Sustainable roads - Long-Life Asphalt Pavements

Version for 'bankers'

European Asphalt Pavement Association
Rue du Commerce 77
1040 Brussels,
Belgium

www.eapa.org
info@eapa.org
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Summary

The infrastructure is essential for the economy of a country and a Long-Life Pavements (LLP) concept has been developed to build more cost-effective pavements in meeting the present socio-economic requirements.
In practice the LLP-concept significantly extends the current pavement design life by restricting distress in the pavement surface to achieve low life-cycle costs.
A Long-Life Pavement is defined as a pavement where no significant deterioration will develop in the foundations or the road base layers provided that correct surface maintenance is carried out. This definition implies that all pavement layers, except the road surface layer are considered as permanent pavement layers and common distress mechanisms should, in principle, be eliminated completely.
Well designed and well constructed asphalt pavements according to the Long-Life Pavement concept show service lives of more than 50 years.

This paper gives a state-of-the-art regarding developments in long-life asphalt pavements.
It describes the construction of new pavement structures and the different asphalt mixtures that can be used in building a Long-Life Asphalt Pavement. The basic principles of pavement design are described as well as the concept of LLP in the design procedure. Also the construction and the maintenance of LLP will be addressed.
The final design of a LLP depends on local conditions such as sub-grade type, present and future traffic volumes and materials available.

Chapter 3 describes the economic aspects. When the availability of road lanes and the road user delay costs are taken into account in the cost-benefit analyses of pavements it will show that a number of highways in densely populated areas require low maintenance pavements. A total reconstruction of a road pavement is hardly possible or even impossible.
Low life-cycle costs can be obtained by optimizing maintenance activities, delay and environmental costs. For Long-Life Pavement the recommended life cycle periods for short, medium and long term analysis are in the order of 25, 50 and 100 years respectively.

Procurement and specification issues are addressed in Chapter 4. The technical and functional requirements for LLP will in general be higher compared to traditional pavements. This could be achieved by prescribing functional specifications instead of technical specifications. Then it is up to the contractor to show that a solution meets the requirements. In this way several solutions can be considered by the contractor to optimize the construction.

For a Long-Life Pavement (where no significant deterioration will develop in the foundations or in the road base layers provided that correct surface maintenance is carried out) the durability of the surface layer is the dominant factor for the pavement surface life.
The choice of the surface layer depends on the functional requirements. This could be a combination of comfort, durability, stability, skid resistance and noise reduction.
A wide range of bituminous surface layer products can be considered appropriate depending on specific requirements. The selection of surface course is a matter of identifying the most appropriate materials during the design life.
The annex of this paper gives an overview of the different asphalt mixtures that can be used for surface layers. An overview of the expected durability of these surface layers is shown. The data are based on a questionnaire and a panel discussion of experts and show amongst other things the "European average" of the service life of the different asphalt surface layers.

Content page

1. Introduction

A good infrastructure is essential for the economy of a country. The goal of the asphalt pavement industry is to provide road infrastructure at ever lower life-cycle costs by developing new products that meet the requirements of the road users and the road authorities. This is achieved by developing adequate design-methods, high quality products and new production and maintenance techniques, as well as pavement management systems.

During the last couple of years, the Long-Life Pavements[1] (LLP) concept has been established in Europe and USA. The main purpose of this concept is to build more cost-effective pavements. The LLP-concept is to some extent based on earlier concepts, but mainly on more recent advances in material technology, design and functionality.

In practice, the intention of the LLP-concept is to significantly extend current pavement design life by restricting distress, such as cracking and rutting, to the pavement surface. Common distress mechanisms should, in principle, be eliminated completely. The purpose of this paper is to provide a state-of-the-art regarding developments in long-life asphalt pavements.

The goal of the road is to provide a surface that can be used by the road users in a safe and comfortable way without any hindrance. This means that the availability of the pavement is very important and road maintenance activities should be reduced to a minimum.
In densely populated areas the traffic intensity on motorways is so high that a total closure of a road is impossible. This is one of the reasons for developing the Long-Life Pavement concept.

Well designed and well constructed asphalt pavements according to this Long-Life Pavement concept show very long service lives. This long-life approach aims at extending the life expectancies of asphalt pavements to more than 50 years. In the USA the term Perpetual Pavements is used and it is to some extent a rewriting of long-life pavements concept, but it focuses on resisting specific distresses in the each bound layer. Here the surface course, the binder course and base courses are selected, designed and performance tested in accordance to their deterioration mechanisms such as permanent deformation and fatigue cracking.

Last but not least the objective of these concepts is to produce pavements with long service lives in order to achieve low life-cycle costs.

Since most countries have national pavement design methods, based on local materials and local experience, only a general strategy for long-life pavement design and construction will be described in this document.

1.1. Definition of long-life pavements

Several definitions of long-life pavements have been given. In the USA, perpetual pavements has been closely connected to thick asphalt pavements comprising a three-layered asphalt pavement including a wear-resistant and renewable surface layer, a rut-resistant and durable intermediate layer (binder layer) and a fatigue-resistant and durable base layer [1.]. A perpetual pavement is defined as an asphalt pavement designed and build to last more than 50 years [2.].

In Europe a similar functional definition is used in ELLPAG [3.]:

A long-life pavement is a type of pavement where no significant deterioration will develop in the foundations or the road base layers provided that correct surface maintenance is carried out.

[1] It should be emphasised that the term *long-life pavements* given in this paper is a collective name incorporating many of the features shared by concepts such as perpetual, long-lasting and maintenance free pavements.

This last definition avoids expressing the definition by a certain life-length. In this paper, the functional definition of ELLPAG has been adopted, which implies that all pavement layers, except the surfacing, are considered as permanent. To maintain the overall objective, it is necessary to ensure that all distress mechanisms are limited to the surface layer by using an adequate pavement design method.

The final design of a LLP depends on local conditions such as sub-grade type, present and future traffic volumes and materials available. From these prerequisites, the ultimate goal of low life-cycle costs can be obtained based on optimizing maintenance activities, delay and environmental costs.

2. Construction of new pavements

Today, most countries regard the public road transportation system as an essential pre-condition for economic development and welfare. It is therefore important that the asset is managed professionally through all stages including design, construction and maintenance.

2.1 The pavement structure

A flexible pavement consists of the road structure above the formation level, which normally comprises bitumen-bound and unbound materials. The pavement structure should be able to resist the traffic and environment to which it will be exposed in such a way that structural distress mechanisms are avoided. Normally, pavements are designed as layered structures with relatively low strength in the lower layers and materials with progressively increasing strengths towards the top (Figure 1). The rationales for this arrangement are both technical and economical.

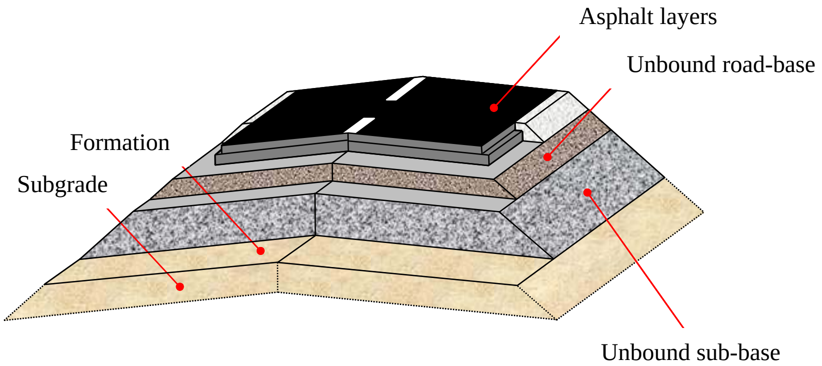

Figure 1. Schematic illustration of flexible pavement structure.

In general the asphalt layers are paved on a bound or unbound road base layer. Starting at the road surface, the first layer is called the surface course. The second layer is mostly called the binder course. The lower layers are the base courses.

For a good bearing capacity of the whole road structure it is important that there is a good bound and interlock between all the (bituminous) bound pavement layers and a good interlock between the unbound pavement layers. It of course also applies to the interlock/bond between the lowest asphalt layer and the unbound base beneath it.
For the durability of the asphalt structure it is also essential to have a good bond between the asphalt layers that can avoid water penetrating between them.

2.1.1 Surface course

The surface course constitutes the top layer of the pavement and should be able to withstand high traffic- and environmentally-induced stresses without exhibiting unsatisfactory cracking and rutting, in order to provide an even profile for the comfort of the user and at the same time possess a texture ensuring adequate skid resistance. Depending on local conditions, functional characteristics such as skid resistance, noise reduction and durability are often required for wearing courses. In some cases, rapid drainage of surface water is desired while in other cases, the wearing course should be impermeable in order to keep water out of the pavement structure. A wide range of surface layer products can be used depending on specific requirements, Surface layers are:

- Asphalt Concrete (AC)
- Béton Bitumineux Mince (Thin Layer Asphalt Concrete – AC-TL)
- Asphalt Concrete Very Thin Layers (AC-VTL)
- Ultra Thin Layer Asphalt Concrete (UTLAC)
- Stone Mastic Asphalt (SMA)
- Hot Rolled Asphalt (HRA)
- Porous Asphalt (PA)
- Double layered Porous Asphalt (2L PA)
- Mastic Asphalt (MA)
- Soft Asphalt (SA)

The choice of the surface course depends on the functional requirements of the road surface. This could be a high durability, noise reduction, splash- and spray reduction, a high skid resistance, impermeability, etc. For example, noise reduction could require the use of a double-layered porous asphalt and that conflicts with the requirement of a very durable surface layer. The durability of surface layers can be improved by using higher quality materials. The higher costs of these will be compensated by the lower costs of traffic management measures and user costs.
In Appendix A the durability of the above mentioned surface layers is shown.

2.1.2 Binder course

Binder courses are designed to withstand the highest shear stresses that occur about 50 – 70 mm below the asphalt surface. The binder course is therefore placed between the surface course and base course to reduce rutting by combining qualities of stability and durability. Stability can be achieved by sufficient stone-on-stone contact and stiff and/or modified binders.

2.1.3 Base course

The base course is perhaps the most important structural layer of the pavement, which is intended to effectively distribute traffic and environmental loading in such a way that underlying unbound layers are not exposed to excessive stresses and strains. This often implies comparatively high stiffness of the base course. Next to this the base course should also show adequate fatigue resistance. There are several possible strategies to achieve a base course exhibiting long-life characteristics. One approach to ensure that the fatigue life is long enough is to restrict the tensile strain at the bottom of the base course below a certain fatigue limit, under which no damage develops.

2.1.4 Unbound materials and foundation

Since the formation and sub-soil often constitute relatively weak materials, it is of utmost importance that the damaging loadings are effectively eliminated by the layers above. In this case, unbound road-base or sub-base layers consisting of uncrushed or crushed aggregate can be suitable. Generally, unbound materials originate from locally available sources, such as native soil, crushed/uncrushed granular materials and re-used (secondary) material. The type and thickness of the unbound materials used for the unbound road base layers technically depend on the structure to be designed (traffic loading) and the stiffness of the sub-grade. In some countries, climatic conditions may also require relatively thick pavement structures in order to avoid frost-related heaves.

Furthermore, economic factors, such as availability and transportation costs, also have a significant impact on the amount of unbound materials desired in a pavement. In some cases adequate bearing capacity can be achieved using one of a variety of available stabilization techniques.

2.2 Design

For pavement design computer models are used. Today most pavement models are based on so-called semi-mechanistic methods, implying that they partly are based on fundamental engineering principles. Semi-mechanistic procedures consist in principle of a structural response model and associated performance models. Response models relate traffic loading to stresses and strains in the pavement structure, while performance models relate calculated stresses and strains to rate of deterioration.
The two main distresses considered in semi-mechanistic methods are rutting, originating in the sub-grade, and fatigue cracking, initiated in the bottom of the asphalt layer (Figure 2).

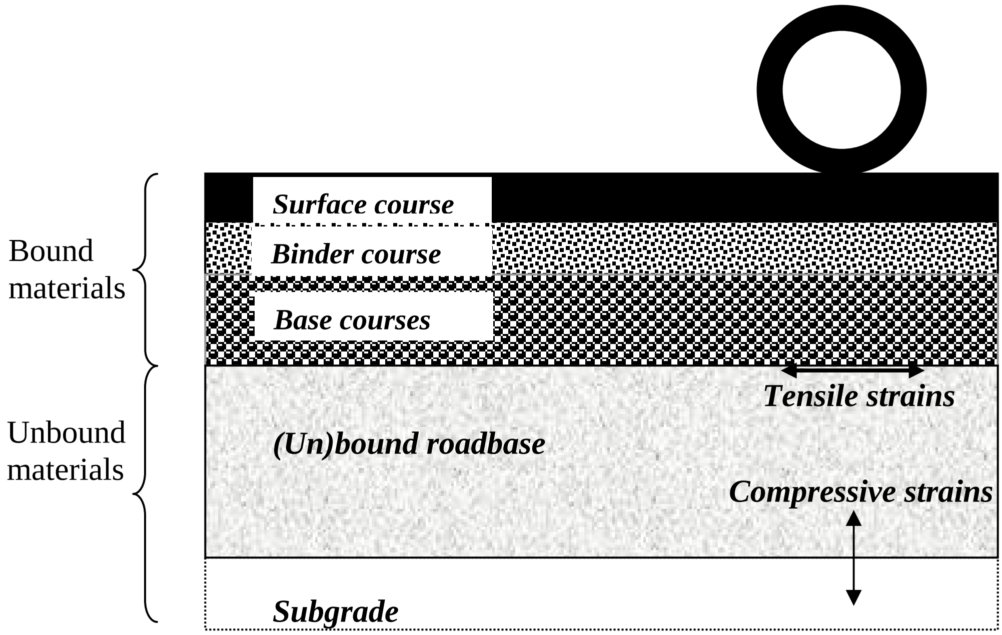

Figure 2. Example of pavement structure and the two traditional design criteria.

Fatigue cracking initiated in the bottom of the asphalt layer is considered by limiting the tensile strains induced by the traffic at the bottom of the asphalt layers. This is normally a function of the load, the expected number of load applications during the design period, the fatigue characteristics of the asphalt mixture, the temperature and the thickness and the stiffness of the pavement layers.
Structural rutting originating at the sub-grade is considered by limiting the compressive strain induced at the top of the sub-grade, normally as a function of the expected number of load applications during the design period, and the thickness and the stiffness of the pavement layers.
Alongside the traditional fatigue cracking at the bottom of the base course and rutting in the sub-grade, the other deterioration mechanisms (such as rutting in the bituminous layers, crack initiation in the surface layer) have to be addressed separately. They are difficult to address in (the 'old') semi-mechanistic design methods and therefore additional testing might be needed.

In general, deterioration, such as fatigue, is within the semi-mechanistic framework generally obtained from laboratory testing, which is assumed to represent field conditions. The fatigue results obtained at laboratory testing are subsequently related to the strain response obtained from the structural model. Consequently, the life of a given pavement structure subjected to repetitive traffic loading can be calculated when the strains in the structure as well as the relationship between the strains and deteriorations have been established.

2.2.1 Fatigue cracking

Fatigue is one of the main distress mechanisms considered in flexible pavement design and is generally considered to be caused by excessive tensile strains due to repetitive traffic loading. An increased asphalt thickness reduces the traffic-induced strains in the bottom of the bituminous base layer and, consequently, increases the fatigue life.

In principle, the design philosophy of long-life pavements does not differ significantly from traditional semi-mechanistic design methods. However to restricting structural deterioration to the pavement surface, conservative design criteria should be used.
This could be done by using a high number of standard axles in the pavement design. In [3.] pavement designs above a traffic level of 80 million standard axles (80 kN) are assumed to be designed as long-life pavements.
The other method is to use a conservative threshold for allowable asphalt strain values. Studies report that the maximum tensile strain at the bottom of the asphalt layer should be restricted to $50 – 70 \times 10^{-6}$ m/m [4., 5., 6. and 7.]. It should be emphasised that these threshold levels may not be universally applicable since they are derived using a given pavement system, design method, bituminous mixes and laboratory test method.

2.2.2 Permanent deformation

The other major deterioration mechanism considered in semi-mechanistic design is rutting, originating in the sub-grade. As in the case of fatigue cracking most semi-mechanistic methods are equipped with performance models for calculating permanent deformations using transfer functions.
In order to eliminate structural deterioration for long life pavements threshold values for allowable strain values have been mentioned. For example [4.] suggested that the maximum tensile strain at the top of the sub-grade should be restricted to 200×10^{-6} m/m.

2.2.3 Other mechanisms

Next to the two above mentioned classic design criteria there are other mechanisms that could cause pavement distress. Depending on the design, the materials used and the climatic conditions there might be a need to take more failure modes into account like reflective cracking, surface initiated (top-down) cracking, low-temperature cracking, frost heave and ageing.

2.3 Construction

Like traditional pavement construction, the construction of LLP should at least be executed in accordance with public requirements. In this case, technical and functional requirements on LLP will in general be higher compared to traditional pavements. One way of ensuring higher quality is to prescribe functional demands instead of technical specifications.

This emphasises the contractor’s roll in achieving long-life performance compared when technical specifications are used. When functional demands are used, it is up to the contractor to show that a solution meets the requirements. At least two benefits can be identified:
- improved flexibility meaning that several solutions may be considered, and
- an increased concern from the contractor to optimize the production, e.g. compaction [9.].

One of the most important construction-related aspects is mixture composition. An optimal recipe should result in a homogenous material structure which facilitates adequate compaction.

In the context of long-life pavements, it is still necessary to periodically replace the surface course in order to fulfil the functional requirements of the road surface.

2.4 Maintenance

For motorways with a very high intensity the availability of the road is of utmost importance and therefore disruption to traffic has to be avoided. Long-life pavements are defined as pavements, which do not show any structural deterioration. Consequently, the end of a pavement's life will not be reached as long as correct surface maintenance is carried out.
The maintenance or the renewing of the surface layer has to be done in a short time period to minimise the hindrance to traffic. The durability of the surface depends on the type of surface layer, and the choice of the surface layer depends on the functional requirements. This could be a combination of comfort, durability, stability, skid resistance, surface water drainage and noise reduction. The selection of the (new) surface course is a process where the different functional requirements have to be met.

3. Economic aspects

The overall purpose of LLP is to achieve lower annual costs by increased pavement life and fewer and more cost effective maintenance activities. In order to assess the economic benefits of LLP, the full financial consequences should be considered [3.]:

- Initial construction costs
- The loss of pavement capital due to pavement deterioration
- Agency costs due to periodic maintenance and traffic management at road works
- Road user costs, primarily due to delays at road works
- The costs due to accidents involving road users and workers at road work sites
- The environmental economical impacts of road construction and maintenance

Intuitively, a LLP probably results in an increase in construction cost compared to traditional pavements, but lower maintenance-related costs. Some of the costs included in Cost/Benefit Analysis (CBA) are relatively simple to determine while others are relatively difficult.
The agency costs consist mainly of direct costs including maintenance and traffic management costs but also indirect costs in terms of administration. The cost of traffic measures during maintenance works on motorways are high and can be more then 50% of the total job costs.
Costs associated with road user delays can be obtained using models based on measured traffic flows and road capacities. Road safety costs are more difficult to appreciate, primarily due to lack of relevant data.
The three main areas of concern for environmental costs are recycling of pavement materials, pollutant impacts related to fuel consumption and noise impacts related to maintenance work.

The review presented by FEHRL [3.] showed that only the UK takes special account of the economic aspects of LLP. Using CBA, UK experience has shown that pavements classified as LLP are expected to be more cost-effective than traditional road pavements since the small increase in construction cost is compensated by lower direct maintenance costs and indirect disruption-related costs. For a 10 year period, the total savings by adopting the LLP principal in the UK, are expected to reach 350 Million Euro [3.].

The traditional Life Cycle Cost Analyses (LCCA) can be used for calculating the present worth of costs for pavement alternatives and it is the primary tool used for economic comparisons.
For these LCCA studies the time span that is taken into account is mostly between 20 and 40 years. When dealing with Long Life Pavements this time span should be longer and might have to go up to 100 years.

In [8.] Haas et all. suggest a framework for LCCA applications which recognizes short, medium and long term cycle periods, functional class of highway, public and private sectors and likely or preferred LCCA method. Reasonable life cycle periods for short, medium and long term analysis are in the order of 25, 50 and 100 years respectively. This paper [8.] also gives a numerical example which shows how an agency could calculate an internal rate of return (IRR) for a base investment alternative involving a long life pavement design.

4. Procurement and specifications

An important aspect, which affects the final result in the field, is the means by which quality is defined, measured, controlled and ensured. Performance specifications are often considered to recognize the relationship between construction quality and long-term performance. By rationally controlling variables that impact long-term performance, the quality of the final product can be improved. In order to achieve long-life performance, aspects such as these should be considered in addition to the technical demands.

5. Summary and conclusions

During the last couple of years Long-Life Pavements- and Perpetual Pavement concepts have been established in Europe and in the USA. The main purpose of these concepts is to develop a framework in which more cost-effective pavements can be produced.
When the availability of road lanes and the road user delay costs are taken into account in the cost-benefit analyses of pavements it will show that a number of highways in densely populated areas require low maintenance pavements. That means a total reconstruction of a road pavement is hardly possible or even impossible.
This is one of the reasons for developing the Long-Life Pavement concept.

A long-life pavement is defined as a type of pavement where no significant deterioration will develop in the foundations or the road base layers provided that correct surface maintenance is carried out.

This definition implies that all pavement layers, except the road surface layer are considered as permanent pavement layers.

The choice of the surface layer depends on the functional requirements. This could be a combination of comfort, durability, stability, skid resistance and noise reduction. There might be even additional requirements like surface water drainage or water impermeability.
A wide range of bituminous surface layer products can be considered appropriate depending on specific requirements. The selection of wearing course is a matter of identifying the most appropriate materials during the design life.

Design procedures and design criterion are available to design Long-life pavements. Any design parameter and criterion used should not be taken out of its context since they are closely linked to a specific design guide, test methods used, materials used and the construction of the pavement, etc.

In general the technical and functional requirements for LLP will be higher compared to traditional pavements. A way to achieve this is by prescribing functional specifications instead of technical specifications. Then it is up to the contractor to show that a solution meets the requirements. In this way several solutions may be considered by the contractor and the contractor will optimize the construction.

The traditional Life Cycle Cost Analyses can be used for calculating the present worth of costs for pavement alternatives and it is the primary tool for economic comparisons. For Long-Life Pavement the recommended life cycle periods for short, medium and long term analysis are in the order of 25, 50 and 100 years respectively.

6. Literature references

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Appendix A

Durability of surface layers in Europe

A.1. Introduction

A long-life pavement is a type of pavement where no significant deterioration will develop in the foundations or in the road base layers provided that correct surface maintenance is carried out. This means that the durability of the surface layer is now the dominant factor for the pavement surface life.

There are several asphalt mixes that can be used for surface layers. To get insight in the service life of surface layers the EAPA Technical Committee investigated the durability of the surface layers used in Europe. This annex gives an overview of the different asphalt mixtures and the expected durability of surface layers. The data are based on a questionnaire and a panel discussion of experts.

A.2. Asphalt mixtures

In the description of the asphalt mixtures (1 to 7) the definitions are from the European Asphalt Standards EN 13108 – 1 to 7 and they are quoted with inverted commas.

1. Asphaltic Concrete (AC)
"Asphalt in which the aggregate particles are continuously graded or gap-graded to form an interlocking structure". Dense asphalt concrete is often used as the 'basic' surface layer.

2. Asphalt Concrete for very thin layers (AC-TL)
"Asphalt for surface courses with a thickness of 20 mm to 30 mm, in which the aggregate particles are generally gap-graded to form a stone to stone contact and to provide an open surface texture". This mixture is often used in France and is called BBTM (Béton Bitumineuse Très Mince).

3. Soft Asphalt (SA)
"Mixture of aggregate and soft bitumen grades". This flexible mixture is used in the Nordic countries for secondary roads.

4. Hot Rolled Asphalt (HRA)
"Dense, gap graded bituminous mixture in which the mortar of fine aggregate, filler and high viscosity binder are major contributors to the performance of the laid material". Coated chippings (nominally single size aggregate particles with a high resistance to polishing, which are lightly coated with high viscosity binder) are always rolled into and form part of a Hot Rolled Asphalt surface course. This durable surface layer was often used as a surface layer in the UK.

5. Stone Mastic Asphalt (SMA)
"Gap-graded asphalt mixture with bitumen as a binder, composed of a coarse crushed aggregate skeleton bound with a mastic mortar". This mixture is of often used as a surface layer in case high stability is needed. The surface structure also has good noise reducing properties.

6 Mastic Asphalt (MA)
"Voidless asphalt mixtures with bitumen as a binder in which the volume of filler and binder exceeds the volume of the remaining voids in the mixed". This mixture is very durable and was often used as surface layer in certain countries.

7. Porous Asphalt (PA)

"Bituminous material with bitumen as a binder prepared so as to have a very high content of interconnected voids which allow passage of water and air in order to provide the compacted mixture with drain and noise reducing characteristics".

8. Double layered Porous Asphalt (2L-PA)

The top layer with a grain size 4/8 mm is about 25 mm thick and the second/bottom layer is porous asphalt with a course aggregate (11/16 mm). The total thickness is about 70 mm. Because of the finer texture at the top (that gives less tyre vibrations), it gives a better noise reduction than a single layer porous asphalt.

9. Asphalt Concrete for ultra thin layers (UTLAC)

Asphalt for surface courses with a thickness of 10 mm to 20 mm, in which the aggregate particles are generally gap-graded to form a stone to stone contact and to provide an open surface texture. Several varieties of this layer are often used to provide a good, new noise reducing surface layer.

The difference between the mixtures with regard to structure and skeleton are also illustrated figures 3, 4 and 5.

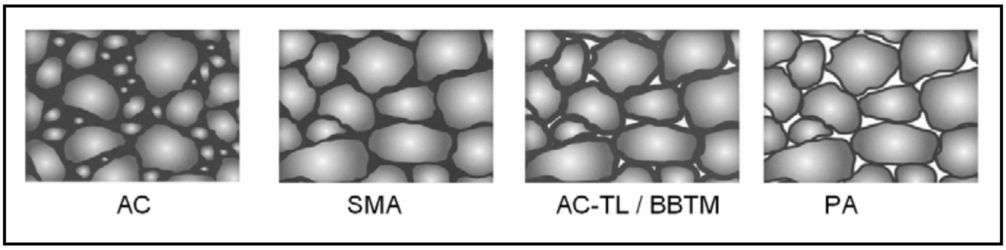

Figure 3: Difference in structure between AC, SMA, BBTM and PA.

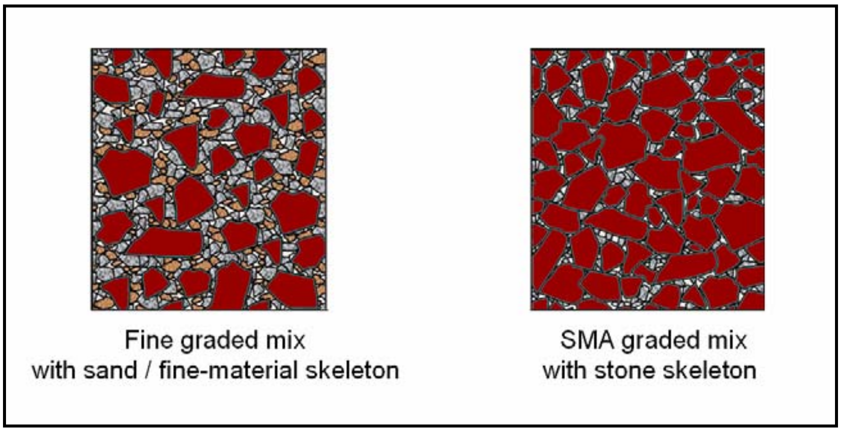

Figure 4: Difference between Sand skeleton and stone skeleton mixtures

Figure 5: Structure of Double layered Porous Asphalt

A.3. Basic assumptions for determining the durability of the surface layers

The expected durability is based on the best practice. This means that surface layers are expected to be laid on a properly designed road where the durability of the surface layer is not determined by bottom-up fatigue cracking.
Also, it is assumed that the mix is properly designed and well compacted. As an example, a SMA surface layer that shows rutting in the SMA layer is an improperly designed mixture.

The data shown are is not valid in case of using studded tyres.
The durability of surface layers also depends on the local conditions, the local climate, the mix formula used, the type of bitumen used, the type of aggregate used, the maximum allowable axle loads and the actual axle loads used (because excessive high axle loads have a strong negative influence on the service life of the pavement surface layers). In some cases or countries the skid resistance of the surface layer is the dominant factor for determining the service life, so the durability depends on the required friction level and the PSV-value of aggregate that has been used.

Figure 6 shows the Durability of Surface Layers expressed in years of service life for major roads / motorways / heavily trafficked roads.

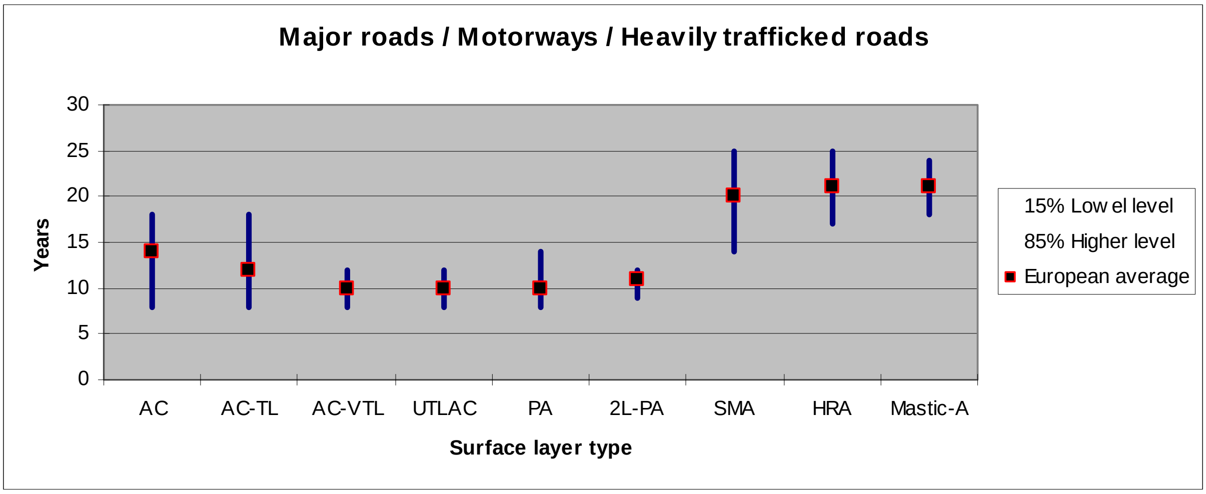

Figure 6: Durability of surface layers on major roads