERTIES	103
B.2.1	Other surface characteristics	103
B.2.1.1	Megatexture and evenness	103
B.2.1.2	Light and glare properties	104
B.2.1.3	Drainage, splash and spray	105
B.2.2	Emission of inhalable particulate matter into the air.....	108
B.2.3	Structural strength and bearing capacity	109
B.2.4	Use of natural resources	110
B.2.5	Construction-related aspects	111
B.2.5.1	Paving equipment.....	111
B.2.5.2	Laying time and traffic closure	112
B.2.5.3	Maintenance and rehabilitation	114
B.3	SUSTAINABILITY ASPECTS.....	115
B.3.1	Sustainable construction.....	115
B.3.2	Criteria for determining end-of-life.....	115
B.3.3	Recycling properties.....	115
B.3.4	Energy consumption and emissions during transportation	118
B.3.5	Potential effects of climate change.....	119
APPENDIX C: SYSTEMS FOR CHECKING OR VERIFYING TAL PERFORMANCE .		120
C.1	CE-marked products according to the EN 13108 series	120
C.2	Proprietary products	120
C.3	Noise-related classification	121
C.3.1	HAPAS in the United Kingdom.....	121
C.3.2	C_{road} in the Netherlands.....	122
C.3.3	SRS system in Denmark.....	123
C.3.4	Dutch COP testing system.....	124
C.3.5	CEN Noise Classification System.....	124

ABSTRACT

ERA-NET ROAD initiated a transnational research project titled “Optimization of thin asphalt layers”. The DRI-BRRC-VTI Consortium was trusted with carrying out the project and began with a State-of-the-Art report covering, among other things, a literature study and an inventory of experience with using thin asphalt layers (TAL). The results of this phase of the project are given in the present report.

This study was limited to thin asphalt mixtures with a maximum thickness of 30 mm, which means that surface dressings or slurry seals were outside the scope of the project. Neither were top layers of double-layer porous pavements considered as TAL, even though such top layers often are 20-30 mm thick. Mix design and optimization was the subject of another study in this project and is therefore not treated here.

The main conclusions are that the application of TAL is certainly worthwhile, in particular as a renewable “skin” of a stable road construction having sufficient bearing capacity. The skin serves road users’ need for sufficient skidding resistance and other important functions.

The use of TAL seems to be increasing due to the needs of road administrations for cost effective maintenance of the road infrastructure which, in many ways, are consistent with the needs for lower traffic noise levels in residential areas near major roads, which may be one of the positive effects when a TAL is applied.

The environmental impact of road transport CO₂ emission is currently widely discussed. Road surface characteristics are one of the parameters that influence rolling resistance and hence energy consumption and CO₂ emission. TAL offer relatively low rolling resistance because of their favourable surface texture. Therefore they may have a positive impact on the reduction of CO₂ emissions.

The report attempts to evaluate the various properties of TAL, comparing with more conventional and traditional surfacings such as dense asphalt concrete 11 or SMA 11. TAL in general comes out somewhat better than the references in most respects; for example concerning cost, use of nature resources, rolling resistance, and traffic noise emission.

However, there are also problems, for example concerning durability under severe traffic, and bearing capacity (very little extra capacity provided by TAL). If studded tyres are used the wear of TAL is usually significantly worse than the wear of thicker pavements with larger chippings although there are special TAL with larger chippings than is usual in TAL, which are well adapted for this purpose.

There are several special types of TAL; not the least a huge variety of commercial products offered on the market; so-called proprietary TAL. A special type of thin layer is the asphalt rubber surfaces, presently under trials in Sweden for adaptation to north European climate and conditions. In USA, some of these layers are paved as thin as half an inch (approximately 12 mm) and yet they provide very good performance.

ABBREVIATIONS AND ACRONYMS

In the table below, acronyms and abbreviations used in the report are explained.

AADT	Annual Average Daily Traffic
AC	Asphalt Concrete
AOC	Attestation of conformity
A _N	Abrasion value according to EN 1097-9 (percent fragmented material in Nordic abrasion test)
AR	Asphalt rubber (binder which contains 15-20 % by weight of rubber granules)
ASTM	American Society for Testing and Materials
BBTM	Very thin asphalt concrete (used in CEN, abbreviation from the French name Beton Bitumineux Tres Mince)
BBUM	Beton Bitumineux Ultra Minces (ultra thin asphalt concrete)
CEN	European Committee for Standardization
CPX	Close Proximity (method) (tyre/road noise measurement close to a test tyre, often using a trailer)
DAC 11	Dense(-graded) asphalt concrete, with maximum aggregate size 11 mm
dB	decibel, unit for sound pressure level, re. 20 µPa
dB(A)	dB, the sound signal has been filtered by the standard A-weighting filter
DVS	Dutch Centre for Transport and Navigation
ΔC_{road}	Dutch correction for road surface influence on traffic noise
EOTA	European Organization for Technical Approval
ETA	European Technical Approval
HAPAS	Highway Agency Product Approval Scheme (UK)
HSE	Health, Safety and Environment (Occupational consideration etc. etc.)
ISO	International Organization for Standardization
LCC	Life Cycle Cost
LCA	Life Cycle Assessment

MPD	Mean profile depth according to ISO 13473-1
NMAS	Nominal Maximum Aggregate Size (typically the smallest sieve size which allows all the aggregate to pass the sieve).
PA	Porous Asphalt, sometimes also called drainage asphalt
PAC	Porous asphalt concrete, pervious asphalt, drainage asphalt
PAC	Polycyclic Aromatic Compounds (often used to describe cancerogenic compounds originating from coal tar products).
PIARC	World Road Association (comes from the original name Permanent International Association of Road Congresses; the latter not used any more)
PMB, PmB	Polymer modified bitumen (typically related to EN 14023)
PMS	Pavement management system
RA	Reclaimed Asphalt (European term linked to EN 13108-8)
RAP	Reclaimed Asphalt Pavement (US term)
RR	Rolling resistance
RRC	Rolling resistance coefficient
SoA or SotA	State-of-the-Art
SMA	Stone mastic asphalt (Europe), or Stone matrix asphalt (USA)
SPB	Statistical Pass-By (method) (statistical analysis of individual vehicle noise levels from several vehicles measured 7.5 m from the centre of the lane)
STA	Swedish Transport Administration (formerly SRA = Swedish Road Adm.)
TAL	Thin asphalt layer or Thin asphalt layers
ToR	Terms of Reference
TRL	Transport Research Laboratory in the UK (nowadays called TRL Limited)
TUG	Technical University of Gdansk in Poland
UL-M	Ultra mince (ultra thin), from family BBUM
UTLAC	Ultra Thin Layer Asphalt Concrete, according to EN 13108-9, EOTA Guideline, or proprietary product
UTBWC	Ultra Thin Bonded Wearing Course
WG	Working Group (such as in CEN or ISO)
ZOAB	Very open asphalt concrete, porous asphalt

EXECUTIVE SUMMARY

ERA-NET ROAD initiated a transnational research project titled “Optimization of thin asphalt layers”. The DRI-BRRC-VTI Consortium was trusted with carrying out the project and began with a State-of-the-Art report covering, among other things, a literature study and an inventory of experience with using thin asphalt layers (TAL). The results of this phase of the project are given in the present report.

The main conclusions are that the application of TAL is certainly worthwhile, in particular as a renewable “skin” of a stable road construction having sufficient bearing capacity. The skin serves road users’ need for sufficient skidding resistance and other important functions.

The use of TAL seems to be increasing due to the needs of road administrations for cost effective maintenance of the road infrastructure which, in many ways, are consistent with the needs for lower traffic noise levels in residential areas near major roads. This may be one of the positive effects when a TAL is applied.

The environmental impact of road transport CO₂ emission is currently widely discussed. Road surface characteristics are one of the parameters that influence rolling resistance and hence energy consumption and CO₂ emission. TAL in general offer relatively low rolling resistance because of their favourable surface texture. Therefore they may have a positive impact on the reduction of CO₂ emission. Furthermore, since TAL only requires a thin skin of material, superior materials can be used in lesser quantities, thus reducing the road administrator induced CO₂ emissions associated with extraction, manufacturing and transport of these materials.

The use of TAL in Europe seems to increase although available statistics make it difficult to distinguish between TAL and other hot-mix asphalt.

In the "perpetual pavement" concept the philosophy is that the pavement base has eternal bearing capacity and is paved with a thin long-lasting "skin" of surface layer which eventually – due to water, ageing and other climatic action – must be renewed from time to time.

TAL provide a “skin” with favourable functionalities, such as noise reduction potential, relatively low rolling resistance, relatively good anti-spray properties and efficient light reflection. This has accelerated the use of general product categories and proprietary products addressing these demands, also implying relatively high sustainability and low construction as well as maintenance costs. The fast laying of TAL implies shorter closure to traffic and this favours the use of TAL. Provided the pavement base is of appropriate quality TAL offer solutions to many of the functionalities mentioned above and this is probably why there is immense interest in products of this nature.

Despite this, one shall not forget the problems and limitations associated with TAL. For example, bearing capacity is only marginal in many cases, and resistance to wear from studded tyres is poor, unless one uses large maximum aggregate sizes, in which case the thickness needs to be relatively high. The open-textured or even porous kinds of TAL may offer very good noise properties, but at the expense of limited durability under heavy traffic load; for example in sharp curves or at large gradients. The porosity will also quickly get

clogged by dirt. Another problem worth mentioning is that it is not possible to dismantle TAL by milling with the techniques we have at hand without downgrading the material.

The project group sent out a questionnaire to key experts. Unfortunately, the project team received rather limited response and an interview round was not very successful either. Most respondents mentioned noise reduction as their primary motivation to apply TAL. Also cost reduction and fast paving operations seem to be important motivation, like good resistance of TAL to skidding and rutting. A few respondents mentioned durability problems as a disadvantage.

Policies on applying TAL vary substantially from country to country. Countries with extensive usage of TAL include the UK, Switzerland, Sweden, Norway and the Netherlands. Also Denmark and Austria use TAL relatively extensively. In Sweden, to some extent also in Norway and Switzerland, TAL is used on the highway network, while in the Netherlands and the UK usage is limited to municipal roads or city streets as well as provincial or trunk roads.

The authors have tried to evaluate the potential advantages and disadvantages of applying TAL compared with standard DAC 11 or SMA 16. The three most important advantages are

- Noise reduction
- Lower cost
- Less required working space

Other advantages include, for example, higher skid resistance (at low and medium speeds), improved sustainability in most respects, better rut resistance and faster laying.

The three most important disadvantages are

- Weather conditions while laying TAL are more critical
- Dismantling by milling with present techniques downgrades the material
- Susceptibility to cracking related to substrate deficiencies

Other disadvantages include, for example, susceptibility to ravelling, delamination and frost damage, manual laying is not possible, shorter lifetime, and rather low skid resistance in wet weather for some TAL variants.

Mostly, TAL were found to have fine skid resistance properties, although a few exceptions were reported. Durability of skid resistance was excellent according to a UK study, but several studies reported poor acoustic durability. Still, experience of TAL is too short and much longer time series need to be studied.

The sensitivity of TAL to the weather conditions during laying has been mentioned as a major disadvantage. Road administrations and contractors are often forced - by numerous factors - to apply TAL during cold weather and then their durability may be low. Perhaps this can be counteracted by optimizing the laying process.

TAL must be CE-marked in order to be marketed as complying with an EN 13108-series product standard. These standards specify asphalt mixes, not their final application on the road. The ETAG 16 guideline on ultra thin layers intends to deal with the entire process, including paving operations and the final application. Products complying with this guideline

will probably be an additional route for CE-marking in the future. The impact of this CE-marking on the market still has to be seen in the daily practise of procuring asphalt materials.

At present, classification of pavement acoustic characteristics is limited to declaring product properties in Denmark, the Netherlands and the UK. CEN work on this is at an initial stage. No system exists for checking pavement product conformity of production concerning its noise characteristics.

At least two countries represented in the PEB are highly interested in the effect on TAL of the exposure to traffic with vehicles using studded tyres. The present review concludes that aggregate quality and the proportion of large aggregate are the main parameters determining wear resistance of dense and gap-graded asphalt concrete wearing courses.

The report also discusses the concept of using Asphalt rubber (AR) pavements as thin layers in the various pavement systems. In a broad context, a multitude of benefits of using an AR as a pavement preservation strategy were enlisted, including less reflective cracking, reduced maintenance, excellent durability, less raveling, good rut resistance, good skid resistance and smooth ride, better drainage facilities, reduced tyre/road noise, cost effectiveness, beneficial engineering use for old tyres, and higher energy efficiency.

However, it must be noted that these are the merits of AR typical for the conditions in the USA. In Europe so far, there has been a different scenario when one takes into account the derived benefits of AR, as observed in relation to a few similar pavement strategies of comparable quality. Nevertheless, ongoing research and practical applications, the results of which so far are reasonably positive, will determine whether the AR concept could be a success in Europe as well.

The report indicates that the actual achievement of both excellent functional properties and good durability (lifetime) is nothing which comes easily. In practice, it is often difficult to realise both these requirements simultaneously since they are frequently in conflict with each other. The information made available through this report should, therefore, serve as a basic guideline for achieving the best compromise between the goals.

1. INTRODUCTION

Thin asphalt layers have been used in several European countries and countries outside Europe for more than 15 years with promising results. They seem to be cost effective pavements, fast to build and may have good surface properties. Development in recent years shows that thin asphalt layers can reduce noise, increase traffic safety (skid resistance and forward visibility during wet condition) and be durable.

In the frame of ERANET ROAD II, a call was issued in 2009 for a comprehensive study of this type of road surface. The overall purpose of the study should be to optimize thin and very thin asphalt surfacing with thickness up to 30 mm.

The first phase of the project to study such wearing courses consists in gathering detailed information on the use of thin layers and the experience obtained in Europe and elsewhere, if possible. A literature review has been carried out for this purpose. This review of the literature has been supplemented by an inventory amongst distinguished specialists because the experience of Project Consortium partners is that although knowledge and experience can be found in regular literature, essential information may often remain hidden for example in unpublished research reports from institutes and contractors.

The present State-of-the-Art review has been organized so that after an initial overview of the character and history of thin asphalt layers, the method for searching literature and supplementary information is described and the result of the inventory is summarised. The use of thin asphalt layers and the main reasons for preferring them is dealt with in Chapter 6 while Chapter 7 describes performance characteristics such as skidding resistance, noise and rolling resistance, characteristics which are incentives for future application of thin layers. Durability is a major concern and is dealt with in Annex B. This Annex also describes various surface characteristics such as evenness and the ability to reduce splash and spray, but also constructional aspects such as laying time and traffic closure are mentioned.

Annex B also contains information about sustainability aspects, including recycling of materials and the influence on climate change of constructing and maintaining road infrastructure with thin asphalt layers. Methods and systems for checking the performance of thin asphalt layers are described in Annex C.

A concise summary of findings concerning all performance aspects is presented in Chapter 8.

An essential challenge is to investigate how asphalt technological aspects and performance characteristics are interrelated (some are conflicting) and how they can be optimized. The questions as to how, why and where to use thin asphalt layers is discussed in the present report, and a preliminary overview of advantages and disadvantages (risks) involved when applying thin asphalt layers is attempted.

2. PURPOSE AND LIMITATIONS

2.1 Purpose

The general purpose of the project is to collect, analyse, summarize and report information on asphalt surface layers 10 - 30 mm thick, including all types of hot-mix design and application methods. Proprietary and special products, like types with rubber-modified bitumen shall be dealt with. Focus shall be on asphalt technology aspects and on performance characteristics assessed to be important for future application of thin layers.

The present report on the State-of-the-Art Review carried out by the DRI-BRRC-VTI Consortium aims at documenting the results of literature reviews and an inventory of expert knowledge not yet documented in regular literature.

In the second phase of the work the Project Consortium will attempt at recommending improvement and optimization. Gaps in available knowledge shall be identified and directions shall be pointed at for research needed to fill these gaps.

2.2 Limitations

The study was limited to thin asphalt mixtures, which means that surface dressings or slurry seals were outside the scope of the project.

Focus was on hot mix asphalt. In this connection, so-called warm mix asphalt was considered a special hot mix application.

The maximum thickness was more or less arbitrarily defined to be 30 mm.

Double layers are composite constructions and they have not been considered as being TAL. Thus, double layer wearing courses, even the top layer of such pavements, were outside the scope of the present project.

Mix design and optimization was the subject of another study in this project and is therefore not treated here.

3. BASICS AND HISTORY OF THIN ASPHALT LAYERS

3.1 *What characterizes a thin asphalt layer?*

A "Thin Asphalt Layer" (TAL) is characterized by three main features:

Feature number 1 – Various gradations:

The layer consists of a mix of aggregate particles which follow a size distribution called a gradation, and the aggregates are bonded together by a bituminous binder to a homogenous plant produced mixture. In some cases the application of the material on the road intentionally leads to a heterogeneous layer structure.

Feature number 2 – Surface characteristics in focus:

The Thin Asphalt Layer is the surface layer of the road which means that the functionality – in broad terms – is directed towards the interface between the road structure and tyre or shall display certain properties towards the drivers of the vehicles or other road users.

Feature number 3 – Typical thickness 10-30 mm:

By the Terms of Reference (ToR) for this project the Project Executive Board (PEB) has defined it geometrically as asphalt layers with a thickness between 10 and 30 mm.

To solve some of the "interface issues" mentioned under feature 2 several distinct asphalt material solutions have been developed over the years – sometimes with quite different approaches. The geometrical definition in the ToR cuts horizontally through many separate product types that normally will not be considered close together. The project team has tried to cope with this problem in this State-of-the-Art report and decided to use the abbreviation TAL for "Thin Asphalt Layer(s)" (both singular or plural) to accommodate and abide to the requirement of the PEB. For this reason it must be understood, that TAL will not generally be defined or found in literature outside the scope of this project, as technical literature will not use thickness in the same distinct way as in the ToR of this project.

The abovementioned three features have further consequences or implications that can be derived as follows:

Regarding Feature number 1 – Various gradations:

A homogeneous plant produced mixture means that neither surface treatments nor slurry surfacings will be covered by this project as they have other characteristics. A surface treatment is not a product but the result of an "in-situ" process and does not when applied have a homogeneous structure with a well defined layer thickness. Slurry surfacings are also the result of an "in-situ" process and even though a well defined layer thickness can be

accomplished slurry surfacings are more seen as a maintenance solution rather than as a normal "construction element" in the tool box for new construction.

Regarding Feature number 2 – Surface characteristics in focus:

When Thin Asphalt Layers are identical with surface layers a lot of technical and functional requirements become important in different situations. Texture, skid and wear resistance, noise reducing capability, light reflection can be highlighted just to mention a few items that emerge because Thin Asphalt Layers act as interface to the road users and the surrounding environment. Many of the chapters in this report give details on these aspects.

Regarding Feature number 3 – Typical thickness 10-30 mm:

The geometrical definition in Terms of Reference is presumably intended to give a description of Thin as opposed to Thick. But it will be demonstrated in the next subparagraph and throughout the project that the "thin-thick" issue can have different meaning due to variations in national historical tradition – often linked to traffic intensity level. An example: Some years ago what in France would be considered as a thin asphalt concrete surface layer would at the same time in Denmark be seen as a thick asphalt layer.

The general description of the asphalt materials or pavement solutions covered by TAL will involve characteristics such as:

- Particle size distribution – normally called "aggregate gradation" – which like in Figure 3.1 on the Y axis will show the amount (mass percentage) passing different square sieves as a function of the sieve size plotted on a logarithmic scale in mm
- Binder properties which can be a range of grade of binder, binder percentage and in some cases whether or not the bituminous binder is modified with polymers, crumb rubber or other chemicals to enhance the material properties (the rheology) of the resulting binder
- TAL can be "standard asphalt" just applied in layers between 10 and 30 mm but for some products the pavement solution is unavoidably linked to special features during the paving operation. This is the case for a special family of asphalt materials that requires special conditions for tack coating during paving
- Normally, a tack coat shall be applied on the underlying layer, with the intention to enhance the adhesion of the TAL to the underlying layer. Thus, paving of TAL is a "two-component" procedure, where first a tack coat is applied, followed by applying the TAL mix.

Feature 2 defines TAL as a surface layer and in order to define the role of TAL in the total pavement structure Figure 3.2 shows a typical cross-section on a normal pavement structure used for medium to high traffic intensity. Figure 3.3 and 3.4 show typical surface of two types of TAL. The surface in 3.4 was selected essentially based on its very favourable noise properties.

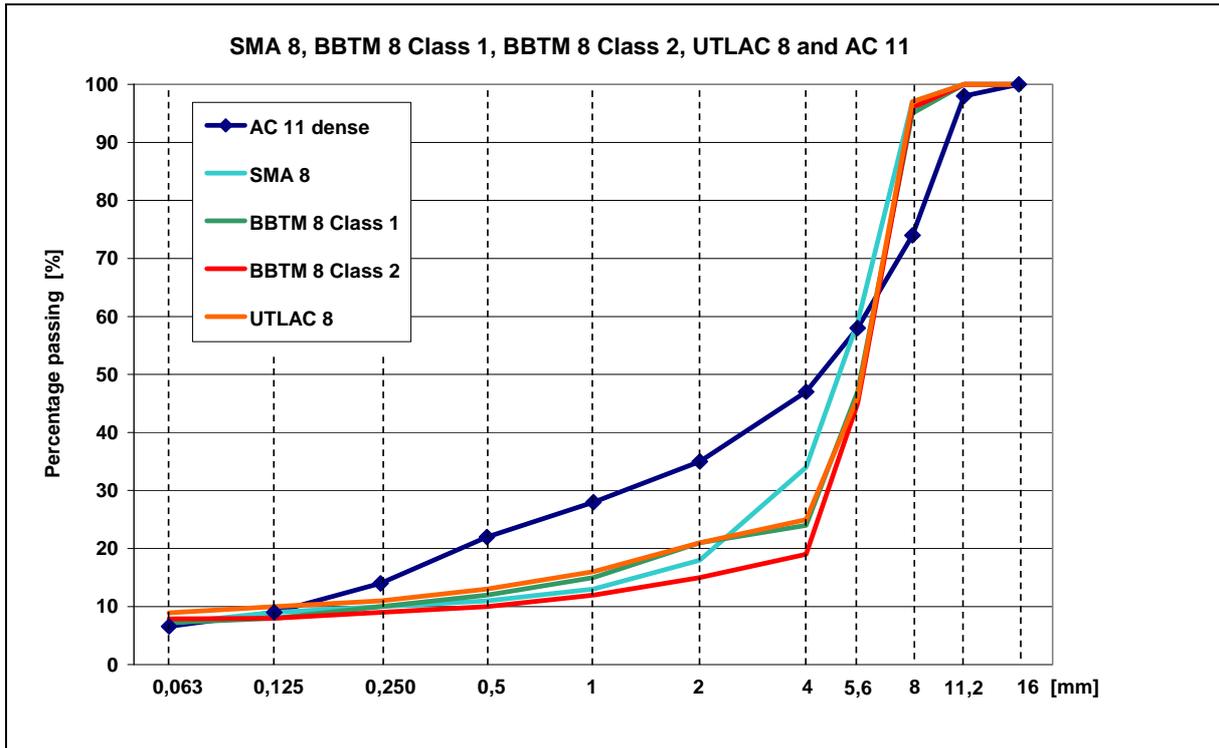


Figure 3.1: Grading curves for TAL from test sections in Denmark (noise-reducing pavements and reference surface AC 11d from the first block of test sections near Herning, Denmark).

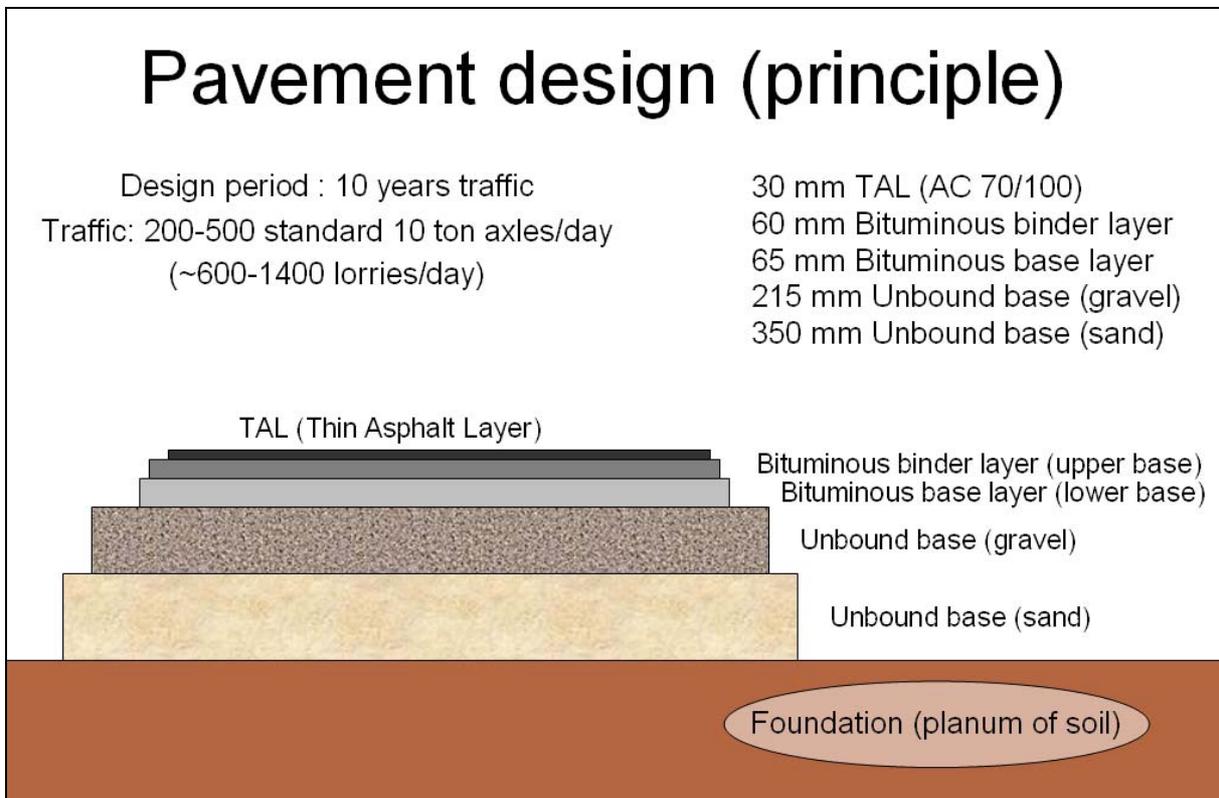


Figure 3.2: Cross-section of a typical asphalt pavement designed for 10 years of traffic.



Figure 3.3: Close-up picture of a two years old thin UTLAC pavement with 8 mm maximum aggregate size. The size of the black and white squares is 10x10 mm.



Figure 3.4: A close-up view of the surface of a proprietary thin asphalt layer called "Microflex", as paved on Kasteelenlaan in Ede; four years old when the photo was shot. The aggregate size is 2-6 mm. The coin is 23 mm in diameter.

Beginning from the top, TAL is the upper layer serving the interface to traffic. The next layer is typically an asphalt binder course or upper bituminous base layer followed by a lower bituminous base. These three layers are the bituminous bonded part of the pavement where the last two provide the bearing capacity. TAL may or may not contribute to the bearing capacity. Further down come the unbound bases of gravel and sand and in the end the soil foundation. Cement or lime treated base layers can also in some countries be used, but in relation to TAL in the pavement structure in this report the main question is: Will TAL contribute to the bearing capacity or not? This will be largely independent of whether the sufficient bearing capacity originates from a stabilized base or from the bituminous layers. The important thing is that sufficient bearing capacity is available at the interface between TAL and the underlying structure.

3.2 Terminology and standards

3.2.1 General

In a survey of performance of UK "thin surfacings", the following categorization was used [Nicholls et al, 2006]:

- Paver-laid surface dressing (PLSD)
Ultra-thin surfacings developed in France
- Thin asphalt concrete (TAC)
Generally with polymer-modified binder
- Thin stone mastic asphalt (TSMA)
Generally unmodified bitumen with fibres
- Multiple surface dressing (MSD)
Binder and aggregate applied separately
- Micro-surfacing (MS)
Thick slurry surfacing, generally with modified binder

3.2.2 TAL in this project

TAL or Thin Asphalt Layers, as defined within this project, are a large family of in-plant produced hot asphalt mixes which can be paved with nominal layer thickness between 10 and 30 mm (see also section 3.1). Consequently, TAL may meet the specifications set out in one of the product standards of the EN 13108-series ('Bituminous mixtures – Material Specifications') or criteria described in the ETAG 16 guideline.

As already mentioned, cold applications such as slurry surfacing as defined in EN 12273 'Slurry surfacing – product standard' are not considered within this project.

It should also be mentioned that the top layer of double-layer porous asphalt, where the top layer is usually 20-30 mm thick, is not considered as TAL, since it is considered as a composite structure together with the bottom layer.

Of the five UK categories presented in the previous section, only the three first would fit the definition in this project.

3.2.3 Terminology and standardization in CEN

With respect to the European normalization framework (CEN) the following documents are of interest:

- EN 13108-1 ‘Bituminous mixtures – Material specifications – Part 1: Asphalt concrete’
- EN 13108-2 ‘Bituminous mixtures – Material specifications – Part 2: Asphalt concrete for very thin layers’
- EN 13108-3 ‘Bituminous mixtures – Material specifications – Part 3: Soft asphalt’
- EN 13108-4 ‘Bituminous mixtures – Material specifications – Part 4: Hot rolled asphalt’
- EN 13108-5 ‘Bituminous mixtures – Material specifications – Part 5: Stone Mastic Asphalt’
- EN 13108-6 ‘Bituminous mixtures – Material specifications – Part 6: Mastic Asphalt’
- EN 13108-7 ‘Bituminous mixtures – Material specifications – Part 7: Porous Asphalt’
- prEN 13108-9 ‘Bituminous mixtures – Material specifications – Part 9: Bituminous mixture for Ultra-thin Asphalt concrete (UTLAC)’
- ETAG 16 “Guideline for European Technical Approval of Ultra Thin Layer Asphalt Concrete

The European standard EN13108-1 constitutes the widest product standard in the EN 13108-series of ‘Bituminous mixtures – Materials specifications’ (see also 6.5.2). The standard sets out the specifications for many types of asphalt concrete for both surface, binder and base layers. In some countries (e.g. Denmark) this standard also embraces the majority of surface layers defined in the ToR as TAL.

The European standard EN13108-2 constitutes a second part of the EN 13108-series of ‘Bituminous mixtures – Materials specifications’ (see also 6.5.2). The standard sets out the specifications for asphalt concrete for very thin layer applications. Asphalt concrete for very thin layers is to be used for surface courses with a thickness of 20 to 30 mm.

The European standard EN13108-3 constitutes a third part of the EN 13108-series of ‘Bituminous mixtures – Materials specifications’ (see also 6.5.2). The standard sets out the specifications for asphalt concrete with very soft binders. The gradations are similar to Asphalt Concrete in EN 13108-1, but several traditional used gradations could not be fitted in EN 13108-1. As many countries did not have experience with these types in the more traffic intensive part of middle Europe the product standard has a dominant Nordic influence. The majority of the mixes in this standard fall within the definition of TAL.

The European standard EN13108-5 constitutes a fifth part of the EN 13108-series of ‘Bituminous mixtures – Materials specifications’ (see also 6.5.2). The standard sets out the specifications for stone or split mastic asphalt or SMA. Such mixes are characterized by a discontinuous grading, a high mastic content and an open surface texture. The thickness of an SMA layer may vary between 25 and 50 mm. Therefore, some SMA-C mixes¹⁾ (nominal

¹⁾ SMA-C and SMA-D refer to Belgian tender specifications, where SMA-C is essentially an SMA 10 (maximum aggregate size is 10 mm), and SMA-D is essentially an SMA 0/6.3.

layer thickness between 30 and 40 mm) and SMA-D mixes (nominal layer thickness between 25 and 30 mm) may be considered as thin asphalt layers.

The guideline for European Technical approval of ultra thin layer asphalt concrete ETAG 16 is at present still a document being drafted within EOTA, but in parallel product specifications for UTLAC are presently subject to CEN Enquiry as prEN 13108-9 after having been drafted in CEN/TC 227/WG 1 (the working group for asphalt materials under CEN Standardization Technical Committee 227, working on road materials in general).

There are important differences within the European standardization between on one hand the asphalt mixes such as very thin layers or SMA-D and on the other hand the ultra thin asphalt layers as defined in the guideline:

- With respect to very thin layers or SMA-D mixes there are test methods available as described in the EN 12697-series: ‘Bituminous mixtures – Test methods for hot mix asphalt’. The 12697-series, consisting of about 45 parts, provides the standardization (and harmonization) of methods to test asphalt mixes. The series does not set out any material specification. Moreover, one disposes of product standards (EN 13108-series) which set out the product specifications. Finally, the latter standards are also linked to EN 13108-20 which defines the ‘initial type testing’ or ITT-study and to EN 13108-21 which sets out the ‘Factory Production Control’ or FPC (internal production control assessment). There is nothing available with respect to paving operations or a quality control of the asphalt mix following the road works.
- With respect to ultra thin asphalt layers or UTLAC:s only a guideline document (ETAG 16) is being drafted within EOTA. The document does not contain any strict specifications but a guide how to characterize the materials in order to fulfil the essential requirements of the European Community. In contrast with the EN 13108-series, where the responsibility for the product standard stops when the “loose mix on the lorry” leaves the asphalt plant, the EOTA guideline describes the entire process, including the paving operations. This is due to the fact that the paving operations for ultra thin layers are more critical in comparison with thicker asphalt layers (>20 mm) in order to guarantee a good quality and durability of the application.

Quite recently (March 2010), a prEN 13108-9 ‘Bituminous mixtures – Material Specifications – Part 9: Bituminous mixture for Ultra Thin Layer Asphalt Concrete (UTLAC)’ has been drafted. The new product standard will deal with the specifications of ultra thin asphalt layers characterized by a nominal thickness of 10 to 20 mm. In analogy with the other standards within the EN13108-series no requirements related to paving operations or quality control following the road work will be included. The latter topics remain within the scope of the ETAG guideline.

It is important to remember that the route through EOTA ends up in an ETA which assures the asphalt producer/asphalt contractor that the company can market a proprietary product not fulfilling a European product standard but through the ETA is capable of having the product CE-marked according to the Road Construction Product directive. Applying for an ETA is a company and product specific application route that is costly. It will perhaps in many cases be more economical for the companies if they can reach the CE marking status through the EN 13108-9. The reason is that they will presumably already have third party inspection on the

premise with regard to CE marking activities linked to other asphalt materials. So, in practise, the ETAG will only have importance for UTLAC products falling outside the framework of EN 13108-9.

The above standards are of direct interest in relation to a large part of the TAL family since their technical properties or characteristics (such as surface texture, skid resistance, noise reducing capacity, etc) to a large extent can meet the functional properties set out especially for this kind of application. Nevertheless, other types of asphalt mixes are also applied with a nominal layer thickness of 30 mm or even less. Such asphalt mixes are described in other parts of the EN 13108 series and will be discussed later in this report.

3.2.4 Terminology in PIARC

Within the PIARC (World Road Association) two terms are related to thin asphalt layers:

- ‘thin asphalt surfacing’: a bituminous surface course with an average laying thickness of 30 to 50 mm (*this seems to be related to the UK definition; see 3.2.1*)
- ‘very thin asphalt surfacing’: a bituminous surface course with an average laying thickness of 20 to 25 mm

As a synonym for surfacing the term overlay is used in both cases. It is unclear if the term surfacing or overlay covers hot mix asphalt applications or also includes cold surfacing techniques. Moreover, a layer thickness up to 50 mm for a thin application seems rather strange.

3.3 Historical review

This paragraph describes in very general terms the historical evolution of TAL, as a detailed historical background is beyond the scope of this report. Even though it may be interesting, it is difficult to cover all the different asphalt products as the evolution is influenced by national developments and regional conditions for traffic intensity, climate and material availability.

MacAdam designed a number of farm road constructions which at that time meant a vast improvement of the bearing capacity but the surface was in general an unbound surface.

As society evolved the population grew and the need for road transport increased. This meant that people living close to the roads were becoming annoyed by dust problems and the traffic intensity demanded some form of capping layer with a better load spreading ability and better riding comfort. This started an era for bituminous solutions. In some cases macadam with a penetrating oil or tar product or oil gravel road was sufficient to combat the dust and bearing capacity problem on the rural roads, but when higher demand was imposed from traffic more sophisticated products were needed. Inspiration of the present day concept of Soft Asphalt evolved from the early developed materials in this period.

In approximately the first third of the 20th century, in larger towns mastic asphalt was applied. Sometimes on cobble stone pavement or on top of cement bound materials².

² If sufficient bearing capacity is present, thin mastic asphalt layers might still be a possibility for TAL. For road applications, price considerations often prohibit the use of mastic asphalt as other solutions are more economical.

Then the development in society called for even higher bearing capacities and the Marshall dense-graded asphalt concrete entered the scene. The concept of TAL was gradually forgotten.

In the later part of the 20th century the demands from road users increased on parameters such as evenness, skid and wear resistance etc., which called for more sophisticated products and applications. Especially in countries or regions where good quality aggregate was scarce a technical-economical incentive for producing a cheaper asphalt material for the bituminous base quickly developed, and the concept of a thinner surface layer (TAL) was reintroduced. This layer could be accepted to be more expensive but was more tailor-made to the needs of the traffic. Due to the oil crisis in the 1970's, wearing courses requiring less material (especially bitumen) became more interesting.

The Novachip process is a surface treatment process that places a thin (12–20 mm)³ and course aggregate hot mix wearing course over a polymer modified tack coat/membrane, using only one piece of special equipment for the paving process. It was developed in 1986 by Screg Routes STP in France, intended to increase skid resistance and seal old pavement surfaces and was suggested as a better alternative to surface dressing, with no loose chippings after the paving process. The following years, a French patent (1989) and a US patent (1990) were registered. The NOVACHIP TM is a registered trademark of Societe Internationale Routiere, which is a subsidiary of Screg Routes STP.

Novachip was then used widely in Europe and USA. However, it never became popular in Denmark as the patent rights were too expensive, while it became popular in the next-door neighbour Sweden. At the present time the patent rights seem to have been released.

By and by in the 1990's, several other proprietary TAL appeared on the market, mainly in France, Netherlands, and the U.K. In the U.K., a system called HAPAS (Highway Authorities Product Approval Scheme) for type approval of proprietary road surfacings was established in the late 1980's, which appeared to be useful as an acceptance system for TAL in the U.K.. The first TAL⁴ certificate was issued in 2000. At the present time, there are 37 "thin surfacings" certified by HAPAS in the U.K.

In the last two decades, other functionalities like anti-spray properties, light reflection, noise reducing capabilities, low rolling resistance, etc., have come along and accelerated both general product categories and proprietary products that address these demands. In the "perpetual pavement" concept it is taken in its extreme form, where the philosophy is that the base of the pavement, having eternal bearing capacity, is paved with thin long-lasting "skins" of surface layer which eventually – due to water, ageing and other climatic action – must be renewed from time to time.

TAL offers the solution to certain or many of the functionalities mentioned above and this is why there is immense interest in products of this nature.

³ In Sweden it is commonly applied as a 20-30 mm thick layer

⁴ The commonly used UK term for thin asphalt layer (TAL) is "thin surfacing"

4. METHODS AND SOURCES OF DATA COLLECTION

4.1 Overview

In order to collect information on the use of thin asphalt layers and the experience obtained in applying such surfacing, a search for and review of literature was carried out. The transportation database was searched for terms containing keywords assumed to cover the field of interest here while proprietary products were searched via Google. In parallel with this search, an inventory was made among institute and contractor specialists who were requested to reveal experience not yet published in regular literature.

The inventory is described in Section 4.2 and the literature search is described in Section 4.3.

4.2 Questionnaire and interviews

A questionnaire was made comprising a list of eight questions about thin layers in order to obtain information which cannot be found in literature. The questionnaire can be found in Annex A.1. The number of questions was deliberately kept low in order to have a reasonable response ratio. The following topics were treated:

- Types of TAL used
- Motivations to use TAL
- Basic documents
- Tests on TAL
- Experience with TAL
- Research needs

The questionnaire was sent to a selection of 23 persons which were expected to have experience in the field (see Annex A.2). These persons originate from eleven different European countries. Seven addressees had responded when this was written.

At the same time, a number of experts were contacted and requested to take part in an in-depth interview about the subject. In this way, experience from six European countries was compiled.

The results of the answers to the questionnaire and the interviews are woven into the following chapters and annexes, while a summary is given in Chapter 5.

4.3 Literature searches and databases

4.3.1 Transportation research database

A literature search was carried out for information on TLA in the Transportation Database (OECD, ITRD, International Transportation and Research Documentation). Products/trade names for TAL were searched in the Google Product or Google.

The keywords listed in Table 4.1 were used as search terms in the Transportation Database. The trade/products names listed in Table 4.2 were used as search terms in Google Products/Google.

The keywords and phrases listed in Table 4.1 were used as search terms in the Transportation Database. The keywords/phrases listed are those that came out with a positive search result. The question marks ("?") are used as a truncation. This means that when searching for “Thin asphalt layer?” the search results will also include references on thin asphalt layers.

Table 4.1: Keywords and key phrases for the search in the Transportation Database.

Thin asphalt layer?	Thin application <u>and</u> wearing course? asphalt
Ultra thin process? <u>and</u> asphalt layer?	Cost effective <u>and</u> wearing course? Pavement?
Asphalt rubber technology	Modified thin asphalt layer?
Very thin asphalt layer?	Very thin surface layer?
Ultra thin asphalt layer?	Ultra thin overlayer?
Modern thin asphalt layer?	Thin stone mastic asphalt <u>or</u> Thin SMA
Thin hot mixture asphalt layer	

Table 4.2: Trade/product names for the search in Google Products/Google.

Safepave	Bitugrib
Euroduit	Nanosoft
Novachip	UTLAC
Masterpave	TLA
TbK or TB K	UL-M
Combifalt	

4.3.2 Personal networking and contacts with colleagues

A search for TAL was carried out through personal contacts to key persons from asphalt companies in Denmark. These companies have been working on research and development of TAL for many years. Some of the asphalt contractors have an international parent company and key persons were asked to promote contacts.

Also a search for information about TAL was carried out among known proprietary TAL products to obtain updated information on the properties. The companies are known to improve their products regularly to keep up with international development of TAL.

4.3.3 Essential conferences

Two of the authors attended a BAFU-OFEV Tagung (seminar) about implementation of Swiss low-noise road surfaces (of which many were thin layers) held in Olten, Switzerland, 9 September 2009.

The Dutch Road Research Institute (DVS) in June 6th 2007 organized a seminar in Delft with the title “Experience with very thin noise reducing layers” as a part of the IPG project on optimizing thin layers for noise reduction. DRI participated in this interesting seminar.

4.3.4 Work with TAL within the consortium

The three members of the consortium have been active during the latest 10 years in various aspects of research, development and full scale testing and demonstration of TAL products. This has been in the framework of EU projects like SILVIA [Thomsen et al, 2006], SILENCE [Nielsen et al, 2006] and in national and international projects. DRI has focused on developing TAL pavements with optimized noise reduction without compromising aspects like traffic safety (skid resistance), durability, etc [Bendtsen & Raaberg, 2007].

In the SILVIA project what might be called a first generation of noise-reducing thin layers were developed and tested in full scale on three urban roads [Thomsen et al, 2006]. In the SILENCE project a second generation of noise-reducing thin layers were developed and tested in full scale on an urban road [Thomsen et al, 2008].

In cooperation with the Dutch Road Research Institute (DVS), DRI has developed and tested first and second generation noise-reducing thin layers for application on highways [Bendtsen et al, 2008; Bendtsen et al, 2009]. As a crucial part of this research information on international experience with TAL has been collected and integrated in the research [Bredahl Nielsen et al, 2005; Bendtsen & Raaberg, 2005].

5. SUMMARY OF THE INVENTORY

5.1 Overview of responses

The following persons responded to the questionnaire:

- Ian Walsh, Jacobs Engineering (UK) Ltd, Maidstone (United Kingdom)
- Jacob Groenendijk, KOAC.NPC, Apeldoorn (the Netherlands)
- Peter J. Andersen, Vejdirektoratet, Copenhagen (Denmark)
- Jostein Aksnes, Statens vegvesen Vegdirektorat, Oslo (Norway)
- Olivier Ripke, Bundesanstalt für Straßenwesen, Bergisch-Gladbach (Germany)
- Erik Van den kerkhof, Colas Belgium, Brussels (Belgium)
- Cliff Nicholls, TRL Ltd, Wokingham, Berkshire (United Kingdom)
- Berwich Sluer, BAM Wegen nv, Bunnik (the Netherlands)
- Kenneth Olsson, Skanska, Farsta (Sweden)

The following persons were interviewed:

- Wim van Keulen (van Keulen advies), Vlijmen, the Netherlands
- Jostein Aksnes (Norwegian Public Road Administration - NPRA, Road Directorate), Geir Refsdal, Rolf Johansen and Jan Lindahl (NPRA, Eastern Region), Olle R. Larsen (Kolo Veidekke), Norway
- Alain Jacot (Société d'Analyses & Contrôles Routiers, SACR), Zürich, Switzerland
- Johann Litzka (Austrian Association for Research on Road - Rail – Transport, FSV), Jürgen Haberl (PMS-Consult, Engineering Office for Traffic and Infrastructure), Peter Riederer (BPS, Oberösterreichische Boden- und Baustoffprüfstelle GmbH), Michael Kostjak (Swietelsky BaugesmbH), Ronald Blab (Vienna University of Technology), Austria
- Gaetano Licitra (ARPAT, Agenzia Regionale per la Protezione Ambientale della Toscana, and University of Pisa), Pisa, Italy
- Bjarne Bo Jensen (NCC Roads A/S), Lars Ladehoff (Colas Danmark A/S), Uffe Mortensen (Pankas A/S), Niels Christoffersen and Uffe Mortensen (Inreco A/S), Denmark

The Danish experts were interviewed by telephone calls by Erik Olesen, the others were interviewed at personal meetings by Luc Goubert.

Most respondents mention noise reduction as motivation for using TAL. Other important motivations are cost reduction and speed of laying. Reduced working space, good skid resistance and good rut resistance are also mentioned as advantages. Few respondents mention durability problems as a disadvantage.

Various ranges of thickness are mentioned, ranging from “15 – 25 mm” up to “25 – 35 mm”. Voids contents vary from 1 % up to 24 %.

The most common bad experience with TAL is ravelling (Figure 5.1 left part) and delamination (Figure 5.1 right part). Also mentioned are substrate-related cracking and frost susceptibility. The good experiences are the noise reduction and the excellent skidding resistance. Various respondents mention specific solutions which have been developed to prevent or at least to reduce the problems with TAL, such as modified bitumen and/or the use of CaO (hydrated lime) to reduce ravelling susceptibility, a special tack coat to prevent delamination, etc.



Figure 5.1: Most common problems with TAL: ravelling (upper left) and delamination (upper right) (photo courtesy of Ian Walsh, Jacobs Engineering (UK) Ltd) compared to TAL in very homogeneous and good condition (N201 in Heemstede, the Netherlands).

All respondents see an important role for TAL in the future, mainly because of the high priority given to the traffic noise problem. Annex A presents the details of the interviews.

5.2 TAL usage according to the inventory

Figure 5.2 shows the area of TAL in absolute figures for some European countries, intended to give an impression of to what extent TAL are used in the countries, and the large variation. The areas have to be considered as approximations and in some cases also as minima; e.g. for Belgium only the area built by Colas is taken into account and in Austria only the TAL on highways is accounted for, as no other values were available. For Sweden, only the national roads are included; while it is known that also communal roads use TAL. Countries not indicated in Figure 5.2 may also have TAL; for example, in France and Spain there is a substantial amount of TAL.

Figure 5.3 shows the percentages of the main road (national) network covered with TAL for some countries (no data available from GB and NL).

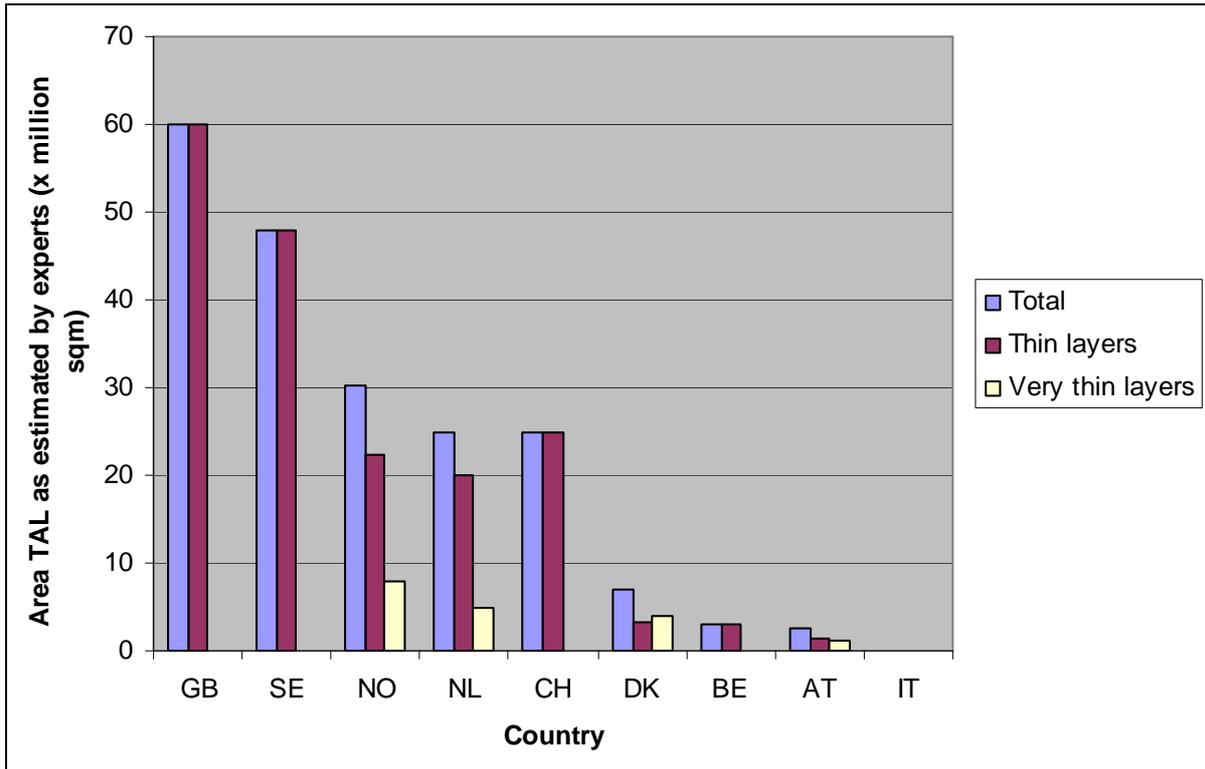


Figure 5.2: Area in millions of square metres of thin and very thin asphalt layers in some countries. Not all roads in the countries concerned are included in these estimates, so the estimated areas must be considered minimum values. Note that according to the interviewed Italian expert, there are no TAL at all in Italy.

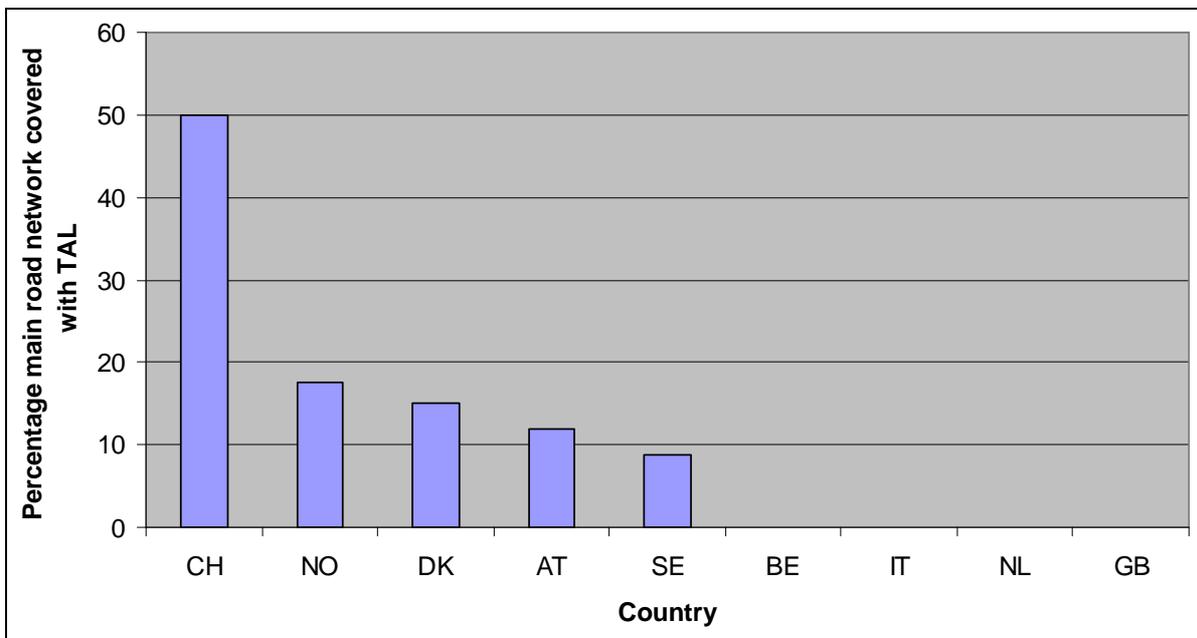


Figure 5.3: Percentage of the main road network covered with TAL; estimates based on interviewed experts. No data are available for GB. NL has a large percentage of TAL on communal roads, but nothing on the main roads.

An uncertainty factor in these diagrams is the different definitions used for TAL. For example, in the U.K. a "thin surfacing" is defined as "a proprietary bituminous product with suitable properties to provide a surface course that is laid at a nominal depth of less than 50 mm" [Nicholls et al, 2006]. This is quite different from the TAL that this report is intended to cover. Other countries may have corresponding national definitions or common terminology which is inconsistent with the TAL definition in this project, and this might have influenced the collected data.

An illustration of how the data in Figure 5.2 is distributed across Europe appears in Figure 5.4. Note that the lack of data for many countries may distort the picture.

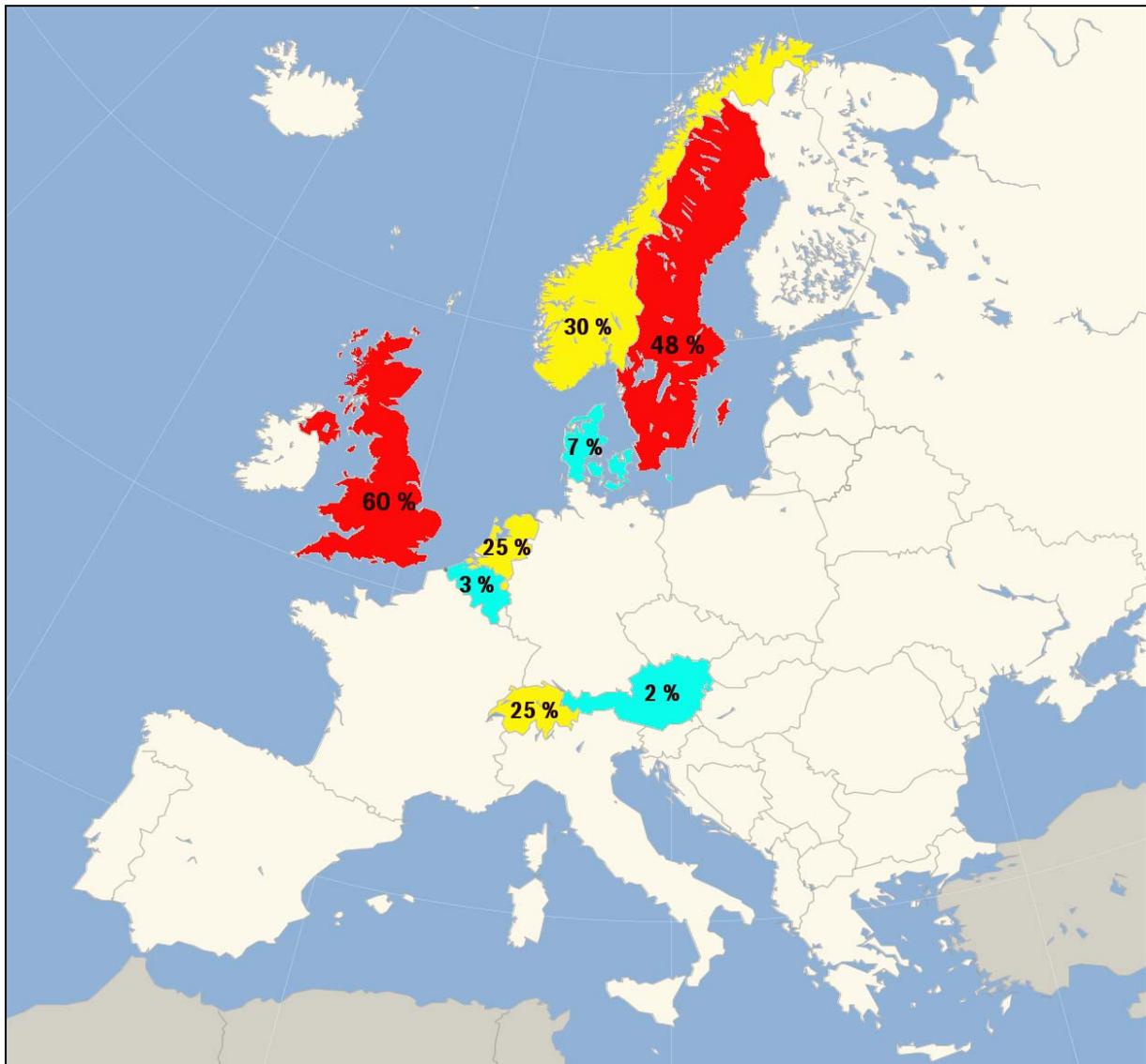


Figure 5.4: The data in Figure 5.2 (for "total", with percentages indicated for each country) illustrated on a European map. Colour codes: Red = Very high usage, yellow = high usage, blue = low to moderate usage, white = no usage or data missing. Note that, for example, France and Spain use TAL extensively, but quantitative data are missing and thus the colour is white.

The Swedish data contain both what is named TSK (tunnskikt), i.e. "real" TAL, but also so-called remixing, which also meets the definition of TAL. It is worth noting that as much as 5 million m² of TSK is laid annually in Sweden; most of it is TSK with NMA = 16 mm, and the trend is increasing [Olsson, 2010].

See further Annex A.

6. THE USE OF THIN ASPHALT LAYERS

6.1 *Time trends*

In the latest decade many countries have moved into a direction where the end-user (the road user) has been put in focus. It has been a challenge both to provide different functionalities of the pavement to the road user and to maintain the achievements from former optimization of other functionalities.

In general the road user has no insight in very important pavement properties like bearing capacity because the road user naturally focuses on visible aspects and experience gained from driving on the road (texture, riding comfort, evenness etc.). This means that for the road users' perception of the road it is virtually the road surface as an "interface" to traffic that counts.

For the road owner/road administration achieving the desired bearing capacity in addition to the road users' demands in the most economical way is normally also linked to optimizing the cost through the use of higher specialized surface layers over thick lifts of stabilized bases or bituminous bases. Due to the very specialized nature of the surface layers they are normally more expensive per tonne than standard dense graded asphalt concrete which means that in order to remain in a competitive market they need to function in smaller layer thicknesses.

On the other hand if a specialized surface layer provides the majority of the needs of the road user, the road owner/road administration can obtain the necessary bearing capacity by using materials and techniques that even though they may have to be used in thicker lifts over the total pavement structure will give a more economical solution.

In the lower part of the construction many options can come into play depending on the local situation and especially material availability. At the bottom soil with low bearing capacity can be upgraded by stabilization with lime. Unbound base layers can also be treated with Portland cement or foam bitumen again in order to upgrade materials (perhaps locally available) with inferior bearing capacity to a higher level.

The thickness of the bituminous base can in these situations be reduced. If surplus amounts of reclaimed asphalt materials are present, the application of bituminous bases with a high amount of recycled material can also be a manner to optimize the total pavement economy.

Combining the incentive of the road users and the road administrations both groups have a common interest towards using TAL for surface layers, so it is a general trend that will only become more and more pronounced.

Even though the general trend is towards TAL it is important to highlight one exception and to give a word of caution.

The exception is when a high level of noise reduction is desired and the pavement structure is demanded to provide as much noise reduction at the source as possible. In this case thick lifts of porous asphalt is needed. And yet again even here TAL shows its possibility. The concept of two layer porous asphalt includes a thin layer of small aggregate porous asphalt as a kind of

filtering layer over a thick lift of coarse aggregate. This combination has shown excellent noise-reducing ability.

The word of caution concerns the fact that even though we have a great variety of highly specialized TAL at our disposal the TAL concept has not solved all problems yet.

As a "Rule of Thumb" a layer thickness is typically between 2.5 and 4 times the nominal maximum aggregate size (NMAS). The general explanation for this is:

- If you pave a layer thickness smaller than 2.5 times NMAS you will experience problems in achieving the sufficient and desired level of compaction and thereby endangering the durability of the pavement.
- If you pave a layer thickness larger than 4 times NMAS you will risk that the traffic loadings will generate permanent deformation (rutting) in the layer.

This means that TAL defined in the project with the defined layer thickness of 10 – 30 mm normally have a NMAS of approximately 12 mm or smaller.

Wear by studded tyres and snow chains is still a major problem in many regions. If your winter conditions call for and allow the extensive use of studded tyres then you might find that TAL with small or medium-sized aggregates is not the optimum surface layer. A "Rule of Thumb" associated to resistance against wear from studded tyres is "The larger the aggregate the better"; typically starting from 16 mm and up. In Norway and Sweden, TAL with 16 mm max aggregate (such as Novachip or similar) are frequently and increasingly used despite severe studded tyres exposure and works fine. These have thicknesses of 20-30 mm [Olsson, 2010], which then "violates" the first explanation to the "Rule of Thumb" above.

Although, the time trend is an increasing use of TAL in most countries, it is not a consistent trend. For example, in the U.K. where TAL and SMA have largely replaced the much noisier and traditional hot rolled asphalt (HRA), especially in municipalities and cities, the trend is a return to HRA at the expense of TAL and SMA, since HRA requires even less of the high-quality aggregate that TAL needs, following the problems to get access to such material in the U.K. [Lee, 2010].

6.2 The drivers for the use of thin asphalt layers

There are many drivers for the use of TAL. This can be deduced from the initial part of the present report. This paragraph will sum up drivers, some of which are generally applicable while others are linked to either certain traffic situations or pavement materials. Depending on your national or regional view you can prioritize them or rank their importance in different order. Some of the drivers act in combination. Because of this some overlapping in the explanations may occur.

Road user's demands (in general):

The demands from road users, the transport sector and the society constitute an ever increasing incentive to optimize the functionalities towards the "interface" to traffic. For some functional properties it means that only the "contact surface" is of interest. As the product becomes more and more sophisticated the price increases, and when only the contact surface is important the layer thickness is minimized in order to stay competitive. An example is

colour of the roads surface where light colour aggregates reflect the light from street lamps in order to save energy (typically electrical energy in urban areas).

Differentiate materials in surface layer and bituminous base layer

Many functional properties are linked to "contact area" or the texture depth of the surface layer. When the properties are not associated to "bulk" properties of the surface layer there is a very strong technical and economical incentive to minimize surface layer thickness as the surface layer normally is more expensive than underlying layers. Examples of properties in this respect can be aggregate characteristics like polish and wear resistance.

Saving natural resources

As natural aggregates of premium quality for road surfaces are either scarce or have to be hauled in over large distances at the expense of fuel consumption (energy and CO₂) and cost TAL can provide a reduction in cost and a better management of natural resources by a slow exploitation rate.

Local/inferior materials for base layers

The TAL-concept leads to the possibility to use an increased amount (relatively) of local material for base layers (less energy consumption and transport cost). Through upgrading local inferior materials to provide an enhanced contribution to the bearing capacity the TAL concept can permit technical-economical pavement structure solutions. Upgrading can take place either through lime stabilization of the soil or through treatment of the unbound pavement layers with Portland cement or foam bitumen.

TAL – functionalities following from small maximum aggregate sizes and open texture

The TAL-concept means that the nominal maximum aggregate size is 12 mm or less. Lowering the NMA to 8 or 6 mm (or even smaller) when you traditionally have used 12 – 16 mm (or even larger) you will experience improved functionality with respect to noise-reducing capability (if open texture types are chosen) and also reduced rolling resistance. The last point at the moment is the subject for several projects worldwide.

Some of the proprietary products within TAL that have been optimized for their noise reducing capability have shown excellent initial noise-reducing effects without having the same clogging problem as porous asphalt. Open textured TAL are virtually "self-cleaning" by the action of the passing traffic.

At some point in the development of noise reducing surface layers many road engineers had serious reservations towards lowering the NMA as it was expected to bring down the skid resistance to an unacceptable level. This has been proven not necessarily to be the case; according to French experience, where the thinner layers have increasing macrotexture and better skid resistance than their conventional counterparts [Bendtsen & Raaberg, 2007].

TAL integrated in the "Perpetual Pavement" concept

The rationale behind the concept of "Perpetual Pavement" is that roads with very high traffic intensity are constructed "once and for all" with respect to bearing capacity while the surface layers are renewed from time to time. TAL is unavoidably an integrated part of this concept. Even though the surface layers are intended to be repaved, extremely high durability is needed because high traffic intensity makes road closures due to maintenance unacceptable on the grounds of traffic delay costs etc. In these cases even very costly artificial aggregate (like

bauxite) may be technically economical due to the high polishing and wear resistance. With such expensive aggregates it is important to minimize the amount used per m².

TAL – speeding-up paving operations

A major favourable feature of TAL is that paving operations may be performed relatively fast, which is very important in order to reduce obstruction to traffic. Fast paving operations also mean cost savings. Part of the reason is the faster cooling of thin layers.

TAL - versatile concept in urban areas due to layer thickness

Resurfacing city streets with kerbs between the road and the pedestrian areas or bicycle lanes will normally involve a lot of manual labour in order to raise the kerbs and adjust the gutters. This part of the rehabilitation job is an expensive part relative to the paving operation. With sufficient kerb height TAL perhaps provide two or even three resurfacings before the curb has to be adjusted for height.

In urban areas flyovers and bridges with roads beneath can cause the authorities extra maintenance burdens. If the road passing under the bridge shows fretting (loss of bituminous mortar) and ravelling (loss of stones) but has sufficient bearing capacity a new surface layer can be paved without having very much influence on the allowed clearance under the bridge. Necessary operations like either excavating the road or elevating the bridge are very costly parts of a rehabilitation project if clearance height is on the brink of being insufficient.

TAL – when mass is important

The report will not deal with specific surfacing solutions for bridges, as especially bridge decks for orthotropic steel bridges are more or less tailor-made in combination with protective membrane built-up. But for surfacing cement concrete bridges asphalt materials developed for the use in TAL may provide a possibility due to their lower mass per square unit compared to traditional pavement solutions.

Now some special drivers for TAL will be mentioned which are associated to specific asphalt material solutions and therefore not applicable to all TAL.

UTLAC – a combination of protective membrane and surface layer

If maintenance shall be performed on an old, worn road surface showing initial fretting and ravelling and perhaps even hairline surface cracks due to ageing (not due to insufficient bearing capacity) a special type of TAL can be an optimum solution. The application of UTLAC means that a large amount of unbroken polymer modified bitumen emulsion is spread just before the hot open graded asphalt mix is placed creating an extremely good bond. As the amount of residual binder from the emulsion is approximately twice the amount from a normal tack coat operation the UTLAC will provide an almost perfect protective membrane shielding the underlying layers from water from above.

Soft asphalt – in case of insufficient frost heave protection

It can not be stressed often enough that the TAL-concept will only provide durable solutions if the surface layer is placed on a structure with sufficient bearing capacity. But on the tertiary road network and in domestic areas where the overwhelming majority of traffic is passenger cars insufficient protection against extreme frost heave can be the case. Either due to the fact that the rural road has developed over time and is not properly constructed or the domestic area was only meant for lighter traffic and a certain risk for frost heave was acceptable from

an economical point of view. In these cases with low to medium traffic the soft asphalts provide a technical-economical solution. Due to the soft binder the material follows the movements of the road structure. In case of extreme frost heave cracks may occur but during the first 3-5 years the binder is capable to close the minor cracks. This is done due to a combination of elevated summer temperature and "massaging" (after compaction) from the traffic until the binder is aged to an extent where the soft asphalt more or less turns into an asphalt concrete.

6.3 Where thin asphalt layers may not be the optimum choice

6.3.1 Words of caution related to wear resistance and bearing capacity

The previous section describes a number of reasons why thin asphalt layers may be preferred. However, some words of caution may be justified: thin asphalt layers may be a poor choice of pavement type in some cases.

First of all, when wear by tyres is exceptional, such as on high-volume roads in countries and regions with a substantial proportion of studded tyres, given that aggregate quality is the same, TAL will generally be worn faster than the thicker pavements do, in case they use small aggregate sizes (and TAL usually do so). See further Section 6.6.4.

A problem exists towards open-textured surfaces which is not unique for TAL but is true for all open-textured mixes irrespectively of their layer thickness. Since TAL often are open-textured, the problem applies to TAL somewhat more than to conventional AC or SMA. In domestic and urban areas where parking or sharp turns occur the surface may have some problems to endure the shearing forces under the tyres. This is especially pronounced in parking areas when the drivers use the servo steering ability available in many cars.

When relatively high bearing capacity of the wearing course is needed, thin layers will not provide this. See further Section 9.3.

6.3.2 Words of caution related to grooved rumble strips

A recently noticed problem in Denmark and perhaps elsewhere, that contains some potential problems for TAL in several respects, is a conflict between different departments within the road administrations. TAL can be produced with excellent noise reducing capability even in very thin layers. Therefore TAL is often chosen as an optimum solution by road engineers considering taking technical, economical and environmental (noise) aspects. Then when the traffic markings shall be placed (thermoplastic stripes between opposing lanes and at the kerb) another department focusing on traffic safety and activities to avoid collisions and drivers falling in sleep demands that rumble strips shall be grooved into the pavement. See an example in Figure 6.1.



Figure 6.1: Grooved rumble strips in TAL on a two-lane highway near Skive, Denmark.

This is of course important, but has two major disadvantages:

1. The grooves increase the noise level tremendously when the traffic occasionally hits them and thereby render the investment in a noise reducing pavement of less value, unless the rumble strips are milled with a sinusoidal shape, see [Kragh, 2007a]
2. Making grooves in a TAL takes away a large percentage of the layer thickness that was intended to protect a perhaps leaner asphalt binder course beneath. This is especially a technical point when the grooved traffic markings are made to prevent head-on collisions, because this could be just over the longitudinal joint of the asphalt materials (both surface layer and for the layers beneath) decreasing the durability of the pavement.

6.4 Types of roads and traffic where thin asphalt layers are useful and popular

The concept of thin asphalt layers is very versatile when applied correctly and when the requirements for its use are fulfilled. The requirements for a durable TAL are:

- The underlying road structure has to provide sufficient bearing capacity. Depending on the nature of the asphalt material may or may not contribute, but if the surface characteristics are open textured or contain a soft binder no additional contribution can be expected.

- The underlying structure shall have the correct evenness and longitudinal and transversal profile, as there is virtually no levelling possibility in TAL without endangering the durability of the layer.
- A tack coat should be applied on the underlying layer before the TAL mix is applied. All asphalt materials need to be tack coated to the substrate and this is also true for TAL. For UTLAC the polymer modified tack coat is especially good.

If the conditions are met different types of TAL can cover all traffic categories and all climates (wet/dry and hot /cold), but the resistance against studded tyres is limited due to the small aggregate size.

Many of the TAL applied today are used for their noise reducing and "anti-splash" capability which is linked to the open texture of the surface.

It is a problem to extract meaningful figures for the use and application of various types of asphalt as many countries interpret the European standard differently. As an example the Road Standards in Denmark (the interpretation national guideline of the European product standards) specify several asphalt types like AC (EN 13108-1), BBTM (EN 13108-2) and UTLAC (prEN 13108-9) according to asphalt concrete. As asphalt concrete include both surface layers and base layers it is not possible to extract data covering the use of TAL. By engineering judgement 95 % of all hot mix surface layers applied in Denmark are in accordance with the TAL definition of this project.

Figures 5.2-5.4 show the total area of applied TAL in a few EU countries.

6.5 Families and categories of thin asphalt layers

6.5.1 Introduction

Based on the geometrical definition of TAL used in this report (hot mix asphalt with a nominal layer thickness < 30 mm), a particular TAL may correspond to one of the European product standards of the EN 13108-series or the ETAG 16 guideline as listed in Section 3.2.2.

It should be noted that based on the functional properties frequently associated with TAL some hot mix asphalt types are generally of less importance such as those described in EN 13108-1 or EN 13108-6. Other types are only used in particular countries or regions within Europe. For example: soft asphalt mixes in Scandinavia or hot rolled asphalt in Ireland or UK.

Reclaimed asphalt or RA is described in EN13108-8 'Bituminous mixtures – Material specifications – Part 8: Reclaimed Asphalt'. Since this standard doesn't deal with a new asphalt layer as such, no further attention will be paid to this standard. Moreover, the use of RA in TAL throughout Europe is probably either very restricted or even not permitted.

In contrast to the situation in Denmark, a large part of all hot mix surface courses in Belgium are not in accordance with the definition of TAL in this report. In Belgium, only about 5 % of all surface layers meet the criteria of EN 13108-2. The use of porous asphalt according to EN 13108-7 is also very limited (about 1 % of all surface courses).

6.5.2 Product families according to the CEN 13108 series of standards

In general, the hot mix asphalt types as described in the EN 13108-series and the ETAG guideline can be divided in two major categories (except for mastic asphalt):

- Hot mix asphalt with a sandy skeleton
- Hot mix asphalt with a stony skeleton

The major difference between the two families is the grading curve. Asphalt mixes with a sandy skeleton are characterized by a continuous grading curve while mixes with a stony skeleton are typically based on a discontinuous grading.

The standards for Asphalt Concrete and Soft Asphalt embrace both types of grading curves even though the discontinuous ones are not as open as some of the other types. The important distinction between Asphalt Concrete and Soft Asphalt is not the gradation but the binder type. Asphalt Concrete is produced with a penetration grade bitumen 160/220 or harder and gives a contribution to the bearing capacity. On the other hand Soft Asphalt uses softer grades of binder than 160/220 (either penetration graded or viscosity graded) and the materials will not contribute to the bearing capacity of the pavement.

Hot mix asphalt with a sandy skeleton is described in EN13108-1 (Asphalt concrete). Such mixes contain a large amount of sand and are characterized by a low void content (typically between 2 and 7 %). Therefore, asphalt concrete is a closed mixture which doesn't meet the functional properties for TAL. Nevertheless, asphalt concrete is used both in base courses and top layers.

Hot mix asphalt with a stony skeleton is described in EN13108-2, EN13108-5, EN13108-7, prEN13108-9 or the ETAG 16 guideline. Such mixes are characterized by a high (>70 %) stone contact and are gap graded (discontinuous grading). Generally, such mixes do contain a high void content (up to 25 % for porous asphalt). SMA, as described in EN13108-5, contains a high mastic (filler + binder) content and is characterized by lower void content, although it still maintains an open surface texture. The latter mixes, due to their favourable surface properties (such as open texture) are frequently chosen as an appropriate top layer.

Mastic asphalt according to EN 13108-6 is characterized by very high mastic (filler + bitumen) content. It is produced at very high temperatures (typically between 180 – 240 °C). Mastic asphalt is a very dense mixture (void content < 3 %). In contrast to all other types of asphalt, mastic asphalt does not require any compaction. In Belgium, mastic asphalt is not used as a top layer (only on bridges, roof parking decks, foot paths or for quick maintenance works during wintertime).

Due to the normally used size of the embedded chippings in Hot Rolled Asphalt (EN 13108-4) and the type of heterogeneous structure from top to bottom of the pavement layer, the material has only theoretical and not practical possibility to fit within the definition of TAL in the ToR.

6.5.3 Proprietary pavements

A commercial market for thin asphalt layers has been established in Europe for more than 10 years now; especially in the Netherlands, France and the UK, and especially focused on the local and urban communities, such as the road and street departments of medium-sized and large cities. Road construction companies have been very active in producing products that answer to this market. Table 6.1 presents a list of such products. These TAL focus on a certain property that they are optimized for; most commonly low noise.

Figure 3.4 shows the surface of a typical advanced proprietary TAL, named Microflex.

Table 6.1: Example of proprietary TAL offered by European road construction companies. These examples are from France, the Netherlands and the UK.

Dubofalt	Novachip	DuraSilent
Nobelpave	Tapisville	Nobelpave HS
ZSM	Fluisterfalt	Deciville
Micropave	Microville	SilentWay
SilenTONE	Decipave	Topfalt
Viagrip	Twinlay-m	Microflex LS
MASTERpave	Stil Mastiek	Microflex HS
Micro-Top 0/6	Bruitville	Microville HS
Micro-Top 0/8	Duolay	Colsoft
Ultraphone	Minifalt	Thinpave
Redufalt	Konwé Stil	UL-M
Accoduit	Rugosoft	Nanosoft

6.5.4 Asphalt rubber thin layers

Asphalt Rubber (AR) is a mixture of 80 % hot paving grade asphalt (bitumen) with 20 % ground tyre rubber produced from waste tyres; also referred to as crumb rubber. Figure 6.2 shows typical crumb rubber granules used in AR pavements. The rubber is added to bitumen at a high temperature and mixed usually in 45-60 minutes with a high shear mixer. After the mixing interaction, the hot AR product acquires unique elastomeric properties. The hot AR is



then pumped into a conventional hot plant and mixed with aggregate and placed like a conventional asphalt concrete (in USA called Hot Mix Asphalt or HMA), except for a few significant differences. The differences relate to the gradation of the mineral aggregate and the percent binder.

Figure 6.2: Crumb Rubber Granules – used in Swedish AR binders in 2007; free of wire and other contaminants. Photo by courtesy of Mats Wendel, Swedish Transport Administration.

The AR hot mix is generally either a gap graded or an open graded mix. The total rubber content is approximately 1.8 % by weight of the total mix in both types. The gap graded mix contains about 7-8 % AR binder and is generally placed as the final structural course 50-75 mm in thickness. The AR gap graded mix (often referred to as ARAC) is a volumetric mix design using the Marshall procedure and designed for 5.5 % air voids. This mix is fairly similar to the SMA pavements used in Europe, except for the AR binder.

A second type of AR mix called the asphalt rubber open graded friction course (simply referred to as asphalt rubber friction course, ARFC) was developed to improve the long term durability and provide good wet weather skid resistance, and less splash and spray. In addition to these good properties it has also been observed (in US conditions) that the ARFC reduces cracking, provides a very good ride quality, and is noise-reducing. The open graded version contains generally 9 % binder, has 18-22 % air voids, and is placed as the final wearing course with a thickness ranging from 12.5 to 25 mm. The maximum aggregate size is typically 9.5 mm. Figure 6.3 shows typical pavement cores of two different sections: one that has three different asphalt concrete (AC) layers, namely, ARFC, ARAC and an existing/new conventional AC layer along with the corresponding typical range of thicknesses as shown in Figure 6.3(a). In Figure 6.3(b), one can observe a two-layer system that comprises an ARFC overlay upon a Portland cement concrete (PCC) structure with corresponding typical thicknesses for each layer. Figure 6.4 shows the typical appearance of the surfaces of ARAC and ARFC.

Thus, a combination of lower aggregate maximum size in the AR, and inclusions of crumb rubber in the mix, consequentially incrementing an increase in the percentage of AR binder content, has made it possible for AR mixtures variants (ARFC and ARAC to a large extent) to be used as thin asphalt layers in the USA and elsewhere. In the USA, AR has been successfully used for over 40 years. Besides being a standard material, it has offered many benefits including less reflective cracking, less maintenance with more durability, less ravelling, good rut resistance, good skid resistance, smooth ride, less splash & spray and better drainage, cost effectiveness, and is environment-friendly. The film thickness of an AR binder is about 19-36 micrometers compared to about 9 micrometer for a typical HMA [Way et al, 2010].

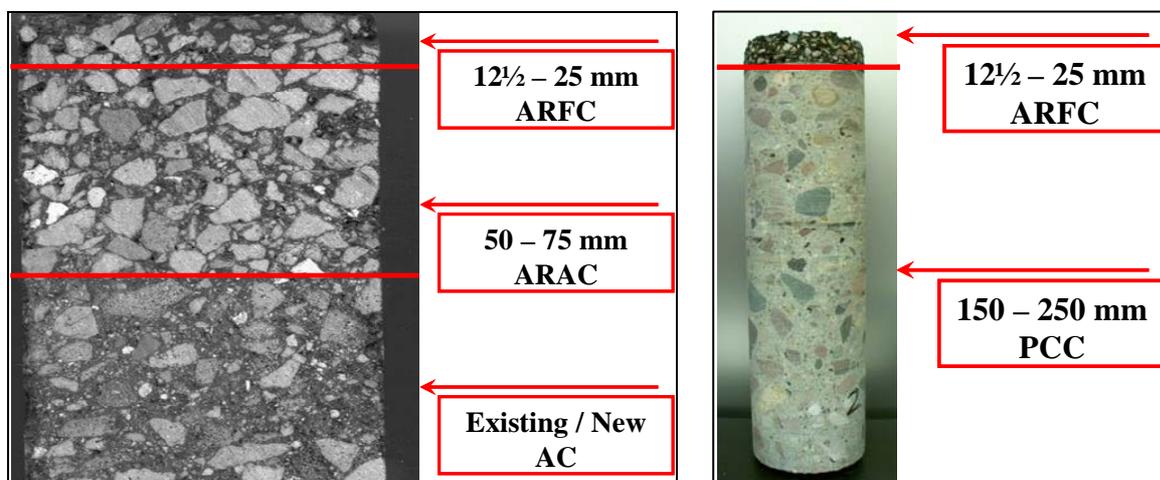


Figure 6.3: Corresponding thicknesses of: (a) Triple-layer ARFC, ARAC, AC, and (b) Two-layer ARFC, PCC.



Figure 6.4: Typical Field Sections of (left) Asphalt Rubber Gap Graded (ARAC), (right) Asphalt Rubber Open Graded (ARFC) [Source: Arizona Department of Transportation].

Between 1989 and 2004, a total of 135 projects were constructed using the ARAC and ARFC mixes, totalling over 33333 lane-km in Arizona. All these projects were built on interstates (motorways) and major arterial roads. As an extra benefit, the ground tyre crumb rubber from over fifty million tyres has been recycled into the Arizona in-service pavements.

Following the successful experience of the Arizona projects, the technical know-how was adopted by the California Department of Transportation (CALTRANS) to develop a reduced thickness design guide for AR mixes using AR gap graded mix as the standard [Kirk & Holleran, 2000]. The various designs have shown that the multi-layer systems using AR binders such as shown in Figure 6.3 have proven to be the most cost-effective. In California, AR is specified to include 18-22 % crumb rubber by total mass of the AR blend. The most commonly used asphalt rubber products in California are RAC-O (Rubberized Asphalt Concrete – Open graded) and RAC-G (Rubberized Asphalt Concrete – Gap graded) with a thickness of 30-60 mm, based on limited experience with thicker layers and economic considerations.

Many other states in the USA, such as Florida, Texas, South Carolina, Washington, Louisiana and New Mexico are also using AR. Furthermore, it is also worth mentioning that a few states in Canada have tried AR pavements.

AR using the wet process, was introduced in southern Europe many years ago; primarily in Portugal and Spain. Currently, the length of roads paved with AR pavements in Portugal and Spain is substantial. The grading of the aggregate and terminology in the Portuguese pavements seems to be a little different than that used in USA, which also is the case for the rubber content. The gap-graded version used in Portugal has a void content of around 14-16 %, which in USA would be similar to an open-graded type. Other countries that have been using AR pavements are Austria, Italy and the Netherlands. Slovenia is starting-up a project on AR in 2010.

In 2007, the Swedish Road Administration (SRA), now reorganized into the Swedish Transport Administration (STA), started a development project to investigate the potential of rubber asphalt pavements for Swedish highways. The objective of the project was to investigate if the AR concept developed and tried in USA could be an interesting alternative for asphalt pavement construction and maintenance in Sweden. It was / is hoped that the long-term effect of the project would be reduced annual and life cycle costs, noise reduction and lower emission of particles as well as improved friction.

The types of AR pavements tested in Sweden so far are listed in [Sandberg, 2010]. The Swedish term for AR is GAP for the dense-graded version and for GAÖ for the open-graded version. Reference pavements have been either SMA 16 or SMA 11.

The thickness of the Swedish AR pavements is generally 30 mm for 11 mm aggregate size and 25 mm for 8 mm aggregate size. Technically, this means that the AR pavements with NMAS 8 or 11 mm are thin layers. Test sections have been laid on various highways, ranging from arterials in cities with 50 km/h posted speed, over regional and national highways with 70-90 km/h posted speed, up to motorways with 110 km/h posted speed. Traffic volume ranges from very small on regional highway to very high on motorways.

Trial sections monitored annually were laid in 2007, 2008 and 2009 [Sandberg, 2010]. Significant noise reductions compared to conventional SMA were noted only for the open-graded variant. Conclusions from a recent seminar focused on the Swedish experience of asphalt rubber pavements suggest that asphalt rubber is a very promising concept also for European conditions, and even in winter climates where studded tyres are used. For seminar presentations and other information, see [Gummiäsfalt, 2010]. The main conclusions from the seminar are presented in Section 7.7.5.

As asphalt rubber has been demonstrated in USA to be a very cost-effective pavement in a very thin version (<20 mm thick) and some of the Swedish tests sections were only 30 mm thick and could well be made thinner, this may be one of the most interesting types of TAL. Therefore, a closer examination of present results would be justified in a later follow-up report.

6.5.5 Remixing and other recycling into thin layers

Hot in-place recycling is a process in which an existing, often rather worn, asphalt course is carefully heated with infrared radiation, in order that a certain thickness of the layer is picked-up and the material disintegrated, then mixed again, perhaps adding some fresh material and finally relaying the mix in a new binder or wearing course. This is made in an integrated operation, in one machine or a train of machines. During repaving the properties of the asphalt surface course are changed. The new layer will be plane and even, as after laying a new asphalt layer.

A normal TAL is not created in this way, as it requires high-quality aggregate and binder. However, the resulting layer of hot recycling may serve to give an existing pavement an extra lifecycle; albeit not having the quality of a regular TAL. As the layer thickness often is 30

mm or somewhat lower, however, one must consider these recycled surfaces as a special type of low-quality TAL, which is the justification for mentioning them here.

There are four different methods for hot in-place recycling:

1. Reshape = repaving without changing the composition of the asphalt (no new material is added)
2. Repaving = the surface profile is restored as in the reshaping method and a new add-mix is applied and both layers are compacted at the same time
3. Remix = hot in-place recycling with a change to the composition of the asphalt (some new material is added and mixed with the old material)
4. Remix plus = hot in-place recycling with modified asphalt composition and laying of a new surface layer (made of fresh material) with a second screed

During hot in-place recycling the asphalt course is gently heated up by an infrared heater. A special construction machine, the remixer, picks up the heated asphalt material, mixes it and, depending on the method used, immediately relays it with a variable screed (reshape) or thoroughly mixes it with hot bitumen and/or additional mix and then lays it (remix). In the "remix plus" method (also called "remix compact") the loosened asphalt material is thoroughly mixed with hot bitumen and/or additional mix and is laid by the first screed of the remixer. A second screed in the remixer, immediately behind the first, lays an additional new mix⁵.

The method is useful especially for long homogeneous road sections. After laying the asphalt surface course, chippings may be applied to increase the initial grip and are finally compacted with rollers while hot. For more information; see [Wirtgen, 2003].

In some countries, such as Germany and Sweden, the remix method has become popular and large areas have been laid in Sweden at a thickness of around 30 mm. One version reconditions the pavement at a temperature of only 100 °C, using an SBS modified emulsion⁶, with good results. In "remix plus" the top layer is often around 15 mm. In all four hot in-place recycling methods, the relaid or new layer(s) is/are compacted by rolling.

6.6 Effect of climate on the preference for thin asphalt layers

6.6.1 Dry versus wet climate

The preference of TAL in dry and wet climate, respectively, is unavoidably linked to the surface texture of the chosen pavement with regard to what is acceptable considering all other conditions being equal. In order to assure the road users safe driving condition TAL with an open surface textures will be preferred under wet climate conditions as these types of materials initially were commended for their ability to reduce splash and spray and maintain wet skid resistance – which are important factors for overtaking lorries and braking during rainy conditions. This becomes even more important when the road consists of several lanes, irrespectively of whether the transversal profile is sufficient or not.

⁵ Part of the information in this section is from: <http://www.kutter-dsk.de>

⁶ See for example: <http://www.peab.se/Miljo--framtid/Innovativ-teknik/Eco-Paving/>

When the local conditions and the climate change imply the possibility of extreme weather occurring from time to time this consideration must be taken seriously. Possible candidates range from open graded AC over SMA and BBTMs and UTLACs to PA. Driver safety is the main concern and the wet conditions for the open textured road surfaces may have a recognised drawback on the durability. Here it is important to focus on material types that have thick bituminous mortar films on the aggregates. This highlights candidates like SMA and UTLAC – the first often includes bituminous mortar stabilized by the addition of cellulose fibres and the second which has its unique sealing capability in form of the thick applied polymer modified tack coat which is "boiled up" into the structure of the surface layer creating a good and virtually impermeable bond.

In climates where precipitation hardly occurs the range of materials is larger. Under these conditions dense graded materials can also be acceptable candidates. The dense grade materials offer better side support to the larger aggregates in the mix which may in the long run improve the durability of the pavement- This increased side support may also increase the surface resistance against shearing forces.

But if the dry climate is combined with a hot climate (which is often the case) then some word of caution are appropriate with regard to the dense graded ACs. The high service temperatures in the surface layers accentuate rutting (permanent deformations) as a likely failure mechanism. In order to avoid a potential rutting problem the asphalt producers may be tempted to use a too lean mix design. This creates two problems for the durability of the pavement.

In spite of the dry conditions water or moisture can easily penetrate thin bituminous mortar films and reach the aggregate which may be moisture susceptible. If de-icing salts are used at winter times moisturized microclimatic conditions in the pores of the pavement can have an effect even when you think the pavement is dry and no moisture action can occur.

The second problem with lean dense graded mixes in hot, dry climates is that the thin bituminous mortar films may show accelerated hardening over time leading to premature failure due to fretting (loss of mortar) and ravelling (loss of aggregates) because the binder becomes brittle.

6.6.2 Hot versus cold climate

Bitumen

In the asphalt concrete mix the most climate sensible component traditionally is the bitumen part. The viscoelastic properties of the bitumen depend on the temperature – and on the traffic load. This means that during hot climatic conditions the bitumen is like a viscous liquid and permanent deformation or rutting of the asphalt mix can occur when the temperature is high.

In cold conditions the critical property of the bitumen in the mix is elastic stiffness. The bitumen can become very brittle, resulting in cracks during the loading by the traffic when the temperature is low.

Traditionally during the pavement design and the design of the asphalt mix a proper selection of the type of bitumen can minimize the climatic influences of very high, very low temperature or a combination of both. If necessary an alternative is to choose polymer modified bitumen. An example of a design method with focus on the climatic behaviour is the Super-pave performance grade binder selection.

Ageing

Ageing or oxidation of bitumen is the result of the reaction with oxygen in the air. The reaction results in bitumen which becomes harder and more brittle whereby the pavement is more exposed to cracking. Normally the rate of the ageing process is slow but hot climate with high temperature speeds up the process.

In the asphalt pavement the most critical parameter for the ageing is the air void content. A high air void content results in a higher rate of ageing. Other parameters affecting the ageing are the bitumen film thickness and the aggregate grading (dense- or gap-graded).

Because the ageing of bitumen happens faster on the surface of the pavement, TAL is more critical to ageing than thicker layers of wearing course asphalt. The open structure also gives higher exposure to oxygen than denser structures, which may increase oxidation and thus decrease the durability.

Since most of the ageing occurs during production, transportation, laying and compaction of the asphalt mix, the ageing process can be minimized with optimum plans for the production of asphalt and an optimum choice of bitumen type.

In the process of laying asphalt – depending on the grade of bitumen – the temperature of the asphalt during the paving is 150 – 180 °C and during the compaction with selected types of rollers the temperature is 130 – 170 °C. When the temperature is 90 – 100 °C the compaction must be finalized because the viscosity of the bitumen at this temperature is so high that further compaction work is useless.

The decrease of the temperature depends on the thickness of the asphalt layer. The thicker the layer the slower it cools down and the longer the asphalt mixture can be compacted, the less weather sensitive the laying and compaction process. That means that in cold climate the laying of TAL is restricted, difficult or impossible. See further Section 6.6.3.

Aggregates

Aggregates in asphalt concrete are not sensitive to hot or cold climate in the same way as the bitumen part. The most critical parameter in relation to the climate or weather is the ability to resist degradation caused by cycles of freezing and thawing when the aggregates are in saturated conditions.

Setting up proof specifications with requirements to

- Soundness
- Los Angeles Abrasion
- Crushed Content
- Flakiness

minimises the climatic influence from aggregates in TAL.

6.6.3 Thin asphalt layer performance in cold region – Example from Japan

The Hokkaido Island in Northern Japan has long and cold winter seasons. The annual snowfall in Sapporo is 5 m per year and the average temperature in January is -5°C . Winter maintenance of roads is carried out by spreading wet salt and by the use of snow ploughs equipped with steel. Rotary snow removers are also used. The use of studded tyres has been prohibited from 1990 and nowadays only snow chains are used [Bredahl Nielsen et al, 2005].

It has been a challenge in the Hokkaido area to develop pavement types effectively reducing splash and spray, having high skid resistance and at the same time providing a high structural resistance to the wear of snow ploughs and snow chains. Ordinary SMA provides excellent durability but is limited in its technical performance, while porous asphalt has excellent technical performance but poor durability; and especially so in cold climate. For this purpose, a new class of very open SMA pavements has been developed which intends to combine the best properties of the two types of pavement and which will work well in cold climate.

These pavements are constructed as a "hybrid" of stone mastic asphalt (SMA) and porous asphalt pavements (see Figure 6.5 and 6.6). The mix is dense with a very open surface texture in the upper 10-13 mm, equivalent to the maximum aggregate size; something which is rather typical of many TAL. The binder is standard SBS modified binder. The pavement is laid by an ordinary asphalt paver in one pass and the mix requires severe quality control during production as it is quite sensitive to the amount of mortar. Bleeding during compaction is often observed. These pavements are new to Japan, and to a cold climate in general, and the practical experience therefore still were limited in 2005, but they had so far shown good performance [Bredahl Nielsen et al, 2005].

Probably, the Japanese have not constructed these as TAL, i.e. with thickness less than 30 mm, since they generally use 13 mm maximum aggregate. But, if these very open SMA pavements were constructed with a maximum aggregate size of 8 or 10 mm they could be laid as thin layer pavements.

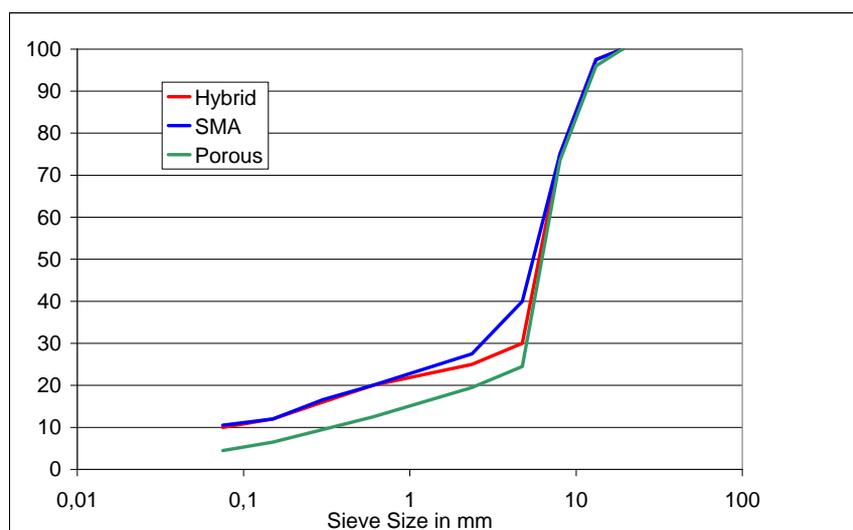


Figure 6.5: Material gradation curves for porous asphalt pavement, new "hybrid" pavement and regular SMA pavement [Bredahl Nielsen et al, 2005].



Figure 6.6: Porous asphalt (right) and the very open SMA pavement (left), both with maximum 13 mm aggregate size [Bredahl Nielsen et al, 2005].

In fact, this type of pavement is nothing new to Europe. Compare with Figure 3.1 where it appears that the BBTM class 1 and UTLAC pavement types have grading curves which very much resemble those of the Japanese open SMA. The only difference is that the Japanese use larger aggregate (up to 13 mm versus up to 8 or 10 mm). Yet, the Japanese experience is of interest to this project since they have demonstrated a possible adaptation of such a pavement type (as BBTM 1 and UTLAC) to a cold climate. That is, essentially they have confirmed that a type of pavement with grading similar to that of BBTM or UTLAC has better durability in cold climate than a porous asphalt pavement (which is not surprising). The big question-mark is, however, how such a pavement would work under the action of studded tyres. It may be worthwhile to try the UTLAC and BBTM class 1, taking the Japanese experience into account, in a cold region in Europe, both with and without the use of studded tyres.

6.6.4 Interaction with studded tyres

VTI has developed an extensive model for the prediction of wear due to studded tyres [Jacobson and Wågberg, 2004], which summarises the Swedish experience. The model is based primarily on tests using VTI Circular Test Track (CTT) in which 28 samples can be tested at the same time. These results have been correlated to ten field test sites where surface wear has been followed up since the early 1990's. The laboratory tests include testing materials comprising different gradations, stone size maximum as well as aggregate properties such as petrology, density, shape, resistance to fragmentation and resistance to wear. The parameters shown to have significant impact on surface wear resistance were (based on CTT and field tests):

- Aggregate quality
 - On a descending quality scale: Porphyry, quartzite, granite, gneiss
- Proportion of coarse aggregate (> 4 mm)
 - The larger, the better. Range 45-67 %
- Maximum aggregate size
 - The larger, the better. Range 8-16 mm
- Mixture type (aggregate gradation: Dense or gap graded)
 - Gap graded better than dense graded. Factor is partly a result of “proportion of coarse aggregate”
- Use of mixed aggregate qualities
 - Wear resistance is given by proportional contributions from each aggregate source
- Binder type (modification)
 - Dense asphalt concrete seems dependent on binder while gap graded is not
- Degree of compaction and air void content
 - Inadequate compaction is detrimental in many ways, which are of greater importance
 - Range 94-96 % degree of compaction shows clear detrimental effects while 97 % nominal degree of compaction only shows indicative effects
 - Indicative effects between high (worse) and low air voids. Range within specifications (range varying for different mixes)
- Wet or dry surface
 - Wet surfaces are generally worn at a greater rate compared to dry
- Type of stud and stud force
 - Properties of studded tyres are very important and subject to legislation
- Speed
 - Greater vehicle speed results in greater wear. Range 60-110 km/h

Climate zone has earlier been shown to influence wear resistance, but the rationale behind it is still unclear. The comments given to the factors influencing wear resistance given above can of course not be interpreted as general conclusions but valid within the ranges of observations reported. Furthermore, the factors influencing wear resistance are probably interacting.

To model the contribution of aggregate quality on wear resistance, aggregate resistance to wear is assessed using the Nordic abrasion test, EN 1097-9. The Nordic abrasion test is a ball drum test, similar to Micro deval, aimed at assessing fragmentation of coarse aggregate fractions. The test reports percentage fragmented material (A_N). For gap graded wearing courses, the wear relative to a reference is reported based on A_N and maximum aggregate size (NMAS) as equal to $1,547 + A_N * 0,143 - NMAS * 0,087$. For dense graded mixes, the model is different in the way that NMAS is exchanged with parameters considering the fraction of large aggregate and Marshall air voids.

To summarise, aggregate quality and proportion of large aggregate can to a large extent explain and predict wear resistance of dense and gap graded asphalt concrete wearing courses. However, a number of other parameters, such as climate conditions and material properties will interfere.

6.7 Countries or regions with policy-driven use of TAL

As appears in Figures 5.2-5.4, there are some countries where TAL are used more systematically, driven a little harder than in other countries by certain policy-related issues.

In Sweden and Norway the main use is of TAL with NMAS of 11-16 mm on the main road network, with 16 mm most common in Sweden and 11 mm most common in Norway, although also to a lesser extent on local roads. The reason is above all, is in Sweden that these TAL appear to have good resistance to wear of studded tyres and are relatively inexpensive to repave, while in Norway it is mainly a matter of volume of material used, as studded tyre use has decreased. As described elsewhere; moreover, it has become popular to produce relatively thin layers by remixing, due to environmental concerns and economy.

Switzerland uses a lot of TAL on the main road network; presently around 50 % (see Section A.3.3). This is entirely driven by a policy to reduce noise. The main surface for this purpose is AC MR8 which is dense asphalt concrete with 8 mm NMAS and a thickness 20-30 mm, with a grading giving it a much rougher macrotexture than normal AC8. MPD values are more like those of an SMA8; in fact its gradation curve is very similar to that of Swedish SMA8.

In the Netherlands, TAL have become very popular on the municipal (mostly 50 km/h) and provincial (mostly 80 km/h) road networks. Cities have turned their interest from DAC and SMA to the thin layers as the low noise solution on low-speed roads. In order to encourage the use of quieter road surfaces in urban areas, an economic bonus was given by the Dutch authorities to communal and regional road administrations which applied low-noise surfaces. For 2001 and the next three years there was available about € 50 million (in total) for the quiet roads compensation scheme. More than 15 million € were paid in two years in such bonuses.

What the Dutch government did was to provide a compensation for the extra costs of low noise pavements compared to the costs of a conventional asphalt pavement. This included normal maintenance for 15 years and a new top layer after 7-8 years. The contribution was fixed and depended on the kind of road surface: one or two porous layers, open- or semi-open or any other noise-reducing elements. The prime target was to stimulate the local authorities to gain experience. The second target was to stimulate research by the road builders and to put together a lot of information about the behaviour of these kinds of roads.

The surfaces had to be tested according to the C_{road} procedure (see Section C.3.2) and provide a certain noise reduction in new condition in order to be eligible for the bonus. Even if this bonus system is now abandoned, it was considered to be a success and had indeed the effect of opening the eyes of the street authorities for the advantages of using thin layers.

The DWW (now RWS) a few years ago issued advice for road authorities that they are now allowed to use thin layers at up to 80 km/h when noise reduction is needed.

In the U.K. hot rolled asphalt (HRA), usually with rather course stones rolled into the mastic, was the dominating surfacing on trunk roads as well as on local roads and streets. However, for economic reasons and because of noise issues, cities became interested in TAL in the period 1995-2005 (approximately), as illustrated by the rapidly expanding HAPAS certification of TAL systems (see Section C.3.1). As shown in Section 7.8, the experience of the first decade of use of TAL was largely positive.

Even London has started to use TAL extensively. It is interesting to note that the 2007 publication "London Asphalt Specification", which is intended to give the street authorities in Greater London guidance regarding selection of surfacings, recommends an extensive use of TAL. The first edition from 2007 was followed by a second edition in 2009 [Walsh, 2009]. The major table specifying wearing course for roads where traffic may cause noise disturbances is shown in Table 6.2. In the document it is pointed out explicitly "It is strongly recommended that only TSCS⁷ should be specified in preference to generic Stone Mastic Asphalt [SMA]".

Table 6.2: Preferred materials in the "London Asphalt Specification", edition 2009. The surface courses designated as ST6 and ST10 are TAL (6 and 10 are NMAS in mm), while ST14 with thickness 35-50 mm is thicker than TAL considered in this project. S1H is an HRA surface. Road Type 1 means >10msa⁸ [<600cv/day] and Road Type 2 means 2.5 to 10msa.

8 Preferred options for materials selection					
	Option 1	Option 2	Option 3	Option 4	
Road Type 1					
Surface course	ST14, or ST10 or ST 6	ST14 or ST10 or ST6	S1H	S1H	
Binder course	Bi1S	Bi1S	Bi1S	Bi1A	
Base	Ba1A	Ba1H	Ba1H	Ba1A	
	preferred	when overlaying /inlaying cracked material		When maximum stiffness is required	
Road type 2	Option 1	Option 2	Option 3	Option 4	
Surface course	ST14 or ST10	ST14 or ST10	S2H	S2H	
Binder course	Bi2S	Bi2H	Bi2H	Bi2C	
Base	Ba2A	Ba2H	Ba2H	Ba2C	
	preferred	when overlaying /inlaying cracked material		When maximum stiffness is required	

⁷ TSCS = Thin Surfacing Course Systems

⁸ msa = Millions of equivalent standard axles (exerting or applying a force of 80kN and passing during the pavement design life)

Another interesting note is the following: "Fretting of the surface of roundabouts and sharp bends can be the result of too large an aggregate size being used in the Thin Surfacing. Normally a 10mm aggregate size material is recommended. Thin Surfacing laid in winter is more prone to early fretting as the surface is more likely to have been insufficiently compacted. The greater the texture depth, the more prone to fretting is the surface" [Walsh, 2009]. There are several more interesting recommendations pertaining to TAL in the document.

6.8 Use in ERA-NET ROAD countries compared to other countries

In order to reflect both the national and regional practices, the figures published each year by EAPA (European Asphalt Pavement Association) are a very useful source [EAPA, 2007a]. Those figures give an overview, from a number of European countries, about the asphalt production, asphalt application and the use of binders. The data have been established with the assistance of the members of EAPA, and are at present the best available and reliable for the asphalt industry.

With respect to surface courses, the EAPA overview of 2008 gives detailed information about the production of each type of asphalt based on the European product standards (EN 13108 series). Data are expressed as a percentage of the total amount of surface courses. Consequently, no precise data is available with respect to the nominal layer thickness of a particular application (except for mixes defined by EN13108-2). The overview does not contain any data for mixes defined in either prEN13108-9 or the UTAG 16 guideline. In Table 6.2 an overview is given with respect to countries both within and outside the ERA-NET ROAD framework.

It should be noted that the policies within Europe with respect to the use of TAL may differ substantially. As already mentioned TAL in Denmark represent about 95 % of all surface courses. In Belgium, this figure is probably much lower and is dependent of the region (Flemish or Walloon region). For example, at present the Flemish tender doesn't specify TAL as defined in EN13108-2 but the Walloon region does. Moreover, in Flanders SMA-C⁹⁾ (40 mm) is the standard choice for a top layer on a motorway. Another example is given by porous asphalt. Porous asphalt (either in a single or twin layer application) is the standard choice on motorways in the Netherlands, while in Belgium any use of porous asphalt is very rare. The main reason is problems encountered during winter maintenance although climate conditions can be considered similar to those in the Netherlands.

It appears in Table 6.2 that there is not much resemblance to Figures 5.2 and 5.3, if any at all. This is explained by the sometimes confusing definitions of TAL and by generally poor or even missing statistics. However, at least one thing is worth noting in Table 6.2; namely that Spain is using TAL extensively.

⁹⁾ See footnote p. 8

Table 6.2: Overview of production of TAL within Europe (% of the total production of hot mix and warm mix asphalt), where the column 13108-2 would be within the TAL definition used in this project. However, there should also be at least a TAL-relevant column for 13108-9 (UTLAC) but such data is missing. Source: data published in 2008, see the main text.

	<i>Country</i>	<i>13108-1</i>	<i>13108-2</i>	<i>13108-3</i>	<i>13108-4</i>	<i>13108-5</i>	<i>13108-6</i>	<i>13108-7</i>
<i>Inside ERA-NET</i>	AT	75.8	2.0	-	-	20.0	0.2	2.0
	CH	13.0	3.0	-	-	-	7.0	9.0
	DK	25.0	-	10.9	-	7.8	0.02	0.1
	GB	n.a.						
	NO	n.a.						
	SE	21.0	-	8.0	-	10.0	0.13	0.07
<i>Outside ERA-NET</i>	BE	33.9	2.0	-	-	10.6	0.3	0.6
	FR	n.a.						
	GE	20.0	-	-	-	9.0	1.0	-
	NL	80.0	-	-	-	9.0	-	7.0
	SP	82.2	11.0	-	-	4.2	-	2.6

7. PERFORMANCE: SPECIAL KEY PROPERTIES

7.1 *Macrotexture*

In order to use a thin layer, the maximum aggregate size (NMAS) must not be large. Small NMAS means low macrotexture. This might cause problems with wet skid resistance and hydroplaning. In order to counteract this, TAL are often designed with an open texture (gap-grading) which gives high macrotexture even with small NMAS. Such macrotexture is favourable to noise emission and rolling resistance, since it is related to low megatexture.

Both megatexture and macrotexture are critical for the environmental properties noise and rolling resistance; the latter being proportional to fuel consumption and thus CO₂ emission. Most of the proprietary surfaces listed in Table 6.1 have been designed with substantial efforts to optimize megatexture and macrotexture; some using advanced methods and materials to achieve such properties.

7.2 *Skid resistance*

7.2.1 *International survey*

The Danish Road Institute conducted a literature study in 2005 on thin layers where the conclusions regarding traffic safety were the following [Bendtsen et al, 2005]:

- Generally, measurements show that thin noise reducing layers have a high skid resistance.
- No special information about the performance of thin layers during winter conditions was found.

7.2.2 *French experience*

The Danish Road Institute (DRI) and DVS in the Netherlands in 2005 conducted study tours to France in order to collect information on noise reducing thin layers. The main findings on traffic safety issues were [Bendtsen & Raaberg, 2005]:

- The thin layer pavements have an excellent skid resistance
- The skid resistance is better for TAL than for ordinary dense asphalt concrete. This is due to the surface texture of the thin layers being rougher
- Skid resistance increases with decreasing maximum aggregate size. An explanation could be that the number of contact points between the pavement and the tyre is larger with smaller aggregate. TAL with 6 mm aggregate show better skid resistance than pavements with 10 mm aggregate
- The polished stone value of the TAL is good due to high quality aggregate
- Skid resistance can be improved on newly laid TAL by applying sand during compaction
- Reduction of splash and spray is better when using 10 mm aggregate than when applying 6 mm aggregate.

7.2.3 Danish measurements

Thin noise reducing pavements have an open surface structure in order to reduce noise generated from air pumping and at the same time having a smooth even surface in order to reduce the vibrations generated in the tyre which also induces tyre/road noise. It is generally not considered that there is a correlation between skid resistance and tyre-road noise. Skid resistance is related to the pavement micro- and macro texture where as noise is mainly related to macro texture.

The skid resistance of a series of Danish test sections with TAL has been measured by the ROAR device operated by DRI. The measurements are carried out using 20 % slip and pre-wetting the pavement surface with a 0.5 mm water film, meaning that the measurements are performed under wet conditions. The results from measurements on a series of thin layers with different aggregate size can be seen in Figure 7.1 where there is a quite clear tendency that the skid resistance is increasing when the maximum aggregate size is decreasing. A physical explanation for this could be that the sharp edges of the aggregate improve the skid resistance and when the aggregate size is reduced the number of sharp edges pr meter road surface is increased.

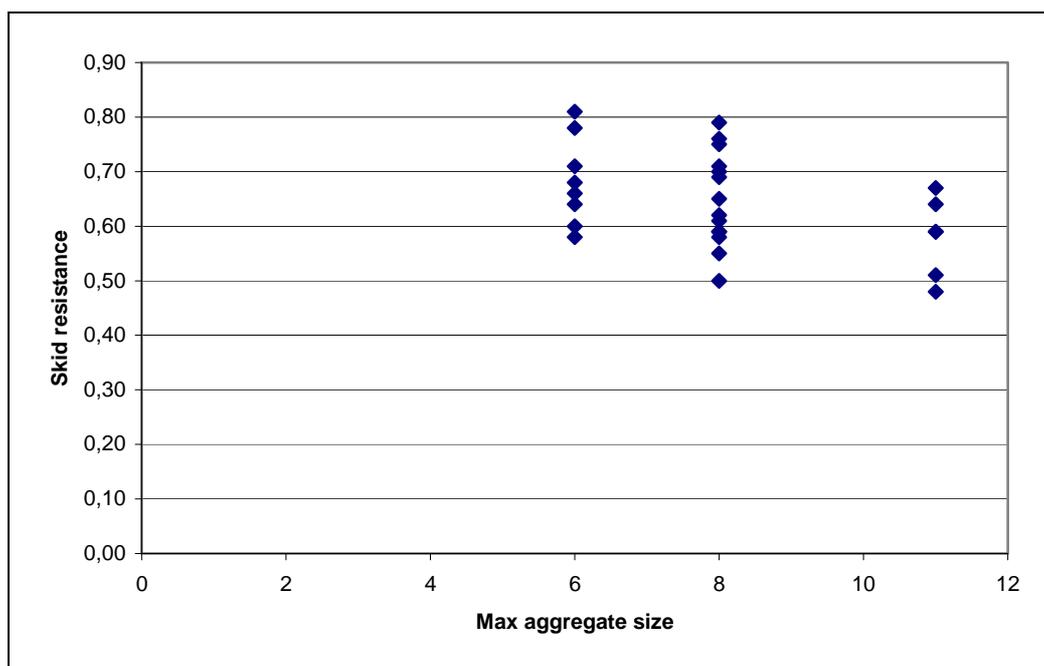


Figure 7.1: Maximum aggregate size and the skid resistance measured on Danish test sections with thin layers [Bendtsen & Raaberg, 2007].

On the basis of the available data and the analyses carried out the following tendencies can be seen [Bendtsen & Raaberg, 2007]:

- All pavements included in the test show skid resistance fulfilling the requirements set by the Danish Road standards
- Generally the noise reducing thin layers have high skid resistance when they are new

- There is a little reduction in skid resistance as pavements (dense reference pavements as well as noise reducing thin layer pavements) get older
- The skid resistance of the noise reducing thin layer pavements is marginally higher than that of dense reference pavement in Denmark
- No correlation has been found between macro texture (MPD) and skid resistance
- The general tendency seems to be an increase in skid resistance if the maximum aggregate size is reduced
- The inclusion of oversized aggregates did not influence the skid resistance.

Figure 7.2 shows the results of skid resistance measurement 2004 and 2006 on noise reducing TAL test sections and a reference section on the Danish motorway M10 at Herning [Bendtsen & Raaberg, 2007]. There are not long enough time measurements available to give any conclusion on the long time performance of skid resistance.

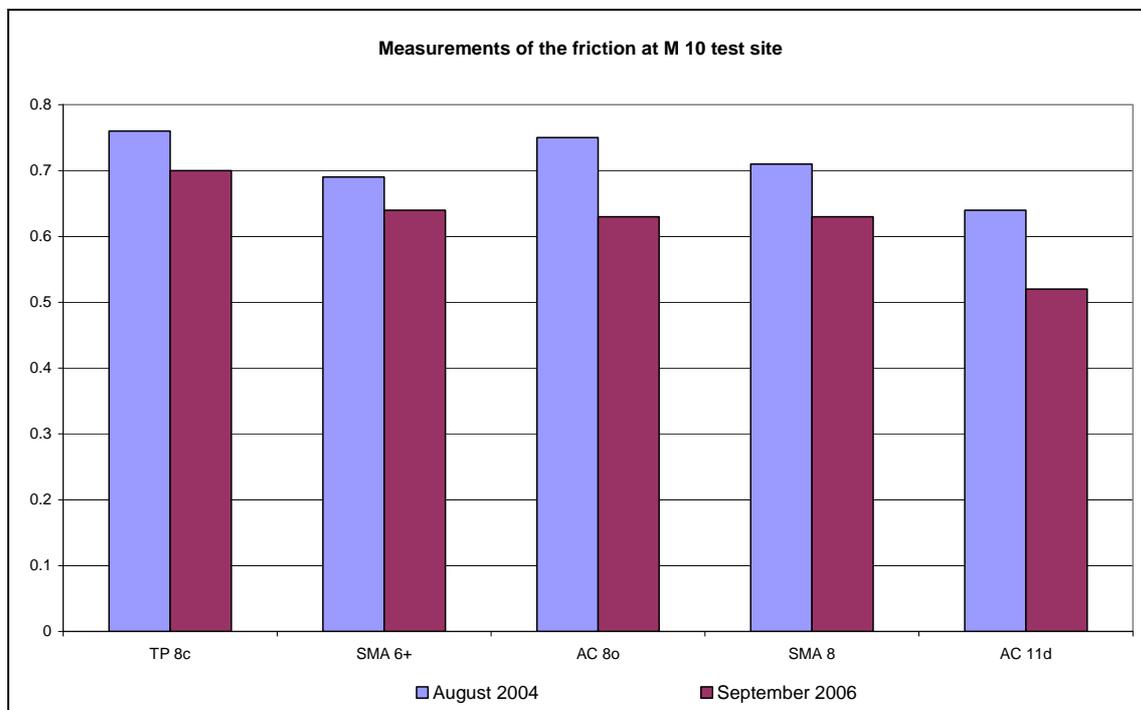


Figure 7.2: Comparison of skid resistance measured in 2004 and 2006 at test sections with noise-reducing thin layers on Highway M 10 in Denmark [Bendtsen & Raaberg, 2007].

7.2.4 Experience in the United Kingdom

Please refer to Section 7.8 and Figure 7.13.

7.2.5 Experience in the Netherlands

Skid resistance measurements were performed on 30 thin asphalt layers similar to SMA pavements. These were the main conclusions [Groenendijk, 2004]:

- Most surfaces show a wet skid resistance (test at 50 km/h with 86 % slip) after installation of more than 0.4. Some values are initially around 0.3 but after two weeks of traffic the skid resistance already increases significantly. The end report of IPG also confirms these findings [Bennis et al, 2008]
- There is a clear decrease of skid resistance within the first week after opening for traffic. After this week skid resistance increases again. This evolution continues the first 6 months and is dependent on traffic density.
- Eventually skid resistance decreases again. Nine thin noise reducing layers were monitored by KOAC-NPC for CROW. The wet skid resistance of eight surfaces decreased. One surface had a large increase probably due to ravelling [Bijma, 2006]. Ravelling may occur and may compensate this effect of decreasing skid resistance which is why the intervention level at the end of lifetime may be reached later.
- Very locally, a lack of roughness may be caused by faults in production / transport / installation (demixing), visible as a permanent bituminous layer covering the microtexture of the aggregate [Groenendijk et al, 2006].
- Texture measurements show MPD values equal or a bit smaller than DAC. It is advised to require a minimal MPD value.

Due to lack of skid resistance measurements for ZOAB similar thin layers, measurements of double layer ZOAB are used as estimation [Groenendijk, 2004]:

- Most surfaces show a wet skid resistance after installation of less than 0.38, which is the requirement. Within 2 weeks this increases significantly.
- Eventually skid resistance decreases again. Ravelling may occur and may compensate this effect which is why the intervention level at the end of lifetime may be reached later.

7.3 Influence on road traffic noise

Tyre/road noise is generated by four major processes [Sandberg & Ejsmont, 2002] with minor contributions from other mechanisms:

1. **Tyre vibration:** Vibrations are generated by the contact between the pavement surface and the tyre tread pattern blocks. Tyre vibration dominates tyre/road noise in the frequency range 300 to 1500 Hz; the rougher the surface, the higher the noise levels. A larger maximum aggregate size leads to higher tyre/road noise levels.
2. **Displacement of air - The air pumping effect:** When the tyre tread pattern rubber blocks hit the road surface, air is pressed out of the cavities between the rubber blocks and between the tread and the road surface. When the blocks leave the road surface air is sucked back into the cavities. This air pumping to the surroundings generates noise

at frequencies above 1000 Hz. If the road surface is open or porous the air pressure gradients will be lower since the porosity "short-circuits" the pressure gradients, and the noise is reduced.

3. **The horn effect:** The curved tread pattern of the tyres and the plane road surface act as an acoustical horn which amplifies the noise generated around the contact point between the tyre and the road surface. If the road surface is porous (and therefore sound absorbing) there will be less amplification.
4. **Propagation effects:** The propulsion noise and tyre/road noise propagate from the vehicle to the road surroundings. During this propagation noise is reflected from the road surface. If the road surface is porous sound may be attenuated due to phase effects on the reflected sound field.
5. **The effect of stiffness:** If the pavement is almost as soft as the tyre, tyre deflections will be much smaller and less noise will be generated.

7.3.2 Noise optimization of thin layers

The basic concept of using open textured thin layer pavements for noise reduction is to create a pavement structure, with as big cavities at the surface of the pavement as possible in order to reduce the noise generated by air pumping, and at the same time ensuring a smooth surface so the noise generated by tyre vibration will not be increased. Such a noise reducing open textured pavement can be thin, as the mechanisms determining the noise generation only depend on the surface structure of the pavement.

Figure 7.3 illustrates two types of pavements with an open surface texture. The pavement texture having a "positive profile" will give rise to higher noise levels from tyre vibration than the pavement texture having a "negative profile". Good compaction and cubic aggregate shape generate a pavement surface with "negative" texture.

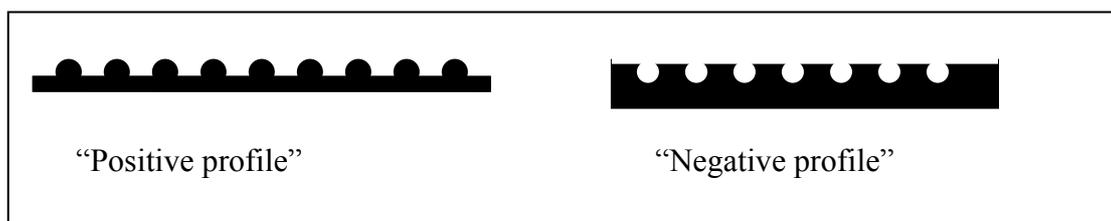


Figure 7.3: Sketch of pavements with "positive" and "negative" profile of the surface texture [Bendtsen et al, 2008]

A qualitative model has been suggested for the surface texture influence on the generation tyre/road noise, see Figure 7.4. X is the difference in height between the highest points of a road surface profile. H is the average distance between the highest points of the road profile. The Mean Profile Depth (MPD) is an indicator for the openness of a pavement surface.

To obtain as little tyre/road noise as possible:

1. Reduce X and H to secure a smooth surface to reduce tyre vibration
2. Increase MPD to reduce the noise generated by air pumping.

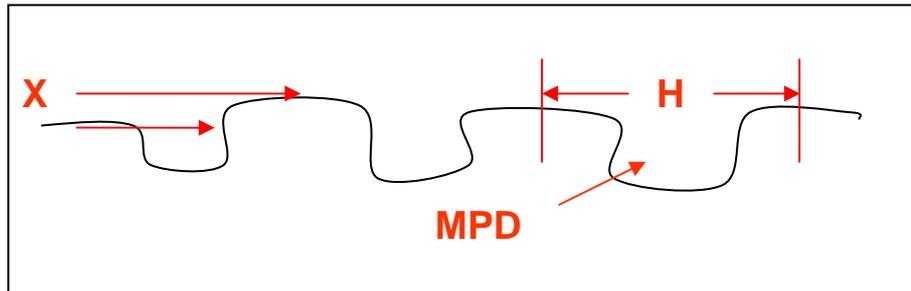


Figure 7.4: Illustration of road surface texture parameters influencing tyre/road noise generation [Fujikawa, 2004], [Bendtsen et al, 2008]

7.3.3 The Kastrupvej example

As a part of the EU project SILENCE the Danish Road Institute initiated a project to test optimized noise-reducing thin SMA layers in the laboratory [Nielsen et al, 2006]. A full scale experiment with seven test pavements has then been launched in 2007 in Copenhagen. The aim was to establish an even surface with a “negative texture profile” with open cavities. The noise optimization was done by using:

- small maximum aggregate size NMA (4, 6 and 8 mm) to reduce noise generated from tyre vibration
- high built-in air void content to reduce noise generated from air pumping. The SMA pavements have air void contents of 8.8 to 15.3 %¹⁰). These SMA pavements do not have communicating pores through the whole thin layer, but they have an open surface texture
- a small proportion of oversized aggregate (8 mm aggregate) added to the mix to obtain a more open surface structure; referred to as “4+8” and “6+8”
- as cubic aggregate as possible to reduce noise from tyre vibration. Triangular and round aggregate is expected to result in a rougher surface giving rise to more noise from tyre vibration.

Table 7.1 and Figure 7.5 give key information on the mix design and Figure 7.6 shows one of the surfaces.

Table 7.1: Mix characteristics for the thin layers on Kastrupvej [Thomsen et al, 2008] (a minus sign “-” means that no data are available).

Pavement	Max. aggregate size [mm]	Binder [%]	Air void [%], geometric
DAC 11	11	5.4	-
OGAC 6	6	-	-
SMA 6+8-a	6 + 5/8	7.1	3.4
SMA 6+8-b	6+ 5/8	7.0	5.7
SMA 6	6	6.9	15.3
SMA 4	4	7.0	8.8
SMA 4+8	4+ 5/8	6.7	10.2
SMA 6+8 (Opt.)	6+ 5/8	6.5	13.9

¹⁰) This is much higher than normally would be considered an SMA, but it was an adaption made in this Danish project.

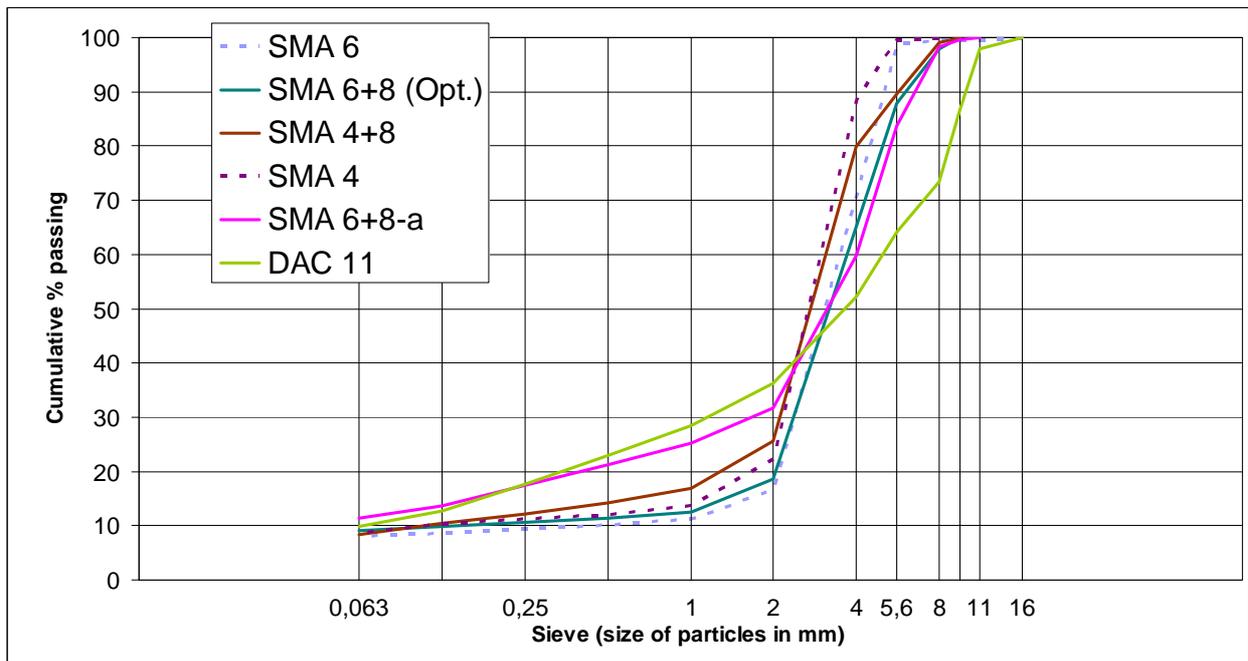


Figure 7.5: Grading curves for the SMA pavements [Thomsen et al, 2008].



Figure 7.6: Optimized noise reducing SMA 4, Kastrupvej, when the pavement was three months old. The black and white squares are 10 x 10 mm [Thomsen et al, 2008].

Also an optimized open-graded asphalt concrete (AC 60 = OGAC 6) was constructed on the test road. Figure 7.7 shows the noise reduction for passenger cars relative to the dense graded asphalt concrete reference DAC 11 when the pavements were a few months old. The OGAC 6

yielded the best noise reduction for passenger cars of 4.3 dB followed by the SMA 6+8 (Opt.) of 3.7 dB.

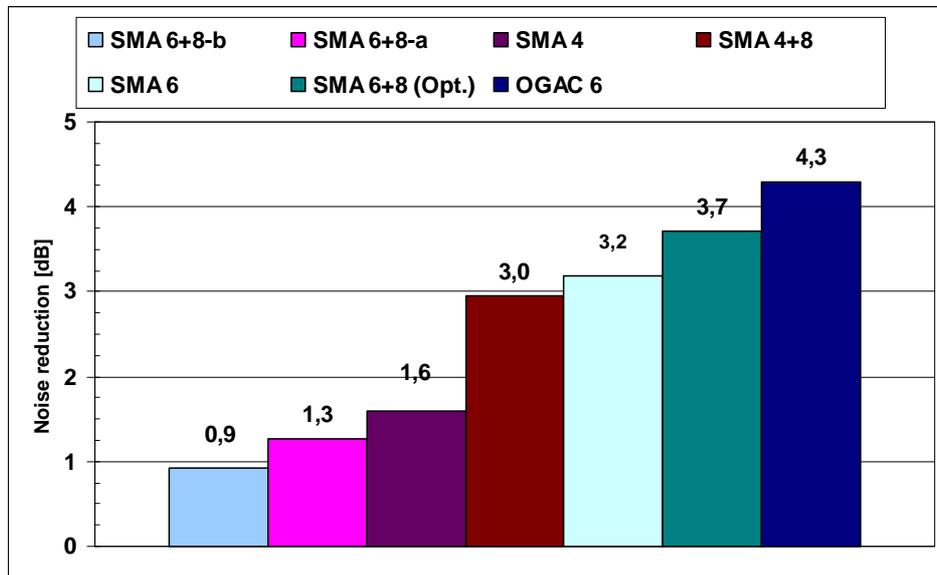


Figure 7.7: Roadside noise reduction for passenger cars relative to the reference DAC 11 of the same age when the pavements were a few months old at reference speed 50 km/h and reference temperature 20 °C [Thomsen et al, 2008].

7.3.4 French experience

Trends in the development of thin asphalt layers in France optimized for noise reduction are presented in [Bendtsen & Raaberg, 2005]. Table 7.1 shows the average noise reduction measured at thin layers with 6 mm nominal maximum aggregate size relative to dense asphalt concrete with 10 mm aggregate, AC 10d. Results are given for two types of thin layers, with larger built in air void content in type 2 than in type 1. Table 7.2 shows the average noise reductions relative to dense asphalt concrete with 14 mm aggregate, AC 14d, which is sometimes used as a reference pavement. The noise reductions were 3 to 4 dB for passenger cars and 2 to 3 dB for trucks relative to AC 10d, and 1 dB higher than this relative to AC 14d.

Table 7.1: Average noise reduction at French thin layers with 6 mm maximum aggregate size relative to AC 10d [Bendtsen & Raaberg, 2005].

Type of TAL	Passenger car (90 km/h)	Multi-axle trucks (80 km/h)
Type 1	2.7 dB	1.9 dB
Type 2	3.7 dB	3.1 dB

Table 7.2: Average noise reduction at French thin layers with 6 mm maximum aggregate size relative to AC 14d [Bendtsen & Raaberg, 2005].

Type of TAL	Passenger car (90 km/h)	Multi-axle trucks (80 km/h)
Type 1	4.2 dB	3.0 dB
Type 2	5.2 dB	4.2 dB

7.4 Influence on rolling resistance

In recent years VTI has studied the relation between rolling resistance coefficient (RRC) of tyres on various road surfaces and its relation the Mean Profile Depth (MPD) of the surface texture. An extensive measurement program was conducted in 2009 in Sweden and Denmark. The results are shown in Figure 7.8 and 7.9, with all results plotted as RRC versus MPD.

Figure 7.10 shows the test equipment in action in Sweden.

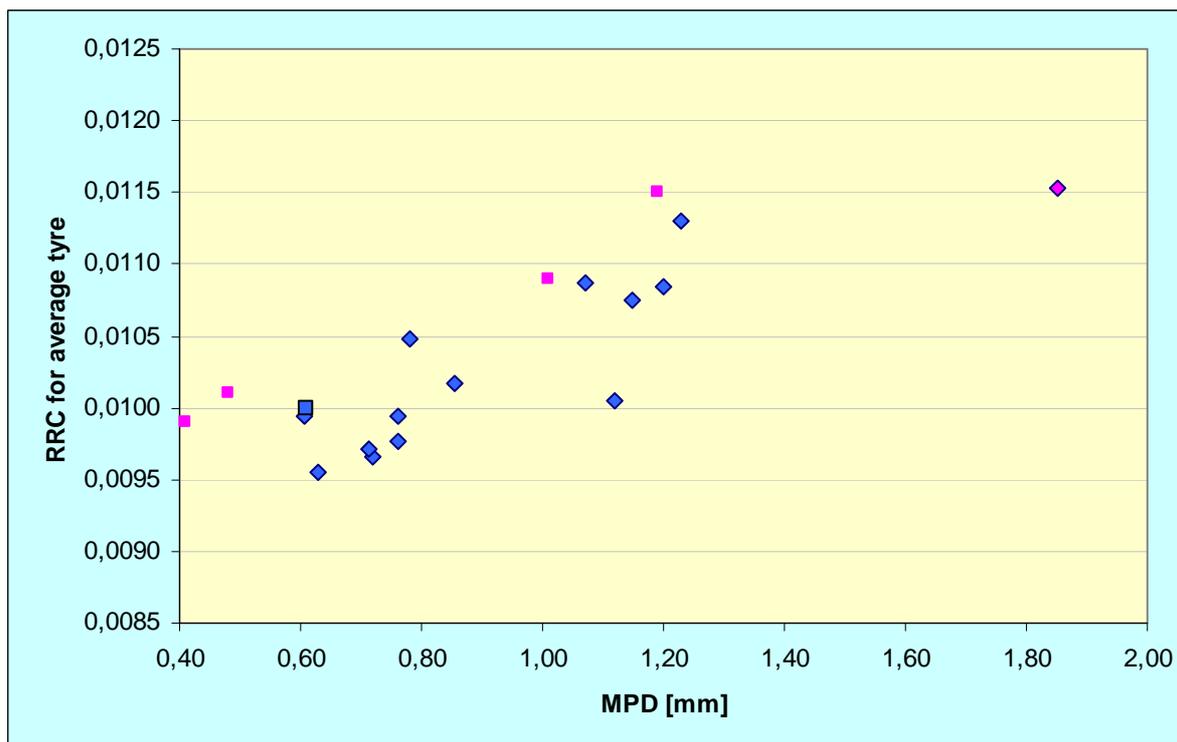


Figure 7.8: Rolling resistance coefficient (average of three tyres) normalized to 80 km/h and 16 °C, measured on road surfaces in Sweden and Denmark in 2009. The blue symbols are thin layers, the pink symbols are thicker pavements. Measurements made with RR trailer of the Technical University of Gdansk, as ordered by VTI and DRI.

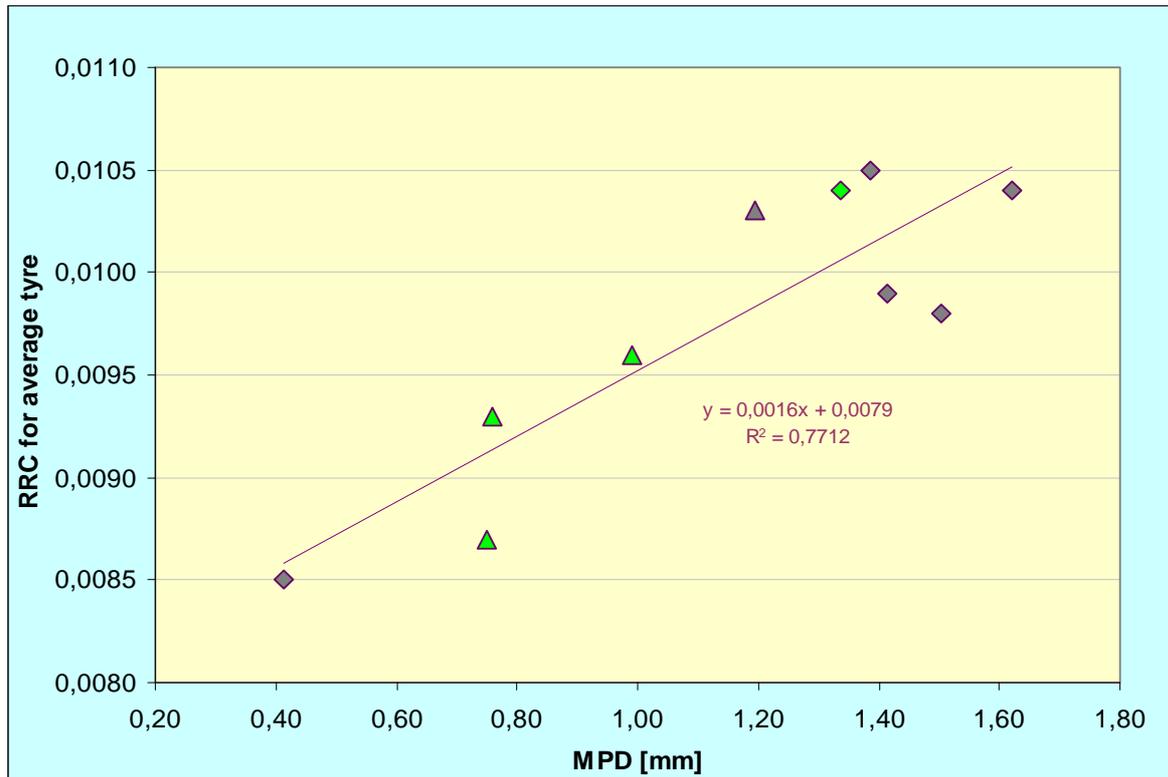


Figure 7.9: Rolling resistance coefficient (RRC) as a function of MPD. The RRC values are averages for the 3 test tyres; test speed was 80 km/h. AR pavements are shown with symbols filled with green colour; grey symbols are conventional asphalt pavements (AC and SMA).

Figure 7.8 shows the results of measurements on motorway M10 at Solrød and on local road Kongelundsvej, both in Denmark, and on various highways near VTI in Linköping, Sweden. Pavements of thin layer type are indicated as blue symbols and conventional pavements (> 30 mm thick) as pink symbols. Measurements were made with three test tyres of passenger car type, mounted on the RR trailer of the Technical University of Gdansk in Poland.

Caution shall be observed in interpreting the results since one cannot exclude the possibility that there is a small bias between the Swedish and Danish measurements, which were made two months apart and at quite different temperatures. However, a temperature correction to 16 °C has been made, utilizing the correction factor suggested in ISO 28580.

The results in Figure 7.8, with the caution expressed above, suggest that the TAL give somewhat lower RRC than the thicker pavements, given the same texture (MPD). This could occur due to the possibly more favourable macrotexture of TAL with a more "negative"¹¹⁾ profile than the other pavements.

More results of measurements and more on relations between RR and MPD are presented in [Sandberg, 2011].

¹¹⁾ Negative here refers to the profile peaks being directed downwards rather than upwards, which is an advantage for RR but a disadvantage for wet skid resistance.



Figure 7.10: The Rolling Resistance Trailer of the Technical University of Gdansk conducting measurements of RRC for one of the test tyres on one of the test sections near VTI.

Figure 7.9 shows the results of measurements on highways and motorways in Skåne in southern Sweden, with the purpose to see any differences or similarities between asphalt rubber (AR) and AC/SMA surfaces. The AR surfaces were thin layers (25-30 mm thick). AR pavements are shown with symbols filled with green colour; grey symbols are conventional asphalt pavements (AC and SMA > 30 mm thick). Measurements were made with three test tyres of passenger car type, mounted on the RR trailer of the Technical University of Gdansk in Poland.

The results in Figure 7.9, again with the caution expressed above, suggest that there is no significant RRC difference between AR and AC/SMA surfaces. Further discussion of these results and the tests can be found in [Sandberg, 2010].

It should be noted that the main advantage of TAL with regard to rolling resistance (RR) would be that TAL are often made with a little lower texture (MPD) than most of the thicker surfaces; mainly due to the use of smaller NMAS. It is clear that texture has a substantial influence on RR.

7.5 Thickness and weight advantages

Pavements of TAL are often used on concrete bridges and steel bridges. For concrete and steel bridges in the Nordic countries the TAL is a part of the waterproofing systems protecting the bridge deck against water and de-icing salts [Wegan, 2001]. In these systems with medium and light type of traffic the type of the wearing course is SMA, UTLAC and asphalt

concrete in a thickness from 20 mm. On larger bridges the thickness of the surfacing is up to 50 mm.

On bigger roads and on motorways paved with TAL, due to the requirement of noise reduction, the adjacent bridge deck is usually paved with the same TAL, retaining the properties of noise reduction and visual appearance.

When waterproofing smaller and older bridges with reduced weight capacity, the use of TAL becomes apparent due to the reduced stress on the bridge system. In the design of the 3690 meter long Messina bridge, which spans the Strait of Messina in Italy, with a main span of 3300 m length, one critical design criterion is a thin wearing course to reduce the weight of the bridge deck [Tækker, 2009].

On these bridges an alternative to TAL is thin pavements with synthetic binders based on epoxy, polyurethane or acrylate. The same principle applies for overpasses and elevated roads.

7.6 Economy

Assessment of investment decisions in economic terms can be made from a society perspective, as well as from a road owner perspective. Holistic society perspectives can make use of *Socio-economic cost benefit analysis* in which costs of society, road users and road owners are taken into account. In this way, the society can ensure the most value for money to the tax payers and society as a whole. However, decisions cannot be made solely on the socio-economic costs due to budget limitations. Therefore, road owner costs are also of great interest in the decision making. In both cases, it is preferred to analyse costs occurring during all stages from planning until far ahead in the future. *Life-Cycle Cost Analysis* (LCC or LCCA) is the common term used for Cost Benefit Analysis including all stages in a product life cycle. LCC requires a life cycle period and a discount rate. In the case of pavement wearing courses, the life cycle period can be either the period in which the road is maintained at the present standard or the expected life of the pavement. The period needs to be at least as long as that of the longest lasting wearing course. A discount rate is needed to consider the positive effects of postponing expenditures and allow capital to generate benefits elsewhere. Costs and benefits are usually calculated, discounted (to *present values*) and summed to a base year, often referred to as *net present value*. For more detailed information on socio-economic project assessment in Europe, the reader is referred to the HEATCO report [Bicket et al., 2006].

LCC can be done for many purposes. In the case of thin overlays, the following examples are given:

- Decide on strategy to maintain pavement at given standard
- Decide on whether a functional or environmental improvement corresponds to expectations on value for money
- Relate different options to each other regarding improvement of functional or environmental properties of a road (e.g. to meet noise or particle mitigation requirements)

Road owner costs are mainly related to planning, design, construction, maintenance and operation activities. Thin overlays could be an option in the construction phase but certainly

in the maintenance phase. Then, the cost of thin overlays and their expected impact on future needs for maintenance is determining their contribution to net present value. The impact on future needs for maintenance is often simplified to just stating the estimated life length of a treatment. However, success in a pavement life cycle perspective is also dependent on maintaining structural capacity over time and preferably increases it if needed to meet increasing traffic volumes. For the same reasons, selecting the proper maintenance option should also be related to the historic evolution of performance and the corresponding deterioration mechanisms. Table 7.3 refers to costs found in literature and public sources. The costs used in LCC should be representative of the present values during the whole calculation period. However, since our knowledge about future costs is limited, it is generally accepted to use present costs if no reliable information is available about future costs.

Table 7.3: Examples of costs reported from public sources.

Thin overlay cost	Expected life	Reference cost	Expected life	Note
\$140.000 /mile Thin lift w spray paver	Equal to ref.	\$210.000 /mile Cold plane w 2" overlay		1
\$85.000 /mile Thin overlay	2-4 years	\$120.000 /mile Thick overlay	6-8 years	2
\$75.000 – 86.000 /mile Thin overlay	-	\$127.000 - 148.000 /mile Thick overlay	-	3
€4,3 /m ² Thin overlay, 25 mm	-	€6,8 /m ² Overlay, 40 mm	-	4

1. Abadie C “Louisiana Bituminous Surface Preservation Program” Louisiana Asphalt Pavement Association Conference 2009. Baton Rouge. USA
2. Choi J-H, Bahia H “Life-Cycle Cost Analysis-Embedded Monte Carlo Approach for Modeling Pay Adjustment at State Departments of Transportation” TRR 1900. 2004. pp. 86-93.
3. Gransberg D “Life-Cycle Cost Analysis of Surface Retexturing with Shotblasting as an Asphalt Pavement Preservation Tool” TRR 2108. 2009. pp.46-52.
4. Karlsson R. LCC tool for investment decisions. Commission for Swedish Transport Administration.

The expected life and costs reported in the table above differ. Life expectancy and costs will differ from object to object depending on the conditions present. For a more detailed discussion on life expectancy or maintenance intervals, the reader is referred to later sections in this report. Regarding costs, one can conclude that many mechanisms behind costs of overlays are related to the weight of materials used; e.g. the cost of bitumen and transport of materials. Cost of aggregate probably varies both between regions and within regions for a large number of reasons such as availability, quality, volumes, market, etc.

Overlay properties may influence road users in a number of ways such as:

- Friction may influence accidents
- Macro texture may influence friction, fuel consumption, tyre wear and noise levels
- Longitudinal evenness may influence fuel consumption, vehicle condition and goods
- Rutting may influence friction by aqua planning

Furthermore, speed adaption and comfort is related to all these road surface properties. The consequences of road surface properties inflicted on road users may in turn be priced, transformed into road user costs, to allow cost benefit analysis of investment alternatives. Road user costs may also be inflicted by the treatment itself, for example delay time costs due to queuing during maintenance. Pricing of time, accidents, noise etc. differ between countries. The reader is referred to the HEATCO report [Bicket et al, 2006] for a review of pricing principles and levels in Europe.

7.7 The special properties of asphalt rubber thin layers

In a broad context, the following provides a summary of the derived benefits of using an Asphalt rubber (AR) as a pavement preservation strategy, referring to common US motorway conditions:

- Successful field performance history (over 40 years)
- Less reflective cracking
- Reduced maintenance
- More durable
- Less ravelling
- Good rut resistance
- Good skid resistance
- Smooth ride
- Good in hot & cold climates
- Allowance for higher binder contents
- Less splash & spray: better drainage
- Less tyre/road noise
- Cost effective
- Beneficial engineering use for old tyres
- Reduced induced stresses in PCC pavements due to thermal gradients
- Reduced climate change impacts
- Environment-friendly and energy efficient

Transferred to European conditions, most of the benefits listed above would be comparable to those of European SMA pavements, and the benefits of AR in comparison would be limited, as far as we know presently. Nevertheless, it is hoped that ongoing experiments will show that some of the benefits mentioned above will count as positive also in comparison to SMA. If this will be the case the future for AR in Europe is bright.

These sections document a few special properties of AR mixtures that earmark and establish the potential use of AR as a thin pavement layer. Evaluation of AR based on life cycle cost, energy efficiency, and structural mix designs are detailed with notable examples from various research studies in the United States.

7.7.1 Cost Considerations

Gap-graded AR (generally referred to as ARAC), generally 50 – 75 mm thick when laid in USA and 25-30 mm when laid in Sweden, is primarily placed to address cracking on cracked pavement sections. An ARFC (the open-graded variant) may be placed as an overlay depending upon the traffic volume and type of the highway. As mentioned previously (Section

6.5.4), ARFC as applied in the US is one of the thinnest asphalt pavements ever applied as it may be only 12 mm thick. The finished AR product is generally 25 to 50 % more expensive, but is actually more cost effective when considered in a life cycle cost analysis [Kaloush et al, 2008]. Figure 7.11 (a) shows maintenance costs in dollars per lane-kilometre for a conventional overlay and AR-ACFC (ARFC or AR open graded mix) over time in years. As observed, AR requires less maintenance costs, and a corresponding low percent cracking as shown in Figure 7.11 (b), and therefore has a longer service life. Figure 7.12 shows two other comparative accounts between conventional and AR overlays with regard to the rutting pavement distress and smoothness properties. As observed, AR pavements provide better resistance to rutting during the design life: furthermore, smoothness is lower than the conventional pavements over the years to provide better skid resistance and ride.

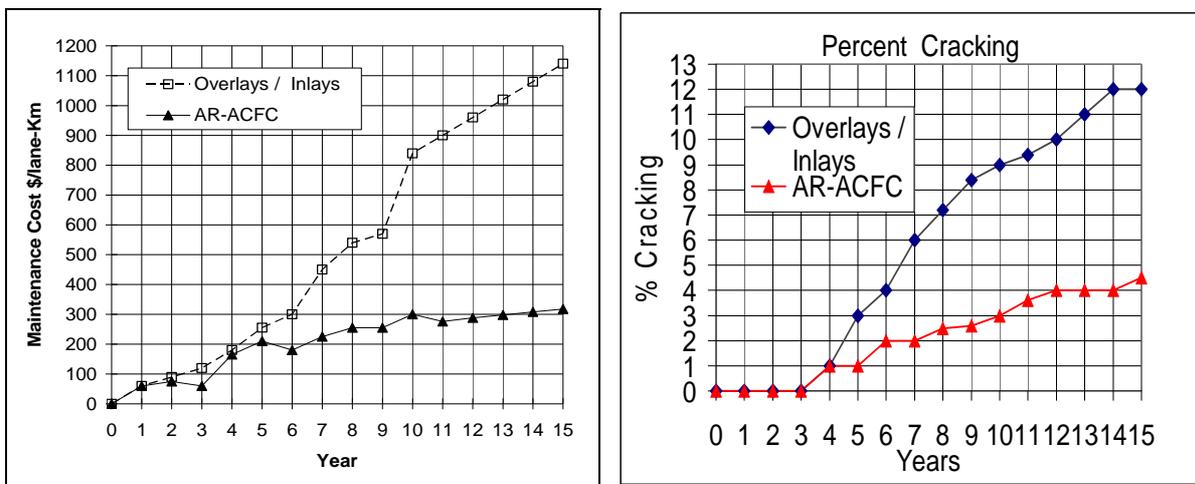


Figure 7.11: Conventional Overlays (AC or SMA) versus Asphalt Rubber, referring to US conditions: a) Maintenance Costs; b) Percent Cracking [Kaloush et al, 2008].

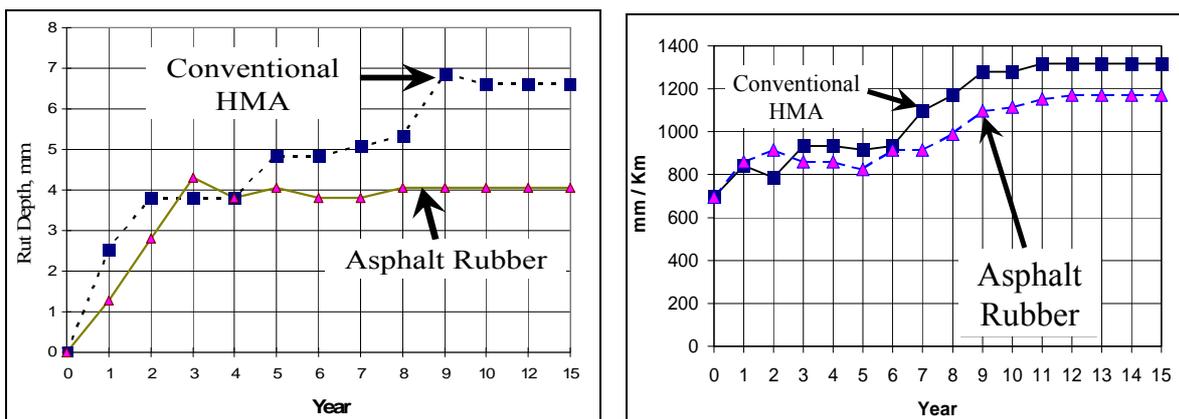


Figure 7.12: Conventional Overlays versus Asphalt Rubber: a) Rut Depth in mm; b) Smoothness [Sousa, 2006].

7.7.2 Energy Savings Considerations

Various research studies conducted by Sousa documents that the energy savings by using AR pavements (both gap graded and open graded designs) is quite impressive [Sousa et al, 2006]. Table 7.3 represents the heat of combustion values for crumb rubber modifier used in AR. The table has been reproduced from another published article by Kaloush et al, 2008 [Kaloush et al, 2008]. The 310267 kJ/Kg represents energy savings in terms of less AC overlays needed over the life of the pavement. It is also the result of using less than ½ of the thickness of the conventional HMA with equal or better field performance. The 310267 kJ/kg energy savings refers to a 50 mm ARAC (AR gap graded) overlay used as an alternative to a conventional 100 mm asphalt pavement overlay. This has been a common practice of Arizona DOT for over 135 pavement preservation projects built to date. Furthermore, 566109 kJ/kg energy savings refers to a 25 mm ARFC (AR open graded) mix used on the top of a PCC pavement in comparison to a 125 mm conventional HMA overlay. The 107860 kJ/kg energy savings refers to the mining and transport energy components associated with using thinner AR pavements compared to the thicker conventional HMA pavements.

Table 7.3: Energy Utilization (kJ/kg) for Asphalt Rubber [Sousa et al, 2006; Kaloush et al, 2008].

Process	Energy Gain / Loss (kJ/kg)
Tyre Shedding	-1744
Shred Transportation	-1744
Granulation	-3586
CRM Transportation	-1744
Steel Recovery	+1900
Asphalt Saved	+209325 to 46516
Aggregate Saved	+107860
Total Gain / Loss	+310267 to 566109

7.7.3 Reduced Thickness Design Considerations

Owing to the successful field performance of AR sections in the various states of the USA, California Department of Transportation (CALTRANS) developed a reduced thickness design guide for AR mixes that can provide the same service life as any thicker conventional HMA pavements [Kirk and Holleran, 2000]. The historical studies and mix designs indicated that the AR gap graded mixes needed a significant increase in binder content over dense graded mixes. However, the AR gap graded mixtures had the least percentage of reflective cracks, one third less than a 100 mm conventional overlay and less than one half a 200 mm overlay. Hence, AR gap graded mix was chosen as the standard in the reduced thickness design guide. Owing to its higher binder content in comparison with a conventional dense graded mix, an AR mix would provide higher confidence in the design, apart from being more conservative. The various designs have shown that AR mixes have proven to be very cost-effective, and the multi-layer systems using AR binders have proven to be the most cost-effective. Also, high binder content ARFC mixes used in combination have provided superior field performance.

7.7.4 Life Cycle Cost Considerations

Life cycle cost analysis (LCCA) is recognized by public agencies as an effective tool to assist in the selection of construction, rehabilitation, and maintenance treatments. Hicks and Epps utilised life cycle cost process to compare results to evaluate LCC for pavement containing conventional binders with similar applications containing AR binders [Hicks and Epps, 2000]. It was found that AR is cost effective in many of the applications used by the state highway agencies of Arizona, California, and Texas in the United States. The results of the study indicated that the use of asphalt rubber products is a cost effective solution in using AR as a mix and/or chip seals applications. In addition, AR allows a thickness reduction, eventually increasing the cost effectiveness of AR applications. It was recommended that AR is most cost effective when reflection cracking is expected and it was emphasized that AR binders will not be cost effective unless the thickness of the layer is reduced or extended life is achieved. Table 7.4 presents total mix cost for different pavement scenarios and cost per square meter per 25 mm normalized thickness for each pavement type [Carlson, 2009]. As observed, cost per square meter per 25 mm thick of each pavement type for an ARFC open graded mixture is about 9 % lower than a conventional HMA pavement while ARAC gap graded mixture is about 16 % more expensive than the conventional HMA pavement. It must be noted that a typical ARFC mix is placed as a 25 mm lift, a pavement which is a reduced thickness one. This accounts for a huge savings in the cost of the AR pavement in comparison to the conventional HMA pavement.

Table 7.4: Total Mix Cost in US Dollars of Different Pavement Types [Carlson, 2009].

Mix	Bid Price per Ton	Cost per Square Meter/25 mm
HMA Dense	\$79	\$4.66
ARAC Gap	\$94 (+16%)	\$5.42 (+16%)
ACFC Open	\$75	\$3.72
ARFC Open	\$82 (+9%)	\$4.05 (-9%)

7.7.5 Main conclusions from Swedish seminar in 2010

In September 2010 an international invitational seminar was held in Sweden [Gummiasfalt, 2010]. Experience of asphalt rubber in North America and Europe was shared, with a focus on an ongoing Swedish research program. The conference Chairman made the following conclusions at the end of the seminar (copied from [Andersson, 2010]):

- In Sweden 45 % of recycled tyres goes to "other than burning"
- In Arizona 80 % of recycled tyres goes into Asphalt rubber pavements
- No future problems in getting access of rubber granulate in Sweden
- The working conditions were not significantly worse regarding PAH, Anilin, Naftalen than conventional...
- Benzotiatol, emanating from the vulcanization process, is the probable cause for observed irritation and "illness"
- Asphalt rubber seems to generate lower concentration of PM10 than conventional...

- No substantial increase regarding dangerous leakage was observed for the asphalt rubber compared to the conventional...
- Better performance for wear resistance and crack propagation
- Good friction results, no problem
- Marginal effect regarding lower noise, 0-1 dB(A)
- Were overall satisfied with the performed project
 - From a technical and environmental point of view
 - From a productivity point of view ("no big differences from other...")
- Focused efforts in development of alternative PMB.

It should be added that long-term performance must be studied more and applications made also in other European countries until asphalt rubber surfaces can be recommended for wide applications in Europe. C/B ratio is so far uncertain, but present situation seems promising.

7.8 Overall assessment of TAL performance in the U.K.

During the 1990s, various categories of thin surfacing were introduced into the UK. They rather quickly gained a substantial share of the surface course market in all parts of the UK network. When the first of the thin asphalt surfacings laid in the UK were approaching their expected service lives around 2005 it was decided to review the evidence on performance and update the earlier assumptions about their service life [Nicholls et al, 2006].

The data base collected included maximum aggregate sizes of 6, 10 and 14 mm on a total of 128 sites. The thickness is not given, and one can wonder how thin a layer with NMAS of 14 mm may be, but at least some 14 mm surfacings were of the "ultra-thin paver-laid surface dressing" developed in France. All five categories of thin surfacings listed in Section 3.2.1 were represented. Parameters monitored were skid resistance, texture and visual condition.

Data had been gathered on the various categories of thin surfacing system after periods in service of up to 12 years for paver-laid surface dressing (PLSD), 13 years for thin asphalt concrete (TAC), 10 years for thin stone mastic asphalt (TSMA), 10 years for multiple surface dressing (MSD) and 6 years for micro-surfacing (MS).

Nicholls and his co-authors made the following conclusions, slightly edited by this Editor [Nicholls et al, 2006]:

The results collected from the monitoring showed that there is a minimal risk of either skid resistance or texture depth reducing significantly. See Figure 7.13. The main failure mode for all the categories appeared to be fretting¹², which tended to occur towards the end of the serviceability life. From a visual assessment of the performance of each of the systems, the following conclusions on the typical behaviour were drawn:

- PLSD systems can be expected to give a 10 year service life.
- TAC systems can be expected to give a service life of more than 13 years.
- TSMA systems can be expected to give a service life of more than 10 years.
- MSD systems can be expected to give a 7 to 8 year service life.
- There were insufficient data on MS systems to estimate the typical service life.

¹² Fretting and ravelling are essentially the same property, namely loss of aggregate

There was no clear difference in the durability for any category of thin surfacing systems whether the aggregate size is 0/10 mm or 0/14 mm. There were insufficient data on 0/6 mm aggregate size systems to determine whether a change to that size will have an influence on the durability.

The findings from the monitoring were that thin surfacing systems can routinely be constructed successfully to provide a safe surfacing with adequate skid-resistance, texture and visual condition and that these properties are maintained in service. Therefore, the evidence supports the acceptance by the Highways Agency of these systems for use on trunk roads in England [Nicholls et al, 2006].

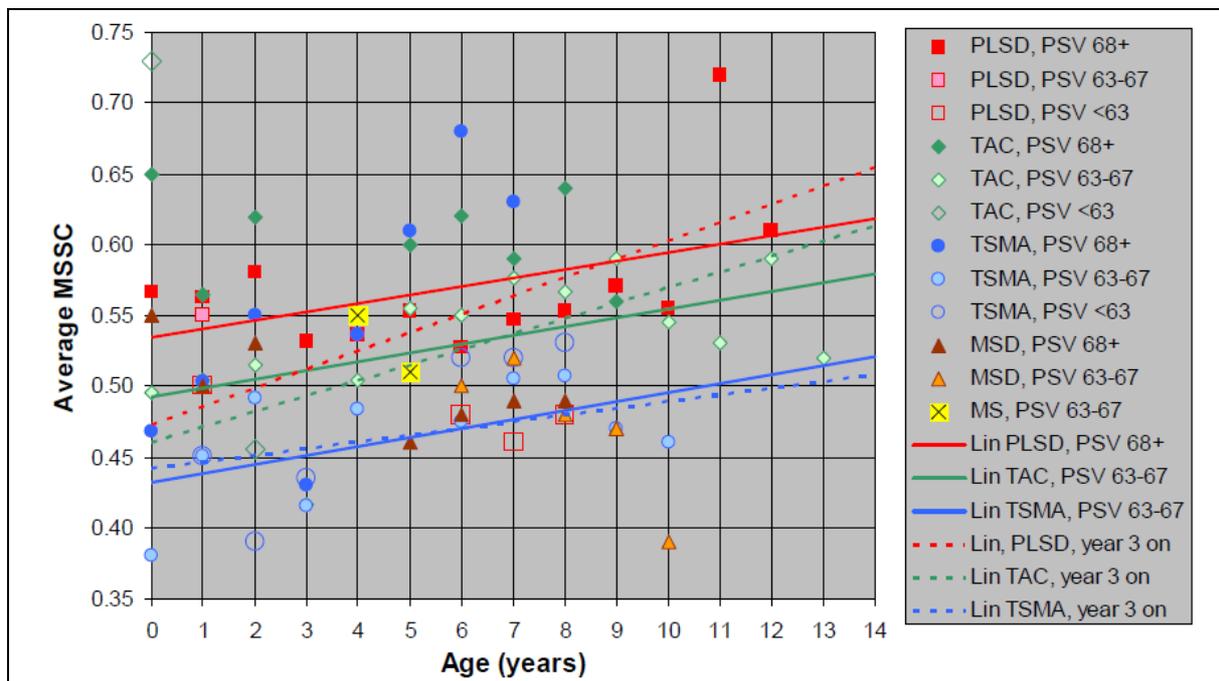


Figure 7.13: Mean Summer SCRIM Coefficient (MSSC) measured on a range of UK thin surfacings plotted as a function of surface age. From [Nicholls et al, 2006].

7.9 Other performance properties

Other aspects of performance are treated in some detail in Annex B. See also the summary in the next chapter.

8. SUMMARY OF PERFORMANCE

Table 8.1 summarizes the major advantages and disadvantages of TAL compared with DAC 11, based on the responses from the questionnaires. Compared to SMA 16, a reference surface commonly used in Nordic countries, the table would look almost the same. Some advantages of TAL would even be more pronounced, like the noise reduction and the cost reduction. On the other hand TAL does not have a better rut resistance than SMA 16.

Table 8.1: Major advantages and disadvantages of TAL compared with DAC.

Major advantages	Major disadvantages
Noise reduction may be from marginal to very high depending on TAL type	Ravelling susceptibility
Skid resistance is generally good at low and medium speeds	Delamination susceptibility
Cost reduction in general, due to thinner layer and fast paving (exceptions exist)	Frost susceptibility
Most features improve sustainability	Susceptibility to cracking related to substrate deficiencies
Some types have potential for lower rolling resistance	Some specially optimized proprietary TAL may be expensive
Reduced working space needed	Weather conditions during laying are critical
Good rut resistance	Manual placement not possible
Speed of laying is high	Intrinsic shorter lifetime
	Aggregate quality must be high; may be difficult to find quality aggregates
	Tack coating needed between TAL and basecourse
	High-speed skid resistance and/or hydroplaning may be a problem
	Noise reduction decreases over time

Table 8.2 compares the performance of TAL with those of some other common road surface types: DAC 11, SMA 11, single layer porous asphalt 0/8 (SLPA 0/8) and two-layer porous asphalt (TLPA 8+16). Reference is the DAC 11 surface. “+” and “++” mean a better respectively a much better performance for the given criterion; “0” means a similar performance as the reference surface and “-” and “--” indicate a worse, respectively much worse behaviour. This table is based on the answers received in the questionnaires, literature and “expert judgement” by the authors.

Table 8.2: Comparison of five common road surface types, including TAL. All evaluations are made in comparison to DAC 11. The colours mean: Green = Better than DAC and SMA 11, Red = Worse than DAC and SMA 11, Yellow = about equal to DAC and SMA 11.

	TAL	DAC 11	SMA 11	SLPA 0/8	TLPA 8+16
Noise	+	0	0	+	++
Skid resistance	+	0	0	0	0
Cost	+	0	-	-	--
Working space	+	0	0	0	-
Rut resistance	+	0	+	+	+
Speed of laying	+	0	0	0	-
Ravelling	-	0	0	-	--
Delamination	-	0	0	0	-
Frost susceptibility	-	0	+	-	--
Weather conditions during laying	-	0	0	-	-
Cracking	-	0	0	0	0
Manual placement	-	0	-	-	-
Lifetime	-	0	+	-	--
Noise reduction decreases over time	-	0	0	-	--
Splash and spray	0/+	0	+	++	++
Hydroplaning	0/+	0	+	++	++

9. SYSTEMS FOR CHECKING OR VERIFYING TAL PERFORMANCE

This important subject is treated in Annex C.

10. MIX DESIGN AND OPTIMIZATION OF TAL

Mix design and optimization of TAL would normally be an important section in a State-of-the-Art report. However, since this subject will be the main topic of a report in Stage 2 of this project, this section has been cut out from the State-of-the-Art report and was instead integrated into the Final Report for this project (see the Preface).

11. CONCLUSIONS

The use of thin asphalt layers (TAL) in Europe seems to increase although available statistics and inconsistent definitions make it difficult to distinguish between TAL and other hot-mix asphalt.

In the "perpetual pavement" concept the philosophy is that the pavement base has eternal bearing capacity and is paved with a thin long-lasting "skin" of surface layer which eventually – due to water, ageing and other climatic action – must be renewed from time to time.

TAL provide a "skin" with favourable functionalities, such as noise reduction potential, relatively low rolling resistance, relatively good anti-spray properties and efficient light reflection. This has accelerated the use of general product categories and proprietary products addressing these demands, also implying relatively high sustainability and low construction and maintenance costs. The fast laying of TAL implies shorter closure to traffic and this favours the use of TAL. Provided the pavement base is of appropriate quality TAL offer solutions to many of the functionalities mentioned and this is probably why there is immense interest in such products.

Despite this, one shall not forget the problems and limitations associated with TAL. For example, bearing capacity is often only marginal, and resistance to wear from studded tyres is poor, unless large maximum aggregate is applied, in which case the thickness needs to be relatively high. Open-textured or even porous TAL may offer good noise properties, but at the expense of limited durability under heavy traffic load; for example in sharp curves or at large gradients. Pavement porosities also tend to quickly get clogged by dirt. Another problem worth mentioning is that TAL cannot be dismantled by milling with the techniques at hand without downgrading the material.

The project group sent out a questionnaire to key experts. Unfortunately, the response was rather limited and a round of interviews was not very successful either. Most respondents mentioned noise reduction as a primary motivation to apply TAL. Also cost reduction and fast paving seem to be important, like good resistance of TAL to skidding and rutting. A few respondents mentioned durability problems as a disadvantage.

Policies on applying TAL vary substantially from country to country. For example TAL represents 95 % or so of all new Danish hot mix surface courses, while in Belgium this percentage is much lower and differs between regions. Also in Sweden, there is a substantial difference in the use of TAL between regions; not necessarily correlated with climatic conditions. Countries with extensive usage of TAL include the UK, Switzerland, Sweden, Norway and the Netherlands. Also Denmark and Austria use TAL relatively extensively. In Sweden, to some extent also in Norway and Switzerland, TAL is used on the highway network, while in the Netherlands and the UK usage is limited to municipal roads or city streets as well as provincial or trunk roads.

The report gives general advice and a few examples of published life cycle costs (LCC) compared with the cost of thicker overlays. This topic was further studied in another phase of the project. The LCC of TAL cannot be assessed with any accuracy until TAL lifetime and performance over time has been documented. Until then we must rely on calculation based on engineering judgement concerning the TAL lifetime.

Major advantages of applying TAL compared with standard DAC 11 or SMA 16 are

- Noise reduction
- Higher skid resistance (at least at low and medium speeds)
- Lower cost
- More sustainable
- Less required working space
- Better rut resistance
- Faster laying

Major disadvantages of applying TAL compared with standard DAC 11 or SMA 16 are:

- Susceptible to ravelling
- Susceptible to delamination
- Susceptible to frost damage
- Susceptible to cracking related to substrate deficiencies
- Weather conditions while laying TAL are more critical
- Manual laying is not possible
- Shorter lifetime
- Noise reduction decreases rather rapidly with time
- Some variants may offer rather low skid resistance in wet weather
- Dismantling by milling with present techniques downgrades the material

The advantages and disadvantages listed above are not consistently valid across all types of TAL and surface conditions, but are fairly representative of TAL as a family of wearing courses. However, it is recognized that experience about long-term performance of TAL is still insufficient; and consequently one needs to continue studying time series in the future.

The sensitivity of TAL to the weather conditions during the laying has been mentioned as a major disadvantage. Road administrations and contractors are often forced - by numerous factors - to build TAL during cold weather and then their durability may be low. Perhaps this can be counteracted by optimizing the laying process; thus this is recommended for study.

TAL must be CE-marked in order to be marketed as complying with an EN 13108-series product standard. These standards specify asphalt mixes; not their final application on the road. The ETAG 16 guideline on ultra thin layers, however, intends to deal with the entire process, including paving operations and the final application. Products complying with this guideline will probably be an additional route for CE-marking in the future. The impact of this CE-marking on the market still has to be seen in the daily practise of procuring asphalt materials.

At present, classification of pavement acoustic characteristics is limited to declaring product properties in Denmark, the Netherlands and the UK. CEN work on this is at an initial stage. No system exists for checking pavement product conformity of production concerning its noise characteristics.

At least two countries represented in the PEB are highly interested in the effect on TAL of the exposure to traffic with vehicles using studded tyres. The present review concludes that

aggregate quality and the proportion of large aggregate are the main parameters determining wear resistance of dense and gap-graded asphalt concrete wearing courses.

TAL as defined in this project with layer thickness 10 – 30 mm normally have 12 mm NMA or smaller. When winter conditions call for extensive use of studded tyres and snow chains, TAL may not be an optimum surface layer, as the rule in such cases says: “The larger the aggregate the better”. Therefore, in Sweden and Norway a special type of TAL, designated TSK, with NMA of 11 or 16 mm is widely used.

In the future it is necessary to look closer at the need for transportation of materials for construction and maintenance projects, in order to reduce energy consumption and the emissions following this. TAL may have both positive and negative influences on this, depending on the mass of material needed and the availability of this material near the construction or maintenance project. The need for high-quality aggregate in TAL is one issue, while the lower mass of material is another one.

The report also discusses the use of asphalt rubber (AR) pavements as thin layers. A multitude of benefits of using AR were listed, including less reflective cracking, less raveling, good rut resistance, good skid resistance and smooth ride, better drainage facilities, reduced tyre/road noise, cost effectiveness, beneficial engineering use for old tyres, and higher energy efficiency. A combination of lower aggregate size in the AR, inclusions of crumb rubber in the mix, consequentially incrementing an increase in the percentage of AR binder content, has made it possible for AR mixtures to be used as thin asphalt layers that have provided substantial benefits such as reduced thickness design, higher durability, and lower maintenance during the course of AR design life cycle.

However, it must be noted that these are the merits of AR typical for the conditions in the USA. In Europe so far, there has been a different scenario when one takes into account the derived benefits of AR, as observed in relation to a few similar pavement strategies of comparable quality. Nevertheless, ongoing research and practical applications, the results of which so far are rather positive, will determine whether the AR concept could be a success in Europe as well.

The report indicates that the actual achievement of both excellent functional properties and good durability (lifetime) is nothing which comes easily. In practice, it is often difficult to realise both these requirements simultaneously since they are frequently in conflict with each other. The information made available through this report should, therefore, serve as a basic guideline for achieving the best compromise between the goals.

12. ACKNOWLEDGEMENTS

It is gratefully acknowledged that Annex B.2.2 (about particulate matter) was written by Mr Mats Gustafsson, VTI. As this was his only contribution to this report, he is not listed as a co-author. Nevertheless, his contribution is valuable.

Mr Goubert would like to thank the following individuals for their willingness to filling out a questionnaire and sharing their knowledge with the project team:

- Ian Walsh, Jacobs Engineering (UK) Ltd, Maidstone (United Kingdom)
- Jacob Groenendijk, KOAC.NPC, Apeldoorn (the Netherlands)
- Peter J. Andersen, Vejdirektoratet, Copenhagen (Denmark)
- Jostein Aksnes, Statens vegvesen Vegdirektorat, Oslo (Norway)
- Olivier Ripke, Bundesanstalt für Straßenwesen, Bergisch-Gladbach (Germany)
- Erik Van den kerkhof, Colas Belgium, Brussels (Belgium)
- Cliff Nicholls, TRL Ltd, Wokingham, Berkshire (United Kingdom)
- Berwich Sluer, BAM Wegen nv, Bunnik (the Netherlands)
- Kenneth Olsson, Skanska, Farsta (Sweden)

Further, Mr. Goubert and Mr. Olesen would like to thank the following individuals for agreeing to be interviewed:

- Wim van Keulen (van Keulen advies), Vlijmen, the Netherlands
- Jostein Aksnes (Norwegian Public Road Administration - NPRA, Road Directorate), Geir Refsdal, Rolf Johansen and Jan Lindahl (NPRA, Eastern Region), Olle R. Larsen (Kolo Veidekke), Norway
- Alain Jacot (Société d'Analyses & Contrôles Routiers, SACR), Zürich, Switzerland
- Johann Litzka (Austrian Association for Research on Road - Rail – Transport, FSV), Jürgen Haberl (PMS-Consult, Engineering Office for Traffic and Infrastructure), Peter Riederer (BPS, Oberösterreichische Boden- und Baustoffprüfstelle GmbH), Michael Kostjak (Swietelsky BaugesmbH), Ronald Blab (Vienna University of Technology), Austria
- Gaetano Licitra (ARPAT, Agenzia Regionale per la Protezione Ambientale della Toscana, and University of Pisa), Pisa, Italy
- Bjarne Bo Jensen (NCC Roads A/S), Lars Ladehoff (Colas Danmark A/S), Uffe Mortensen (Pankas A/S), Niels Christoffersen and Uffe Mortensen (Inreco A/S), Denmark

13. REFERENCES

AAB (2006): “Hot mix asphalt. General specification” (in Danish), Danish Road Directorate November 2006.

Abbott, P. (2008): Personal communication between Mr P. Abbott, TRL Ltd in the UK and Mr J. Kragh, Danish Road Institute/Road Directorate, June 2008.

Aksnes, Jostein; Hansen, Odd Durban; Haukland, Frode; Storeheier, Svein Å. (2010): "CPX-målinger på forsøksdekker 2010". SINTEF IKT Notat # 90E354.05/TB, Trondheim, Norway.

Andersson, Per (2010): "Asphalt Rubber Seminar in Sweden september 29-30 – Closing remarks". See further [Gummiasfalt, 2010] below.

Bahia, H.U.; Faheem, A. (2007): “USA Experience with OGFC and other thin layers”, presentation during the Workshop on “Experience with very thin noise reducing layers”, Technical University of Delft, the Netherlands, June 6th 2007.

BBA (2008): "Guidelines document for the assessment and certification of thin surfacing systems for highways", British Board of Agreement (BBA), 2008. See (www.bbacerts.co.uk).

Bendtsen, H.; Raaberg, J. (2005): French Experiences on Noise Reducing Thin Layers. Technical note 28, 2005, Danish Road Institute, Road Directorate (www.roadinstitute.dk).

Bendtsen, H.; Raaberg, R.; Thomsen, S. (2005): International Experiences with Thin Layer Pavements Milestone – M2. Technical note 29, 2005, Danish Road Institute, Road Directorate (www.roadinstitute.dk).

Bendtsen, H.; Raaberg, J. (2007): Safety and Noise Reduction, Thin Layers. Technical note 52, 2007, Danish Road Institute, Road Directorate (www.roadinstitute.dk).

Bendtsen, H. et al. (2008): DRI-DWW Thin Layer Project - Final Report. Danish Road Directorate/Road Institute, DRI report 159, 2008 (www.roadinstitute.dk).

Bendtsen, H.; Ellebjerg, L. (2009): "Two-layer porous asphalt – lifecycle. The Øster Søgade experiment". Report 165, 2009, Danish Road Institute, Road Directorate. Website: www.roadinstitute.dk.

Bendtsen, H.; Lu, Q.; Kohler, E. (2009): "Acoustic aging of asphalt pavements - A Californian / Danish comparison". Report 171, 2009, Danish Road Institute, Road Directorate (www.roadinstitute.dk).

Bennis, T.; Hofman, R. (2008): "Eindrapportage IPG wegdekken – Monitoring." Document DVS-2008-046, 2008 of the Dutch “Noise Innovation Programme”, Rijkswaterstaat (RWS), Dienst Verkeer en Scheepvaart (DVS), P.O. box 5044, 2600 GA Delft, the Netherlands. Download at: <http://vwww.stillerverkeer.nl/index.php?section=&page=actuelelijst>

Bicket, P.; et al (2006): "HEATCO – Deliverable 5, Proposal for harmonised guidelines". Contract No. FP6-2002-SSP-1/502481, Lead contractor: IER, Germany. 2006.

Bijma, R. W. (2006): "Textuurmetingen, stroefheidsmetingen en gedetailleerde visuele inspectie op stille wegdekken (Uitvoering 2006)". Project number e0601378, KOAC-NPC, 10 November 2006, KOAC, Apeldoorn, the Netherlands.

Bredahl Nielsen, Carsten; Bendtsen, Hans; Andersen, Bent; Ertman Larsen, H.J. (2005): "Noise reducing pavements in Japan. Study Tour Report." Danish Road Institute, Road Directorate. Technical note 31, 2005. (www.roadinstitute.dk).

Brosseaud, Y. (1996): "Revetements Routiers: les betons bitumineux très minces: caractères spécifiques, bilan des réalisations et perspectives", Proceedings of the Eurasphalt&Eurobitume Congress, Strasbourg, May 7-10, 1996.

Brosseaud, Y.; Abadie, R.; Legonin, R. (1997): "Couches de roulement très minces et ultra-minces en matériaux bitumineux à chaud, bilan d'emploi et comportement", Bulletin des Laboratoires des Ponts et Chaussées n°207, pp. 55-71.

Brosseaud, Y. ; Abadie, R. ; Legonin, R., (1997): " Bétons bitumineux très minces et ultra-minces", Observatoire des techniques de chaussées n°94 published by S.E.T.R.A., 92223 Bagneux Cedex, France, ISSN 1250-8683.

Carlson, D. D. (2009): "What's New with Asphalt Rubber". Arizona State University Pavement, Materials and Transportation Conference, Arizona State University, Tempe, AZ, USA, February 2-4, 2009.

Cooe (2011): Cooe is a Danish project started in 2011 focusing on rolling resistance of road surfaces; see the project website at: <http://www.cooe-co2.dk/>

CROW (2004): "The method Croad 2004 for traffic noise". Publication n° 200 of CROW (in Dutch), CROW, P.O. box 37, 6710 BA Ede, the Netherlands (www.crow.nl) (April 2004, ISBN 90 6628 401 3).

CROW (2007): "Karakteriseren van dunne asfaltdeklagen". Publication n° 239 of CROW (in Dutch), CROW, P.O. box 37, 6710 BA Ede, the Netherlands (www.crow.nl) (March 2007, ISBN 978 90 6628 486 9).

CROW (2010): Spreadsheet from CROW, P.O. box 37, 6710 BA Ede, the Netherlands (www.crow.nl). Downloadable from the following website: <http://vwww.stillerverkeer.nl/index.php?section=&page=actuelelijst>

CRTN (1988): "Calculation of Road Traffic Noise (CRTN)", Department of Transport, Welsh Office, Her Majesty's Stationery Office, 1988.

Delorme, J-L. (1993): "Formulation mise en oeuvre et adherence des enrobes bitumineux", Bulletin de liaison des Laboratoires des Ponts et Chaussées n°185, pp. 139-143.

EAPA (2007a): “Long-Life Asphalt Pavements – Technical version”. European Asphalt Pavement Association, Brussels, Belgium (<http://www.eapa.org/>).

EAPA (2007b): “Asphalt figures 2007“. EAPA, European Asphalt Pavement Association, Brussels, Belgium (<http://www.eapa.org/>).

EAPA (2008): “Asphalt figures 2008“. EAPA, European Asphalt Pavement Association, Brussels, Belgium (<http://www.eapa.org/>).

ECRPD (2010): “Integration of the Measurement of Energy Conservation in Road Pavement Design, Maintenance and Utilisation (ECRPD)”, European project under the Intelligent Energy Executive Agency (IEEA), acting under powers delegated by the European Communities, see: <http://www.roadtechnology.se/ecrpd.eu>

Fujikawa, T.; Oshino, Y.; Mikami, T.; Tachibana, H. (2004): “Examination on Effects of Road Roughness Parameters for Abating Tyre/Road Noise”, CD-ROM Proceedings, Inter.Noise conference 2004, Prague, the Czech Republic.

Graetz, B. (1998): “Langzeitwirkung von Duennen Schichten bezueglich der Erhaltung relevanter Oberflaechenmerkmale”, Bitumen, vol 60(2), pp.67-70.

Groenendijk, J. (2004): Dunne deklagen als standaard maatregel voor groot onderhoud?. Project number e0400766, KOAC-NPC, 11 November 2005, Apeldoorn, the Netherlands.

Groenendijk, J. (2011): "Thin asphalt layers, road surfaces of the future? Case study: TAL in the Netherlands". Presentation at the final OPTHINAL seminar, Sterrebeek, Belgium.

Groenendijk, J.; Gerritsen, W. (2006): Vraagspecificaties voor Stille Wegdekken, Project number e0500969, 2006, KOAC-NPC, Apeldoorn, the Netherlands. Downloadable from: <http://www.stillerverkeer.nl/stillewegdekken/downloads/Achtergrondrapport%20KOAC-NPC.pdf>

Gummiasfalt (2010): "Seminarium om gummiasfalt". Website for seminar on asphalt rubber pavements, in Gothenburg, Sweden, 29-30 September 2010: <http://www.gummiasfalt.se/>

Gustafsson, M.; Blomqvist, G.; Gudmundsson, A.; Uthus, N. S. and Juneholm, M. (2009): "Tyre induced particle emission from pavement abrasion". ETTAP09 - 17th Transport and Air Pollution Symposium - 3rd Environment and Transport Symposium, Toulouse, France, June 2009.

Hammoun, F.; Hamlat, S.; Terrier, J.P. (2008): “Laboratory evaluation of the resistance to tangential forces of bituminous surfacing”. Proc of the Eurasphalt&Eurobitume Congress 2008, Copenhagen, Denmark.

Hanson, D.I. (2001): “Construction and performance of an ultrathin bonded hot mix asphalt wearing course”, Transportation Research Record No. 1749, pp. 53-59, Transportation Research Board, Washington, DC, USA.

Hartjes, J.M.; Voskuilen, J. (2008): “Classificatie van asfaltmengsels met behulp van de RSAT proef”. Proceedings of ‘Infradagen’, June 2008, Technical University of Delft, the Netherlands.

HAPAS (2011): “The Highway Authorities Product Approval Scheme (HAPAS)”. See: http://www.bbacerts.co.uk/certificate_search_results.aspx?SearchType=Product&KeywordSearch=Thin%20Surface

Hatakeyama, K.; Makabe, T; Emukai, T. (2010): "Study on Ultra Thin Overlay Method Applicable in Medium to Low Temperature Range". Proceedings of the 11th International Conference on Asphalt Pavements, International Society for Asphalt Pavements (ISAP), Nagoya, Japan, August 1-6, 2010.

Hicks, R.G. and Epps, J. A. (2000): Life Cycle Costs For Asphalt Rubber Paving Materials, Proceedings of the Asphalt Rubber 2000 Conference, Vilamoura, Portugal, November 14-17, 2000, ISBN 972-95240-9-2.

Highways Agency (2006): “Highways Agency internal guidance on how to treat noise reducing pavements in noise prediction”, 2006.

ISO/CD 11819-2: “Acoustics – Measurement of the influence of road surfaces on traffic noise – Part 2: The close-proximity method”, ISO/CD 11819-2:2000, 2000-12-13

Jacobson, T.; Wågberg, L.-G. (2004): "Prediction models for pavement wear and associated costs". Swedish National Road and Transport Research Institute, Linköping, Sweden.

Johnson, Ann M. (2000): “Best Practices Handbook on Asphalt Pavement Maintenance”. Professional Engineering Services, Ltd. 213 Townes Lane, Wayzata, MN 55391.

Judycki, J.; Jaskula, P. (2003): “Testing of performance properties of asphalt mixes for thin wearing courses”. Proceedings of the 6th RILEM Symposium, Zurich, Switzerland.

Kaloush, K., Biligiri, K., Rodezno, M., Belshe, M., Way, G., Carlson, D., and Sousa, J. (2008): Asphalt Rubber Asphalt Concrete Friction Course Overlay as a Pavement Preservation Strategy, the 4th International Gulf Conference on Roads, Doha, Qatar, 10-13 November 2008.

Kirk, J. V.; Holleran, G. (2000): Reduced Thickness Asphalt Rubber Concrete Leads to Cost Effective Pavement Rehabilitation, Synopses for 1st International Conference World of Pavements Sydney, Australia, February 20-24, 2000.

Kragh, J. (2007a): “Traffic noise at rumble strips – Internoise paper 2007”, Danish Road Institute / Road Directorate, Report 156, 2008, www.roadinstitute.dk

Kragh, J. (2007b): “Noise Classification - Asphalt Pavement, Danish Road Institute / Road Directorate, Technical Note 61, 2007, www.roadinstitute.dk

Kragh, J. (2008): “Road Surfacing - Noise reduction time history”, Danish Road Institute / Road Directorate, Report 161, 2008, www.roadinstitute.dk

Lee, David (2010): Personal communication with David Lee, Department for Transport, Highways Agency (member of the PEB of this project).

Litzka, J.H.; Pass, F.; Zirkler, E. (1994): “Experiences with Thin Bituminous Layers in Austria”. Transportation Research Record 1454, Transportation Research Board, Washington, DC, USA.

McDaniel, R. S.; Thornton, W. D. (2005): "Field Evaluation of a Porous Friction Course for Noise Control." In Proceedings (CD-ROM) of the TRB 84th Annual Meeting, Transportation Research Board of the National Academies, Washington D.C., 2005.

MIRIAM (2011): MIRIAM is an international project started in 2009 focusing on rolling resistance of road surfaces; see the project website at: <http://miriam-co2.net/>

Nicholls, J.C.; Daines, M.E. (1992): “Spray Suppression by Porous Asphalt”, Highways Resource Centre, Transport Research Laboratory, Second International Symposium on Road Surface Characteristics, Berlin, 1992.

Nicholls, Cliff; Carswell, Ian; Gibb, Mike; Williams, John (2006): "Service Lives of Thin Surfacing Systems in the UK". Paper at the conference Transport Research Arena Europe 2006, Gothenburg, Sweden.

Nielsen, C. B.; Nielsen, E.; Andersen, J. B.; Raaberg, J. (2004): Development of Durable Porous Asphalt, Mixes From Laboratory Experiments. Road Directorate/Danish Road Institute, Danish Asphalt Industries, NCC Roads. Proceedings 3rd Eurasphalt & Eurobitume Congress Vienna 2004 – Paper 090.

Nielsen, C. B.; Nielsen, E.; Raaberg, J. (2005): Durability of porous asphalt (in Danish Holdbarhed af drænasfalt). Report 139, 2005, Danish Road Institute, Road Directorate (www.roadinstitute.dk).

Nielsen, E.; Raaberg, R.; Bendtsen, H. (2006): Noise reducing SMA pavements – Mix design for SILENCE - F2. Technical note 39, 2006, Danish Road Institute, Road Directorate (www.roadinstitute.dk).

Olsson, Kenneth (2010): Interview of Mr Kenneth Olsson, Skanska AB, Farsta, Sweden, by Mr Erik Olesen, DRI.

Perveneckas, Zigmantas; Vaitiuk, Valerija (2009): “Pilot Sections of “Hot On Hot” asphalt Paving Technology in Lithuania”. Lithuanian Road Administration.

Resendez, Yadhira A.; Sandberg, Ulf; Rasmussen, Robert O.; Garber, Sabrina (2007): "Characterizing the splash and spray potential of pavements". Report from the Transtec Group, Inc., Austin, TX, USA (produced for FHWA, May 2007).

RMV (2006): Prescription for the Measurement and Calculation¹³⁾ of Traffic Noise, RMV 2006 (in Dutch). May be downloaded from www.stillerverkeer.nl. The site is an initiative by The (Dutch) Ministry of Housing, Spatial Planning and the Environment, the (Dutch) Ministry of Transport, Public Works and Water Management, and CROW, P.O. box 37, 6710 BA Ede, the Netherlands (www.crow.nl).

Rungruangvirojn, Pichaya; Kanitpong, Kunnawee (2009): "Measurement of Visibility Loss Due to Splash and Spray: Comparison Between Porous Asphalt, Stone Matrix Asphalt, and Conventional Asphalt Pavements". TRB presentation 09-1913, Transportation Research Board, Washington, DC, USA.

Sabita Guideline (2008): "Guideline for thin layer hot mix asphalt wearing courses on residential streets". Manual 27, May 2008, ISBN 978-1-874968-33-7, published by Sabita, Howard Place 7450, South Africa.

Sandberg, Ulf; Ejsmont, Jerzy A. (2002): "Tyre/Road Noise Reference Book". Informex, SE-590 39 Kisa, Sweden (www.informex.info).

Sandberg, Ulf; Masuyama, Yukieei (2005): "Japanese machines for laying and cleaning double-layer porous asphalt – Observations from a study tour". Swedish National Road and Transport Research Institute (VTI), and Chalmers University of Technology, Gothenburg, Sweden and Laboratory of Seikitokyo Kogyo Co., Iwafune-Cho, Japan.

Sandberg, Ulf (2010): "Asphalt rubber pavements in Sweden – Noise and rolling resistance properties". Proc. of Inter-Noise 2010, Lisbon, Portugal, 13-16 June 2010.

Sandberg, Ulf (Editor) (2011): "Rolling Resistance – Basic Information and State-of-the-Art on Measurement methods". Deliverable # 1 in MIRIAM SP 1; see [MIRIAM, 2011].

Schulze, C.; Gharabaghy, C. (2008): "Kronausbrüche bei Offenporigen Asphalten – Prognoseprüfung und Bewertung", Aachener Strassenbau- und Verkehrstage, Institut für Strassenwesen – RWTH, Aachen, Germany.

Schwanen, W.; van Leeuwen, H.M.; Peeters, A.A.A. (2007): "Acoustic optimization tool RE3: Measurement data Kloosterzande test track". Report M+P.DWW.060.44.8. of the subproject 1.2.4. of the Dutch "Noise Innovation Programme" Rijkswaterstaat (RWS), Dienst Verkeer en Scheepvaart (DVS), P.O. box 5044, 2600 GA Delft, the Netherlands.

Setra (1997): "Bétons bitumineux très minces et ultra-minces", Observatoire des techniques de chaussées n°94.

Sousa, J. B. (2006): State of the Art on Asphalt Rubber, Asphalt rubber 2006 Proceedings, Palm Springs, California, October 25-27, 2006, ISBN 962-405-091-0.

Sousa, J. B., Way, G. B., and Carlson. D. D. (2006): Energy Consumption of Alternative Scrap Tire Uses, Proceedings of the Asphalt Rubber 2006 Conference, Palm Springs, California, October 25-27, 2006, ISBN 962-405-091-0.

¹³⁾ RMV = Reken- en Meetvoorschrift = Calculation and Measurement Prescription

SPENS (2009): "Sustainable Pavements for European New Member States – Summary Report". Report available from FEHRL, Blvd. de la Woluwe, 42, 1200 Brussels, Belgium. Also downloadable from: <http://spens.fehrl.org>

Sridhar, R.; Sureshia, S.N.; Bose, S.; Veeraragavan, A. (2005): "Study of polymer and fibre modified open graded friction courses", Indian Roads Congress Journal vol. 66(2), 291-318.

Svedberg, Bo (2010): Call for seminar 2010-05-12 on "Framtidens materialförsörjning, en utblick (Future supply of material – a prospective survey)". Institutionen för samhällsbyggnad, Luleå Tekniska Universitet, Luleå, Sweden.

Tækker, Christina (2009): "Messina bridge heads into basic design stage". COWI, Denmark. Document downloadable from the COWI website <http://www.cowi.com/menu/news/newsarchive/transport/Pages/Messinabridgeconstructionstage.aspx>

Thomsen, S.; Bendtsen, H.; Andersen, B. (2005): "Thin noise reducing pavements for urban roads - Measurement report". SILVIA-DTF-DRI-009-02-WP4-20050801, SILVIA deliverable, downloadable from www.trl.co.uk/silvia

Thomsen, S.; Bendtsen, H.; Andersen, B. (2006): Noise reducing thin pavements. Urban roads. Danish Road Directorate/Road Institute, DRI report 149, 2006 (www.roadinstitute.dk).

Thomsen, S.; Bendtsen, H.; Andersen, B. (2008): Optimized thin layers - urban roads, the Kastrupvej experiment. Technical note 66, 2008, Danish Road Institute, Road Directorate (www.roadinstitute.dk).

van Vliet, W.J. (2007): Personal communication, 2007, between Mr H. Bendtsen and Mr van Vliet, Rijkswaterstaat, Dienst Verkeer en Scheepvaart, Postbus 5044 2600 GA Delft, the Netherlands.

Walsh, Ian (2009): "London asphalt specification: Guidance on the selection and recommendations for the use of road surfacing materials and European Standards for Asphalt". Job No. 11412, The London Technical Advisors Group (LoTAG), Transport for London; published by Jacobs UK Ltd. Downloadable at the website (check for latest edition): <http://www.lotag.com/lotasphalt2.htm>

Way, G. B.; Carlson, D. D.; Sousa, J. B.; Kaloush, K. E.; and Biligiri, K. P. (2010): Introduction To Asphalt-Rubber Pavement Noise Reducing Characteristics, Inter Noise 2010, Lisbon, Portugal, 13-16 June 2010.

VBW (2004): "Richtlijn dunne asfaltdeklagen". Vereniging tot Bevordering van Werken in Asfalt, April 2004, Breukelen, the Netherlands. Downloadable from: http://tweninfraconsult.web-log.nl/tweninfraconsult/files/richtlijn_dunne_deklagen_vbw.pdf

Wegan, Vibeke (2001): "Surfacing of concrete bridges". Report 106, (2001), Danish Road Directorate/Danish Road Institute, Hedehusene, Denmark. Downloadable at: http://www.vejdirektoratet.dk/pdf/Report_106.pdf

Wirtgen (2003): "Material and Process Procedure Principles for the Hot Recycling Process". Report No. 27-30, Wirtgen GmbH, Windhagen, Germany.

VROM (2002): "Guideline Low Noise Pavements, background document for the "Regulation for the Stimulation of the Application of Low Noise Pavements" (in Dutch), Dutch Ministry of Housing, Spatial Planning and the Environment, 2002.

Zareh, A.; Way, G. B. (2009): Asphalt-Rubber 40 Years of Use in Arizona, Asphalt rubber 2009 Proceedings, Nanjing, China, November 2-4, 2009, ISBN: 978-988-18681-1-4.

APPENDIX A: QUESTIONNAIRE AND INTERVIEWS

A.1 Questionnaire

ERANET ROAD

project OPTHINAL - Optimization of thin asphalt layers

Task 2: Inventory

Author: Luc Goubert, BRRC

QUESTIONNAIRE

1. Introduction

Thin asphalt layers have been used in several European countries and abroad for more than 15 years with mostly good results. They seem to be pavements that are cost effective, fast lying and may have a good surface. Developments in recent years show that thin asphalt layers can reduce noise, increase traffic safety (skid resistance and visualization during wet condition) and be durable.

In the frame of ERANET ROAD II¹⁴⁾, a call was issued end 2008 for a comprehensive study of this road surface type. The purpose of the project is the optimization of thin and very thin asphalt surfacing in thicknesses from 15 to 30 mm.

A consortium of the Danish Road Institute, the Swedish National Road and Transport Research Institute and the Belgian Road Research Centre has won the tender and the project was initiated on the 1st of July 2009¹⁵⁾.

Gathering of detailed information about use of and experiences with thin layers in the different European countries (and if possible also abroad) are an important part of the study.

A literature survey is carried out, but it is our experience that by far not all knowledge and experience can be found in regular literature, but remains often hidden e.g. within unpublished research reports of institutes, contractors etc. In order to make our study as complete as possible, we would like to ask a few questions to a selection of distinguished specialists in the field. The questions are listed on the subsequent pages.

We thank you in advance for your time and effort to complete them. If the answers can be found in documents (like research reports), please feel free to simply refer to that document

¹⁴⁾ More information on ERA NET ROAD can be found on the website: www.eranetroad.org

¹⁵⁾ the effective start of the project has been delayed later on, due to administrative issues

and enclose them (or tell how we can obtain it). Please note that it could also be very useful for the project if you only answer to some of the questions listed in this document.

The completed forms should be returned to:

Luc Goubert
Research scientist
Belgian Road Research Centre
Woluwedal 42
B-1200 Brussels
E-mail: L.Goubert@BRRC.be

2. Questions

- 2.1. How much m² of thin layers do you have in your country/region? Which percentage of top layers consists of thin layers? Do you have information about ratio thin layers¹⁶⁾/very thin layers¹⁷⁾?
- 2.2. Which are the motivations to use thin layers in your region/country? If there is more than one, please rank in order of importance. In case you don't use thin layers, do you have a motivation not to use them?
- 2.3. Which types are used?
 - 2.3.1. thickness
 - 2.3.2. void content
 - 2.3.3. modifier
 - 2.3.4. tack coat
 - 2.3.5. type of skeleton/grading curve
 - 2.3.6. which lab tests are performed (a priori tests)
 - 2.3.7. which is the basic document
 - 2.3.7.1.tender specifications
 - 2.3.7.2.certification system
 - 2.3.7.3.national or EU standard
- 2.4. Which a posteriori (in situ) performances are imposed and how and when are they verified?
 - 2.4.1. skidding resistance
 - 2.4.2. noise
 - 2.4.3. evenness
 - 2.4.4. texture (MPD...)
 - 2.4.5. durability
- 2.5. Which good or bad experiences did you have with thin layers (if any)? Are there recurring problems?
- 2.6. Did you find specific solutions for problems?
- 2.7. Which are the remaining problems/research needs?
- 2.8. How do you see the role of thin asphalt layers in the future?

¹⁶⁾ 20 – 30 mm thick

¹⁷⁾ < 20 mm thick

A.2 List of addressees for questionnaires

The OPTHINAL questionnaire was sent to the experts listed in Table A1 together with their affiliations and e-mail addresses.

Table A1: Receivers of the questionnaire on TAL distributed to a selection of European pavement experts.

<i>Name</i>	<i>Affiliation</i>	<i>E-mail</i>
M. Ahadi	Svevia	Mansour.ahadi@svevia.se
T. Ahokas	Tero Ahokas	Tero.ahokas@tiehallinto.fi
J. Aksnes	Statens vegvesen Vegdirektorat	Jostein.aksnes@vegvesen.no
E. Andersen	Kolo Veidekke	Eivind.andersen@veidekke.no
P.J. Andersen	Vejdirektoratet (Road Directorate)	pja@vd.dk
J. Bork	Sønderborg Kommune	jbor@sonderborg.dk
Y. Brosseaud	LCPC	Yves.brosseaud@lcpc.fr
K. Eskola	Trafikverket	Katri.eskola@tiehallinto.fi
A. Fossbakk	Skanska	Arne.fossbakk@skanska.no
J. Groenendijk	KOAC-NPC	groenendijk@koac-npc.nl
R. Hofman	RVS	Rob.hofman@rws.nl
B.-B. Jensen	NCC Danmark	bbj@ncc.dk
L. Ladehoff	Colas	Lars.ladehoff@colas.dk
K. Laukkanen	VTT	Kyosti.laukkanen@vtt.fi
G. Licitra	Arpat Toscana	g.licitra@arpat.toscara.it
K. Lundström	Vägverket (National Road Administration)	Kristina.lundstrom@vv.se
J.C. Nicholls	TRL	cnicholls@trl.co.uk
K. Olsson	Skanska	kenneth.olsson@skanska.se
B.W. Sluer	BAM Wegen bv	b.sluer@bamwegen.nl
G. van Bochove	Heijmans	GBochove@heijmans.nl
E. Van den Kerkhof	Colas	Eric.vandenkerkhof@colas.be
B. Wamsler	Vejdirektoratet (Road Directorate)	bow@vd.dk

A.3 Results of the interviews

A.3.1 Summary of interview with an expert from the Netherlands

Interviewers: Luc Goubert and Anneleen Bergiers

Dutch specialist: Wim van Keulen (van Keulen advies, Vlijmen)

Location and date of the interview: Vlijmen, May 18 2010

The original motivation in the Netherlands to use thin layers was adapted from France, namely their capacity of noise reduction. Later, their low cost became the main motivation. The main future objective is a higher durability. The functional life time is 7 years; at which time an increase of noise by 2 dB at 50 km/h has been reported. A bitumen layer may be applied on the surface or a fine very open asphalt concrete may be installed, which extends life time with one to three years.

Some laboratories already have developed new thin layers with longer life time (10-15 years) but current market conditions do not stimulate launching it on the market. Newly developed thin layers contain a higher percentage of bitumen and fewer voids, namely 11-14 % accessible voids, by adding a specific small sand fraction which fills up the voids.

Wim van Keulen expects the application of thin layers to remain limited even when durability is improved because of the limited need. An important problem is the restricted time frame to use planned budgets which stress pressure on installations even within bad weather conditions which causes problems with durability. A possible solution is a budget which is time independent.

A.3.2 Summary of the interview with a Norwegian panel of specialists

Interviewer: Luc Goubert

Panel of Norwegian specialists: Jostein Aksnes (NPRA Road Directorate), Geir Refsdal, Rolf Johansen and Jan Lindahl (NPRA, Eastern Region), Olle R. Larsen (Kolo Veidekke)

Location and date of the interview: Oslo, June 29 2010

Introduction

One has to distinguish between three “types” of asphaltic layers which are thinner than 30 mm and which are nowadays used in Norway:

- Ultra thin (Novachip etc.) (also referred to as *type 1* hereafter)
- Thin surfacings¹⁸⁾ according to the “*Norwegian Pavement Design Guidelines*” (*type 2*)
- “Ordinary” asphalt concrete or SMA applied as a thin layer (typically 50 – 60 kg/m²) (*type 3*)

¹⁸⁾ These are in principle not in the scope of the OPTHINAL project

Reasons why it is (not) used

In Norway, about 6.2 million m² of TAL are applied, mainly on roads with AADT less than 5000. In that case, the wear of the road is not much influenced by studded tyres, but rather by other factors like frost/heave. The use and hence negative impact of studded tyres on roads has decreased by 25 % in Norway, due to improvement of “ordinary” winter tyres, the use of de-icing salt and the introduction of fees for entering certain areas with studded tyres.

The reason why TAL of *type 3* are quite widely used in Norway on these low volume roads are mainly economical, rather than environment (noise) or safety driven. With TAL, simply less material is needed per m². Maximum aggregate size is 11 or 16 mm, mainly 11 mm. In performance related contracts 16 mm is used.

Ultra thin layers (*type 1*) are not so widely used, as their ranking lifetime/cost is not very good, in none of the AADT classes. When they are applied, also rather large aggregate sizes are used (11 or 16 mm). Remarkably, 16 mm aggregate sizes are used in a 20 mm Novachip ultra thin surface layer.

Special attention is paid to the tack coat, especially when a thin asphalt layer (or a surface dressing) is applied in any kind of crossing.

Thin asphalt layers are often applied on roads showing ruts. The intervention level for ruts is in Norway 25 mm of rut depth on at least 10 % of the section. Specific problems occur when applying a thin asphalt layer or a surface dressing:

- in ruts, the emulsion is not reaching the top of the layer (for surface dressings)
- compacting is difficult in the ruts (the use of a compacter with pneumatic tyres could probably solve this problem)
- thin asphalt layers cool very quickly after application. The use of more than one roller can be a solution for this problem

Solutions applied in Norway to address the specific problem of ruts are the prior milling of the surface or the application of a levelling layer. A technique commonly used in Norway is preheating with infrared before applying the thin asphalt layer, which allows the large aggregate to be partially pressed into the sub layer, allowing the use of large aggregates in relatively thin layers.

Noise becoming more and more an issue in densely populated areas, thin layers with maximum chipping size 8 mm are more and more used (of all three above mentioned types). To counter the increased susceptibility to wear due to the smaller chipping size, special attention is paid to the aggregate quality and PmB is used.

Bad experiences

The main bad experience with thin layers is the relatively quick cooling when applied at lower ambient temperatures, e.g. in autumn.

Other doubts are about the skid resistance: Norwegian experience is that in general the skid resistance is lower the larger the maximum aggregate size is. Studded tyres tend to improve

skid resistance, but too much use of them is bad for the durability of the road surface. Discussions are ongoing about the optimal percentage of studded tyres in the car population.

Another observation which is made in Norway is that the ultra thin layers tend to wear out before the threshold for rutting is reached.

TAL are not used on a number of roads because of the poor bearing capacity of the underground. A thicker wearing course is in that case needed to provide the necessary bearing capacity of the road.

A priori tests

A priori tests routinely carried out are:

- aggregate quality
- grading curve
- binder content
- adhesion
- void content (not for ultra thin type)

Laboratory tests for durability and deformation resistance are under development.

Tests in Norway have shown that adding a polymer to the binder results in 30 – 35 % less deformation for dense asphalt at 50 °C and 10000 wheel passes. Nevertheless, polymers are not routinely used for economic reasons on thin layers of the DAC type. Craftsmanship is considered to be at least as important as mixture design; especially to avoid inhomogeneity, mainly caused by segregation of aggregates and/or of binder. To stimulate craftsmanship more and more performance based contracts are used.

The methods used are standardised in a Norwegian handbook for road building, but differ from one region to another due to varying climatic conditions. In the north of the country pre-heating is systematically used. CEN standards about asphalt are strictly followed in Norway.

A posteriori tests

Skid resistance is only measured when there appears to be a problem. Initial rutting is measured in some cases, namely on highly trafficked roads. Evenness is also measured sometimes, but this is not a standard requirement.

The whole road network is systematically monitored once a year. Pictures are taken of every 20 m section and put into a database. This allows following the evolution of the state of the roads and contractors get access to this database. MPD values are also systematically measured and fed into the database, but these data are not used so far.

Noise is only measured in the frame of research projects. It is done with the NPRA CPX trailer, which is normally operated by SINTEF.

Remaining problems/research needs

Thanks to the systematic annual monitoring, a large volume of data is available and lots of answers can be distilled from these figures. E.g. the average service lifetime for ultra thin layers (*type 1*) as a function of the AADT:

- | | |
|----------------|------------------|
| ○ AADT < 1500 | 13.5 years |
| ○ 3000 – 5000 | 11 – 13 years |
| ○ 5000 – 10000 | 8.5 – 10.5 years |
| ○ AADT > 10000 | 6 – 7.5 years |

Research should aim at extending the service life and or reducing the costs. As noise is becoming a more and more important issue, it should also be addressed. The balance between the wear of the stones and the mortar should be studied in order to avoid (or at least reduce) the increase of noise by the wearing away of the mortar: the wearing away of the mortar causes an increase of the texture. A better “balanced” wearing would maintain a smoother and less noisy road surface. Moreover, a road surface with larger stones (> 10 mm) at the surface tends to be slippery.

It is believed that mixtures with stronger mortars (more wear resistant) and softer binders could be interesting. Stones could gradually be pressed into the mortar during lifetime, leading to a permanently smooth road surface, even under the action of studded tyres.

The future

It is expected that TAL will be more and more used in the cities to abate traffic noise. The wide use of TAL is also a matter of volumes and political choice. If the contractors would be given a guarantee that a substantial amount of TAL will be constructed the coming years, it would encourage them to invest in machinery. It does not pay if every now and then “a little bit” of TAL is ordered by the road authority.

Concluding remarks

After all, the scope of application of TAL is rather narrow:

- not too high AADT (maximum 3000 – 5000)
- enough bearing capacity of the under layers
- without severe levelling problems

But a slight increase of the use of TAL is, nevertheless, expected the coming years.

It is also mentioned that in 2011 a 4 – 5 years Norwegian national research project will start aiming to improve lifetime of road surfaces in general. It is not specially focused on TAL, but they will be considered. Budget of the project will be between 20 and 40 million NOK.

A.3.3 Summary of the interview with a Swiss specialist

Interviewer: Luc Goubert

Swiss specialist: Alain Jacot (Société d'Analyses & Contrôles Routiers, SACR, Zürich)

Location and date of the interview: Zürich, June 30 2010

Introduction

In 2008 there was a reorganization of the management of the major road network in Switzerland. The total network of national roads, comprises a network of 2000 km of highways, was brought under the responsibility of the Federal Authority. The transfer caused a major impetus with respect to the abatement of road traffic noise in Switzerland. A global noise map was made, based on point measurements and calculations (interpolations), giving rise to actions to abate the traffic noise on black spots along the national roads.

The decision was taken to use henceforth only noise reducing wearing courses on the highways and the standard wearing course applied is a Swiss TAL version “AC MR8”¹⁹⁾. PA 8²⁰⁾ is no longer used due to its vulnerability to damage caused by the widely used snow chains in winter period.

In Switzerland between 5 and 6 million m² of AC MR8 are constructed each year. Up to now it has been applied on about 50 % of the highway network, which represents between 25 and 30 million of m².

Reasons why it is (not) used

The reason why it is used is entirely the noise reduction.

Bad experiences

In Switzerland, one sees hardly other advantages for TAL than noise reduction. One is not sure that TAL are cheaper than conventional road surfaces, when one considers the whole life cycle. Another disadvantage is the more difficult construction: compaction is delicate due to the fast cooling down of the mixture once it is applied. Also problems with initial skid resistance have been reported.

Types used

AC MR8 is laid with a layer thickness of 20 up to 30 mm and has between 5.5 and 13 % of voids. PmB is always used. For the tack coat also modified bitumen is applied (dose 100 – 200 g/m²).

In Switzerland, one uses the available European Standards for the specifications of the materials for bituminous mixtures, which are adapted by the National Swiss Association for

¹⁹⁾ asphalt concrete “macro-rugueux” with 8 mm maximum chipping size

²⁰⁾ porous asphalt with 8 mm maximum chipping size

Standardization (SNV). These standards are given a national annex “NA” which fixes limits. A series of Swiss standards describes the conception, construction and requirements for the laid asphalt courses. An overview of the relevant EN and Swiss standards can be found in the Swiss standard SN 640 420b. The standard describing the conception, construction and requirements for the laid AC MR8 is the SN 640 430b. Requirements for the mixture are fixed in SN 640 431-1b-NA.

A priori tests

Contractors must have a certificate for their mixtures, which remains valid for a maximum of five years. In these certificates, one can find:

- granulometry (see example in Figure A1)
- binder content
- binder specifications (PEN value etc.)
- voids content
- results of Marshal test
- results of a rutting resistance test (for mixtures intended only for heavily trafficked roads)

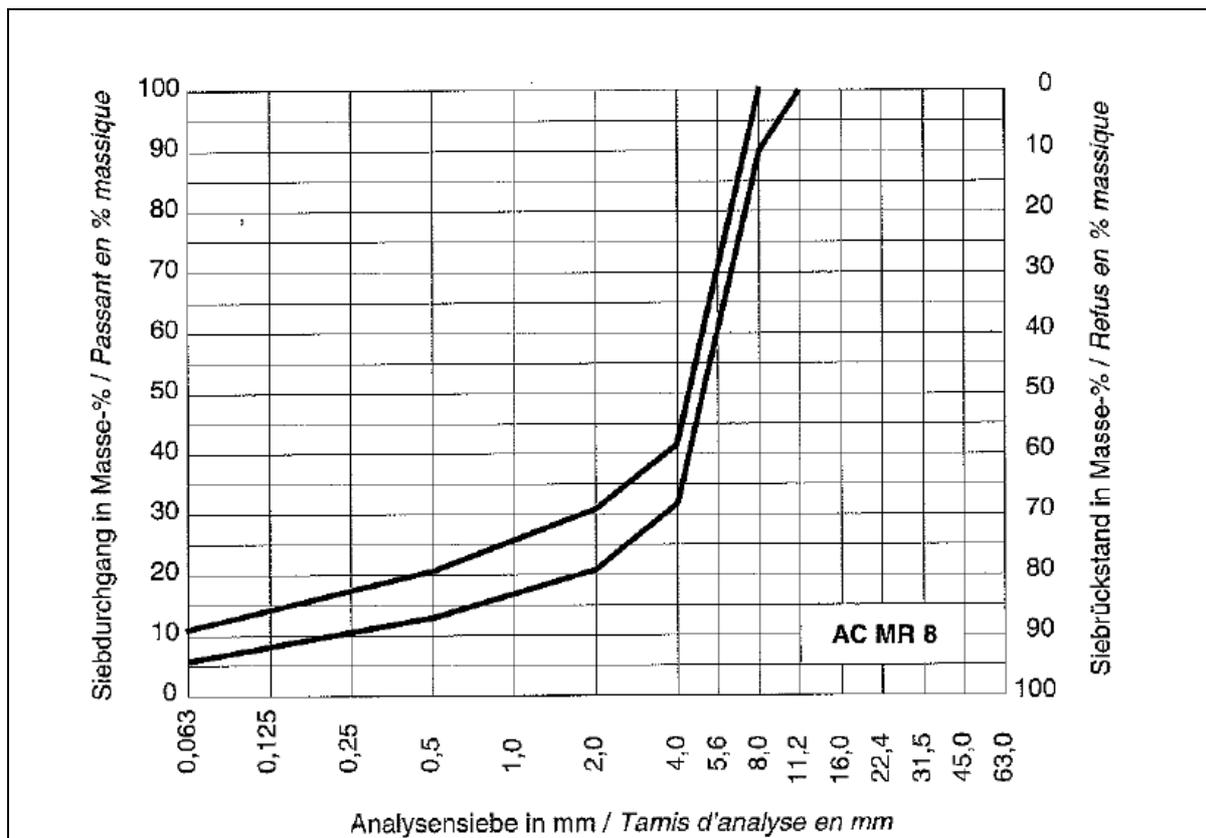


Figure A1: Sieving curve limits for the Swiss gap-graded TAL AC MR8, which is adapted as a standard wearing course on Swiss highways (Source: SN 640 431-1b-NA)

Road authorities take samples of the mixture which are tested in certified laboratories for compliance testing. During the construction of the road, compaction is tested. Producers of asphalt mixtures must have their products tested by a certified laboratory and calculate the moving average of the parameters.

A posteriori tests

Skid resistance is measured 2 – 3 months after construction of new wearing course on highways; for other roads it is not tested systematically. Longitudinal evenness is tested quite often by means of the APL²¹⁾, but transversal evenness is only measured in case of suspected problem. The “water value²²⁾” must not exceed 4 mm on highways or 6 mm on other roads.

The acoustic quality of the new wearing courses are not checked systematically either, but every four years the federal authorities assess the quality on 7000 km of the main road network. Parameters measured or observed are:

- visual inspection
- longitudinal and transversal evenness
- skid resistance
- acoustic quality by means of noise measurement by the CPX method (first time in 2010)

Remaining problems and research needs

As already mentioned, compacting properly is a problem with TAL and a second remaining problem is the uncertainty of the lifetime of TAL.

The laboratory of traffic facilities in Lausanne (LAVOC) is doing research to solve these problems. One will look for the optimal position between noise reduction and voids contents. For the solution of the compacting problem one is working on lukewarm mixtures. The use of these mixtures would allow a longer time for compacting the layer. The inconvenience would be the hardening time, which is two to three days with a lukewarm mixture, which is much longer than the two to three hours needed for a conventional mixture to harden.

Another alternative to ease the compaction of TAL which is studied is the “bituminous foam” which is obtained by using humid aggregates for the mixture preparation or by adding chemical products to the mixture (like wax).

Pilot research has been carried out by LAVOC; now the testing by means of test sections is being tendered.

The future

Swiss highways will soon be covered by 100 % with TAL, but also on other roads it will be used more and more (also the variant AC MR4 with maximum aggregate size 4 mm and a layer thickness of 15 – 20 mm). Politically, priority is given to traffic noise abatement and one accepts the less good durability.

²¹⁾ Analyseur de Profil en Long

²²⁾ maximum depth of puddles on the road surface

A.3.4 Summary of the interview with a panel of Austrian specialists

Interviewer: Luc Goubert

Panel of Austrian specialists: Johann Litzka (Austrian Association for Research on Road - Rail – Transport, FSV), Jürgen Haberl (PMS-Consult, Engineering Office for Traffic and Infrastructure), Peter Riederer (BPS, Oberösterreichische Boden- und Baustoffprüfstelle GmbH), Michael Kostjak (Swietelsky BaugesmbH), Ronald Blab (Vienna University of Technology)

Location and date of the interview: Vienna, July 2 2010

Introduction

Figures about the area of TAL in Austria are available only for highways. The total area of very thin layers (thinner than 20 mm) on Austrian highways is 1.1 million m² and the area of thin layers (thickness between 20 and 30 mm) amounts to 1.45 million m². The ratio between the two is hence 1:1.3. Between 10 and 12 % of the road surfaces on the highways consists of TAL.

No information is available for secondary roads, which are managed by the states of Austria (*Länder*). Neither is information available about roads owned by the cities.

Types used

Three types of TAL which are most common in Austria:

- LDDH8 (*Lärmmindernde Dünnschichtdecke Heiß*, Noise reducing thin layers “hot”²³⁾, with maximum aggregate size 8 mm)
- LSMA8 (*Lärmmindernde Splitt Mastik Asphalt*, Noise Reducing Stone Mastic Asphalt, with maximum aggregate size 8 mm)
- LSMA11

Voids content for LSMA8 is typically 10 – 11 %, which is considered to be a good compromise between sound absorption and durability. The LSMA types have binders with rubber or polymer modified bitumen.

Also DAC and SMA are sometimes applied in wearing courses with a thickness lower than or equal to 30 mm: DAC 4²⁴⁾ is applied in layers with thickness between 20 and 30 mm; DAC 8 and SMA 8 are applied in thicknesses between 25 and 35 mm and AC 11 and SMA 11 in layers between 30 and 40 mm. There are also thin layer types “BBTM”²⁵⁾ and AC deck D A3, which are applied in thicknesses up to 25 mm. Maximum aggregate size is in both cases 4 or 8 mm.

²³⁾ indicating that the mixture is applied hot

²⁴⁾ DAC is indicated in RVS as “AC deck”

²⁵⁾ beton bitumineux très mince, very thin asphalt layer

For the mixtures the available EN standards are used, but for the constructions a national guideline *RVS 08.16.01*²⁶⁾ is used.

For the roads managed by the Federal Ministry, complying with RVS 08.16.01 is mandatory; for the state owned roads this is recommended.

Reasons why TAL are used

There are several reasons why TAL are being used in Austria:

- good resistance to rutting
- economy (materials used for the top layer are very expensive; high quality aggregates and high quality bitumen must be used)
- especially for highways, noise reduction is very important

On highways, TAL types with 11 mm maximum chipping size are used.

The types are specified in the RVS, while the performance is specified in standards.

A priori tests

The PSV value of the aggregate for the wearing course is always checked.

A posteriori tests

Noise is sometimes assessed; namely on road surfaces which were intended for noise reduction; not on the other types of roads. Measurements are done with an Austrian CPX-like device (see Figure A2), which resembles strongly the ISO CPX method, but not completely. The Austrian CPX method is described in an RVS. Skid resistance is always tested on highways. Conformity with (longitudinal) evenness requirements is always checked by means of the 4 m straight-edge. Transversal evenness is not checked.

There is a texture requirement; the MTD²⁷⁾ value must be at least 0.4 mm. First, a visual inspection is made and if there seems to be “suspect” parts of the road surface, MTD is checked by means of the sand patch method.

The durability is not checked, but by means of an a priori test, the ageing of the bitumen is assessed.

Bad experiences

The problem which is most common is debonding, by failure of the tack coat. This occurs mostly when a TAL is applied on a cement concrete under-layer and when paving is not done correctly. Rutting is a problem when TAL is applied in a too thick layer. A general problem with bituminous wearing courses which occurred the last years is the varying quality of the bitumen. Due to the expensive oil, one tries to extract as much as possible fuel during the

²⁶⁾ *Richtlinien und Vorschriften für den Straßenbau, Guidelines and Prescriptions for Road Construction*, drafted by the FVS, not to be confused with national standards, indicated with ÖNORM, which are made by ÖNI (Österreichischen Normungsinstitut)

²⁷⁾ MTD = Mean Texture Depth, measured by the patch method

refining process, leading to lower quality of the remaining material. In spite of the mentioned problems, TAL are not considered as especially problematic wearing course types in Austria.



Figure A2: The Austrian CPX-like trailer (photo by IFS Ziviltexniker Ges.m.b.H.)

Specific solutions

For a quicker compaction, more compactors are used at the same time, which also requires specific training of the personnel. One tries to limit the distance between the asphalt plant and the construction site and one uses covered trucks to prevent excessive cooling of the mixture during transportation.

Enough tack coat has to be foreseen for the application of TAL on cement concrete and the concrete surface is brushed before the TAL application.

The debonding problem is addressed in research and a wedge-splitting test has been developed to assess this aspect in laboratory. Experiments are carried out on different textures for the under-layer to see which one that gives an optimal bonding. An Austrian standard for this wedge-splitting test is under preparation.

The future

The experts assume that TAL will have a very important role in Austria, both for economical and environmental (noise reduction) reasons.

A.3.5 Summary of the interview with an Italian specialist

Interviewer: Luc Goubert

Italian specialist: Gaetano Licitra (ARPAT, *Agenzia Regionale per la Protezione Ambientale della Toscana*, and University of Pisa)

Location and date of the interview: Pisa, July 9, 2010

Introduction

One has no experience at all with TAL in Tuscany and this may be generalized to the whole of Italy.

Reasons why TAL are not used

On highways, porous asphalt is generally used for its noise-reducing and draining capacity. One of the main inconveniences encountered in the more northern European countries for porous asphalt is its problematic winter maintenance, but this is hardly a problem in the mild Mediterranean climate in Italy. There is hence no incentive to explore other types of noise-reducing pavements for the highways.

As to the secondary roads and city streets, there has been little interest and funding in the past to keep these in a good shape. Multiple spot repairs of wearing courses are very common, which is not very compatible with the use of low noise pavements.

The future

Nevertheless, things are changing, among others under the influence of the European Noise Directive and the action plans foreseen in it. Tuscany region has adopted a project called Leopoldo and its aim is to characterize vehicle emission to serve as input for noise mapping. Part of the project is also the study of low noise pavements and therefore one has planned the construction of ten test sections; six low noise pavements and four reference pavements. One of the test sections, near the village Capolona in the province Arezzo, will have a “micro-drain” wearing course, which is a porous asphalt applied as a thin layer. The thickness will be 30 mm and the length of the test section will be 200 m. Its acoustical and structural behaviour will be monitored and in case of success, it may be used on a large scale to abate traffic noise in the future. Acoustical monitoring will be carried out with the ARPAT CPX device, which is a system with a vehicle-mounted microphone outside a test tyre; see Figure A3.



Figure A3: The ARPAT CPX device.

A.3.6 Summary of interviews with Danish specialists

Interviewer: Erik Olesen

Danish specialists: Bjarne Bo Jensen, NCC Roads A/S, Lars Ladehoff, Colas Danmark A/S, Uffe Mortensen, Pankas A/S, Niels Christoffersen and Uffe Mortensen, Inreco A/S

Location and date of the interviews: Telephone interviews 7 – 11 June 2010

Introduction

Thin asphalt layers are widely used in Denmark. Common types are stone mastic asphalt (SMA), open- or dense-graded asphalt concrete (AC) or UTLAC, all with 6 mm or 8 mm nominal maximum aggregate size.

Recently, very thin asphalt layers with 4 mm maximum aggregate size have been introduced by Colas. Inreco remixes existing pavements with new asphalt; in particular for laying SMA 6+ with 6 mm nominal maximum aggregate plus a small amount of 8 mm aggregate. Inreco used to apply this process in Denmark and Sweden but work in Sweden has been discontinued.

Amounts applied

In 2007 the total production of hot mix asphalt in Denmark was 3.3 million tonnes, 40 % of which were wearing course asphalt [EAPA, 2007b]. The corresponding numbers for 2008 were 3.1 million tonnes and 44 %. Based on the distribution of various layer thicknesses provided by NCC and shown in Table A1, the number of square metres laid 2007 - 2008 in Denmark is estimated in Table A1, assuming the following typical rates:

- thickness < 20 mm: 45 – 55 kg/m² (average: 50 kg/m²)
- thickness 20 -30 mm: 50 – 70 kg/m² (average: 60 kg/m²).

The total area of Danish paved roads is in the order of 400 million m², 40 million m² of which constitute the motorways and other national roads.

Colas estimated its application of very thin layers (< 20 mm) to be significantly lower than that of NCC and Pankas, see further Table A1, while Inreco did not provide an estimate at all. The last columns of Table A1 show the estimated percentages of the national road network presently paved with thin asphalt layers.

Typical layer thicknesses and void contents are given in Table A2.

Table A1: Estimated masses, areas and percentages of various layer thicknesses laid per year in 2007 – 2008 on the national and municipal roads given by three contractors, and the estimated total coverage on the national Danish road network.

Thickness	Total TAL built per year (all roads)				NCC	Colas	Pankas	Total TAL area (only national roads)	
	2007		2008					[10 ⁶ m ²]	[%]
[mm]	[10 ³ t]	[10 ⁶ m ²]	[10 ³ t]	[10 ⁶ m ²]	[%]	[%]	[%]	[10 ⁶ m ²]	[%]
< 20	673	13.5	696	13.9	51	10	40	3.3	7
20 - 30	528	8.8	546	9.1	40	50	60	3.8	8
(> 30)	(119)				(9)	(30)			
Total					100	100	100	7.1	15

Table A2: Typical thicknesses and void contents of the common Danish types of thin asphalt layers.

Type designation		Range of thickness	Normal range of void content	Void content when used as noise-reducing pavement
In DK	In EN 13108	[mm]	[%]	[%]
TB 6k	UTLAC 6	15 – 20	No requirement	13
AB 6t	AC 6d		2 - 4	-
TB 8k	UTLAC 8	20 – 30	No requirement	12
SMA 6	SMA 6		2 - 5	9
SMA 8	SMA 8			16
AB 6å	AC 6o		2 - 4	-
AB 8t	AC 8d			-
AB 8å	AC 8o			16

Motivation for using thin asphalt layers

The major reasons for applying thin asphalt layers in DK are – in that order – low price, high quality, noise reduction. The lower cost is, among others, connected with the reduced need for adjusting kerbstones.

Specifications

According to Danish specifications [AAB, 2006], which are based on EN specifications, the following amounts of tack coat of residue binder from modified emulsion shall be applied: UTLAC 6 (TB 6k): > 600 g/m²; UTLAC 8 (TB 8k): > 700 g/m². For all other types of thin asphalt layers the tack coat shall be 300 – 400 g/m² of 50 % non-modified bitumen emulsion. Colas A/S and Pankas A/S increase the amount of emulsion for open-graded wearing courses.

NCC rarely applies modifier in thin asphalt layers while Colas and Pankas to some extent applies such modifiers.

Requirements on aggregate grading curves are defined in Danish national specifications. As an example, Figure A4 shows the centre points of tolerance intervals specified for AC 8d, AC 8o and SMA 8, respectively.

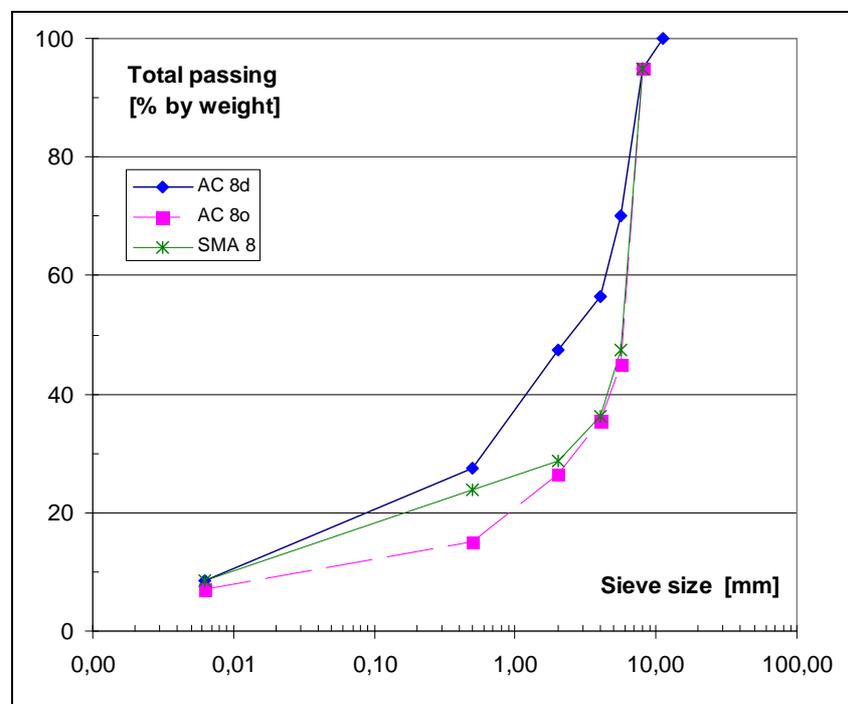


Figure A4: Danish target curves for aggregate grading of AC 8d, AC 8o and SMA 8.

A priori tests

A priori tests are routinely carried out for:

- Bitumen softening point
- Aggregate quality
- Aggregate grading curve
- Stability and plastic flow (Marshall test) - not for UTLAC
- Binder content
- Air void content - not for UTLAC or open-graded types
- Light reflection – when specified.

When the bitumen is modified or if the asphalt is modified in-situ, the contractor must specify the improved properties of the asphalt relative to non-modified asphalt.

A posteriori tests

Skidding resistance requirements are part of Danish national specifications for thin asphalt layers, except for AB 6t (AC 6d). On national roads, measurements are carried out before the road is opened for traffic to verify the requirements.

Danish national specifications for thin asphalt layers comprise requirements on evenness. On the national road network this is verified at the completion of laying the wearing course. Hence, for construction and acceptance of new pavements a 5 m Viagraph simulation is used on measured surface profiles. No direct requirements are specified for surface texture.

Once a year the national road network is monitored (by the Danish Road Directorate Profilograph and ARAN vehicle) to determine pavement condition expressed in evenness (IRI), rut depth, and texture. Based on the texture measurements (MPD), the national road network is screened for skidding resistance problems. If indications of lacking skidding resistance are found, then actual skidding resistance measurements are carried out using the Danish Road Directorate's ROAR equipment. This is usually the case for 5 – 10 % of the national road network.

If local (municipality) roads look fine, no further monitoring is done; else some measurements may be carried out. Often roads are maintained according to performance-based contracts. Such a contract may specify measurement every year or every third year of a) skidding resistance, b) evenness, c) cracks and potholes, and d) rutting.

Contractors shall issue a 5 year guarantee and the durability of thin asphalt layers is 10 – 15 years.

Danish experience with applying thin asphalt layers is generally excellent. For example, UTLAC (TB k) has proved to be resistant to rutting and SMA types are perceived as very fine solutions in many cases.

To obtain full advantage of a thin asphalt layer the underlying base course must be even.

The following research and development needs have been identified:

- UTLAC (TB k) types: increase their durability
- For all types:
 - reduce the effects of acoustic ageing
 - reduce tyre/road rolling resistance.

The future

Thin asphalt layers are already used extensively in Denmark and this is expected to continue.

APPENDIX B: OTHER ASPECTS OF PERFORMANCE

B.1 DURABILITY

B.1.1 Ageing

It is generally accepted that TAL wearing courses are particularly exposed to ageing in road pavements. This phenomenon can be explained by both a layer thickness below 30 mm (large impact of the surface as compared to the total mass of the layer) and the high void content typical of a large number of TAL (especially those characterized by a stony skeleton).

With respect to ageing, two major categories can be identified: asphalt mixes with low rather low void content (typically below 7 %) and asphalt mixes with a rather high void content (above 7 %). The ageing of the first family is limited to the very upper layer (5 mm) since the exposure of the binder to oxygen in the air is restricted to the surface, even when the asphalt mix is characterized by an open surface texture. The voids of such a mixture are not connecting, so the bulk of the asphalt layer can be considered as closed and therefore inaccessible to oxygen. In contrast with the first family, mixtures characterized by a rather high void content (interconnecting pores) are exposed entirely to the action of oxygen. The ageing is likely to proceed homogeneously throughout the whole layer. A typical example is porous asphalt.

Generally speaking, ageing of the binder (both short and long term ageing) can be studied either by evaluating the ageing of the binder (e.g. following the procedures as described in EN 12607 part 1 to 3, EN 15323 or EN14769) or by ageing compacted specimens (conditioning in a heated oven). Short term ageing does occur during bitumen storage, mix production and laying, while long term ageing occurs during the service life of a pavement.

With respect to TAL only a very limited number of studies are reported. The results of a Polish study have been published [Judycki & Jaskula, 2003]. They stated that the ageing of asphalt mixes (Marshall specimen) designed for thin wearing courses did not show any significant differences between the mixes containing different bitumens (unmodified or polymer modified). Both GAP graded asphalt concrete (GAC) and SMA indicated similar ageing properties (by measuring resilient modulus of aged and unaged specimens).

The HAPAS certification procedure does mention in appendix A.4 a methodology for accessing the ageing characteristics of thin surfacing systems [BBA, 2008]. The protocol describes a method for measuring the ageing characteristics by determining fatigue properties (using Indirect Tensile Fatigue) before and after long term oven ageing of cylindrical cores (preferred option is to drill bore core samples from the road). It should be noted however, that the method has yet to be proven and shown to be valid (establishing a relation between lab simulation and ageing in the field). The method is therefore unsuitable for use in specifications. The PIB (Product Information Blad) used in the Netherlands for the certification of DAD (“dunne asphalt deklagen” or thin surface asphalt courses) is quite similar to the HAPAS system. It also recognizes the need for field validation of the ageing procedure and therefore the results are considered as informative.

B.1.2 Acoustical durability

B.1.2.1 Danish long time experiment on acoustical durability

There are not many measurement results published on the long time acoustical performance of thin layers [Bendtsen et al, 2005]. The results of a Danish experiment have been published in [Bendtsen et al, 2009]. The test sections on highway M10 near Solrød in Denmark were established in 2004. Figure B.1 shows a photo from this site. The purpose was to test different types of noise reducing thin open graded pavements on a motorway. Yearly SPB noise measurements have now been conducted over a 5 year period; see Figure B.2 and B.3. There are six test pavements, a dense graded pavement and five noise reducing thin layers.



Figure B.1: Thin layers have been tested since 2004 under heavy traffic load on highway M10 at Solrød southwest of Copenhagen in Denmark.

The traffic volume at this six lane highway is around 90,000 vehicles per day. Table B.1 gives an overview of the slope of the trend lines found at each of the six M10 pavements. For passenger cars the DAC 11 reference pavement and the SMA 8 pavement have the lowest noise level increase of 0.5 to 0.7 dB/year. For the more open graded pavements, the increase varies between 0.8 and 1.3 dB/year. The increase for multi-axle trucks is generally much lower. Figure 3.3 shows the surface of one of the TAL included in this set of trial pavements.

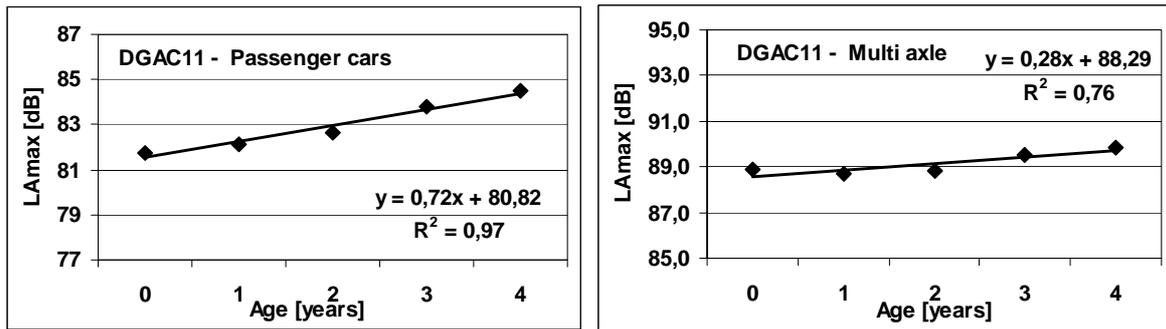


Figure B.2: Pass-by noise levels for passenger cars (left, reference speed 110 km/h) and for multi-axle vehicles (right, reference speed 85 km/h) on the DAC 11 [Bendtsen et al, 2009].

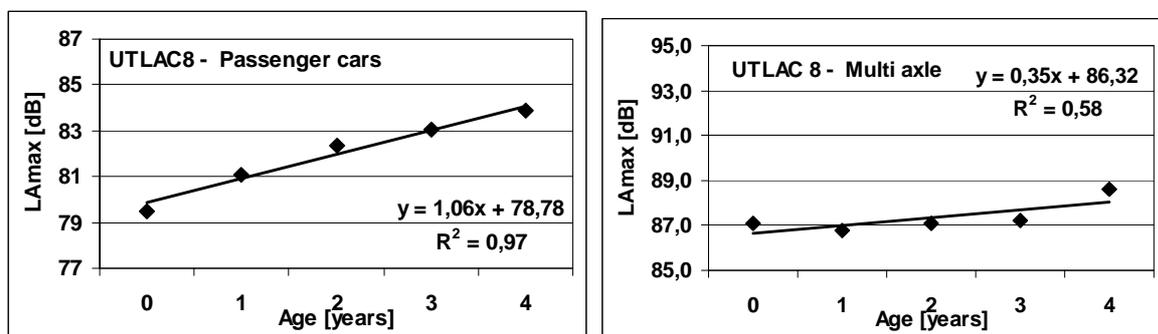


Figure B.3: Pass-by noise levels for passenger cars (left, reference speed 110 km/h) and for multi-axle vehicles (right, reference speed 85 km/h) on the UTLAC 8 [Bendtsen et al, 2009].

Table B.1: Average noise level increase per year for passenger cars and multi-axle vehicles for the six test pavements on M10, using reference speed 110 km/h for passenger cars and 85 km/h for multi-axle vehicles [Bendtsen et al, 2009].

Pavement	Passenger cars	Multi-axle vehicles
DAC 11	0.7 dB/year	0.3 dB/year
UTLAC 8	1.1 dB/year	0.4 dB/year
AC 8o	0.8 dB/year	0.1 dB/year
SMA 8	0.5 dB/year	0.2 dB/year
SMA 6+	0.9 dB/year	0.6 dB/year
SMA 8+	1.3 dB/year	0.7 dB/year

One task in the European project SILENCE was to look into the development with time of pavement acoustic performance [Kragh, 2008]. Among the available data were French data for several types of thin layer asphalt. Figure B.4 shows data from 17 sections of road with very thin asphalt concrete (BBTM 6 Type 2). For each section the time history of passenger

car pass-by noise levels are shown. All of these have been forced to origin at 0 dB and the curves show the increase in noise level with increasing pavement age. 0 dB was defined as the intercept of the linear regression of noise level on pavement age. The figure also shows the regression line for all the individual data points. The spread of observations is large. The average slope is 0.78 dB per year and the standard deviation s_R of the residuals in the y-direction is 1.9 dB.

Similar figures can be found in [Kragh, 2008] for several other types of pavement. Table B.2 summarizes the results for thin layer asphalt pavement. The table states the average slope, the standard deviation s_R , the number N of road of sections and the maximum pavement age in the database.

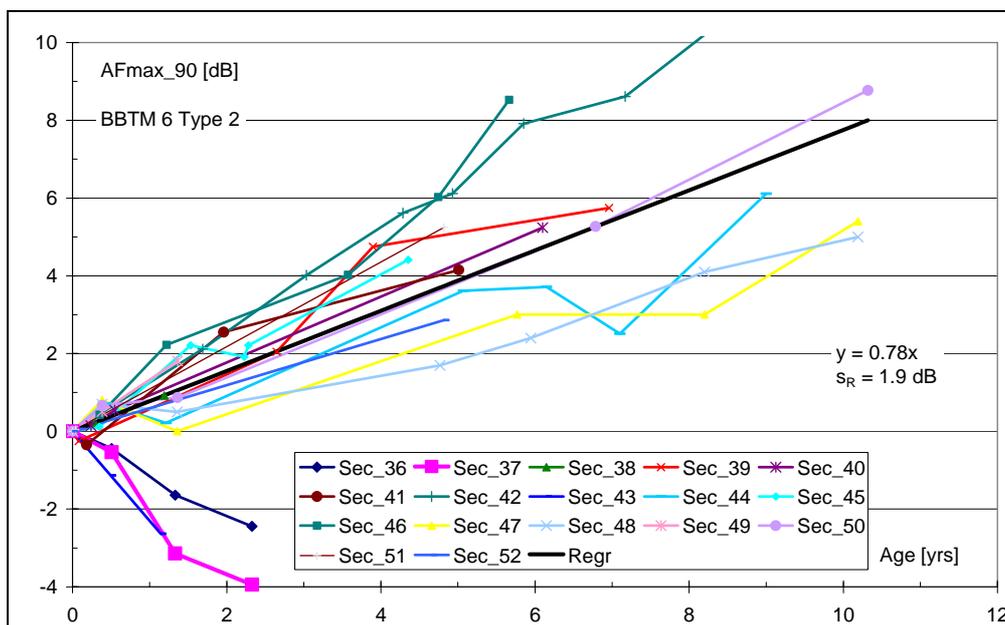


Figure B.4: Passenger car pass-by noise level at each of 17 sections of road with BBTM 6 Type 2 in the French database; see further the text. From [Kragh, 2008].

Table B.2: Summary of ageing performance for thin layer asphalt derived from the LCPC data base

Pavement	v [km/h]	Slope [dB/yr]	s_R [dB]	N [-]	Max age [yrs]
Very Thin Asphalt Concrete 0/6-type 1	90	0.25	1.6	11	11
Very Thin Asphalt Concrete 0/6-type 2		0.78	1.9	17	8
Very Thin Asphalt Concrete 10-type 2		0.42	1.6	7	8
Ultra Thin Asphalt Concrete 0/6		0.58	0.6	2	8

The following conclusions for highways were drawn in [Bendtsen et al, 2009]:

- The noise level on asphalt pavements normally increases with time
- The increase occurs continuously and before significant pavement deterioration with ravelling and cracks etc. begins
- A linear regression gives a good fit of the relation between pavement age and noise both for passenger cars and multi-axle heavy vehicles. This was also seen in the European SILENCE study
- The yearly increase in noise level is generally around twice as high for passenger cars as for heavy vehicles.

Different parameters have been used to characterize the increase in noise levels which is often expressed as dB per year. Two main factors affect the changes in pavement noise properties. One relates to the physical/chemical changes in the materials caused by weather elements and time, and the other has to do with the wear and tear caused by traffic. It can be argued [Bendtsen et al, 2009] that the combined effects of both the physical age of a pavement and the wear and tear from traffic determine the increase in noise levels. The age reflects an accumulated effect of changing weather conditions like sun radiation, rain, ice, freeze/thaw, oxidation, etc.

B.1.2.2 Norwegian long time experiment on acoustical durability

A research and development project named 'Environmentally friendly pavements' has been conducted under the auspices of the Norwegian Public Roads Administration and in close cooperation with research institutions and the road industry. The project focused on the noise and dust properties of road surfaces. The project was started in 2004 and was completed in 2008; however, some measurements have continued through 2010.

A number of different types of thin layer pavements were tested as part of this project, all of which were dense and two of which were proprietary. NMAS was either 6 or 8 mm.

The Editor has processed data found in [Aksnes et al, 2010] and plotted them as "noise reductions" versus the age of the surfaces in Figure B.5. The data were collected with the CPX method using various reference tyres specified for that method during various years (Tyre A or Tyre SRTT). The tyres were of different ages and, although the Norwegians attempted as well as possible to account for possible changes from year to year, there is unavoidably an uncertainty due to the stability of the reference. The reference level is an average level measured on various SMA11 surfaces during various years.

The Figure shows that the deterioration of noise reduction is fast. Half of the initially high noise reduction is lost after only one year and after three years approx one dB of noise reduction remains. Note that all these roads are exposed to wear of studded winter tyres during the winter season. These data should be fairly representative also of Swedish and Finnish conditions. What remains to study now is how the structural condition and rut depths develop over time for these thin layers.

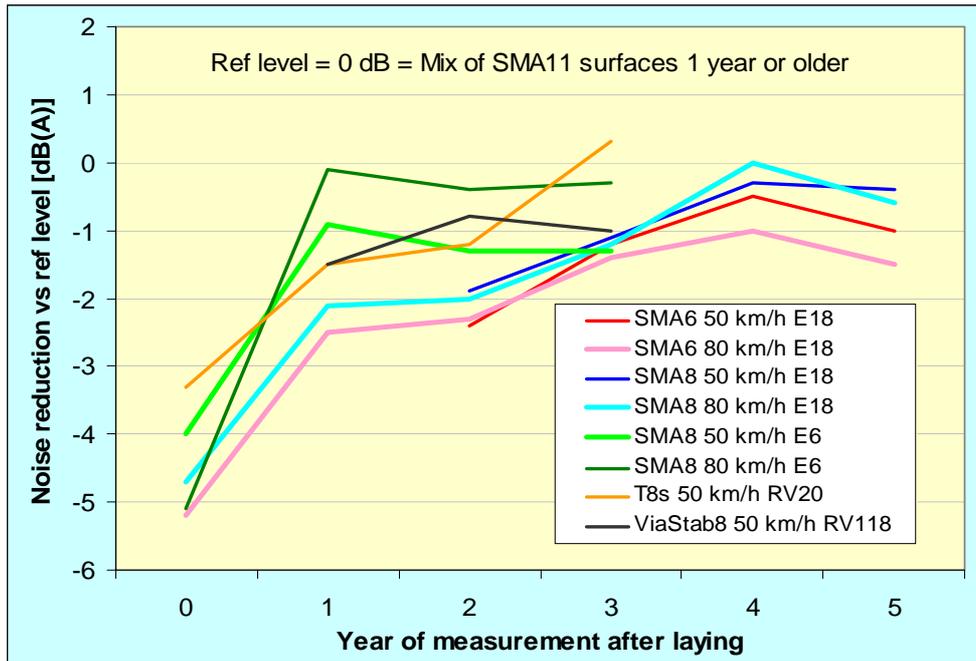


Figure B.5: Noise reduction versus age of Norwegian TAL compared to a reference level of SMA surfaces one year or older. Data processed by the Editor from [Aksnes et al, 2010].

B.1.2.3 Acoustical durability of Dutch thin layers

Figure B.6 shows the development of noise levels of Dutch TAL over time, compared to two-layer porous asphalt and special low-noise paving blocks [Groenendijk, 2011].

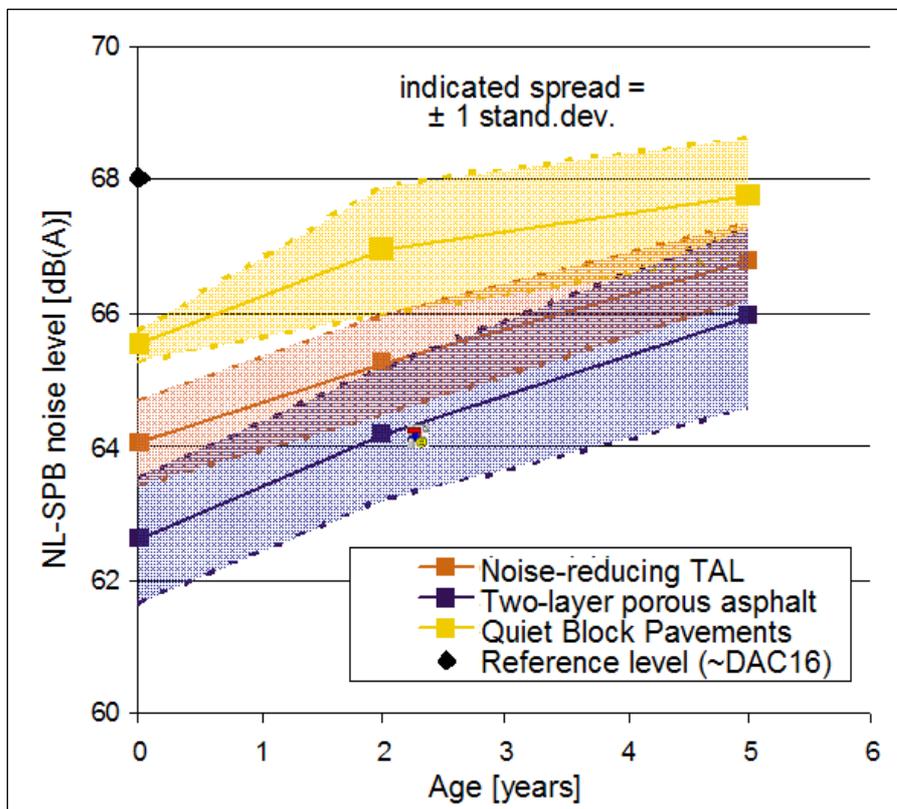


Figure B.6: Noise level changes with age of surfaces in the Netherlands. From [Groenendijk, 2011].

B.1.3 Wear by traffic

B.1.3.1 General

TAL characterized by a low void content usually show good to excellent resistance to wear by traffic, as long as the bonding with the adjacent underlying layer is assured, and therefore no delamination occurs (see B.2.5.1 for discussion on tack coats). Typical examples include asphalt concrete or SMA.

However, TAL as designed according to EN 13108-2, or porous asphalt mixes, are very much prone to wear by traffic due to their high void content and therefore open structure. It is generally recognized that these types of asphalt mixes are not suitable for paving at locations such as intersections, roundabouts, locations with turning movements (e.g. parking lots, bus stops, etc), sharp curves or other adverse geometric sections. In the latter cases, surface damage can occur quickly due to the high tangential forces that may occur. Such forces cause the loss of aggregates at the surface resulting in ravelling. It should be noted however that ravelling is a complex phenomenon and other parameters such as for example the ageing of the binder, the stripping of the binder from the aggregate (loss of adhesion) or the exposure to low temperatures during winter may contribute as well.

Finally, too high tangential forces may even cause the displacement of asphalt material at the surface, especially at sections with slowing traffic.

Several test methods, some of them still under development and undergoing field validation, reflect the importance of the impact of traffic on TAL. Illustrative in this context are:

- The Cantabro test as described in EN 12697-17 used to evaluate the cohesive strength of porous asphalt [VBW-asfalt, 2004] or Open Graded Friction Courses (OGFC) [Sridhar et al, 2005].
- The tribometer or T2R as developed at LCPC in France [Hammoun et al, 2008]
- The Rotating Surface Abrasion Test or RSAT designed by Heijmans in the Netherlands [Hartjes et al, 2008].
- The Aachener Rafeling Tester (ARTe) developed by the 'Institut für Strassenwesen – RWTH' in Aachen [Schulze et al, 2008]

B.1.3.2 Danish project HOLDA

Porous pavements are normally considered to have a shorter lifetime than dense pavements. One of the reasons for this is the very open pavement surface structure where the binder is exposed to oxidation, causing the binder to become harder as time goes by. When the binder becomes harder the risk of ravelling increases. This ageing phenomenon might also apply to TAL pavements designed with very open surface structures in order to reduce splash and spray, as well as noise. The Danish Road Institute has together with Danish Asphalt Industries and NCC Roads carried out a research project "HOLDA" on optimization of the life-time of porous pavements [Nielsen et al, 2004; Nielsen et al, 2005].

The aim of this project was to design a porous pavement, which has better durability than a reference pavement built in the Øster Søgade experiment in Copenhagen [Bendtsen & Elle-

bjerg, 2009], evaluated only by tests of laboratory produced materials. The research was organised in two parts; designing and testing asphalt mixes and optimizing the bituminous mortar. An analysis of variance of the particle loss data from the Cantabro tests was performed. It is assumed that the Cantabro particle loss represents the durability of the mix but it should be borne in mind that the durability of the actual pavement could be different.

The results indicated, as expected, that durability is improved if the voids content in the mix is slightly reduced. However, what is more interesting is that the highest durability was obtained when a highly modified SBS binder developed from a soft virgin binder was used. Therefore, this new binder was estimated to be better than the highly modified binders used earlier in various projects. Although field tests are required for validation, it was concluded that an estimated improvement of the durability of 1.5-2 years could be achieved [Nielsen et al, 2004; Nielsen et al, 2005]. It is not known what possible sacrifices might be needed regarding noise reduction. These results might also be relevant when designing porous or semi-porous TAL pavements, as well as when designing TAL pavements for roads with heavy traffic and maybe also for roads where studded tyres are used.

B.1.4 Typical lifetimes

As mentioned previously, TAL pavements are applied because of their functional properties such as noise reduction and/or the beneficial economics of the system (savings by thinner layer thickness as compared to more traditional approaches). TAL pavements, due to their limited thickness are not supposed to contribute significantly to the dimensional stability of any road construction.

In order to achieve the majority of its functional properties, most TAL are characterized by rather high (mixes as defined by EN13108-2) to even very high void content (e.g. porous asphalt). Consequently, it is generally known and accepted that the average lifetime of such asphalt mixtures is rather limited. Typically, TAL are supposed to last for about 10 years although functional properties may be compromised sooner (such as noise reduction).

In Denmark the lifetime of TAL is estimated to be one year shorter than the lifetime of standard DAC 11 or SMA 11, i.e. approximately 12 years. The European average durability of UTLAC and AC (25-30 mm) is 10 years [EAPA, 2007a].

For Swedish conditions, which logically should be fairly similar to Norwegian and Finnish conditions, an attempt to estimate typical service life times for five major pavement types is presented in Table B.3. It must be noted that for TAL in Sweden the experience so far covers only a few years and not so many types of TAL. It is also difficult to define what service life means; it depends on the type of damage, etc. Except for traffic volume (AADT), the service life will also depend on speed, but no distinction for speed has been made in the table. Consequently, these figures should be considered as very rough, preliminary and based on expert judgement rather than comprehensive statistics. This will be further dealt with in the later part of this project.

Table B.3: Rough estimate of service life times (in years) for five major pavement types in Sweden and as a function of traffic volume (AADT). Times (values) in red colour shall be considered with extra caution as they are expert judgement by one of the co-authors (RK), while the commonly used black values are expert judgements by a number of experts at the STA.

Pavement type (English)	Pavement type (Swedish)	AADT ≤ 250	AADT 750	AADT 1500	AADT 3000	AADT 5000	AADT 9000	AADT 13000	AADT >13000
PAC	ABD	14	12	10	8	7	6	4	3
SMA	ABS	15	15	15	13	11	9	7	5
AC	ABT	17	15	12	10	9	6	4	2.5
TAL	TSK	14	12	11	10	9	7	5	3.5
Soft asphalt	MJOG	16	14	11	8	5	2	1	1

B.1.5 Possibilities of restoring a deteriorated TAL

As a part of the pavement maintenance restoring of deteriorated TAL by repairing the pavements must be executed with suitable methods. The purpose of the repairing is to extend the lifetime of the pavement, maintain a smooth and comfortable surface and prevent water from penetrating.

Cracks and potholes are repaired by crack sealing or crack filling and potholes by pothole patching respectively.

Larger areas with many or bigger cracks and areas with many and bigger potholes are repaired by full-depth patching. In this method the deteriorated TAL is removed by milling and replaced with new asphalt concrete of the same or similar type. Often the asphalt instead of with a paver is laid by hand in selected areas. The method is the same as for other types of asphalt pavement with the exception of the layer thickness. If the temperature is low or in windy weather the thin layer of asphalt may cool down and the quality of the compaction may be insufficient.

After repair of a TAL the surface has construction joints, areas with different types of asphalt, areas with different thickness and areas paved by hand work. Especially for TAL of low noise types repairs may cause the noise level to increase.

B.2 MISCELLANEOUS PERFORMANCE PROPERTIES

B.2.1 Other surface characteristics

B.2.1.1 Megatexture and evenness

Most thin asphalt layers are able to compensate variations in layer thickness up to ± 5 mm. Some rather exceptional thin asphalt layers allow variations up to ± 10 mm. Therefore the under layer should be smooth and only small unevenness may be allowed. This is especially the case for very open asphalt layers. The under layer should be watertight. This may also be achieved with a layer of bitumen under the thin layer. A larger transversal angle is usually applied for very open thin asphalt layers because of the flow resistance of water. An angle of 2.5 % should be enough. Before installation, a thorough check of the under layer is recommended and if necessary measures should be taken, such as filling up holes, improving transversal angle, and grinding the base course to remove unevenness [VBW, 2004].

Most thin asphalt layers show a high resistance against rutting. When the layer is not well compacted or when it is applied too thick, it becomes more sensitive to rutting. However because of the limited thickness of the layer also the depth of the track remains restricted. Rutting may occur easily in under layers when the thin layer is not able to spread out the load of the traffic. Therefore under layers should have enough resistance against deformation [VBW, 2004].

In the Netherlands four different test sections with thin layers have been installed. Texture measurements were performed on six positions of each test section. Texture spectra of thin layers compared to SMA 0/8 are shown in Figure B.7. These monitored thin layers show less megatexture than SMA. Smaller aggregates imply less megatexture. A thin layer 2/6 12 % has more megatexture than a thin layer 2/6 8 % [Schwanen, 2007].

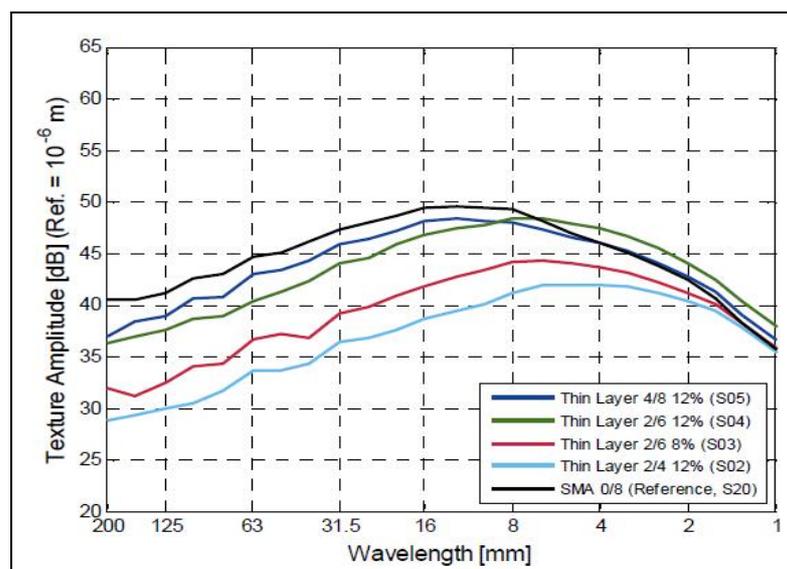


Figure B.7: Texture spectra of thin layers compared to SMA²⁸.

²⁸ Warning: Please consider the wavelength range to the right of 8 mm as most uncertain, as some problems with the texture measurements have been detected afterwards / The Editor

B.2.1.2 Light and glare properties

In urban areas and on major roads entering urban areas from the countryside the road administration has installed lamp posts to improve visibility under dark conditions. Tunnels are another area where electrical light is used – typically in the form of sodium or mercury light bulbs. It was very early recognised that the black surface of the asphalt pavement absorbed a lot of the light demanding increased light intensity to compensate for this. This would result in increased energy consumption. In Denmark, for instance, in order to reduce consumption of electricity the road administrations asked for the addition of a certain percentage of artificial light coloured aggregate. The artificial aggregate was heat treated flint which became shiny white during the transition of the siliceous material in the process. In the 1960's and 1970's it became normal to demand that 20 - 30 % of the aggregate above 2 mm size consisted of this white coloured aggregate. The change of the light reflective properties is now obtained by the addition of white or light coloured aggregates to the asphalt mix during production. The exact content of white aggregates depends on the light properties of the ordinary aggregates in the asphalt mix. Typically the content is 20 – 30 % of white aggregates in a size of the largest fraction used. That means if the asphalt material is DAC 8, then the size of the white aggregates is 5/8 mm.

Due to the energy crises in 1972 and 1979 the original artificial aggregate under the trade name of Synopal became uneconomical to produce and it was tried to make a similar product at lower temperature but some of the properties were inferior to the original product. Test equipment capable of measuring the light reflection of a moist, cut surface was developed in order to avoid the increasing percentage of this more inferior artificial light coloured aggregate and perhaps open the use of light grey natural aggregate. During this development it was found that a general rule of thumb is: the lighter the colour the poorer the adhesion properties are because the adhesion between white aggregates and bitumen is not at the same level as for ordinary high quality aggregates and bitumen.

The introduction of PAMVLE – the light reflection measurement method – improved the durability of the surface layer for the intended use on roads with lamp posts, because different blends of natural aggregate of grey and light grey colour could be introduced and the objective test method demonstrated that the desired light reflection was achieved.

The experience gained showed that only the fraction above 2 mm counted. There was virtually no effect by introducing light coloured sand or finer materials. In order to get the larger aggregate particles more exposed to the light open texture mixes were preferred.

Energy savings for lamp posts can be achieved for urban areas, tunnels and major roads if light coloured road surfaces are used. From a psychological point of view many drivers complain about pitch dark road surfaces when driving at night on roads with no lamp posts. The conclusion of this is that open textured TAL with light coloured aggregates are the optimum choice in these cases. The open texture maximizes the area that reflects the light (either from the lamp posts or from the vehicle itself) and the rough texture minimizes the glare from the vehicles you meet.

From a durability point of view you introduce only the light coloured aggregate in the thin surface layer and not in a more vital thickness of the pavement structure if the aggregate

reveals less than optimum adhesion properties. With a content of white aggregates up to 30 % in combination with the addition of a high quality anti stripping agent the lifetime of asphalt with light reflection properties is at the same level as for ordinary asphalt pavements.

For TAL the experience with light reflectance and lifetime is the same. But light properties are only incorporated in TAL when the authorities require selected specifications to the light reflectance on sections with and without street lighting because on voluntary base the asphalt contractors will like to avoid the additional risk to the durability of the pavement.

B.2.1.3 Drainage, splash and spray

Generation of splash and spray and how it relates to road characteristics

As stated in the review of TAL history, the reduction of splash and spray from traffic travelling at high speeds on wet roads has been used as an argument for using TAL. As will be discussed in the following, it is arguable whether TAL are better than conventional asphalt pavements in this respect.

In rather general terms, the road characteristics which influence splash and spray emission are the following:

Amount of water standing on the surface: The deeper water, the more must be moved away from the tyre/road contact patch. A portion of the water will stick to the tyre rubber and in its tread pattern and be pulled up and then by centrifugal forces be thrown out from the tyre and caught in the wind wake around and after the vehicle. This causes what we call spray: fine droplets easily caught by the wind. But there is a limit as to how much this can be; the remaining water will be pressed away from the contact patch and form what we call splash: a plume of water ejected out towards the side of the vehicle.

Crossfall of the surface: It is common that roads are designed with crossfalls (transversal grade) of about 2 %, but the higher it is the faster the water runs off to the roadside and the lower the water depth.

Depth of ruts: The amount of water may be increased substantially in ruts.

Macrotexture: Low macrotexture means that all water on the road surface must be displaced by the tyre; higher macrotexture means that some water may remain within the macrotexture.

Porosity (voids) of the pavement: If the pavement has high voids content, with connected voids, a certain volume of water may be accumulated in the voids, until the voids are totally filled. The porosity also means that some of the water may run-off to the roadside through the pavement layer. During rainfall, it may take quite a while until the surface will start looking wet, and a pavement with high voids content may never appear to create a "water mirror" on the surface. It should however, be noted that there is some spray also from a highly porous surface looking dry in wet weather, as the air pressed away at the leading edge of the tyre/road contact patch will press up some water to the side, and under-pressure at the trailing edge will pull up water from the pores. This water will create spray; albeit not at all as intense as on a dense surface.

When rainfall starts, it will take some time until the road surface will look wet. Some water is absorbed by the surface micropores, some will be turned into water vapour due to the asphalt often being quite a lot warmer than the air. If the pavement has a significant voids content it will take some time until the voids are filled with water, in the best case an infinite time. This time may be counted in several minutes or in hours. During this time a porous or semi-porous surface may look essentially dry; often for such a long time that the rainfall may finish before the pavement is saturated with water. After rainfall has finished the water in the voids will remain there for some time, which may be counted in hours or even in days; cooling the surface while water vapours. This is actually used in hot climates to reduce the so-called heat island effect.

Splash and spray-related features of thin asphalt layers

It should be clear that all the influencing features mentioned above may be the same on TAL pavements as on conventional and thicker AC or SMA. The features may also vary, both for worse and for better, in relation to the thicker asphalt pavements. It is, therefore, not justified to say that TAL in general are better or worse in terms of splash and spray. However, there are some issues worth discussing:

By definition TAL are generally thinner than "conventional" SMA or AC. Assume that we have a TAL which is porous and an AC which is porous, and consider the following cases (it is assumed in all cases that the voids are connected):

- Porous AC, 50 mm thick, 20 % air voids: This will store up to (effectively) an average 10 mm of rainfall (if water runoff to the side is neglected), as 50 mm with 20 % voids is an equal volume of air as the volume of 10 mm of standing water (50×0.20)
- Thin asphalt layer, 25 mm thick, 20 % of voids: This will store only half the water volume of the previous case; i.e. 5 mm of standing water or rainfall (again, if water runoff to the side is neglected)
- Thin asphalt layer, 20 mm thick, 15 % of voids: This will store only 3 mm of standing water or rainfall (water runoff to the side is neglected).

However, even in the latter case, to take care of 3 mm of rainfall before giving a wet surface is a feature which will be appreciated by travellers in many cases. Depending on whether a semi-porous TAL is compared to a dense or a porous AC, it will come out better or worse. Nevertheless, one can say that the potential water storage property is better for a porous AC than a porous TAL having been exposed to similar dirt volumes causing clogging of the pores, just because of the different thickness.

In opposition to the advantage of porous AC over TAL as discussed above one can argue that a semi-porous 25 mm TAL may be designed to provide almost the same durability as a 30-40 mm thick SMA, at least not being more expensive. In such a case it would be a competitive alternative which would give the extra advantage of some water storage capacity, which will reduce splash and spray.

Apart from porosity and thickness, also NMAAS (nominal maximum aggregate size) is in general different for TAL than for conventional SMA or AC. NMAAS is usually but not consistently lower for TAL. But it is impossible to say that this makes any difference in splash and spray generation.

Studies of splash and spray properties of TAL and other pavements

The authors first note that no measurement results of splash and spray on thin asphalt layers have been found. Nevertheless, a few studies related to porous pavements versus dense pavements shall be mentioned, since they provide some support for the general discussion above about the effect of pavement porosity on splash and spray.

In 2005, DRI did a literature search on thin asphalt layers [Bendtsen et al, 2005]. With regard to splash and spray DRI found, besides some documents discussing or presenting measurement methods, only two documents which provided some data or qualified observations regarding comparison of pavements.

In the first study, test sections with porous pavements and SMA had been constructed on an interstate highway in Indiana, USA and a measurement program covering noise, texture etc. had been carried out [McDaniel & Thornton, 2005]. No quantified measurements of splash and spray were conducted, but visual observations were made and it was concluded that the splash and spray during one rainstorm event was considerably less on the porous pavement than on the SMA pavement. Sight conditions for the driver were significantly improved, when passing or being passed by trucks which typically produce large amounts of splash and spray.

A typical view comparing a porous and a dense asphalt is seen in Figure B.8. This picture is not from any of the studies referenced here, but the view is rather typical.



Figure B.8: Typical view of splash and spray and pavement wetness on a porous compared to a dense asphalt pavement. Picture used by permission from Mr Keizo Kamiya, Pavement Division, Road Research Department, Central Expressway Research Institute, Tokyo, Japan.

The second study presented a summary of results from measurements on splash and spray carried out (starting in 1984) on test sections on A38 at Burton-on-Trent in the UK [Nicholls & Daines, 1992]. Measurements were performed on 33 test sections with porous and non-porous pavements. The results showed that the splash and spray was reduced by 95 % on a porous pavement compared to dense asphalt.

The variables which had been investigated in the study were the speed, rainfall, texture depth and hydraulic conductivity (water outflow). The results showed that the splash and spray on porous asphalt appeared to be very low over a wide range of hydraulic conductivity values; even if the hydraulic conductivity was close to zero the splash and spray would still be only half that on an equivalent HRA (hot rolled asphalt) surfacing.

A model was set up by [Nicholls & Daines, 1992] which can predict the splash and spray generated on porous and hot rolled asphalt depending on the hydraulic conductivity, the texture of the surfacing, the speed of the vehicles, the rainfall and the total recent rainfall. An interesting observation mentioned was that splash and spray is carried over from non-porous surfaces to porous surfaces by distances up to 100 m.

A model was also suggested for characterizing pavement splash and spray properties based on an extensive recent literature study in which VTI took part [Resendez et al, 2007]. The purpose was to propose how the splash and spray-reducing potential of various pavements could be quantified in PMS or similar. The follow-up project, intending to develop this model was given to another consortium; a work which is still ongoing.

Finally, a PhD study on splash and spray properties of various pavements is near finalization in Bangkok²⁹⁾. A first report of this work, indicating substantial advantages of the porous asphalt, has been presented at a TRB meeting [Rungruangvirojn & Kanitpong, 2009].

B.2.2 Emission of inhalable particulate matter into the air

The effects of inhalable wear particle production (PM_{10}) from thin surface layers have not been studied specifically. Instead, the main focus in pavement wear particle research has been the influence of different stone materials and the influence of maximum stone size (NMA). Since thin surface layers normally have small NMA, the influence of this parameter is likely to be the most relevant. Still, little has been published internationally regarding this relationship. Research at VTI, see Figure B.9, showed that SMA pavement with quartzite (NMA = 8, 11 and 16 mm) generates more PM_{10} at lower NMA at all three speeds tested using studded tyres [Gustafsson et al, 2009]. The test with two mylonite SMA pavements differed mainly at 70 km/h, also showing a higher PM_{10} concentration at the lower NMA (8 mm). The results are in accordance with the hypothesis that stone properties that affect the total pavement wear also affect the production of the inhalable fraction. From both laboratory and field studies it is well known that lower NMA results in increased pavement wear, see e.g. [Jacobson & Wågberg, 2004].

²⁹⁾ Ulf Sandberg was a member of the Examination Committee for this PhD work

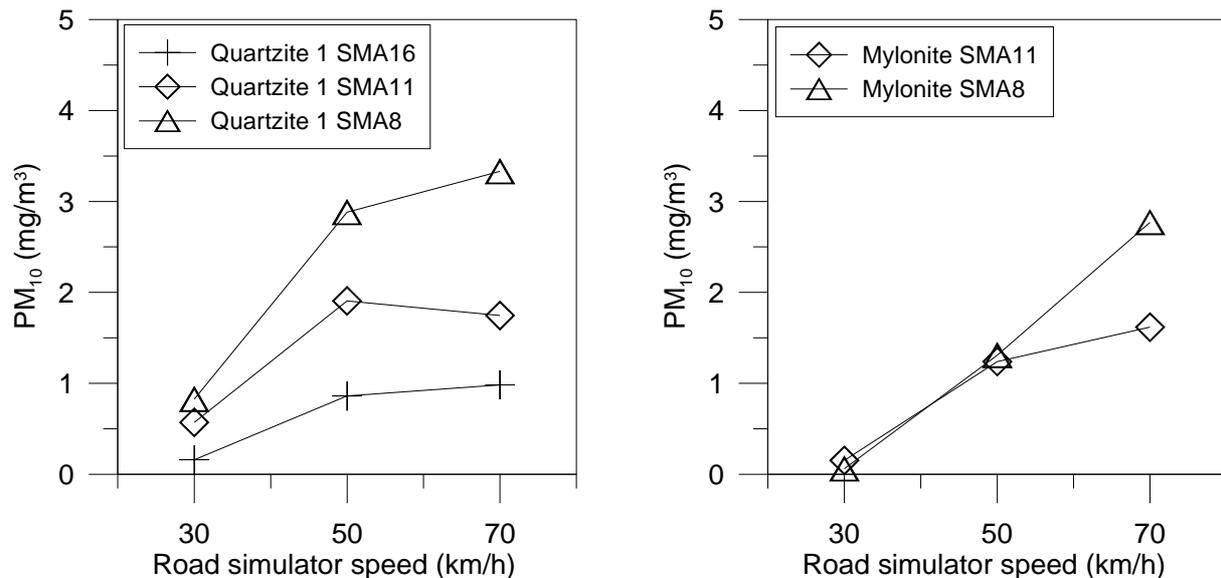


Figure B.9: Mean PM_{10} concentration during stable concentrations at 30, 50 and 70 km/h for three quartzite pavements (left) and two mylonite pavements (right) with different maximum stone sizes. From [Gustafsson et al, 2009].

Regarding stone material choice, this is an important factor for wear particle production. Especially obvious when using studded tyres, but notable also when using non-studded winter tyres or summer tyres. In [Gustafsson et al, 2009] it was shown that two SMA pavements, both with $NMA S = 11$ mm, differed in PM_{10} production as a result of two different quartzite materials. In the SPENS project [SPENS, 2009] it was shown that a limestone pavement's high calcium content contributed markedly to the elements of the coarser fraction of PM_{10} while a diorite pavement gave a different composition with more influence of silica; see Figure B.10.

Ongoing research at the Swedish National Road and Transport Research Institute (VTI) will report more detailed results concerning influence of $NMA S$ and stone material during 2010.

B.2.3 Structural strength and bearing capacity

In the design of flexible pavements the structural strength of the material layers is critical for the bearing capacity.

UTLAC does not contribute to the bearing capacity. That means that the existing pavement shall have a satisfactory evenness and bearing capacity.

For TAL between 20 and 30 mm the E-modulus is approximately 3 000 MPa using bitumen 40/60 or modified bitumen.

This means that before laying TAL - including UTLAC - it is decisive that all bearing capacity is available in all elements of the existing pavement. Any existing structural damages must be repaired before paving. The repair method is patching for levelling adjustment. Frequently the damages are on a level where patching is insufficient. Then paving with TAL is combined with milling operations in the same thickness as the new pavement.

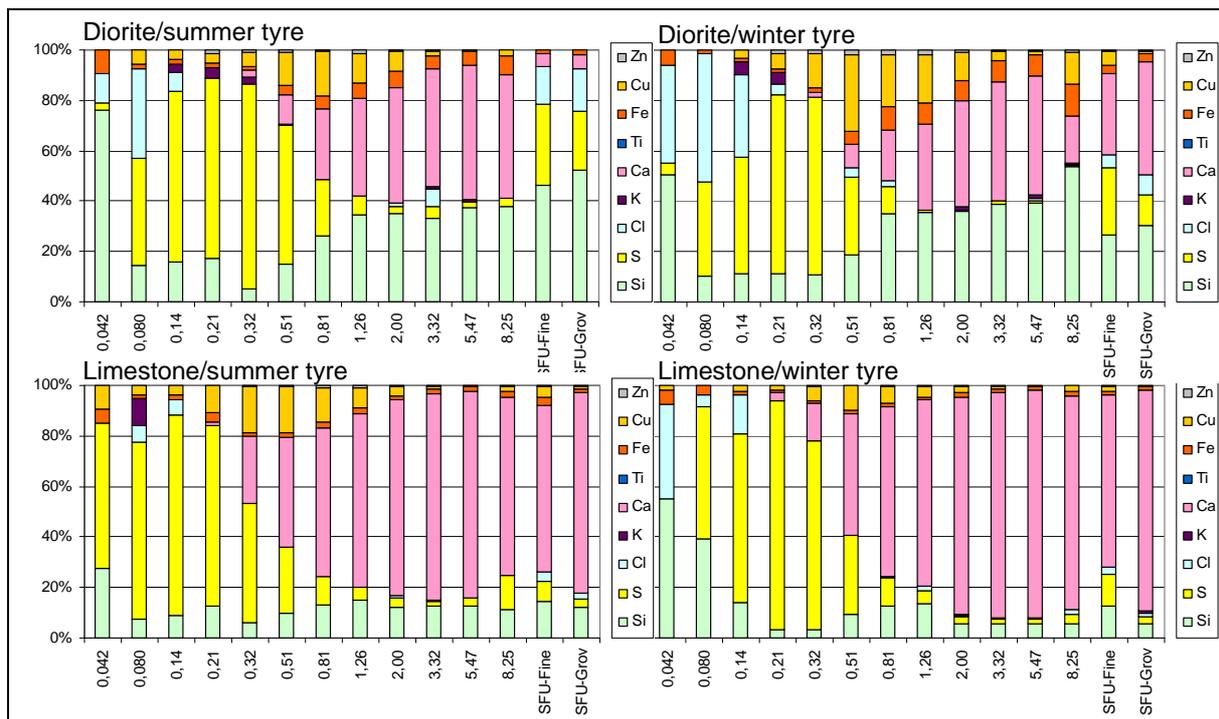


Figure B.10: Elemental analysis of different particle size fractions from diorite and limestone pavements worn with non-studded winter tyres and summer tyres [SPENS, 2009].

B.2.4 Use of natural resources

Under normal circumstances the aggregate for the surface layer needs to be of better quality than the aggregate of the bituminous binder and base course, due to the requirement as the interface to traffic. The necessary bearing capacity for the road can be achieved by using non-premium quality aggregates and perhaps even by upgrading inferior local aggregates. Premium quality aggregate is seldom abundant and must be hauled in over longer distances. By the use of TAL the necessary amount of premium aggregate will be lower and lead to savings in natural resources and energy consumption. This will lead to an overall saving in natural resources of aggregates or at least a slower rate of exploitation.

In some countries, where U.K. is one, it is very difficult to get access to high-quality aggregates, so ways to reduce the need for this are of particular importance. Here, it is indeed important to reduce the thickness of the wearing course which requires such high-quality aggregate. However, in the U.K. where hot rolled asphalt (HRA) has been very popular for decades, HRA surfacings require even less of high-quality aggregate than a TAL, as this is rolled into the mastic. This has caused the road administrations to partly return to the traditional policy of using HRA at the expense of TAL [Lee, 2010].

See further Section B.3.4. The possibilities of recycling are discussed in Section B.3.3.

B.2.5 Construction-related aspects

B.2.5.1 Paving equipment

With the exception of one type of asphalt surface layer TAL can be paved and compacted by standard equipment. But that does not mean that it is unproblematic to construct a TAL of good quality. The special case concerning UTLAC will be discussed separately.

As TAL has minimal thickness there is virtually no possibility for the material during normal paving to compensate for insufficient transversal and longitudinal profiles as well as local pot holes. All such deficits need to be solved by spot repair or even placing a levelling course. Due to the small NMAS it will increase the risk of having permanent deformation (rutting) in the surface layers if the layer thickness of the TAL locally goes above 4 times NMAS.

As explained in Annex B.2.3 it is important that all or nearly all necessary bearing capacity is available in the underlying structure. For this reason the levelling course used to adjust the necessary profile for the surface layer is usually performed as a strengthening layer.

Paving such thin layers of hot mix asphalt as defined by the term TAL requires full attention to a lot of aspects. The heat content of the material itself is rather limited, when levelled off by the screed of the paver the material quickly decreases its temperature due to heat conduction to the underlying layer. After the screed the heat transfer to the air is very sensitive to wind speed, so a windy day in September can have much quicker cooling effect on the pavement than a day in November with no wind at all. The necessary roller pattern to accomplish the desired degree of compaction has typically to be performed within 3 to 5 minutes. Warm Mix Asphalt is a concept where different technology or additives contribute to lower both the mixing and the compaction temperature. This technique can be advantageous to prolong the time window available for compaction. Whether or not this will prove to be correct in the long term perspective is too early to say but the potential is there.

A recent development in paving equipment will be beneficial to preserve the heat content of the surface layer for a longer than normal period. It is a possibility to use a double-layer asphalt/twin paver which simultaneously paves both a strengthening/levelling course and a thin surface layer. As the layers are placed “hot-on-hot” there will be no need for tack coating in between. Due to the heat content of the lower layer the surface layer can be paved extremely thin. The technology from Dynapac is called Compactasphalt® and can be seen in Figure B.11. See also [Sandberg & Masuyama, 2005] and [Perveneckas & Vaitiuk, 2009].

A special paver is also needed for the paving operation for the material UTLAC. One of the most important features of UTLAC is that the open graded hot mix material is paved onto a surface which is sprayed with a polymer modified bitumen emulsion in approximately the double amount of residual binder for normal tack coat. When the hot mix is applied the emulsion has not broken yet and the remaining water boils up and facilitates a very intimate contact between the substrate, the polymer modified binder from the emulsion and the new surface layer. In order to apply this polymer modified emulsion under the paver it must have spray bars close to the screws that distribute the hot material before the screed. Figure B.12 shows a schematic top view of the specially equipped paver for applying UTLAC. In this case a paver from Vögele with the five spray bars (in red) for the polymer modified bitumen emulsion and heating system for the emulsion tank is shown.

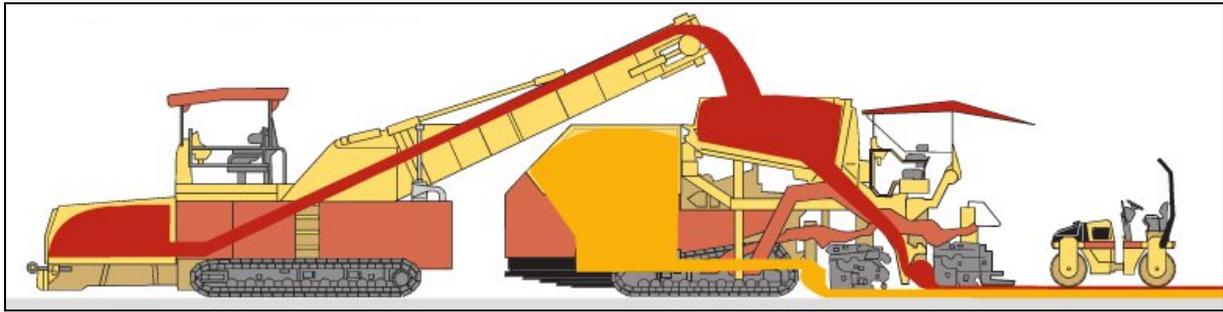


Figure B.11: Compactasphalt® from Dynapac (www.compactasphalt.com)

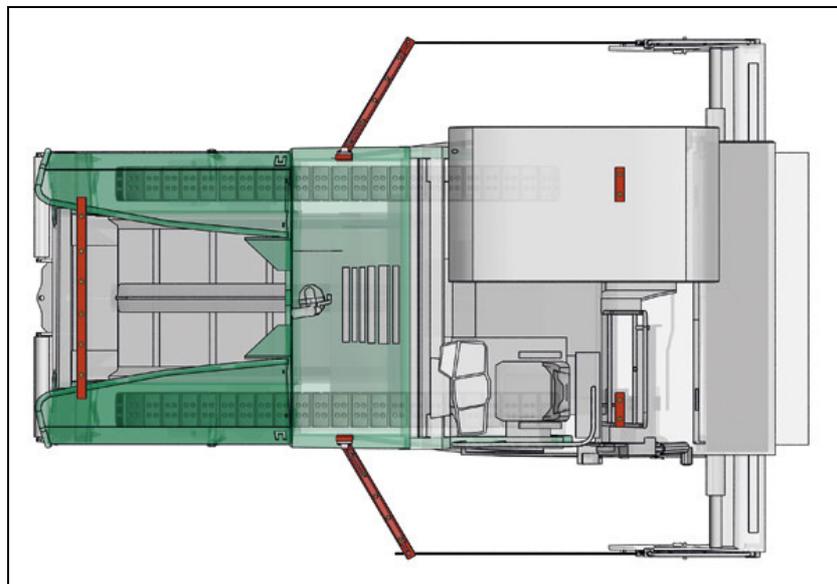


Figure B.12: UTLAC paver from Vögele (www.voegele.info) (schematic top view; the five spray bars for polymer modified bitumen emulsion are indicated in red)

When the concept of placing hot mix asphalt in a non-broken emulsion was introduced the technique was tried out worldwide. Numerous reports exist especially from the period 1989-1991 highlighting initial trials probably due to the fact that professionals were sceptical concerning the new concept. As the technique at that time was newly developed several problems were indicated, bleeding from the spray nozzles, spraying operation continued even after the paver had stopped, etc. These old reports (among others from several states in the USA) are not quoted here. They have little relevance because pavers for UTLAC since then have been improved a lot.

B.2.5.2 Laying time and traffic closure

Based on the Austrian experiences reported by Litzka the finisher should, if possible, not be idling at any time during application [Litzka et al., 1994]. The working speed of the finisher should be coordinated with the deliveries of the hot mix. Any stopping and restarting the paver causes problems with “bumps” and smoothness. Therefore, logistics in general are very

important and critical. The temperature of the material should lie between 150 and 170 °C during application and between 120 and 150 °C during compaction. As thin layers cool down very rapidly, the open structure does help in this respect, efficient compaction is possible only for a few minutes (normally a minimum temperature of about 90 °C is required). Usually, it is not possible to achieve compaction rates of more than 96 %, but the essential goal is to ensure that the rollers press the layer onto the base in time to secure both good bonding and a good internal structure within the layer. In this context, "Sabita's guideline" indicates a minimum compaction time window of 10 minutes necessary for practical reasons [Sabita guideline, 2008].

The Sabita's guideline also illustrates quite well both the impact of the weather conditions on the critical cooling rate of TAL (in this case a 25 mm layer). Attention is paid both to the air and base course temperature as well as the wind velocity. The following example illustrates quite well the impact of these parameters:

- A 25 mm material paved in weather conditions of 13 °C air and 18 °C base temperature, and a wind speed of 20 km/h, has a compaction window of only 7 minutes
- Whereas at 30 °C air and 45 °C base temperature, and no wind, the compaction window is 14 minutes.

The Austrian experiences are backed up by similar findings reported in the USA dealing with UTBWC applications [Hanson, 2001].

It is generally recognized that due to the high cooling rate, manual compaction does not result in a satisfactory quality or performance of a TAL and should therefore be avoided whenever possible. It is also advised to restrict the paving season to a period of April – October, according to the Dutch guideline. In northern Europe and in the Alps this season must of course be shorter.

Due to the high cooling rate, some TAL offer the opportunity to open the road for traffic fairly quickly (after 30 – 90 minutes) following the paving operations. However, the newly laid thin layer shall cool down to a temperature of 35 °C, or lower, before opening to traffic. Nevertheless, in order to avoid any risk of compromising the long term durability of TAL, it is not advised to consider such a practice as standard operations.

In Japan, recently, new research has been performed on ultra-thin asphalt layers in an attempt to improve the ease of construction and traffic closure time for constructions in medium-to-low temperature range [Hatakeyama et al, 2010]. A special kind of lubricating oil, which reacts chemically by water addition, was used which allows a good workability even at low-medium temperatures (Figure B.13).

By spraying water from the roller at the compaction a chemical reaction is obtained between oil and reaction agent that causes an early strengthening by increasing the binder viscosity.

Different amounts of lubricating oil, reaction agent and water were studied. Based on this study specimens were made with the following conditions: 30 % special lubricating oil, 75 % reaction agent, 4 % water, 60 °C at compaction and 7 curing days before tests. After all promising laboratory results, this pavement with a thickness of 10 mm was installed with success on a test section of 3 m width and 15 m length.

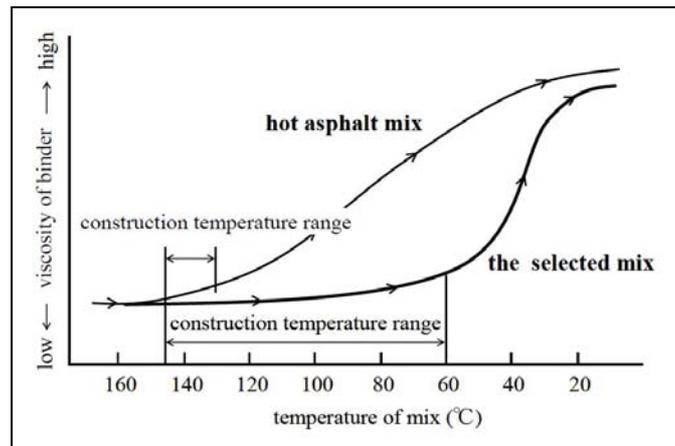


Figure B.13: Ideal transition of binder viscosity according to [Hatakeyama et al, 2010].

These are the main findings of the research:

- Good anti-skidding properties is provided by using the lubricating oil which implies that rolling of the mix is possible around 60 °C
- Viscosity of the binder is increased when spraying water at compaction, which makes it possible to open traffic already after approx. 30 min. of curing time
- Other properties and weather proofing are similar to that of dense-graded asphalt

B.2.5.3 Maintenance and rehabilitation

The purpose of the maintenance of an asphalt pavement is by periodic work – under normal traffic and weather conditions – to keep the pavement as close as possible to its original condition and to improve or extend the functional life or condition by the right repair at the right time.

Conventionally the maintenance consists of the following three categories [Johnson, 2000]:

Preventive maintenance is the routine work to prevent deterioration of the TAL pavement. The point is to improve or expand the functional life of the pavement by surface treatments and operations to retard progressive failures and reduce the need for routine maintenance and service activities. The methods for TAL are crack sealing, small pothole repair and fog sealing.

Corrective maintenance is performed after a deficiency occurs in the pavement. That means the pavement needs repair for loss of fraction, moderate rutting, extensive cracking, potholes, bleeding and ravelling. While preventive maintenance is performed when the pavement is still in a good condition the corrective maintenance is performed when the pavement needs repair and is more costly. The methods for TAL are crack filling, pothole repair, patching, full-deep patching overlays, and milling in combination with overlays.

Emergency maintenance consists of the activities performed in an emergency situation such as dangerous potholes on roads with high level of traffic. On TAL the repair methods are potholes repair, patching, full-deep patching overlays, and milling in combination with overlays.

B.3. SUSTAINABILITY ASPECTS

B.3.1 Sustainable construction

Thin asphalt layers can contribute to a sustainable road infrastructure. If a base course having sufficient bearing capacity is established, a step is taken in the direction of what might be denoted a “perpetual pavement”. TAL can be applied as an easy-to-replace wearing course (the pavement "skin") on top of this perpetual pavement to service a variety of needs, such as skid resistance, rolling resistance (see 7.4) and noise. Sustainability is obtained because this perpetual pavement is easily maintained by renewing the TAL when requirements on one or more of surface properties are no longer fulfilled.

B.3.2 Criteria for determining end-of-life

The condition of the asphalt pavement is determined according to ASTM D 5340, “Standard Test Method for Airport Pavement Condition Index Surveys”. Even the standard is for airports it is very useful for determining the condition of road pavements.

The test method covers the determination of the pavement condition through visual surveys of the pavements using the Pavement Condition Index (PCI) method of quantifying pavement condition.

The pavement of the road is divided into sections. The type and severity of the pavement distress is assessed by visual inspection. Types of distress are alligator cracking, bleeding, block cracking, polish aggregates, ravelling, rutting, etc. The total numbers of types of distress are 16. The severity of distress is low, medium or high in a standardize way for each of the types of distress.

The distress data are used to calculate the PCI which ranges from 0 to 100 with 0 being the worst possible condition and 100 being the best possible condition.

If $PCI < 25$ the rating is that the condition of the pavement is very poor. If the $PCI < 10$ the condition of the pavement is failed which means end-of-life of pavement.

The Pavement Condition Index is useful for all type of pavements including TAL.

The end-of-life of a pavement will not be reached as long as correct surface maintenance is carried out [EAPA, 2007a].

B.3.3 Recycling properties

The possibility of recycling asphalt materials has been one of the large advantages of bituminous materials as opposed to the competition from the other road construction material Portland cement concrete.

With a very few exceptions old asphalt pavement can be recycled to 100 % and the capital investment in the materials can be utilized – depending on age and constituents – also up to

nearly 100 %. This aspect has of course a great impact of saving natural resources both on the aggregate and the binder side.

The few exceptions that exist are linked to the use of materials in asphalt pavement in old days before recycling became an issue. The situation today among the asphalt producers is recognising the fact that recycling ability gives the industry a competitive edge towards the cement concrete that must not be lost. This means that when new additives are offered to the asphalt producers one of the first questions asked is: "Will your product interfere with our future ability to recycling the asphalt material in which it is used? If so forget it." It might not be possible to re-use the effect of the additive the second time around, but the minimum requirement is then that it stays inert and shows no negative effect on the resulting product.

There are three groups of exceptions that to some extent either endanger or prohibit recycling of which the first is the most predominant. The three exceptions are:

1. Coal tar and pitch based on coal tar (PAC/PAH). These products were earlier used as binders or especially addition to bitumen due to their very good adhesion properties. They impose a risk of carcinogenic nature for the workers if they are exposed to either fumes or particulate matter. In some countries (like Denmark) the occurrence of tar and pitch is so seldom that it is allowed to use small amounts of RA containing tar in hot mix asphalt if Health-Safety and Environment (HSE) precautions (protective means) are taken for the workers. In other countries (like Germany) recycling of these materials in hot mix is not allowed but it is possible to recycle the material in cold products (like bitumen emulsion based products). When tar compounds are present in asphalt pavement (like in old base layers) they normally will not show any environmental hazard as their hydrophobic nature will prevent leakage from the bituminous materials.
2. Asbestos fibres (either present as fibres or natural occurring in the aggregate used). Again it is the carcinogenic risk that is the reason for the reservations. The origin of the fibres could be from experimental use as stabilising fibres (the rumour has it that it had been used in some of the very first SMA:s before cellulose fibres were introduced). Heat resistant coating of the brakes in old cars may also contribute as another source of asbestos fibres found in RA. The last source is natural occurrence in aggregates used for asphalt materials.
3. Bituminous materials that for some reason more or less unknown have shown an accelerated hardening profile to an extent that the asphalt producer will not dare to re-use the material for new pavement. This can be associated to the presence of hardening promoters like certain heavy metal atoms either naturally being present in the crude oil (like Vanadium) or originating from catalysts used in the refinery for special processes.

Apart from these exceptions there is no obstacle in general in recycling asphalt materials into new products.

But with respect to the present project of TAL it is important to highlight that there are two sides to the coin:

- Can TAL be recycled into new pavement materials?
- Is it possible to use reclaimed asphalt in TAL?

The first question is definitely answered by YES, but it is becoming virtually impossible to recycle RA from TAL into a new TAL which answers the second question by NO. The reason for these statements is a combination of a lot of technical, practical, economical reasons. Under the seventh framework programme of the European Commission a four year project called Re-Road is presently running (2009-2012) which will look into aspects of recycling asphalt pavement and optimising the best use of RA and identifying the obstacles that prevents higher percentages of RA in surface layers. Information is gathered from the asphalt producers to illustrate the situation and TAL is an important segment of the road market today. The analysis of the responses has been done yet, but some important points can be extracted already:

- The present thickness of many TAL is very small (perhaps 20 – 25 mm) compared to the operational regime of the big milling machines, such as the machine shown in Figure B.14. It is of course possible to mill off such small layer thicknesses. But often no contamination from the aggregate from the layer beneath must occur in the milled-off material because their properties are unacceptable in a new surface layer. This makes the milling process for selected materials almost impossible as the reason for milling might be a worn and cracked surface layer to be replaced.



Figure B.14: Big milling machine in operation at Eaton Place, London, UK, removing the thin surfacing, with a risk for the material to be contaminated by aggregate from the layer beneath.

- TAL has – as earlier mentioned – an NMAS of maximum 10 – 11 mm and even more predominantly either 6 or 8 mm as nominal maximum aggregate size. This means that the reclaimed material in order to be reused must be separated in a manner which will crush the bituminous mortar between the aggregate and not the aggregate. Later this material must be screened/sieved into smaller fractions like 0/6 mm in order to be applicable for recycling into new TAL. Huge problems are associated with handling 0/6 mm fractions of RA because of caking due to the mortar rich material. This will very easily result in lumps of RA in a new TAL which is totally unacceptable from a quality point of view. For this reason the asphalt producers handling RA normally produce a 0/16 mm fraction (and more seldom a 0/11 mm fraction) which makes it impossible to reuse for TAL.
- The particle size distribution of a 0/6 mm fraction of RA will also contain a relative high portion of fines (filler and particle up to perhaps 1 mm) that it is extremely difficult to utilize in the mix design of new TAL.
- Perhaps the most important problem prohibiting the use of RA in TAL today is the extremely high functionality built in the present range of TAL today. In order to produce a noise-reducing open texture of an UTLAC, even special small size fractions of several virgin aggregates need to be available within very tight limits of quality control.

The Re-Road will – when it is finished – hopefully reveal the best route to optimum utilisation of reclaimed asphalt but if a high level of functionality is required of the TAL the present conclusion is that it has to be produced from virgin aggregate resources and that the recycling of old TAL have to be part of either thicker surface layers or part of bituminous base and binder courses and indirectly in that manner save natural resources of virgin materials.

B.3.4 Energy consumption and emissions during transportation

Research projects on future material supply have identified a problem with effects of transportation of materials on energy consumption and the environment. Consequently, there is concern over the increasing transportation work to serve civil engineering construction projects [Svedberg, 2010]. More and more material needs to be transported over longer and longer distances and road construction is part of this problem. A recent European project has studied this problem but does not especially address TAL [ECRPD, 2010].

Increased use of TAL may affect this problem in two opposite ways:

- Less material needed in TAL will require less transportation
- Higher-quality aggregate might need to be transported from quarries or other supplies further away from the construction project

The problem applies to both construction and maintenance operations. The two features of TAL listed above are evidently in conflict. It is difficult to say which one that will dominate; future LCA will need to look closer at this.

B.3.5 Potential effects of climate change

To reduce the impact of road transportation on climate change, essentially the CO₂ emissions, all possibilities to reduce rolling resistance will have to be considered since it directly affects energy consumption and thus CO₂ emissions. It is obvious that this calls for tyres with low rolling resistance. However, it should be equally obvious that rolling resistance properties of road surfaces should be considered [MIRIAM, 2011], [Cooee, 2011].

Present state-of-the-art regarding rolling resistance related to road surfaces shows that the macrotexture of the surface, as represented by the Mean Profile Depth (MPD), is the most influential parameter [Sandberg, 2011]. How does this relate to TAL as compared to other common wearing courses?

The macrotexture of TAL may vary largely due to type of TAL, wear and NMA. In general TAL use smaller NMA, typically in the range of 4 to 8 mm, and in general the MPD is lower the lower the NMA is. Figure B.6 is an illustration of this. This speaks in favour of TAL. However, one of the concepts used when designing special TAL (such as proprietary ones) is to create a relatively high level of macrotexture while still using a small NMA, mainly by using a gap-graded mix to obtain an open or even porous texture. Figure 7 in [Bendtsen & Raaberg, 2005] about French TAL usage is an extreme example of this, where UTLAC has mean texture depths of around 1.5 mm as compared to 0.5 mm for conventional dense surfaces.

In conclusion one may say that TAL of type SMA6 and SMA8, or similar, will be desirable to use in the future since they will reduce rolling resistance. However, proprietary ones attempting to get the maximum possible macrotexture will not be favoured, unless they replace surfacings with rough textures.

APPENDIX C: SYSTEMS FOR CHECKING OR VERIFYING TAL PERFORMANCE

C.1 CE-marked products according to the EN 13108 series

At present, it is compulsory to have TAL CE-marked if they are marketed as complying with one of the product standards of the EN 13108 series (parts 1 to 7 as listed in Section 6.5.1). In the near future, UTLAC applications will be covered by EN 13108-9 (the drafting of prEN 13108-9 is ongoing when this is written). It should be stressed that the latter standard only specifies the asphalt mixes and not the final application on the road, as already discussed at large in Section 3.2.2.

In contrast with the EN 13108 series, the ETAG 16 guideline (being drafted at present) dealing with ultra thin layers will (in the future) take into account the entire process and therefore includes the paving operations and the final application. This is due to the fact that the paving operations for ultra thin layers are more critical in comparison with thicker asphalt layers (>20 mm) in order to guarantee a good quality and durability of the application. Therefore, in the future, products complying with this guideline could be CE-marked.

C.2 Proprietary products

The CE mark on road construction products in accordance with EEC Directive M/124 has for the product standards in the EN 13108-x series become mandatory from the start of 2010. The impact on the market has still to be seen in daily practise of purchasing and contracting asphalt materials. The approach may also be governed to a large extent for the coming years by the attitude among the customers.

If the customers are public road administrations (either state, regional or community level) it will be a question about their interpretation and willingness to abide to the public procurement directive which direct to purchasers to (or limit them to) CE marked product – if available.

One of the loop holes concerning public procurement directive is: who is purchasing the asphalt material (the loose mix on the lorry) that is CE-marked? The public road administration makes a contract for an asphalt pavement and that is Works (not covered by CE marking or Eurocodes) and not a purchase according to a CEN product standard.

This has a big impact on proprietary products depending on the national attitude in the market you operate. If the road administrations are strictly limited to purchase CE-marked products (if available) you have as a company three options:

1. You can try to design and describe your proprietary product in one of the CE-marked asphalt families in the EN 13108-x series. (A lot of proprietary products exist in the material family for UTLAC which now is described in a draft product standard prEN 13108-9. This will eventually become a harmonized European product standard which results in CE-marked products.
2. The European Organisation for technical Approval (EOTA) has for many years worked on designing a guideline for UTLAC product which would enable them to be CE-marked

through this route. The asphalt contractor can in this manner obtain a European Technical Approval (ETA) which fulfils the essential requirements in the road construction directive.

3. The third option is for the company to market their product and highlight that it covers a technical functionality that it is not covered by the CE marking under either CEN or EOTA. This would allow the public road administrations to purchase the product even if it was not CE-marked, because the offered functionality was not covered. The success of this approach would be very dependent of the national attitude/interpretation with regard to public procurement directives.

In the first two options a third party inspection is involved in the initial type testing (ITT) and the survey of the factory production control (FPC). In the last option you as a customer must assure the quality by different approaches. It could be prequalification schemes which among other look into ISO 9001 quality assurance schemes or similar at the asphalt contractor or through making reference to appropriate national guideline for quality control or similar accepted control schemes with regard to the specific job.

C.3 Noise-related classification

C.3.1 HAPAS in the United Kingdom

The following applies to the UK Highways Agency (HA) which is responsible for 4 % of the UK road network (highways and trunk roads) carrying 30-40 % of the road traffic. For information on “non-trunk roads” one would have to contact the County Surveyor Society or many (i.e. thousands of) local road administrations.

For a contractor to build pavement on the national highway network he needs a noise label certificate from the Highway Agency Product Approval Scheme (HAPAS).

The UK HA defines a noise reducing surfacing as one with a Road Surface Influence RSI ≤ -2.5 dB. RSI is defined in the HAPAS guidelines [BBA, 2008], see also Table C.1 and Eq.(C.1) – Eq.(C.2). Noise testing must be made at two road sections with the same pavement type. The noise level used to determine the RSI is a combined SPB noise level from light, dual-axle heavy and multi-axle heavy vehicles. Such surfacing is denoted “Thin surface course system (for highways)”, and it can be any surfacing as long as RSI ≤ -2.5 dB. The producer must certify his product has an RSI ≤ -2.5 dB. There are at present 37 surface products with a HAPAS thin surface certificate [HAPAS, 2011]; many of which also have chosen the option to include a certification of noise. A HAPAS certificate generally has a 5 years lifetime.

The reference for comparison in the UK is a “new” (i.e. at least 12 months old) hot rolled asphalt (HRA) with 20 mm nominal aggregate size and with an aimed mean texture depth MTD = 1.5 mm (sand patch). The reference values were established in the 1970-1980s based on average pass-by measurement results at many sites. Compared to the dense asphalt concrete reference pavements used in other European countries, the British reference is a rather noisy reference pavement.

The Road Surface Influence (RSI) for high (H) and medium (M) speed roads are:

$$RSI_H = 10 \log_{10} \left(7.8 \times 10^{\frac{L_{veh,L}}{10}} + 0.578 \times 10^{\frac{L_{veh,H1}}{10}} + 10^{\frac{L_{veh,H2}}{10}} \right) - 95.9 \quad Eq. (C.1)$$

$$RSI_M = 10 \log_{10} \left(11.8 \times 10^{\frac{L_{veh,L}}{10}} + 0.629 \times 10^{\frac{L_{veh,H1}}{10}} + 0.157 \times 10^{\frac{L_{veh,H2}}{10}} \right) - 92.3 \quad Eq. (C.2)$$

Table C.1: Reference speeds and reference noise levels for various categories of vehicles and roads [Abbott, 2008].

Speed [km/h] / L_{veh} [dB]	$L_{veh,light}$	$L_{veh,dual-axle}$ ($L_{veh,H1}$)	$L_{veh,multi-axle}$ ($L_{veh,H2}$)
High speed	110 / 84.7 dB	90 / 86.6 dB	90 / 89.1 dB
Medium speed	80 / 81.1 dB	70 / 83.8 dB	70 / 86.6 dB

In principle, the full HAPAS certificate cannot be issued until it has been proved that 24 months after construction, the surface in fact still retains $MTD \geq 1.2$ mm. In practice, the noise level is certified shortly after 12 months.

The vehicle noise level L_{veh} , used as a reference is 1 – 2 dB higher than the reference noise level used e.g. in Denmark for classifying road surface noise reduction.

Concerning lifetime average noise performance, calls for tenders are based on the expectation that HAPAS procedures will assure an average noise reduction as given by RSI (measured at the at least 12 months old surface) multiplied by 0.7 [Highways Agency, 2006], limited to a maximum of 3.5 dB. With the UK prediction method [CRTN, 1988] one can use this correction in noise computations.

C.3.2 C_{road} in the Netherlands

The reference pavement in the Dutch system for measuring and computing road traffic noise levels [RMV, 2006] is dense asphalt concrete, most probably DAC 16, but the aggregate size and the pavement age are not given explicitly in [RMV, 2006]. According to [van Vliet, 2007] the reference at high speed roads is DAC 16 and at low speed roads the reference is a mix of DAC 16 and DAC 11. The reference values at 7.5 m distance from the vehicle centre line, at a height of 5 m above the road surface are given in Table C.2.

The road surface correction C_{road} is the increase in noise emission as compared with that on the reference surface. One may express this increase either in terms of an overall A-weighted noise level or in terms of a correction for each octave-band with centre frequencies from 63 Hz to 8 kHz. An octave-band is a range of frequencies in which the highest frequency is twice the lowest frequency.

Table C.2: Reference values at 7.5 m distance at a height of 5 m [CROW, 2004].

Vehicle Category	Reference speed	L_{AFmax}
[-]	[km/h]	[dB]
Light	80	74,8
Medium	70	80,9
Heavy	70	83,5

Earlier, the road surface correction was included in the publication describing the prediction method, but nowadays the Dutch organization CROW on its website publishes a list of correction factors and reports documenting the measurements behind them. Besides corrections for twelve generic surfacings, the table contains corrections for 35 – 40 proprietary products³⁰⁾. For each of these products a test report can be downloaded from [CROW, 2010].

C.3.3 SRS system in Denmark

The Danish SRS system is based on CPX measurements according to [ISO/CD 11819-2]. It was established in 2006 as a 1st generation system [Kragh, 2007b]. The principle is for the contractor to build a test section with new pavement, measure CPX noise levels at a reference speed of 50 km/h or 80 km/h, compare with defined reference noise levels, and declare a pavement noise class; see Table C.3. Noise levels L_A and L_D are measured using the reference tyres A and D defined in [ISO/CD 11819-2] with tyre A in the right side and tyre D in the left side of the trailer. Based on these noise levels the index CPX_{DK} is calculated as

$$CPX_{DK} = 0.85 \cdot (L_A + 1) + 0.15 \cdot L_D + K \quad \text{Eq. (C.3)}$$

K is a trailer correction constant derived from a field calibration. In 2009 two trailers participated and they were issued $K = 0.0$ and 0.1 dB, respectively.

Table C.3: First generation Danish SRS noise classes.

Speed [km/h]	Noise class →	C	B	A
	CPX _{DK} Class limit [dB]	"Noise-reducing" [dB]	"Very noise-reducing" [dB]	"Particularly noise-reducing" [dB]
80	102.0	97 – 99	95 – 97	< 95
50	94.0	89 – 91	87 – 89	< 87

³⁰⁾ In April 2011 it was 37

C.3.4 Dutch COP testing system

For the Dutch main road network there is no system for testing COP of delivered surfacings. But for the local road network, a special detailed procedure was in existence during the years 2001-2004. The testing was mainly based on CPX measurement. The idea was to measure CPX along the delivered roadwork. From this, the average SPB level is estimated, based on a CPX-SPB relation measured on the site or a relation known beforehand. Finally, the SPB level is compared with the COP requirement.

A special law, the “Regulation for the Stimulation of the use of Low Noise Pavements”, was a temporary initiative of the Dutch Ministry of Housing, Spatial Planning and Environment (VROM). The technical background of the law was given in the background document [VROM, 2002]. The local authority could tender and select a contractor according to its normal procedures [VROM, 2002] but recommended that the contract should put the responsibility for complying with the acoustic requirement on the contractor. The reason for the strict COP procedures was that local road administrations could get a refund from the Ministry for applying noise reducing surfacing and that the Ministry wanted to be certain that its money was well spent.

C.3.5 CEN Noise Classification System

Civil servants of the European Commission are working on the development of European standards on noise classification but it is not clear what work already has been done. Therefore CEN/TC 227/WG 1 has created a Task Group « Noise Classification » which is formed with members of CEN/TC 227/WG 1, WG 2, WG 3 and WG 5. The first meeting took place 15 April 2010 in Berlin.

The task of the Task Group is described as follows: “to determine the needs and possibilities/practicalities for drafting European standard(s) for a system for the classification of noise characteristics for surface courses and to determine the needs and possibilities/practicalities of conformity assessment.”

A questionnaire will be sent around to CEN/TC 227 members to explore the needs and ideas regarding a Noise Classification System. The outcome will be communicated in a report to all CEN/TC 227 members. Based upon this report CEN/TC 227 will decide on the needs and future approach of this Task Group.

It is not yet decided exactly what the work of the Task Group will comprise. Possible steps are:

1. Characterization: type approval testing using defined measuring methods and criteria
2. Conformity of production: validation of new surfaces using defined measuring methods and criteria
3. Monitoring: validation of surfaces taking into account the time aspect using defined methods and criteria
4. Classification

The questionnaire should make it more clear how far the Task Group should go. Probably the work will comprise at least points 1 and 2.