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The Mastic Asphalt Industry –

A Global Perspective

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The Mastic Asphalt Industry – A Global Perspective

1. Description of the product

Mastic asphalt (MA) is a dense mixture consisting of coarse aggregate, and/or sand, and /or limestone fine aggregate, and/or filler and bitumen, which may contain additives (for example polymers, waxes). The mixture is designed to be of low void content. The binder content is so adjusted that the voids are completely filled and that even a slight excess of binder may occur. Mastic asphalt is pourable and able to be spread in its working temperature condition. It requires no compaction on site.

On the other hand asphalt mastic – abbreviation AM – is a term used in Europe to describe a mix of sand (that is, without aggregates > 2 mm), and/or limestone fine aggregate, and/or filler and bitumen that is used specially for waterproofing in a variety of applications.

The formulation of the mixture is chosen as a function of

- field of application
- mechanical load
- thermal load
- chemical load
- climatological influences.

2. Fields of application

2.1 Bridge decks

Bridge deck pavements must comply with a large number of conditions, such as: waterproofing, stability against deformation, rugosity, smoothness, aging, etc. The paving must protect the underlying supporting structure against external influences and, therefore, this determines to a great extent the lifetime of the construction. It must withstand the heavy load of traffic and weather conditions. When the supporting structure is made of concrete, it must be protected against the effects of de-icing salt. On steel bridge decks the paving has the function of protecting against corrosion.

It has been sufficiently proven in the past that, for several reasons, in the long run, immediate reopening of the road is impossible on a concrete bridge deck without asphalt paving. Bituminous paving, on the other hand, has demonstrated to be particularly suitable as a result of its visco-elastic properties. Indeed, by installing relatively thin pavements it becomes possible to economically design and build bridges, because the permanent load of the paving is restricted.

Traditional asphalt paving cannot be bonded directly on a concrete or steel base, and neither is it waterproof, so that an intermediate waterproofing layer is necessary. This waterproofing layer must, as a rule, cover the full surface of the bridge deck. Because of possible creeping, nowadays waterproofing layers must be placed to bond completely to the structure.

In order to fully waterproof a structure, a double layer system is absolutely required. Indeed, possible local imperfections cannot be excluded. By applying a second layer, possible failures can be corrected and in this manner a waterproof system is achieved.

For concrete bridge decks (but also for some steel bridge decks) the most common built-up system consists of:

- a bituminous sheet (thickness: 4 to 5 mm) bonded completely to the base by torching,
- a protective layer of mastic asphalt (thickness: 30 to 35 mm) which also has the function of a complementary waterproofing layer.

In some cases the bituminous sheet is replaced by a liquid resin system.

For various reasons, in some countries preference is given to a traditional asphalt concrete layer as protection for the waterproofing layer. The road paving, consisting of mastic asphalt or hot rolled asphalt, is then placed on the top of the protective layer (with a possible leveling layer).

2.2 Flooring (building)

In some European countries mastic asphalt is used as a floating screed in private and public buildings. The relevant standard for this application is EN 13318. So, this type of screed is installed directly or with thermal isolation, on the supporting construction. If desired, floor heating could be incorporated and floor covering with all kinds of materials (carpeting, parquet, linoleum, tiles, etc.) is possible.

Mastic asphalt is chosen for a large number of advantages that are very important in building construction:

- no additional water is added to the building, making the overall drying time of the construction drastically shorter
- can be put into use directly after cooling (this is usually after a few hours!), making the construction time considerably shorter
- can, to a considerable extent, be placed irrespective of weather conditions (e.g. frost)
- has excellent thermal properties, making it possible to comply, in combination with thermal isolation and in thin layers, with heat management requirements
- is completely workable and contains no tar or phenol
- is placed jointlessly (also on large areas!)
- does not require compaction or processing time to reach its final stability
- is considerably wear resistant
- is very resistant to disturbances and shocks due to its visco-elastic properties
- is able to absorb certain variations of conditions (e.g. due to temperature variations, slow settlement) without cracking
- is dense and non-porous
- is not dusty, is odourless and flavourless
- has a dense surface, preventing vermin or bacteria from nestling in the pores
- is apparently non-flammable (classification B_f-s1 according to EN 13501-1)
- does not require special cleaning measures and is easily cleaned with water (also high pressure) and cleaning products
- is durable and therefore economical.

A mastic asphalt floor is placed on a sound and level base at a thickness of 25 to 30 mm, on a separation layer (mostly staple tissue, glass fibre tissue, polyester fibre tissue, etc.). For floor heating, the thickness is ≥ 35 mm.

There is a large number of thermal insulation products available. When selecting this material, one must, amongst other aspects, consider the load on the floor, the processing temperature of the mastic asphalt, etc. An irregular support base must be first levelled with insulating aggregate (e.g. perlite-particles).

The mastic asphalt is transported:

- to the work site → mastic asphalt transportation mixer
- to the building site → dumpers, wheelbarrows or pumps
- to the processing site → metal or wooden buckets

Immediately after spreading the mastic asphalt (generally by hand with wooden floats), the surface is sanded with fine, fire-dried silica sand. This results in a finishing with optimal grip properties, which, however, also makes it possible to lay the final floor covering (carpet, parquet, tiles, etc.) directly on it.

2.3 Flooring (industrial)

This same type of floor is also often selected for industrial applications, such as storage areas, factory floors, workplaces, public buildings, etc. Here, the floor is also installed without bonding (which means with a separation layer) at a thickness of 25 mm (for normal loads) to 35 mm or 2 x 25 mm (for heavy loads). The surface is also finished with dried silica sand. In by far the most cases, the builder-owner does not demand thermal insulation. When the application is done on an important area, mechanical spreading may sometimes be appropriate. However, in most cases manual application is still common.

For floors exposed to chemical products, an acid resistant mastic asphalt composition, resistant to these products (at certain concentrations and at a certain temperature), can be formulated.

Mastic asphalt also proves to be an ideal sub-layer for sports courts. A bituminous sub-layer has proven to be less harmful for sportsmen (e.g., knees), than the hard floors, such as concrete.

On mastic asphalt sub-layer a variety of floor coverings (such as polyurethane, acrylate, etc.), can be applied, as in building construction, to divide the different playing grounds, and also for lined marking.

2.4 Road construction

In some European countries (especially Germany, but also Switzerland, Austria, etc.) there is a tradition of many years to provide motorways with heavy and intensive traffic with a mastic asphalt wearing course.

This type of paving has proven to greatly withstand:

- rutting
- weather influences,
- special traffic lanes and heavy vehicles,
- de-icing salt.

A wearing layer of mastic asphalt is applied at a thickness starting at 25 mm (normal traffic) to max. 40 mm (heavy traffic). The composition obviously depends on the type of traffic. Particularly, the content and type of binder are important here. Mastic asphalt is placed manually or mechanically, with specially designed spreading machines, at the desired thickness.

The surface is heavily chipped with pre-coated aggregates (grade 2/5 or 5/8 mm), that are evenly spread, immediately after placing, on the still warm mastic asphalt. After that, they are rolled, with a suitable roller, into the surface. In this way, a wearing course with an extremely high rugosity can be obtained.

Furthermore mastic asphalt paving proved to offer an important lifetime cycle. Deciding on a wearing layer of mastic asphalt is thus economically sound (taken into consideration the higher price to install, compared to traditional asphalt pavements).

This is possibly the reason why this type of paving is applied on such a large scale in the above-mentioned countries for:

- highways
- city roads
- special lanes
- footpaths and cycle tracks
- bridge decks
- tunnel paving
- etc.

2.5 Rooftop car parks

Actually, this application is characterized by a combination of waterproofing and a road pavement. Obviously these are the two functions rooftop car park pavements have to comply with in the first place. This is therefore very appropriately referred to as a directly trafficable waterproofing. The most applied systems are characterized as follows:

- a bituminous waterproofing layer (sheet);
- a layer of mastic asphalt;
- especially in UK and France: a two layer mastic asphalt (waterproofing and paving layer)

It is advisable to sometimes (e.g. on heavily trafficked rooftop car parks), provide an additional, intermediate layer of mastic asphalt, to protect the waterproofing layer. The great advantage is that with a thin layer a trafficable waterproofing is obtained, making it possible to reduce the permanent load to a minimum. Such a system, hence, makes an economic structure design possible.

There are also numerous applications of thermally insulated roofs of rooftop car parks. In this case the insulation material must show the necessary indentation resistance to support traffic during and after the construction activities. In such cases the formulation must be adapted, because the thermal insulation impedes heat conduction and transmission to other areas, which considerably increases heat accumulation in the pavement.

The normal structure (bituminous sheeting and mastic asphalt) can also serve as waterproofing, on which a finishing layer can be applied later. For various reasons, the builder-owner can choose concrete pavement slabs, tiles, etc., or even green roofs or rooftop gardens.

Because of its waterproofing properties, mastic asphalt paving is often preferred in underground car parks. This application can then be seen as a floor system (see above).

The mastic asphalt composition must be chosen so that the pavement will withstand all weather conditions (very cold in the winter and very hot in the summer), ensuring at all times the waterproofing and trafficable characteristics.

On car park decks due to their large proper weight, traditional spreading machines are not authorized. For the transportation of the mastic asphalt, special transport dumpers were developed that are comparable in size and weight with a passenger car, in order to transport the mastic asphalt to the processing site.

A heating and mixing device guarantees that the mastic asphalt mix is kept homogenous and at the desired processing temperature anywhere on the working site and at all time.

In order to obtain the necessary rugosity, the mastic asphalt pavement is covered, immediately after spreading, with a graded aggregate (chipping). The colour and grade of this aggregate can be freely chosen from an extensive range of materials.

These aggregates must be dried; otherwise, the adhesion of the mastic asphalt is not guaranteed. It is advisable to use a bright colour for this aggregate (e.g., beige or white), as this will considerably reduce the thermal impact of the sun in summer time. This considerably reduces the risk of deformation (e.g., as a result of standing /parking vehicles).

2.6 Hydraulic constructions

Mastic asphalt and asphalt mastic have, in the past, been successfully applied as a pouring mixture to bond rubble stone placed on canal slopes, river banks and sea shores.

Because these are placed on the basic dike structure by posing large rubble stones to protect the shores, these stones must be secured in order to withstand the influences of the changing water level and possibly stormy weather.

Mastic asphalt has proven that these stones can be bonded satisfactorily. Because mastic asphalt is reasonably fluid at the processing temperature, most voids between the rubble stones are filled. Not only are the stones herewith bonded to each other, but with proper dosages, the dike construction is also sealed against incoming water.

There are examples, where riverbeds and canal floors were also impregnated by the same procedure. In dike constructions the mastic asphalt is applied from the top (crown) of the dike, either through free fall (that is to say, by letting it flow down the slope) – which, however, does not always produce a homogenous surface – or with an adapted shovel with which the mortar can be spread much more uniformly. For an optimal fixing of the stones and impregnation of the bank, a quantity of 100 to 120 kg/m² asphalt mastic is necessary.

2.7 Flat roofing

Mastic asphalt is extensively used as flat roof waterproofing. It can be applied to form a continuous waterproof covering over flat, sloped or curved surfaces and can be scurled round pipes, roof lights and other projections. In UK, additionally, the vast majority of roofs have vertical mastic asphalt upstands.

It can be laid on most types of rigid sub-structure such as concrete, pre-cast concrete deck units, timber boarding, metal decking and other proprietary decking units. Thermal insulation materials can easily be laid as part of a mastic asphalt specification to give any required U-value (earlier k-value). Treatments applied to asphalt can provide a surface suitable for traffic, increase solar reflectivity and provide a decorative finish.

Asphalt mastic for roofing is usually laid on a separating membrane of sheathing felt in a two coat application to a thickness of 20 mm.

2.8. Tanking

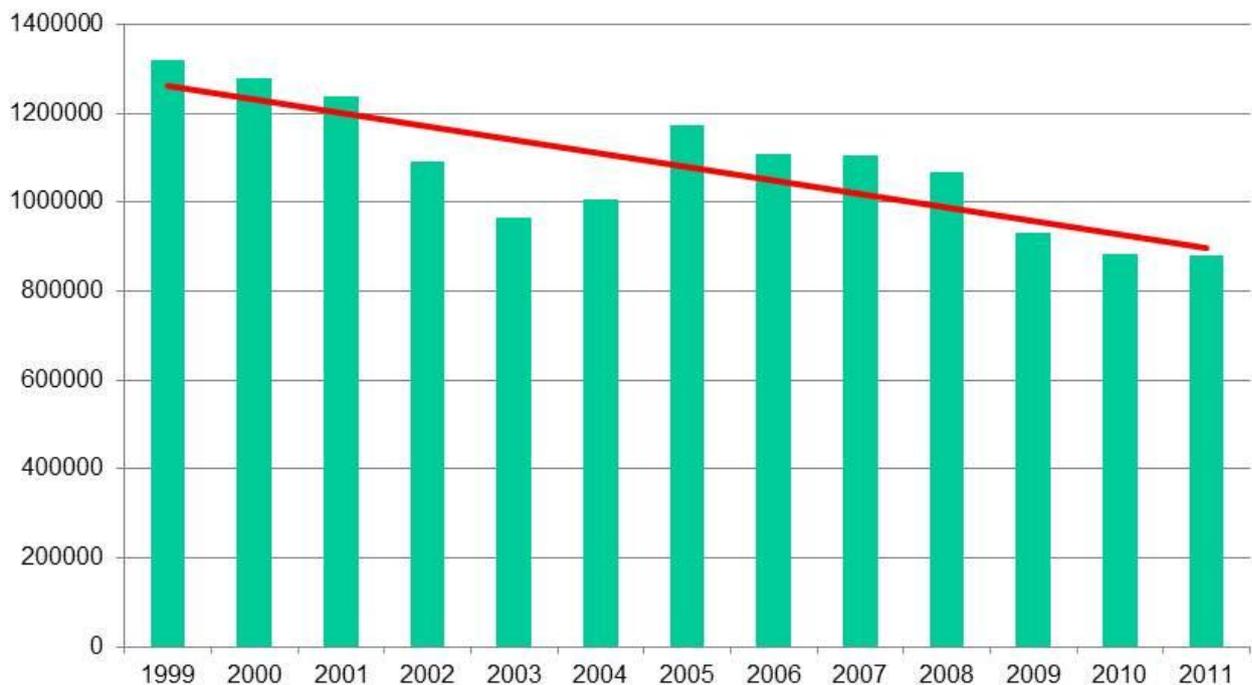
Mastic asphalt (asphalt mastic) provides a continuous waterproof lining “tanking” to walls, floors and foundations to protect structures against water from the ground.

It is applied directly to the upper surface of a structural concrete base and either the outer surface (external tanking) or inner surface (internal tanking) of structural walls. It is subsequently loaded with further concrete or brickwork and will perform as a waterproof lining for the design life of the structure.

3. History and production levels

Mastic asphalt is especially used in Europe since 1890. The European main markets are Germany and France. Mastic asphalt is practically not used in the USA and in Canada. Recently, the mastic asphalt markets in Asia began to grow. The total production level in Europe during the last years can be described as follows:

Mastic Asphalt (MA) Production in Europe



Remarks:

2000: Spain entered

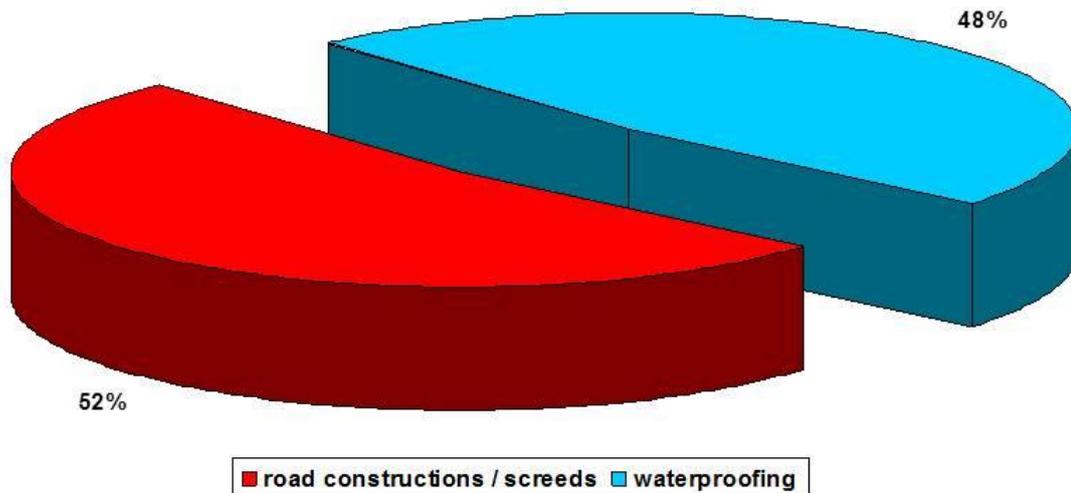
2002: Norway left

2003: Luxemburg left

2004: Russia entered

The following graphic shows the mastic asphalt application areas for the reference year 2011:

Mastic Asphalt Application Fields



4. Production methods

4.1 Mastic asphalt mixing processes

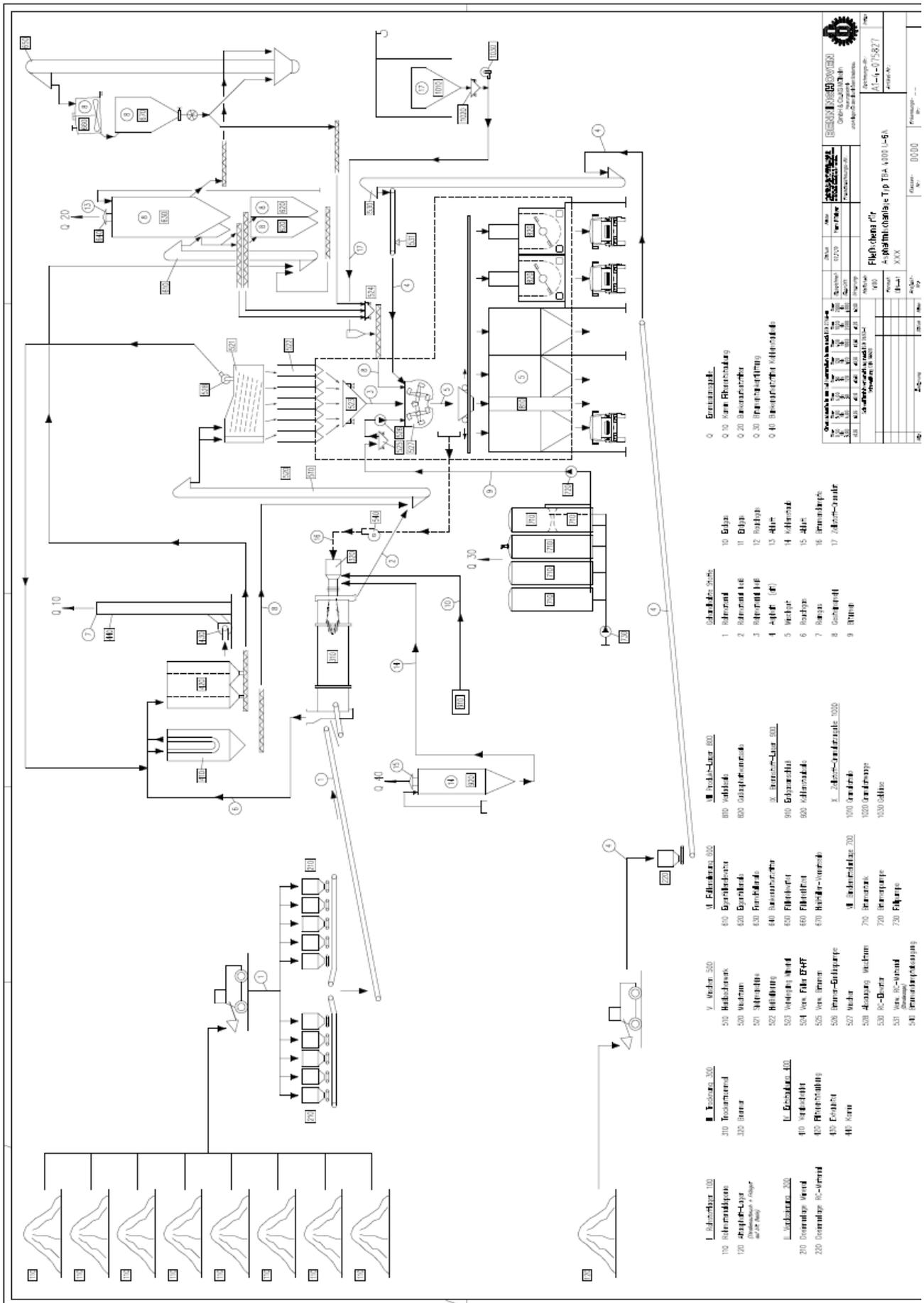
In the past, that means approximately until 1970, mastic asphalt was often manufactured in mobile cookers (usually at the work site) that were filled with the various components. By slowly heating them, the components were brought to the right temperature, where the mixing device (then mostly a horizontally rotating mixer shaft) served to make sure that the mix was homogenous for processing. Of course, in this way no high production rates could be achieved.

Nowadays mastic asphalt is manufactured in (specially designed) stationary industrial plants. These are designed to proportion the materials, dry the mineral aggregates and mix them in a heat controlled environment. Application specifications control the temperatures at which material is produced. Typically, in the past, mastic asphalt production temperatures were in the range of 230 to 270 °C. However in the recent years considerable research and investments have been done (and are still ongoing) to lower these temperatures beneath 230 °C – in some countries even below 200 °C.



Today, the majority of the mastic asphalt production plants is housed.

Here the minerals (sand, limestone fine aggregates and coarse aggregates) are dried, and if required, heated. The different particle sizes are separated by passing through a sieve (after drying) and then (if necessary, with intermediate storing) weighed and introduced into the mixer. The filling material is also dosed into the mixer (if necessary, after preheating).



Scheme of a mastic asphalt production plant with filler heating.

The bitumen (stored in heated storage tanks) is also introduced after dosing into the mixer of the asphalt plant.

The proportions of binder and aggregate shall be combined according to the specific job requirements. Proportioning may be by mass or by volume.

The mixer of the asphalt plant usually comprises a closed pug mill, in which two mixing shafts, rotating in opposite directions, thoroughly mix the different components for 60 to 80 seconds (intermittent batch mixer). Alternatively, slower, single shaft mixers are also used.

The duration of mixing time shall be sufficient to ensure complete homogeneity in the mixture.

After that the mixture is transferred, mostly directly, but if so desired, via an intermediate silo, into the transport unit.

Where the mastic asphalt is only partly mixed before transfer to a mobile mixer, additional mixing in the mobile mixer is advisable until homogeneity in the mixture is obtained.

When the mastic asphalt is not required for immediate use, it may be cast into blocks for subsequent remelting on site. The coarse aggregate content may not yet be included at this stage.

4.2 Definition of the components used in manufacture

4.2.1 Binders: types

4.2.1.1 Paving grade bitumen (complying with EN 12591)

Straight-run bitumen types are mostly used in mastic asphalt mixtures. Bitumen is defined as the residual product from distillation of crude oil in petroleum refining. Bitumen is produced to specification directly by refining or by blending. Bitumen characteristics are generally determined by the principal properties:

- rheological characteristics
- cohesion
- adhesive power on minerals
- aging

For the use of mastic asphalt the different types of bitumen are characterised by

- penetration
- softening point

The denomination of the types of bitumen is based on the typical character of these properties. Paving grade bitumen used normally for mastic asphalt is less than 50 mm penetration.

4.2.1.2. *Hard Grade Industrial bitumen (complying with EN 13305) and Hard Paving Grade bitumen (complying with EN 13924)*

Although straight-run bitumen is most often used, hard bitumen (obtained through mild oxidation of bitumen / air rectified bitumen with $PI \leq +2.0$) is used for certain mastic asphalt applications (e.g. indoor applications).

Hard bitumens are characterised according to the limits of the softening point values. These are bitumen showing hard and brittle characteristics at ambient temperature. Therefore they are only used for indoor applications. A typical grade is H 90/100.

→ NB: It is important to know that no oxidised bitumen with $PI > +2.0$ is used for mastic asphalt.

4.2.1.3. *Synthetic pigmentable binder*

A synthetic pigmentable binder is a synthetic binder, which is easily pigmentable. With this kind of binder you can add a small amount of pigment to the binder to obtain a wide range of coloured asphalts.

The binder is either modified with polymers or not. It is mainly used for small infrastructures such as footpaths, bicycle roads, for aesthetic or safety reasons.

4.2.2 Binders: contents

The binder content of mastic asphalt is depending on the end use. It is so adjusted to the void content in the mineral aggregate that voids are completely filled and can vary between 6 up to 12 percent, but can be increased for special applications.

4.2.3 Binders: additives

4.2.3.1 *Addition of polymers (complying with EN 14023)*

During the past years polymer modified bitumen (i.e., elastomers or plastomers) has also been used more often. This makes it possible to adapt certain characteristics of the base bitumen to the projected application.

Generally, this results in the following:

- superior visco-elasticity
- improved cohesion
- increased adhesive power

4.2.3.2 *Addition of natural asphalt*

Natural asphalts are naturally-occurring mixture of bitumens and mineral matter formed by oil seepages in the earth's crust. Natural asphalts include Trinidad Lake, Rock, Gilsonite, Selene and others. There are not refined bitumens.

In some cases so-called «natural asphalt» has been added for many decades in small quantities (1 to 2 per cent of the final mixture). It is mostly the natural asphalt known as Trinidad-Epuré (EINECS: 310-127-6, CAS: 999999-99-4), which consists of approximately 54 % natural bitumen and approximately 46 % limestone filler. This natural asphalt is mined at the surface on the island of Trinidad (in the Caribbean).

Another type of natural asphalt comes from the USA (Utah) and is known as Gilsonite (CAS number 12002-43-6). The bitumen content of this bitumen is approximately 92 %.

In Europe, production of the Selenizza-asphalt (origin Albania) was resumed. The bitumen content of this asphalt is also approximately 90 %.

Finally, it must also be mentioned that in the past (at present only to a very limited extent) natural asphalt powder was mined in a number of distinctive mountainous areas in Europe (France, Spain, Switzerland).

4.2.3.3 Addition of wax derivatives

Other additives are aimed at influencing viscosity. Although this is a direct function of the temperature, a number of products were developed that increase the workability at a certain temperature.

As a consequence of the tendency during the last years in which the emission of bitumen fumes is kept as low as possible, these additives can thus also provide the same workability at a lower temperature of the mastic asphalt mixture.

These additives belong to the so-called wax derivatives.

4.2.3.4 Addition of pigments

Some efforts have been made to colour mastic asphalt (mostly for aesthetic reasons) and this in spite of the limited possibilities to colour the straight-run bitumen (amongst other things, because of the content).

The most used pigment is certainly iron oxide, which gives a rather red brownish colour.

However, to obtain reliably coloured paving, other binders must be used (see above).

4.2.3.5 Addition of fibres (in combination with the addition of natural asphalt)

In the past, recourse was sought (mainly in Germany) in the addition of natural fibres (mostly of vegetable origin / cellulose fibres).

The purpose was to improve the stiffness (particularly) during and (to a lesser extent) after the placing, e.g., in cases of a sloping subsurface.

4.2.4 Fillers

This is the smallest mineral fraction and contains all particles with a maximum diameter of 0.063 mm (or: passing the 0.063 mm sieve).

For mastic asphalt, crushed limestone is used in most cases.

In acid-resistant mixtures, the usual limestone filler (not acid-resistant!) is replaced by a siliceous filler, which, on the contrary, is considered as acid-resistant.

To obtain a mastic asphalt mixture with a suitable processing temperature (during manufacturing!) it is advised to heat the filler in a device specially provided for that purpose. This makes it possible to introduce the filler at a temperature of approximately 150 to 180 °C (instead of the normal ambient temperature of, e.g., 20 °C).

4.2.5 Mineral aggregates

4.2.5.1 Fine aggregates (former sand)

A distinction must be made between

- natural sand, this is found in natural locations (with a round shape) and
- crushed sand which is obtained by crushing (in a crusher) of rock particles (with a cubical shape).

This refers, basically, to the mineral particles between 0.063 and 2 mm. Of course, the origin of the source rock from which the sand fraction is obtained is of great importance.

In the case of underlayers, e.g., (such as waterproofing layers), what is referred to as “soft” aggregates, are more readily accepted, while what is referred to as “hard” aggregates, will be required for wearing courses. Regarding stability, crushed sand is considered to provide a higher level of security than natural sand, because the cubical structure of crushed sand gives better “anchorage” than is the case with the round particles of natural sand.

4.2.5.2 Limestone Fine Aggregate

Limestone fine aggregate consists of crushed naturally occurring limestone with a calcium carbonate content of not less than 80 %. A substantial proportion is retained on a 0.063 mm sieve and most passes a 2 mm sieve. Limestone fine aggregate may be used as an alternative to, or in conjunction with fillers and/or sand.

4.2.5.3 Coarse aggregates

This refers to all mineral aggregates with a diameter > 2 mm.

There are two sieve-sets in the standard – different from country to country. In the case of mastic asphalt, aggregates with the following particle size are mostly used:

- 5.6 or 4 mm for layers with a thickness up to 20 mm
- 8 or 6.3 mm for layers with a thickness up to 30 mm
- 11.2 or 10 mm for layers with a thickness up to 40 mm

The origin of the mineral particles determines, just as is the case for the “sand fraction”, to a certain extent the use:

- «soft» for base layers
- «hard» for surface layers

The classification of aggregates is based on a number of typical characteristics:

- frost resistance
- shape of the particle
- shock resistance
- abrasion resistance
- density
- water absorption
- etc.

The minerals are usually of natural origin, (from stone quarries); but sometimes «synthetic» minerals are used (e.g. expanded clay) with the purpose of reducing the specific gravity. Currently, there is also a tendency to increasingly use reclaimed mastic asphalt in the production of mastic asphalt (= recycling).

For acid-resistant mixtures, the mineral fraction must, of course, also have the same characteristic.

4.3 Composition

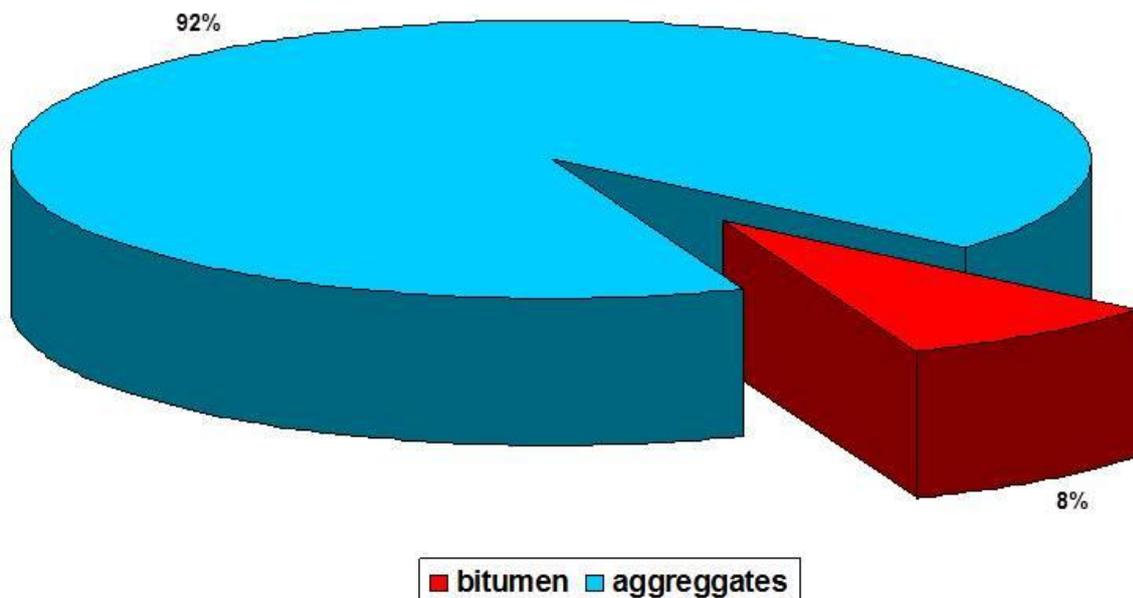
The percentage of bitumen, filler, sand, limestone fine aggregate and coarse aggregate components determine the composition of the mastic asphalt mixture.

Each use, of course, determines the properties the mastic asphalt must have in order to comply with the expected load.

This load can be:

- mechanical
- thermal
- climatological

Mastic Asphalt Components



5. Transport

After production the mastic asphalt is transported to the processing location in mastic asphalt transport mixers, developed specially for that purpose. These mixers are mounted on a truck or chassis of a trailer. These are provided with:

- a heating system with oil or gas burners
- a mixing device with a horizontal or vertical shaft



Mastic asphalt mixer for transportation.

The capacity of these mixers may vary, depending on local regulations.

The purpose of these tanks is to maintain the temperature of the mastic asphalt mixture (if necessary, to even heat it a little) and to prevent disintegration (homogeneity must be maintained).

Transportation can take place under normal circumstances, as long as a number of parameters (temperature, weight, etc.) are respected and therefore registered.

Remelting of block mastic asphalt on site shall be carried out in suitable mechanically stirred mixers or cauldrons. During remelting care shall be taken to ensure that the temperature of the molten mastic asphalt does not exceed the recommended application temperature.

The transport from the mixer to the site is done with the help of dumpers, wheelbarrows, buckets or in some cases with the special mastic asphalt pump.

6. Application methods

6.1 General

Mastic asphalt is spread or floated as a general rule. Mastic asphalt is, by definition, not compacted because of the absence of voids in the composition.

The surface of the mastic asphalt is usually chipped with:

- sand for indoor applications
- aggregate (if necessary, coloured) coated or not with bitumen for outdoor applications.

After cooling, mastic asphalt can be walked or driven on. This makes it possible to immediately put a mastic asphalt pavement into use (for indoor as well as outdoor applications!).

6.2 Hand applied

Indoor and outdoor applications are carried out by hand. This means that mastic asphalt is hand spread to the desired thickness and levelled with a wooden float or screed. Depending on the kind of application and base, the mastic asphalt is placed on a separation layer, in order to keep the asphalt layer separated from the sub-structure.



Hand laid mastic asphalt screed.

This separation layer mostly consists of:

- staple tissue
- polyester fibre tissue
- felt (if necessary, coated with bitumen)

The mastic asphalt is delivered on site in mobile transportation mixers (up to where the work site is accessible), then transferred into so-called dumpers or carts, depending on the distance to the processing site. If necessary, the mastic asphalt is poured into metal or wooden buckets or wheelbarrows to reach the actual processing site. A recent development makes it possible to pump the mastic asphalt with special equipment (such as, e.g., a concrete pump!) to the processing site.

6.3 Machine applied

For large surfaces mechanical pavers are used (mostly in road construction), which can lay mastic asphalt with widths up to 12 m without longitudinal joints. There are also smaller mechanical pavers that can lay smaller widths (e.g., 30 cm) in great lengths.



Machine laid mastic asphalt pavement.

Mastic asphalt requires no compaction (due to the absence of voids), so that it is sufficient to spread at the desired thickness.

As a rule, the surface of mastic asphalt paving is always chipped with sand or aggregates, depending on the desired rugosity (different for, e.g., indoor or outdoor applications!).

In road construction, aggregate, precoated with bitumen, is usually used; these chippings are spread evenly and pressed into the still warm mastic asphalt.

As mastic asphalt only requires cooling off time and no hardening time, it can accept full loads promptly after cooling off. That makes it possible, e.g., to immediately allow vehicles and pedestrians on the road, or put on the final floor covering right away.

6.4 Temperatures of application

Before the year 2008 mastic asphalt was used at temperatures between 230 to 270 °C. The successful lowering of temperatures in the mastic asphalt industry is a result of substantial research and development to limit the emission of fumes to an absolute minimum. Thanks to the use of additives (adding viscosity reducing substances) it is now possible to apply mastic asphalt at temperatures below 230 °C – in some countries even below 200 °C – lowering application temperature by 10 degrees results in reducing to 50 % the fume quantities.

The asphalt industry expects from this development the following results:

- less vapours and aerosols;
- lower emissions at mixing plants;
- lower energy consumption;
- lower equipment wear;
- reduced CO₂ production and emissions;
- minimizing ageing of binders during production and application

Nowadays exposure levels below 10 mg/m³ of fumes of bitumen (hot application) are achievable at lowered temperatures.

The application temperatures can vary from country to country because there are used different kinds of binder sorts for different kinds of application fields. A possible range of the temperatures of application can be described as follows:

Road constructions (machine laid):	165 °C to 200 °C
Screeds in building constructions:	210 °C to 230 °C
Waterproofing:	200 °C to 230 °C

As a general rule hand laid mastic asphalt requires a higher temperature than machine laid mastic asphalt.

Considerable efforts have been undertaken by the members of the International Mastic Asphalt Association IMAA in order to reduce temperature in producing, transporting and application of mastic asphalt. The positive results of these efforts will motivate the industry sector to increase these applications with low-temperature mastic asphalt using appropriate additives.

7. Occupational exposure

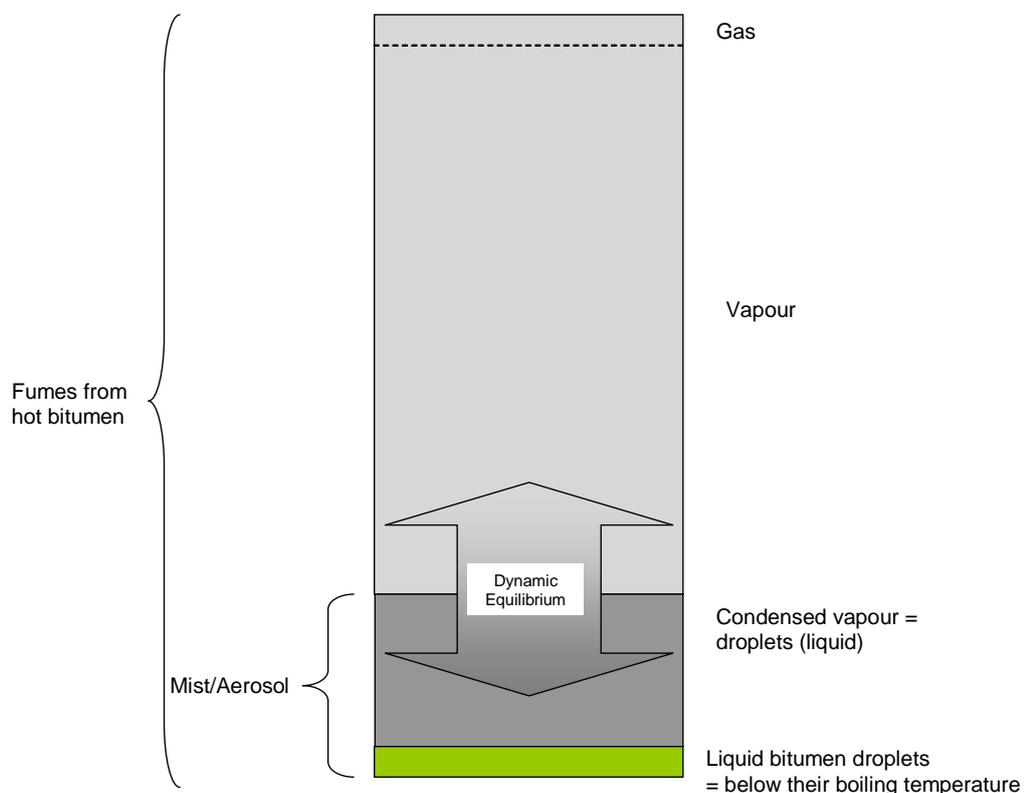
7.1 Exposure Monitoring of bitumen fumes

7.1.1 Bitumen fumes defined

In order to better interpret the meaning of different exposure monitoring results it is important to understand what constitutes bitumen fume and how it is formed.

When bitumen is heated small quantities of hydrocarbon vapours, solid hydrocarbons and sometimes inorganic gases (H_2S) are emitted. Some of the heavier molecules in the vapour will condense on nuclei and form droplets (aerosol phase). At workplaces, the size distribution and the partitioning between gas, vapour and aerosol phase is strongly dependent on several environmental conditions. At different bitumen fume concentrations, caused e.g. by the type of bitumen used, application temperature, changing wind speeds or convective flows and distance from source, the ratio of aerosol to vapour phase can be quite different [CONCAWE 1992, Rühl et al 2006]^{i,ii} Hence, the size distribution might also change considerably. Another factor that noticeably influences the size distribution is the concentration of other environmental aerosols, since these aerosols may serve as condensation nuclei. Starting out from the same bitumen fume concentration at low condensation nuclei concentrations, more mass per nucleus is present than for higher concentrations and hence the particles grow larger. On the other hand, if the number concentration of condensation nuclei is larger, the median diameter of the resulting particles will be smaller. A schematic diagram showing the various phases present in bitumen fumes is shown in figure 1.

Figure 1: Schematic diagram of bitumen fume composition.



Most of the particulate matter evolved from the bitumen is expected to be in the respirable size range, although inorganic particulates from non-bitumen sources can be outside this range. [Calzavara et al, 2003]ⁱⁱⁱ Numerous sampling and analytical methods have been and continue to be employed in the characterization of workplace exposures to fumes from asphalt and the full extent of any relationships between these various methods remains unknown. This is not surprising as vapour, aerosols and PAH from bitumen have different determinants of exposure. In an analysis of paving worker exposures in Finland, France, Germany, Norway, and Sweden, no consistent correlation between levels of fumes from bitumen and vapour from bitumen could be established. [Burstyn et al, 2002]^{iv} However, it was recently shown that the concentrations of aerosols from bitumen measured by the American and the German methods are comparable. (Antony J. Kriech, Linda V. Osborne, Dietmar Breuer, Christoph Emmel and Reinhold Rühl: Side-by-Side comparison of The NIOSH Analytical Method 5042 and the German Method BGIA 6305 for Field Monitoring of Bitumen Fumes. 2008).

7.1.2 Occupational Exposure Monitoring for Asphalt Fumes

Occupational exposure to fumes from bitumen is measured using a personal monitoring sampler. The type of sampler used and the method by which it is analysed can lead to substantial differences between measured values [Ekström et al, 2001]^v. When comparing results of personal exposure monitoring surveys it is important to take into account the method used and the type of value being measured.

At present, an international standardised method for sampling and measuring potential bitumen fume exposure does not exist. Introducing such a standard would reduce future confusion about the interpretation of emission measurements and enable comparison of the results of new exposure studies. Further research is needed to develop a valid and inexpensive method of assessing exposures relevant to protection of worker health.

Exposure monitoring methods for bitumen fumes fall into three main categories that measure:

- **Particulate matter**
TPM (Total Particulate Matter): this includes aerosol matter from the bitumen and inorganic material such as dust, rock fines, filler etc. Because TPM methods collect material from non-bitumen sources the resulting values can suggest artificially high exposure values, especially in dusty environments.
- **Solvent soluble fraction of particulate matter**
BSM/BSF (Benzene Soluble Matter/Fraction) or CSM/CSF (Cyclohexane Soluble Matter/Fraction): these methods rely on collection of the particulate fraction as described above. However, in order to reduce the confounding exposure to inorganic particulate matter a solvent is used to extract only the organic fraction of the particulates. Such methods more accurately define the exposure to the agent of interest (bitumen fume). A sub-set of such methods uses a special monitoring cassette to collect only a specific fraction of the particulate matter, e.g. the Respirable, or Inhalable fraction, one such method is the ACGIH TLV[®] (American Conference of Governmental Industrial Hygienists – Threshold Limit Value).
- **Organic matter**
TOM/THC (Total Organic Matter/Total Hydrocarbon): the sum of the organic part of the particulate fraction plus organic vapour phase collected using a back-up absorbent.

Within each of the above categories there are numerous variables, such as type of sampler (e.g. open face, closed face, inhalable particulate), the type of solvent used to extract the filter (e.g. cyclohexane, benzene, dichloromethane), the type and quantity of sorbent used to capture the vapour phase (XAD2, Tenax™, activated, or coconut charcoal). The resulting differences make it difficult, if not impossible, to directly compare measurements taken using different methods.^{vi, vii}

Table 1 gives an overview of important factors affecting the outcome of exposure monitoring.

Table 1. Factors affecting the outcome of exposure monitoring.

Overall factor	Sub factor	Possible influencing items
Sampling of bitumen fume	Sampler device	Type of sampler (filter media etc.), sampling characteristics (duration etc.).
	Climate	Wind speed/direction, air temperature, weather type.
	Ambient environment	Physical obstacles, noise barriers, tunnels.
	Technical information	Asphalt/bitumen type, application temperature, equipment type.
Analysis of bitumen fume	Definition of bitumen fume and occupational emission limit (OEL):	1. Special solvent soluble fraction of particulate matter. 2. Total Particulate Matter. 3. Aerosol and Vapour.
	Analysis method	Type of solvent, analytical instrumentation, etc.

The above methods of measuring exposure are not bitumen specific and will capture particulate and vapour fractions of any organic material. Therefore exposure levels can be subject to confounding from other organic materials in the workplace, such as solvents used for cleaning and diesel engine exhaust.

In addition to monitoring exposure to fumes from bitumen some studies have evaluated exposure to individual, or groups of Polycyclic Aromatic Hydrocarbons (PAH) as components of fumes from bitumen. A number of different lists of PAHs are used by regulators and scientific advisory bodies. A number of different lists of PAHs are used because different regulators and advisory bodies have their own view of which substances should be regarded as carcinogenic or not.

7.1.3 Exposure during placement of mastic asphalt

The following exposure data are based on measurements taken by the Berufsgenossenschaft der Bauwirtschaft (BGBAU) in Germany. In Germany, the well known BGIA sampling system GSP (BG-Institute for Occupational Safety and Health – BGIA) is used for measuring vapours and aerosols of bitumen on workplaces.

The inhalable aerosol is sampled on a glass fibre filter and the vapour is adsorbed in a cartridge containing XAD-2 resin. Both aerosol and vapour are extracted with tetrachloroethylene. The signals for hydrocarbon vibrations in the range from 3000 to 2800 cm⁻¹ are analysed with Infrared Spectrometry. This range is typical for the aliphatic hydrocarbon bonding. For quantification a synthetic mineral oil for spectroscopy is used.

BG BAU regularly takes measurements on construction sites, so that the number of measuring results is steadily increasing. Several reports have therefore already been submitted on smaller volumes of data collected about exposure to vapours and aerosols from bitumen

during the placement of mastic asphalt (Reinhold Rühl, Uwe Musanke, Kurt Kolmsee, Renate Prieß, Gerd Zoubek and Dietmar Breuer: Vapours and Aerosols of Bitumen: Exposure data obtained by the German BITUMEN Forum. Rem. Occup. Hyg. 50: 459–68, 2006).

The measurements given in the following tables are task-related measurements. It is assumed that each of the tasks can also be carried out throughout an entire work shift. In practice, also other tasks have to be performed, depending on the site. When placing mastic asphalt screeds, for instance, preliminary work such as the laying of insulating materials has to be performed, during which there can be no exposure to bitumen. Therefore the actual exposures during a work shift will be lower than the measurements given in the table. It is also to be taken into account that the measurements given in the tables X1, X2 and Y1 reveal the previous status. The measurements relate to the temperatures of 250° and over that were used in the past. In table Y2 the exposure values listed are for mastic asphalt of reduced temperature.

Table X1

Exposure to sum of vapours and aerosols of bitumen (V+A) as well as aerosols of bitumen (A) during application of conventional mastic asphalt by machine. Measured values are shown in mg/m³ disregarding exposure times. The percentile values are not given for <10 measured values.

The higher measurements for the application of mastic asphalt in the open by machine are, on the one hand, due to the working of larger quantities of mastic asphalt when laying wearing courses or protective layers on bridges. In building construction work the work is performed using buckets or wheelbarrows of mastic asphalt whereas on road construction sites the mastic asphalt is applied directly from the mixer to the area in front of the screed. On the other hand, in the open, external effects such as diesel emissions from passing traffic are taken up in the measurement.

	Activity		Number	Minimum value	50 percentile	95 percentile	Maximum value
	Total data collected	V+A	298	0.1	4.2	34.6	75.4
	215-270 °C	A	298	0.1	2.8	25.7	59.3
outdoors	All outdoors	V+A	222	0.1	3.7	38.5	75.4
	230-255 °C	A	222	0.1	2.6	27.7	59.3
	Charger on the mixer	V+A	67	0.4	6.3	57.1	75.4
		A	67	0.4	5.1	43.0	59.3
	Paver driver	V+A	97	0.3	3.9	37.4	45.9
		A	97	0.3	2.6	28.1	40.7
	Other tasks	V+A	58	0.1	1.5	9.4	14.0
		A	58	0.1	0.7	6.5	10.6
indoors	All indoors	V+A	76	0.5	5.4	25.8	59.1
	215-270 °C	A	76	0.2	3.1	18.1	46.6
	Charger on the mixer	V+A	9	7.0	-	-	23.5
		A	9	4.5	-	-	20.3
	Paver driver	V+A	34	0.9	6.2	36.6	59.1
		A	34	0.3	3.2	23.2	46.6
	Other tasks	V+A	33	0.5	4.1	14.1	16.1
		A	33	0.2	2.2	8.9	9.4

Table X2

Exposure to sum of vapours and aerosols of bitumen (V+A) as well as aerosols of bitumen (A) during application by machine of viscosity-modified mastic asphalt with reduced handling temperatures. Measured values are shown in mg/m³ disregarding exposure times.

	Activity		Number	Minimum value	50 percentile	95 percentile	Maximum value
outdoors	All outdoors	V+A	143	0.3	2.1	7.8	12.0
	180-230°C	A	143	0.3	1.2	6.1	11.0
	Charger on the mixer	V+A	43	0.3	2.4	7.7	12.0
		A	43	0.3	1.6	6.1	9.7
	Paver driver	V+A	57	0.3	2.9	9.1	11.9
		A	57	0.3	2.3	7.1	11.0
	Other tasks	V+A	43	0.3	0.3	2.9	5.8
		A	43	0.3	0.3	2.1	3.7

Table Y1

Exposure to sum of vapours and aerosols of bitumen (V+A) as well as aerosols of bitumen (A) for manually applied conventional mastic asphalt. Measured values are shown in mg/m³ disregarding exposure times. The percentile values are not given for <10 measured values.

	Activity		Number	Min. value	50 percentile	95 percentile	Max. value
	Total data collected	V+A	630	0.1	5.6	28.0	77.0
	208-280 °C	A	619	0.1	3.0	20.3	65.7
outdoors	All outdoors	V+A	103	0.1	2.9	11.1	16.8
	218-275 °C	A	97	0.1	1.4	6.9	11.2
	Charging	V+A	53	0.5	3.3	14.4	16.0
		A	52	0.2	1.4	7.5	11.1
	Bucket transport	V+A	17	0.1	0.6	9.0	9.0
		A	17	0.1	0.4	5.1	5.7
	Wheelbarrow transport	V+A	12	0.7	4.3	12.2	16.8
		A	10	0.5	2.1	9.1	11.2
	Smoothing	V+A	20	0.5	3.8	8.1	8.5
		A	17	0.1	1.6	5.3	6.3
	Sanding	V+A	1	2.4	-	-	2.4
		A	1	1.3	-	-	1.3
indoors	All indoors	V+A	527	0.5	6.1	31.3	77.0
	208-280 °C	A	522	0.1	3.4	22.3	65.7
	Charging	V+A	60	1.3	5.4	24.1	77.0
		A	60	0.4	2.4	13.7	60.0
	Bucket transport	V+A	80	0.5	3.1	8.0	26.3
		A	80	0.1	1.3	4.4	22.5
	Wheelbarrow transport	V+A	97	0.6	5.5	36.1	66.0
		A	95	0.1	3.4	32.8	53.0
	Smoothing	V+A	254	0.8	8.0	33.2	71.7
		A	251	0.3	4.4	23.9	65.7
	Sanding	V+A	36	0.6	5.7	27.9	36.8
		A	36	0.3	3.3	18.6	30.5

Table Y2

Exposure to sum of vapours and aerosols of bitumen (V+A) as well as aerosols of bitumen (A) for manually applied viscosity-modified mastic asphalt with reduced working temperatures. Measured values are shown in mg/m³ disregarding exposure times. The percentile values are not given for <10 measured values.

	Activity		Number	Min. value	50 percentile	95 percentile	Max. value
	Total data collected	V+A	76	0.3	5.1	10.2	12.8
	210-257 °C	A	76	0.3	2.5	6.4	9.1
outdoors	All outdoors	V+A	6	0.3	-	-	3.2
	210-235 °C	A	6	0.3	-	-	2.1
	Charging	V+A	2	0.3	-	-	3.2
		A	2	0.3	-	-	2.1
	Bucket transport	V+A	0	-	-	-	-
		A	0	-	-	-	-
	Wheelbarrow transport	V+A	1	1.0	-	-	1.0
		A	1	1.0	-	-	1.0
	Smoothing	V+A	3	0.5	-	-	1.0
		A	3	0.5	-	-	1.0
Sanding	V+A	0	-	-	-	-	
	A	0	-	-	-	-	
indoors	All indoors	V+A	70	0.5	5.3	10.2	12.8
	215-257 °C	A	70	0.5	2.6	6.5	9.1
	Charging	V+A	27	0.5	5.0	11.1	12.8
		A	27	0.5	2.0	6.5	7.3
	Bucket transport	V+A	2	2.3	-	-	7.3
		A	2	1.7	-	-	5.5
	Wheelbarrow transport	V+A	1	3.6	-	-	3.6
		A	1	2.3	-	-	2.3
	Smoothing	V+A	32	0.6	5.4	9.8	10.8
		A	32	0.6	3.0	5.9	9.1
Sanding	V+A	8	3.5	-	-	10.2	
	A	8	1.6	-	-	2.9	

Since 2008, the application temperatures have been lowered to a maximum of 230 °C to protect the workers from inconveniences. From a work-safety perspective, low-temperature mastic asphalts are an ideal mean for protecting workers handling mastic asphalt (see also „Sachstandsbericht Gesprächskreis Bitumen 2007 / 2009“).

7.1.4 PAH exposures while handling mastic asphalt

In the course of the extensive measurements taken by BG BAU for vapours and aerosols of bitumen during the handling of mastic asphalt, PAH analyses were in certain instances also carried out, in which case two different measuring methods were used. With the standard BGIA method [Lit 1] of determining PAHs, the results for the overwhelming majority of the single PAHs were always below the limit of determination (“measured value < detection limit”) with the customary sampling times of approx. two hours. The results obtained by this method will not be explained in further detail.

It is not easy to clearly present the results for every single substance; for this reason the following tables show the sum of all specified PAHs and PASHs (SumPAH/PASH), the sum of the EPA PAHs (SumEPA-PAH), the sum of the PASHs (SumPASH) as well as the values for benzo(a)pyrene and naphthalene. Benzo(a)pyrene is frequently considered to be the lead substance for the PAH exposure. In the present measurements, naphthalene is usually the single substance with the highest measured values.

Of the 30 measurements taken, 23 were for mastic asphalt applied by hand and 7 for machine application. The samples were taken while stationary (4 sampling systems were used in parallel and analysed together), and also with moving persons. They were taken in the respiratory area of highly exposed workers (usually near the smoother or in the region of the paver). In all cases the measured value obtained was evaluated as the measuring result, without any conversion being made for exposure times, etc.

The 23 measurements for indoor manual application of conventional mastic asphalt have been split into two sub-groups of data collected. In 16 cases the measuring strategy is consistent with the general strategy of the BG-BAU measurements, i.e. an activity-related assessment is made. In 7 cases the measurement corresponds rather to a shift assessment – where the sampling process involved longer phases with waiting periods or other activities. The maximum exposures to vapours and aerosols of bitumen were just under 17 mg/m³ in the “activity-related” sub-group and just under 9 mg/m³ in the “shift-related” sub-group. The PASH exposures are summarised in Table Z_1.

Of the 7 measurements relating to outdoor manual application, 2 were for conventional mastic asphalt and 5 for application at reduced temperatures. The maximum exposures to vapours and aerosols of bitumen were just under 12 mg/m³ for both sub-groups. Due to the low number of cases, both sub-groups are evaluated together. The PASH exposures are summarised in Table Z_2.

Knecht et. al. (1999) reported of comparable PAH exposures at a construction site, where both conventional mastic asphalt and mastic asphalt at reduced temperatures were laid by hand in a house under identical conditions. The measured values obtained there are on a scale similar to the values in Table Z_1: SumPAH/PASH 12.000 µg/m³ (conventional) or 5.950 µg/m³ (reduced temperature); benzo(a)pyrene 0.420 µg/m³ (conventional) or 0.160 µg/m³ (reduced temperature).

Table Z_1:

Exposure to polycyclic aromatic hydrocarbons (PAHs) as well as sulphur-polycyclic aromatic hydrocarbons (PASH) in the case of indoor manual application of conventional mastic asphalt. A distinction is made between “activity-related” and “shift-related” measuring strategies. Measured values are shown in µg/m³ disregarding exposure times. The percentile values are not given for <10 measured values.

		Number	Min. value	50 percentile	95 percentile	Max. value
Activity-related	SumPAH/PASH	16	0.417	2.220	10.082	22.758
	SumEPA-PAK	16	0.366	2.084	8.498	18.448
	SumPASH	16	0.046	0.183	2.251	4.310
	Benzo(a)-pyrene	16	0.002	0.017	0.333	0.460
	Naphthalene	16	0.205	0.917	4.856	9.480
Shift-related	SumPAH/PASH	7	1.393	-	-	2.678
	SumEPA-PAK	7	1.219	-	-	2.201
	SumPASH	7	0.152	-	-	0.502
	Benzo(a)-pyrene	7	0.006	-	-	0.081
	Naphthalene	7	0.172	-	-	1.011

All measurements are around the factor 10 to 100 below the existing international limits for polycyclic aromatic hydrocarbons!

Table Z_2:

Exposure to polycyclic aromatic hydrocarbons (PAHs) as well as sulphur-polycyclic aromatic hydrocarbons (PASH) in the case of outdoor application of mastic asphalt by machine. Measured values are shown in $\mu\text{g}/\text{m}^3$ disregarding exposure times. The percentile values are not given for <10 measured values.

	Number	Min. value	50 percentile	95 percentile	Max. value
SumPAH/PASH	7	2.723	-	-	15.145
SumEPA-PAK	7	2.245	-	-	10.707
SumPASH	7	0.151	-	-	5.526
Benzo(a)-pyrene	7	0.024	-	-	0.453
Naphthalene	7	0.664	-	-	2.360

7.1.5 IARC monograph

Since October 2011 mastic asphalt has been classified under 2B (possibly carcinogenic to humans) according to the IARC monograph no. 103 «Bitumen and bitumen emissions, and some heterocyclic polycyclic aromatic hydrocarbons» (ref. 2011/HSE Committee/035).

Examples for Group 2B: Coffee, Gasoline, Coconut Oil Diethanolamine Condensate.

8. Summary and Conclusions

Workplace exposure measurements are susceptible to variability in magnitude and constituent from a variety of potential confounders, some of which may be introduced in the manufacturing process, others through applications technologies and still others which may pre-exist in the ambient environment. As a result, reported values of exposures over time, between studies, and between the various countries must be considered carefully before use in development of dose-response relationships or potential risk estimates. More research is useful to develop a valid and inexpensive method of assessing exposures. An international standard for such measurements would be helpful to the scientific communities evaluation of bitumen fume exposures.

ⁱ *Bitumens and Bitumen Derivatives, Report 92/104, CONCAWE*

ⁱⁱ *Vapours and Aerosols of Bitumen: Exposure Data obtained by the German Bitumen Forum, Rühl R, Musanke U, Kolmsee K, Priess R, Zoubek G, Breuer D, Ann Occup Hyg. 2006 Feb 24; [Epub ahead of print]*

ⁱⁱⁱ *Air Sampling Methodology for Asphalt Fume in Asphalt Production and Asphalt Roofing manufacturing Facilities: Total Particulate Sampler versus Inhalable Particulate Sampler; Calzavara T, Carter C, Axten C, Appl Occup & Env Hygiene, 18(5) 358-367 (2003)*

^{iv} *Statistical modelling of the determinants of historical exposure to bitumen and polycyclic aromatic hydrocarbons among paving workers, Burstyn I, Kromhout H, Kauppinen T, Heikkila P, Boffetta P, Ann Occup Hyg. 2000 Jan;44(1):43-56.*

^v *International studies to compare methods for personal sampling of bitumen fumes, L. Ekström, A. Kriech, C. Bowen, S. Johnson and D. Breuer, J. Environ. Monit., 2001, 3, 439-445*

^{vi} *Characterizing worker exposure to bitumen during hot mix paving and asphalt mixing operations, Burstyn I, Ferrari P, Wegh H, Heederik D, Kromhout H, AIHA 2002 63(3):293-9.*

^{vii} *Literature Review of Levels and Determinants of Exposure to Potential Carcinogens and other Agents in the Road Construction Industry, Igor Burstyn, Hans Kromhout, Paolo Boffetta, American Industrial Hygiene Assoc. Journal 61:715–726 (2000)*

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