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The Mastic Asphalt Industry – an European Perspective

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Content

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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

The most relevant standards for mastic asphalt applications in the European market are:

- EN 13108
- EN 13318
- EN 12970 (year 2000, not harmonised)

2. Fields of application

2.1 Bridge decks

Bridge deck pavements must comply with a large number of conditions, as: waterproofing, stability against deformation, rugosity, smoothness, aging, etc. The waterproofing layers 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 or steel, it must be protected against the effects of de-icing salt and 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 asphalt mastic (AM), EPDM or liquid resin system.

2.2 Flooring (building)

In some European countries mastic asphalt is used as a floating screed in private and public buildings. So, this type of screed is installed directly or with thermal insulation, 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 easy to install
- 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 non-flammable (classification B_{fl} – s1 according to EN 13501-1)
- does not require special cleaning measures and is easily cleaned with water 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.). In case of floor heating the thickness of the mastic asphalt screed 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.

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 22 to 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.

Special chipping with coarse aggregates (for example 2/3 mm or 3/4 mm) are used for noise reduction purposes. Besides the grain size, also the grain form and the incorporation of the chippings in the mastic asphalt surface are relevant for the noise reduction.

Furthermore mastic asphalt paving proofed 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 system is characterized as follows:

- a waterproofing layer
- one or two layers of mastic asphalt

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. 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, thanks to the root-resistant characteristics of mastic asphalt.

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 traditional spreading machines are not authorized due to their large proper weight. 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 placing 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.

2.7 Flat roofing

Mastic asphalt and asphalt mastic are 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 skirted round pipes, roof lights and other projections. In the UK, additionally, the roofs have vertical asphalt mastic 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.

Also used in flat roofing systems, mastic asphalt is non-flammable: B_{roof} – t3 according EN 13501-5.

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 used in Europe since 1890.

The European main markets are Germany and France. Mastic asphalt is practically not used in the USA. Recently, the mastic asphalt markets in Asia began to grow. Chinese companies became member of the IMAA in 2014, 2015 and 2018.

The total production level by IMAA members during the last years can be described as follows:

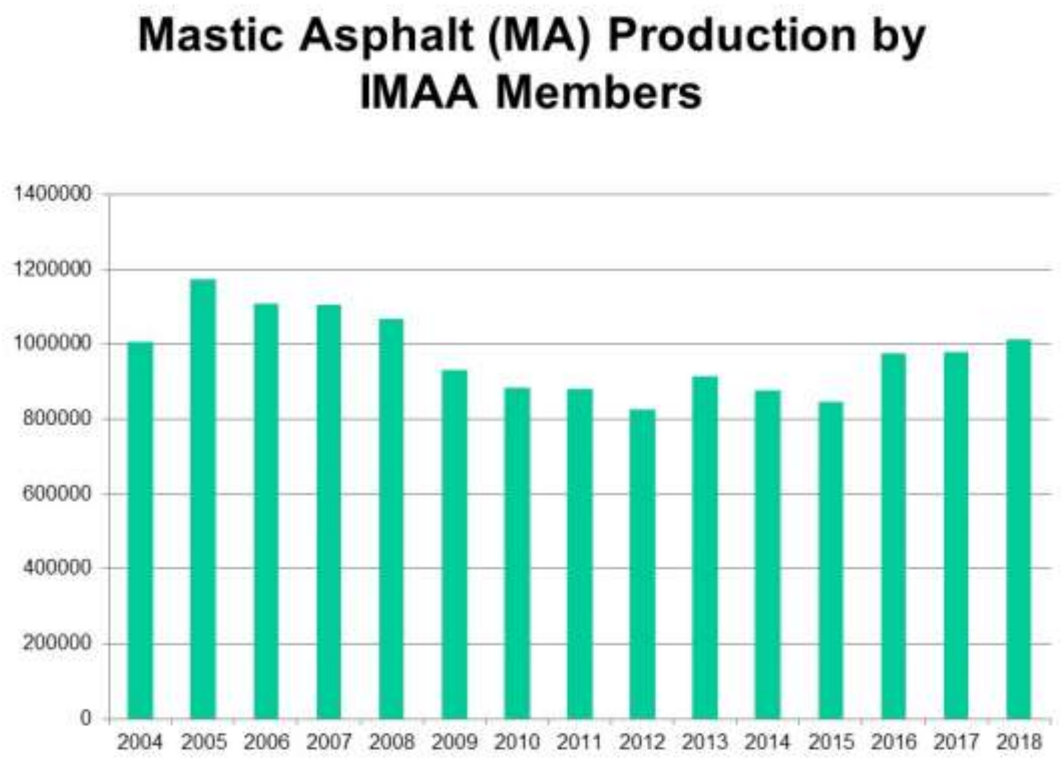

Figure 1: Mastic asphalt production by IMAA members

<u>Remarks:</u>
2004: Russia entered
2014: First Chinese firm entered

The following graphic shows the mastic asphalt application areas for the reference year 2019:

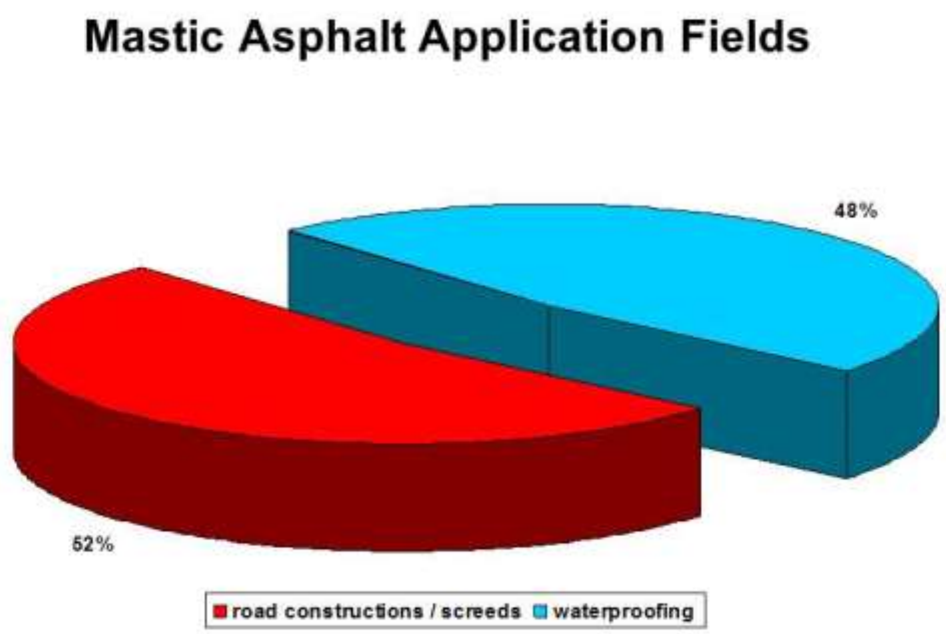

Figure 2: Mastic Asphalt Application Fields for the reference year 2019

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 high production rates could not 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 long past, mastic asphalt production temperatures were in the range of 230ºC to 270ºC. However in the recent years considerable research and investments have been done to lower these temperatures beneath 230ºC – in some countries even below 200°C.

Today, there exist three different kinds of mastic asphalt production methods:

1. Mixing plants for hot rolled asphalt where the mastic asphalt is pre-mixed, with re-mixing in transport cookers.
2. Mastic asphalt production plants where the mastic asphalt gets its final production in the production plant itself in stationary re-mixing installations which are separately operated.
3. In special cases: Production of mastic asphalt in mobile cookers.

Figure 3: Today, the majority of the mastic asphalt production plants is housed.

The minerals (sand, limestone fine aggregates and coarse aggregates) are dried and 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).

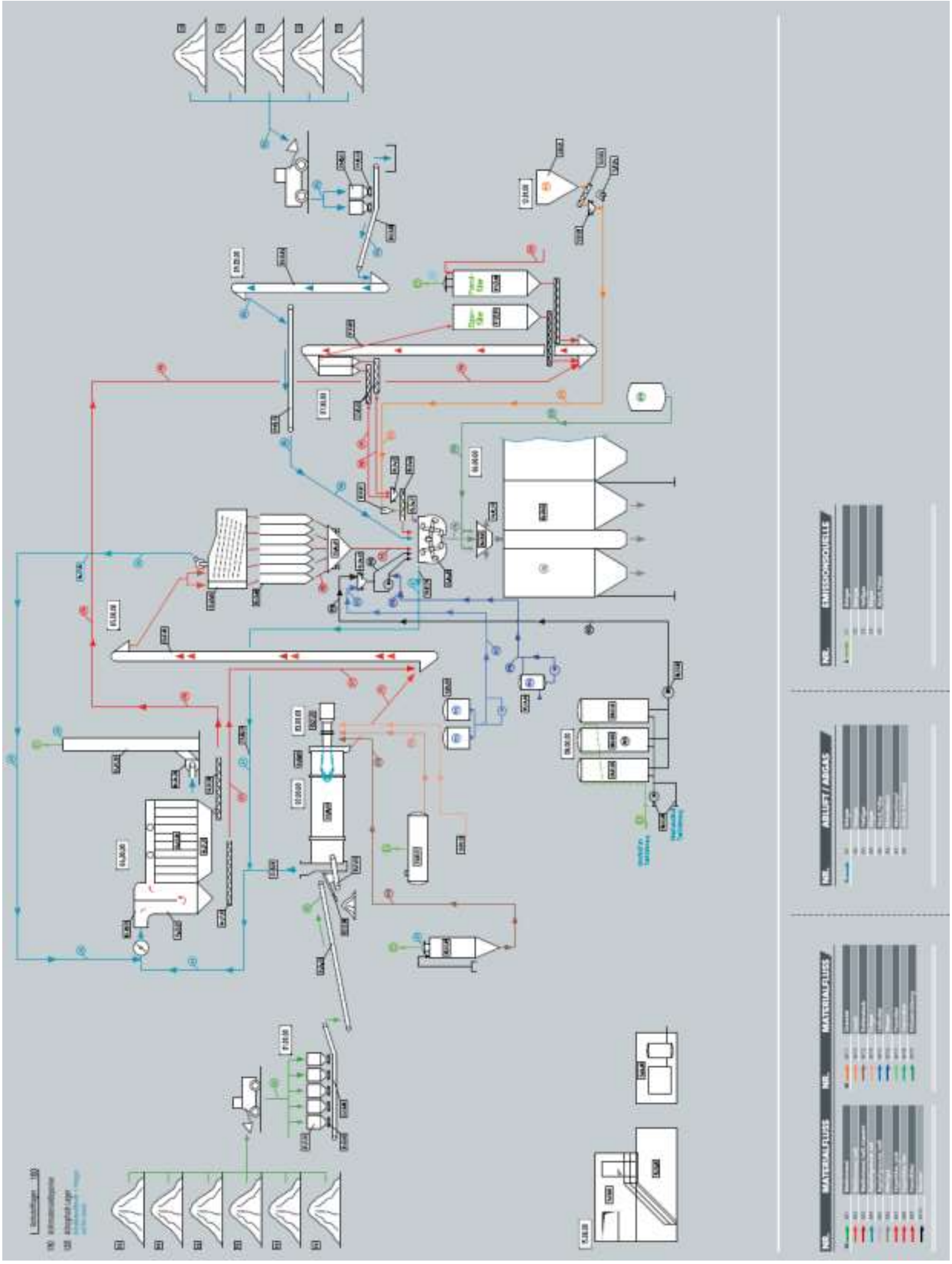

Figure 4: Scheme of a mastic asphalt production plant with filler heating.

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 (in Europe 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 penetration (0,1 mm).

4.2.1.2 Polymer modified bitumen (in Europe complying with EN 14023)

It is an industrially produced bitumen, ready for use, which is modified with polymers and which is continuously mixed in the production plant in special conditioned tanks with stirring devices or with a circulation pump.

4.2.1.3 Hard grade industrial bitumen (in Europe complying with EN 13305) and Hard paving grade bitumen (in Europe 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 ≤ +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.**

4.2.1.4 Synthetic pigmentable binder

A synthetic pigmentable binder is a synthetic binder, which is easily pigmentable. With this kind of binder a small amount of pigment may be added 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 (in Europe 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, Selenizza and others. They are not refined bitumens.

In some cases so-called «natural asphalt» has been added for many decades in different quantities. 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 material 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

Other additives are aimed at influencing viscosity and/or the stability of the mastic asphalt. 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 is kept as low as possible, these additives can thus also provide the same workability at a lower temperature of the mastic asphalt mixture.

For example: Montan waxes, Fischer-Tropsch paraffin and fatty acid amides.

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.
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 4.2.1.4).

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 (according EN 13043). 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 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°C 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 and crushed sand. To increase the stability of mastic asphalt a mixture of natural sand and crushed sand is necessary. 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 Coarse aggregates

There is a basic sieve-set and two additional sieve-sets in the standard, with different combinations from country to country.

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

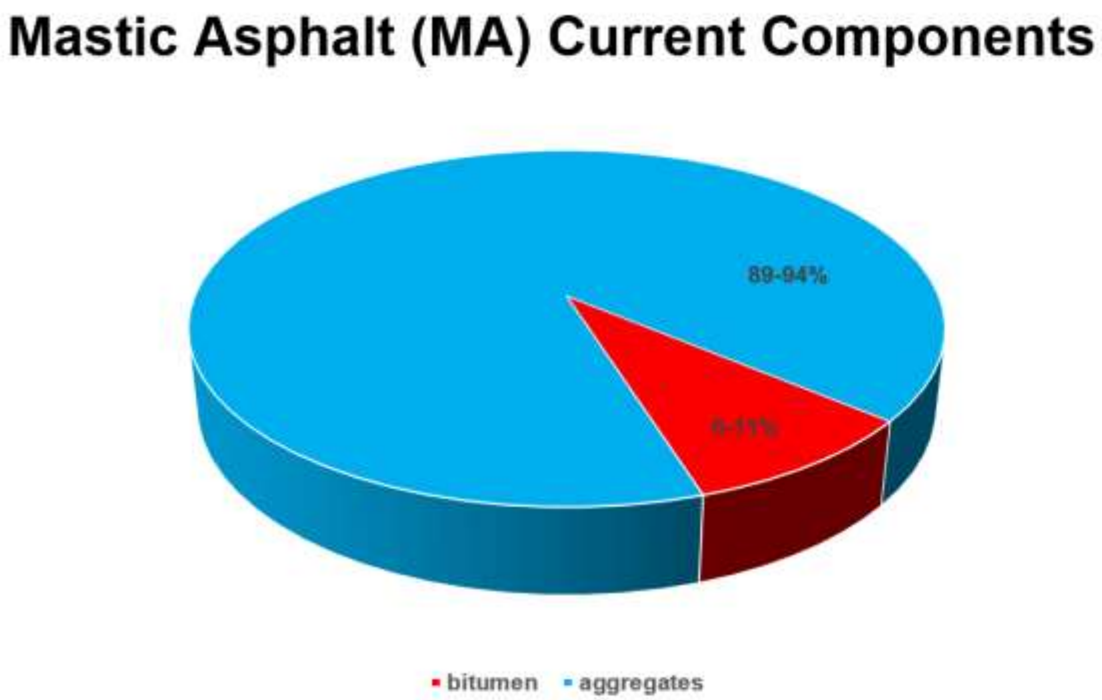

Figure 5: Mastic Asphalt Current Components (Schematic Diagram)

5. Transport

After production the mastic asphalt is transported to the processing location in mastic asphalt transport mixers, developed specially for that purpose. It is of high importance that the filler caps of the mastic asphalt transportation cookers are as hermetically closed as possible. When it is not, the oxygen supply leads to a hardening of the binder. The transport mixers are mounted on a truck or chassis of a trailer and provided with:

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

Figure 6: Mastic asphalt mixer for transportation with horizontal mixing system.

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

The purpose of these cookers is to maintain the temperature of the mastic asphalt mixture (if necessary, to even heat it a little) and to prevent separation (homogeneity must be maintained). The time during which the mastic asphalt is remaining in the cooker may change the quality of the mastic asphalt.

Transportation can take place under normal circumstances, as long as a number of parameters (for example time, temperature, hydraulic pressure of the stirring devices and homogeneity) are respected (registered in protocols in many countries).

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.

Figure 7: 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 14 m without longitudinal joints. There are also smaller mechanical pavers that can lay smaller widths (e.g., 30 cm) in great lengths.

Figure 8: 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, pre-coated with bitumen (fine aggregates need more bitumen [0.5 to 0.7 mass-%], coarse aggregates need less bitumen [0.3 to 0.5 mass-%]), 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°C 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 application fields even below 200°C – it is generally assumed that 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 CO_2 production and emissions
- minimizing ageing of binders during production and application

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 and sidewalk constructions:	165ºC to 200ºC
Screeds in building constructions:	200ºC to 230ºC
Waterproofing (A) bridge decks (machine laid):	180ºC to 200ºC
Waterproofing (B) parking decks (hand laid):	200ºC to 230ºC

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.

6.5 Application protocol

It is recommended to establish during the mastic asphalt application process an application protocol which should describe the following parameters for example:

- date
- site
- origin of the mastic asphalt
- type and kind of the mastic asphalt, recipe code
- kind of the binder, type of the binder
- used machines and working craft
- weather
- location of the application (day's stage), application time, applied quantity
- temperature of the mixture and of the underground (subbase) on the site (location, time)
- taking mastic asphalt to produce laboratory test cubes (location, time)
- special notices as for example interruptions during the application or during the production, directives given by the builder-owner, changes concerning the used machines

7. Occupational exposure

7.1 Exposure Monitoring of bitumen emissions

7.1.1 Bitumen emissions defined

In order to better interpret the meaning of different exposure monitoring results it is important to understand what constitutes bitumen emissions and how they are 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 emissions 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 [1,2] 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 emission 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 emissions is shown in figure 9.

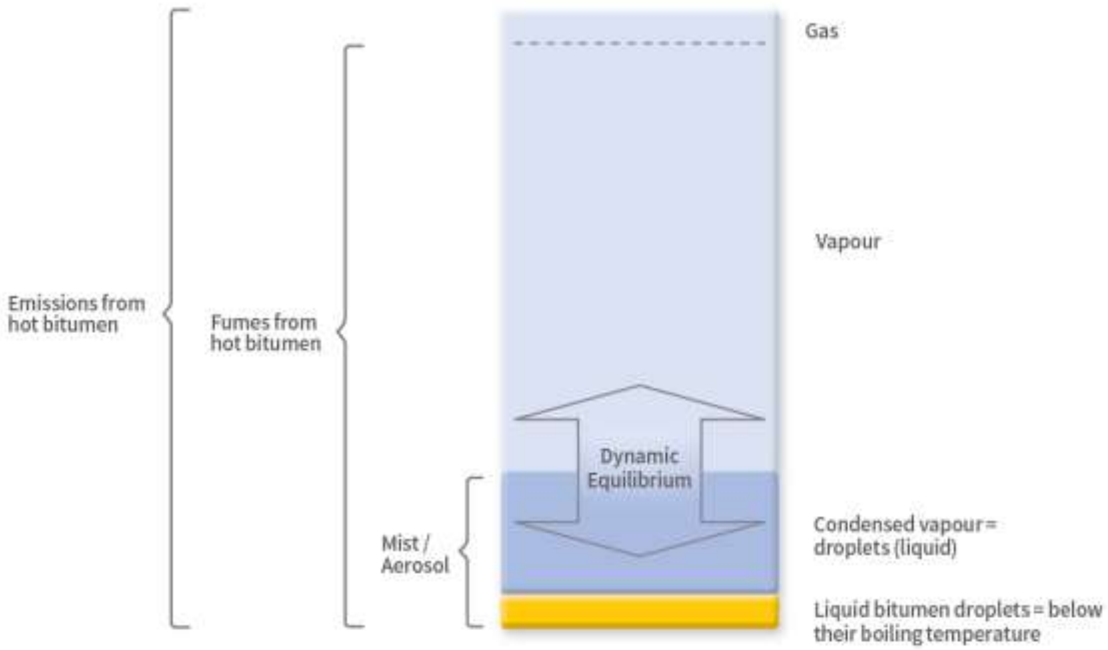

Figure 9: Schematic diagram of bitumen emissions composition [3].

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. [4] Numerous sampling and analytical methods have been and continue to be employed in the characterization of workplace exposures to emissions 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 emissions from bitumen and vapour from bitumen could be established. [5] However, it was shown that the concentrations of aerosols from bitumen measured by the American and the German methods are comparable [6].

7.1.2 Occupational Exposure Monitoring for bitumen emissions

Occupational exposure to from bitumen emissions 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 [7]. 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 emissions 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 emissions 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. [8,9]

Figure 10 gives an overview of important 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.

Figure 10: Factors affecting the outcome of exposure monitoring.

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 bitumen emissions some studies have evaluated exposure to individual, or groups of Polycyclic Aromatic Hydrocarbons (PAH) as components of bitumen emissions. 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 the handling (transport and application) of bitumen used in mastic asphalt

Because bitumen is used as the binder in mastic asphalt, workers are also exposed to bitumen vapours and aerosols during the application of mastic asphalt.

In the European and also international mastic asphalt industry different measuring methods are used (e.g. type of measurement and measurement time periods).

The exposures described below (summaries of German test series published in the IARC monograph no. 103 «Bitumen and bitumen emissions, and some heterocyclic polycyclic aromatic hydrocarbons») were determined on the basis of predominantly person-related workplace measurements during the handling of hot bitumen. These tests measured the emissions of vapours and aerosols from bitumen during hot processing. The measuring process records all organic substances with aliphatic C-H bonds [10] and therefore also any other substances, such as emissions from combustion engines (e.g. unburned fuel).

These measurement data are mostly activity-related exposure data; site change, conversions or other non-exposure times are not taken into account. In practice, activities of this kind can last throughout the shift (the activity value then equals the shift value). In the summer, activities can be significantly longer than eight hours (then shift value = activity value x exposure duration / 8). Particularly on construction sites, worker exposure is, however, frequently less than 8 hours. The shift value is then sometimes significantly lower than the activity value.

In the Human Bitumen Study the exposure was measured during the shift to enable a comparison with the biological data. The measuring pump was therefore also in operation during non-exposure times. From this, a shift exposure of 3,46 mg/m³ (median concentration) was determined for mastic asphalt workers [10]. This value is significantly lower than the activity values acquired at that time. Up until 2008 mastic asphalt was applied at temperatures of up to 250°C, the measurements for the Human Bitumen Study were carried out between 2001 and 2008. The activity values acquired at that time were up to 57.8 mg/m³ (charger on mixer, application of mastic asphalt by machine) and 34.0 mg/m³ (spreader, manual application of mastic asphalt).

The exposure data for mastic asphalt workers relate to the max. laying temperatures of 230°C that were stipulated in 2008 [10].

In the following, exposure data are given as well as basic explanations on the series of tests and techniques applied. The respective current data as well as additional information can be found under https://www.bgbau.de/die-bg-bau/ueber-uns/netzwerk-und-kooperationen/gespraechskreis-bitumen/expositionsbeschreibungen/.

41 measurements were carried out in the area of construction sites where there was no hot processing of bitumen (Figure 11). In this way, it is possible to assess the influence of road traffic on the results of the exposure measurements during asphalt paving, for example.

	Measurements	Minimum value	50 percentile	95 percentile	Maximum value
Outdoors	40	0.07	0.30	1.72	2.30
In tunnels	1	5.60			

Figure 11: Exposure in the non-contaminated area of construction sites (mg/m³ vapours and aerosols from bitumen)

Determination of shift-related exposure from the activity values.

Using the activity-related exposure values given in Figure 11 it is possible to determine the shift values for any shift where there is exposure to hot bitumen vapours and aerosols. Based on the formula = ∑ (Exposure (mg/m³) / duration (h)) the duration and the levels of exposure in the individual activities are added.

Laying of mastic asphalt

In the past, the processing of mastic asphalt at temperatures of up to 250°C led to exposure values that were around 3 to 5 times higher than those determined in rolled asphalt paving (up to 60 mg/m³). Since 2008, in Germany mastic asphalt is processed and applied with viscosity-modifying additives or viscosity-modified binders at a max. temperature of 230°C. Here the exposure to vapours and aerosols from bitumen is in a comparable order of magnitude to the exposure during the processing of rolled asphalt.

Many other countries (e.g. France, Switzerland, Belgium, The Netherlands) are also making efforts to lower the processing temperatures and have already achieved very good results in recent years.

For the laying of viscosity-modified mastic asphalt by machine, a reduction in exposure has been substantiated through adequate measurement data (Figure 12). In the manual application process many companies are still somewhat cautious and the viscosity-modified mastic asphalt is often applied at temperatures of just over 230°C. But even then, the exposure is still well under the exposure values of conventional application methods. Due to organisational reasons, few measurements have been carried during manual application at under 230°C.

Figure 12: Exposure to vapours and aerosols from bitumen during machine application of mastic asphalt with viscosity-modifying additives or viscosity-modified binders at temperatures of up to 230°C

Outdoors	Number	Minimum value	50 percentile	**95 percentile**	Max. value
Charger	43	0.3	2.4	**7.7**	12.0
Screed operator	57	0.3	2.9	**9.0**	11.9
Reworking	43	0.3	0.3	**2.9**	5.8

Figure 13: Exposure to vapours and aerosols from bitumen during manual application of mastic asphalt with viscosity-modifying additives or viscosity-modified binders at temperatures of up to 230°C

	Number	Min. value	50 percentile	95 percentile	Max. value
Outdoors					
Charger	1	-	-	-	0.3
Wheelbarrow transport	1	-	-	-	1.0
Smoothing	3	0.5	-	-	1.0
Indoors					
Charging	3	0.5	-	-	8.6
Bucket transport	2	2.3	-	-	7.3
Wheelbarrow transport	1	-	-	-	3.6
Smoothing	7	1.9	-	-	9.5

Figure 14: Exposure to vapours and aerosols from bitumen during manual application of viscosity-modified mastic asphalt at laying temperatures above 230°C

	Number	Min.	50 percentile	**95 percentile**	Max. value
Indoors					
Charging	24	2.0	5.1	**11.5**	12.8
Smoothing	25	0.6	5.4	**10.0**	10.8
Sanding	8	3.5	-	**-**	10.2

7.1.4 PAH exposure while handling (transport and application) bitumen used in mastic asphalt

The content of Benzo[a]pyrene (BaP) of the bitumen grades used in Germany is between 1.2 and 2.7 mg/kg BaP [11]. This is less than ten percent of the substance-specific limit of 100 mg/kg BaP for the classification as carcinogenic, according to the REGULATION (EC) No 1272/2008 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 16 December 2008 on classification, labelling and packaging of substances and mixtures, amending and repealing Directives 67/548/EEC and 1999/45/EC, and amending Regulation (EC) No 1907/2006.

In the first measurements carried out at the end of the 90's, besides measuring vapours and aerosols from bitumen, different PAHs were measured as well. However, the common measuring and analysing method of the accident insurer institutes at that time nearly always delivered values that were under the detection limit. For this reason, PAH values were no longer determined in Germany at that time.

Then, after around 2009, PAH measurements recommenced on German construction sites. The analysis was carried out at an external laboratory. Since 2012 the analysis has been carried out using a more sensitive method, and once again at the Institut für Arbeitssicherheit (IFA) (Institute for Safety and Health Protection at Work) of DGUV (German Social Accident Insurance). Sampling is mostly carried out with several pumps operating in parallel in order to acquire a sufficient amount of PAH on the filters. Stationary measurements are taken at a place in the column where there is likely to be a higher exposure. In rolled asphalt paving this is on the paver, in manual mastic asphalt application in the proximity of the charger.

Figure 15: Concentrations of polycyclic aromatic hydrocarbons from area sampling at construction sites with and without bitumen application in the Human Bitumen Study [10]

	Bitumen application				
ng/m^3	N	$N_{<LOQ}$[a]	Min	Median	Max
EPA PAHs (with coelution)[b]	15	-	1256	2473	18448
EPA PAHs (without coelution)[c]	15	-	789	2318	16759
cPAHs (with coelution)[d]	15	-	42.5	376.5	2906.0
cPAHs (without coleution)[e]	15	-	16.5	107.0	1217.0
EPA PAHs					
Naphthalene	15	0	172.0	1010.0	9480.0
Phenanthrene	15	0	95.4	267.0	1441.0
Fluorene	15	0	67.3	183.0	1019.0
Acenaphthene	15	0	31.0	75.4	839.0
Pyrene	15	0	26.6	95.4	1017.0
Anthracene	15	0	16.0	46.0	502.0
Acenaphthylene	15	0	17.5	49.0	642.0
Fluoranthene	15	0	23.0	58.2	505.0
Benzo[*ghi*]perylene	15	0	7.2	45.4	301.0
Chrysene coeluted with triphenylene	15	0	17.0	221.0	1222.0
Benzo[*b,j,k*]fluoranthene	15	0	9.0	69.0	467.0
Benzo[*a*]anthracene	15	0	4.0	48.0	519.0
Benzo[*a*]pyrene	15	0	6.0	45.0	460.0
Dibenzo[*a,h*]anthracene	15	1	<LOQ	17.0	118.0
Indeno[1,2,3-*cd*]pyrene	15	0	1.5	11.5	120.0
Other compounds					
Benzo[*e*]pyrene	5	0	23.0	99.0	223.0
1-Benzothiophene	15	0	8.7	81.0	2610.0
Dibenzothiophene	15	0	24.5	120.0	1290.0
Benzo[*b*]naphtho[2,1-*d*]thiophene	15	0	11.0	171.0	888.0

cPAHs: carcinogenic PAHs comprising benzo[a]anthracene, benzo[a]pyrene, dibenzo[a,h]anthracene and indeno[1,2,3-cd]pyrene [12]

[a] $N_{<LOQ}$, number of measurements below limit of quantitation (LOQ)
[b] Sum of U.S. EPA PAHs including compounds with coelution (naphthalene, acenaphthene, acenaphthylene, phenanthrene, fluorene, anthracene, fluoranthene, pyrene, benzo[*a*]anthracene, chrysene coeluted with triphenylene, benzo[*b,j,k*]fluoranthene, benzo[*a*]pyrene, dibenz[*a,h*]anthracene, indeno[1,2,3-*cd*]pyrene, benzo[*ghi*]perylene)
[c] Sum of U.S. EPA PAHs without benzo[*b,j,k*]fluoranthene and chrysene coeluted with triphenylene
[d] Sum of carcinogenic PAHs including compounds with coelution (benzo[*a*]anthracene, chrysene coeluted with triphenylene, benzo[*b,j,k*]fluoranthene, benzo[*a*]pyrene, dibenz[*a,h*]anthracene, indeno[1,2,3-*cd*]pyrene)
[e] Sum of carcinogenic PAHs without chrysene coeluted with triphenylene and benzo[*b,j,k*]fluoranthene

Summary

Exposure to bitumen vapours and aerosols when handling hot bitumen primarily depends on the working method and the processing temperature. Besides this, frequent high variations in the wind conditions have a significant influence (general climatic influences). For this reason, the spread of the values in the individual activities is often quite large.

Most exposures given in the tables are activity-related measurements, whereby with mastic asphalt in particular, the activities may last over the length of a shift (in the summer months in road construction work also longer).

Whereas under the common temperatures in conventional rolled asphalt paving (around 160°C) it is mostly vapours that are prevalent, in earlier conventional mastic asphalt applications (at around 250°C) the aerosols were the main determinants of exposure (Fig. 16). For this reason, in Germany the sum of vapours and aerosols from bitumen are now determined, and, wherever possible also the concentration of EPA-PAHs.

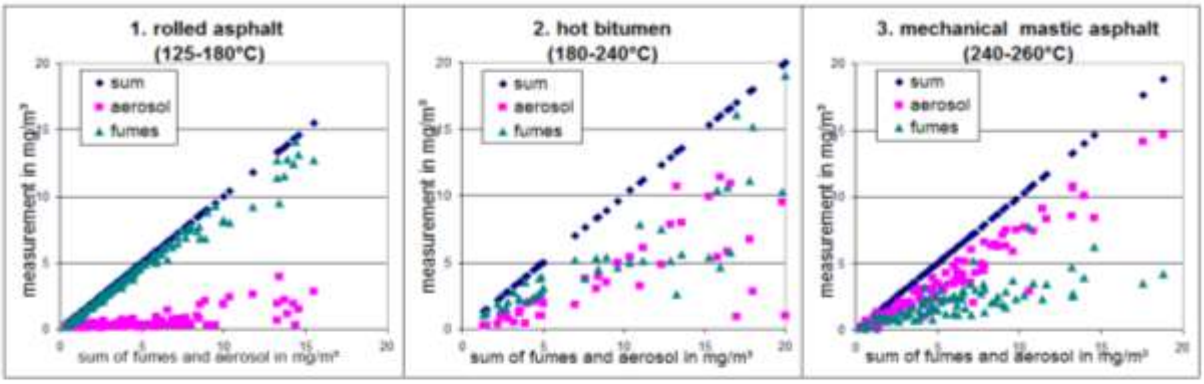

Figure 16: Distribution of bitumen vapours and aerosols according to application temperature [13]

7.1.5 IARC monograph

Since October 2011 the bitumen used in 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».

Cancer

As reviewed in the prior sections, crude oil contains polycyclic aromatic hydrocarbons, some of which are carcinogenic. While most PAHs segregate into other petroleum streams during the refining processes, relatively low concentrations of residual PAHs occur in bitumens. As a result, bitumens have been studied for cancer potential.

Published data suggests that bitumen does not present a cancer hazard. The low levels of PAHs in bitumen are not readily bioavailable and human exposure to PAHs from handling of the bitumen substance is very low. The principal occupational exposure during handling and application of hot bitumen is to its emissions.

A recent review of cancer potential to humans from occupational exposure to bitumen emissions was conducted by the International Agency for Research on Cancer (IARC) in 2011 and published in 2013. The overall evaluation of cancer potential to humans was based on consideration of cancer findings in humans, cancer studies in experimental animals and mechanistic and other relevant data. In that review, IARC noted the potential influence of solvents and temperature on carcinogenic potential.

IARC observed that there were no consistent increases in cancer in either the occupation of paving or in animal studies with paving bitumens, or emissions (see also Clark et al., 2011). Limited evidence was observed for cancer associated with the occupations of roofing and mastic asphalt. No animal data are available for mastic asphalts. Animal studies of Asphalt Fume Condensate (AFC) from a specific type of roofing bitumen, Type III BURA, resulted in evidence of cancer potential to mouse skin.

The overall conclusions are summarised in the table below.

Figure 17: Summary of IARC Evaluation

Occupational Sector	Bitumen Type/Class	Overall Evaluation
Paving	Straight-run bitumens	Occupational exposures to straight-run bitumens and their emissions during road paving are possibly carcinogenic to humans (Group 2B)
Roofing	Oxidised bitumens	Occupational exposures to oxidised bitumens and their emissions during roofing are probably carcinogenic to humans (Group 2A)
Mastic	Hard bitumens	Occupational exposures to hard bitumens and their emissions during mastic-asphalt work are possibly carcinogenic to humans (Group 2B).

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 emissions exposures.

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.

9. Glossary

This glossary represents a consolidated collection of terms used in the mastic asphalt industry. Not all of the terms listed below are used in this document, but are common expressions used in the mastic asphalt supply chain.

AIR-RECTIFIED BITUMEN
(Synonym **SEMI-BLOWN BITUMEN**)
A bitumen that has been subjected to mild oxidation with the goal of producing a bitumen meeting paving grade bitumen specifications. Air rectified bitumens are functionally the same as straight-run bitumens. Air rectified bitumens are used in paving applications as well as selected roofing applications, such as shingle saturants and Type 1 Built Up Roofing Asphalt (BURA), and also for some industrial applications. **AIR-RECTIFIED BITUMENS** have a **PENETRATION INDEX** (PI) ≤+2.0.

ASPHALT
A mixture of **BITUMEN** and mineral materials used as a paving material that is typically produced at temperatures in the range of 140-160°C (280-320°F). In North America the term **ASPHALT** is synonymous with **BITUMEN** as used in Europe and also the term **HOT MIX ASPHALT**.

ASPHALTENES
Highly polar aromatic materials. Asphaltenes have high viscosity or stiffness at ambient temperatures and are responsible for the overall stiffness of **BITUMENS**. They can be precipitated with n-heptane and are sometimes referred to as n-heptane insolubles.

ASPHALT MASTIC
A term of art in asphalt mixture technology referring to the combination of bitumen and the fine mineral portion of the aggregate generally comprised of mineral matter finer than 150 μm.

ASPHALT MIXES (MIXTURES)
Mixtures of graded mineral aggregates (sized stone fractions, sands and fillers) with a controlled amount of **BITUMEN**.

ATMOSPHERIC DISTILLATION
Distillation at atmospheric pressure.

ATMOSPHERIC RESIDUUM
Residuum of **ATMOSPHERIC DISTILLATION** of **CRUDE OIL**.

BINDER
According to EN12597; Material serving to adhere to aggregate and ensure cohesion of the mixture. A more general term used to identify **BITUMEN** plus potential modifiers used to produce **ASPHALT** mixes. The term BINDER reflects that some **ASPHALT** mixes may utilise **MODIFIED BITUMENS**.

BITUMEN, PETROLEUM DERIVED
A dark brown to black cement-like residuum obtained from the distillation of suitable **CRUDE OILS**. The distillation processes may involve one or more of the following: atmospheric distillation, vacuum distillation, steam distillation. Further processing of distillation residuum may be needed to yield a material whose physical properties are suitable for commercial applications. These additional processes can involve air oxidation, solvent stripping or blending of residua of different stiffness characteristics.

BITUMEN EMISSIONS
The complex mixture of aerosols, vapours and gases from heated **BITUMEN** and products containing bitumen; although the term **„BITUMEN FUME“** is often used in reference to total emissions, technically bitumen fume does not include gases (i.e. solid particulate matter, aerosols and vapour).

BITUMEN EMISSIONS (FUME) CONDENSATE see also **ASPHALT FUME CONDENSATE**
The condensate of emissions from heated **BITUMEN**; the chemical composition may vary with the temperature any type of bitumen. It typically has a boiling range similar to kerosene.

BITUMEN EXTRACT
The fraction of **BITUMEN** that is soluble in organic solvents, such as benzene, toluene, carbon disulphide, or dimethyl sulphoxide.

BITUMEN FUME
The complex mixture of vapours and aerosols emitted from heated **BITUMEN**.

BITUMEN GRADING TERMINOLOGY
There are currently three main grading systems employed world-wide for identifying and specifying **BITUMENS** used in road construction.
These systems are **PENETRATION**, **VISCOSITY** and **PERFORMANCE GRADED**. Although each system has test methods that are unique to that system, similar **BITUMENS** are used across all grading systems. The particular system used within a given country or region is generally a result of historical practices or governmental stipulations.

BITUMEN VAPOUR
Refers to vapours which can include gases from heated **BITUMEN.**

BITUMINOUS
Of or related to **BITUMEN**. In this document the terms **BITUMEN** and **BITUMINOUS** refer exclusively to petroleum derived **BITUMEN** as defined above.

BLENDED BITUMENS
Blends of two or more **BITUMENS** with different physical characteristics or blends of **BITUMEN**(s).

CAS REGISTRY
A large database of chemical substance information in the world containing more than 29 million organic and inorganic substances and 57 million sequences. http://www.cas.org/

CAS REGISTRY NUMBER
A number is assigned to a substance when it enters the **CAS REGISTRY** database.

COAL TAR
A dark brown to black, highly aromatic material manufactured during the high-temperature carbonization of bituminous coals which differs from bitumen substantially in composition and physical characteristics. It has previously been used in the roofing and paving industries as an alternative to **BITUMEN**.

COLOURED MINERAL GRANULES
Natural or factory coloured minerals used as light surface protection for bitumen membranes or **BITUMEN** shingles.

CRUDE OIL
A naturally-occurring mixture, consisting predominantly of hydrocarbons but also containing sulphur, nitrogen or oxygen derivatives of hydrocarbons, which can be removed from the earth in a liquid state.

CYCLICS (NAPHTHENE AROMATICS)
Compounds with aromatic and naphthenic nuclei with side chain constituents. They are viscous liquids and represent a significant proportion of the dispersion medium for the **ASPHALTENES** and adsorbed resins in **BITUMEN**.

DYNAMIC SHEAR RHEOMETER
A testing device used to determine the stiffness of **BITUMENS** over a range of temperatures and test frequencies. Typically a standard amount of **BITUMEN** (25 mm in diameter by 1 mm in thickness) tested between two flat plates (25 mm in diameter). An oscillatory stress or strain of known value is applied to the **BITUMEN** sample and the resultant strain or stress is measured. From these data the stiffness of the **BITUMEN** is calculated. The stiffness results are part of the specification within the **PERFORMANCE GRADED** system of specifications.

ELASTOMER
A polymeric substance (natural or synthetic) which when stretched to a length that is less than its point of rupture and released will recovery substantially to its originally length. Examples are vulcanised natural rubber, styrene butadiene latex rubber, styrene butadiene styrene block copolymer.

EQUIVISCOUS TEMPERATURE (EVT)
The temperature at which **BITUMEN** has a viscosity that is optimum for application.

FILLER (Paving)
Fine mineral matter employed to give body to a **BITUMINOUS BINDER** or to fill the voids between aggregate particles.

FLASHPOINT
The temperature at which a combustible vapour forms above the surface of **BITUMEN** in a specific test method. Methods used for **ROOFING BITUMEN** products are EN ISO 2592 or ASTM D92 for Open Cup Flashpoint and EN ISO 2719 or ASTM D93 for Closed Cup Flashpoint.

FOREMAN
Supervises a crew or a particular operation in the placement and compaction process of **ASPHALT**.

GAS OIL
A liquid petroleum distillate with a viscosity and boiling-range between those of **KEROSENE** and lubricating oil.

GILSONITE
A natural, resinous hydrocarbon found in the north eastern Utah, USA.

GLASS MAT OR FELT
A non-woven mat made with short glass fibers adhered together with a resin and suitable for coating and impregnation with **BITUMEN** for roofing products.

HARD BITUMEN
A rheologically stiff bitumen possessing low penetration value and high softening-point. These are used in the manufacture of high modulus **ASPHALT MIXTURES.**

LAKE ASPHALT
Most common form of **NATURAL ASPHALT**, occurring in Trinidad.

MALTENES
Relatively low molecular weight oily fraction of bitumen. The maltenes are believed to dissolve, or disperse the **ASPHALTENES** in the colloidal structure of bitumen. They are the n-heptane soluble fraction of bitumen.

MASTIC ASPHALT
MASTIC ASPHALT (MA) is a voidless asphalt mixture with **BITUMEN** as a **BINDER** in which the volume of the filler and binder exceeds the volume of remaining voids (see EN 13108-6).

MINERAL AGGREGATE
A combination of stone fractions and **FILLER**

MODIFIED BITUMENS
BITUMINOUS BINDER whose rheological properties have been modified during manufacture by the use of one or more chemical agents.

THE MULTIPLE STRESS CREEP RECOVERY (MSCR) PROCEDURE
A rheological test performed on a **DYNAMIC SHEAR RHEOMETER** (DSR) to determine the non-recoverable compliance of a **BITUMEN. NON-RECOVERED COMPLIANCE** of a **BITUMEN** has been shown to correlate to the **BITUMEN'S** contribution to the rutting resistance of an **ASPHALT MIXTURE.**

NATURAL ASPHALT
Naturally-occurring mixture of **BITUMENS** and mineral matter formed by oil seepages in the earth's crust then evaporating through geological forces. Natural asphalts include Trinidad Lake, Rock, Gilsonite, Selenice and others.

OXIDISED BITUMEN
BITUMEN whose rheological properties have been substantially modified by reaction with air at elevated temperatures. This material is also sometimes referred to as "**BLOWN BITUMEN**" and, in the USA, **AIR-BLOWN ASPHALT**.

PAH, PAC
Polycyclic Aromatic Hydrocarbons is the collective name for a large group of several hundred chemicals that have a characteristic structure of two or more fused aromatic rings. They are a class of organic compounds and also a sub-group of the larger family of chemicals - Polycyclic Aromatic Compounds (PAC). PAC can include atoms other than carbon and hydrogen, such as nitrogen, oxygen or sulphur.

PAVING BITUMEN/ASPHALT
A **BITUMEN** used to coat mineral aggregate, mainly used in the construction and maintenance of paved surfaces and hydraulic works.

PENETRATION GRADED BITUMENS
BITUMENS classified by the depth to which a standard needle will penetrate the **BITUMEN** sample under specified test conditions (see ASTM D5 and/or EN1426 for an explanation of the penetration test).

PENETRATION INDEX
Indication of the thermal susceptibility of bituminous binder. The penetration index is calculated from the values of **PENETRATION** and the **SOFTENING POINT**. A **PENETRATION INDEX** of zero is attributed to a bitumen with a **PENETRATION** at 25°C (77°F) of 200 x 0.1mm and a **SOFTENING POINT** of 40°C (104°F). The **PENETRATION INDEX** is calculated as follows (according to EN 12591);

$$I_p = \frac{20 \times t_{RaB} + 500 \times \lg P - 1952}{t_{RaB} - 50 \times \lg P + 120}$$

PENETRATION TEST
Specification test to measure the hardness of **BITUMEN** under specified conditions. In which the indentation into a **BITUMEN** in tenths of a millimetre (0.1 mm) at 25°C (77°F) is measured using a standard needle with a loading of 100 grams and 5 seconds duration. Details of the test can be found in ASTM D5 and/or EN 1426 as well as other sources.

PLASTOMER
A polymer type which exhibits stiffness and strength but does not recover substantially when deformed. Examples of this type of polymer used in **BITUMENS** are ethylene vinyl acetate, ethylene methacrylate, polyethylene, and atactic polypropylene.

POLYMER MODIFIED BITUMEN/ASPHALT (PMB/A) MODIFIED BITUMEN/ASPHALT in which the modifier used is one or more organic polymers.

PUG-MILL
Mixer used to combine stone materials and **BITUMEN** in an asphalt-mixing plant. The mixing is effected by high-speed stirring with paddle blades at elevated temperatures.

REFINERY
A facility composed of a group of separation and chemical engineering unit processes used for refining crude oil into different oil products.

RESINS (POLAR AROMATICS)
Very adhesive fractions of relatively high molecular weight present in the **MALTENES**. They are dispersing agents (referred to as peptisers) for the **ASPHALTENES.** This fraction is separated using solvent precipitation and adsorption chromatography.

ROCK ASPHALT
Naturally-occurring form of **ASPHALT**, usually a combination of bitumen and limestone. Found in south-eastern France, Sicily, USA and elsewhere.

ROLLING THIN FILM OVEN TEST (RTFOT)
A common paving **BITUMEN** test which subjects a thin film of **BITUMEN** on the inside of a rolling glass jar to 163°C (325°F) for 75-85 minutes. See ASTM D2872, or EN 12607-1. The test was designed to simulate aging of the Bitumen trough the Hot-Mix plant.

SELENICE
A **NATURAL ASPHALT** from Albania.

SEMI-BLOWN BITUMEN
Synonym for **AIR-RECTIFIED BITUMEN.**

SOFTENING-POINT
A specification test measuring the temperature, measured in ºC, at which material under standardised test conditions attains a specific consistency (See ASTM D36 and/or EN1427).

STRAIGHT-REDUCED BITUMENS
Similar to **STRAIGHT-RUN BITUMENS** and **STEAM-REFINED BITUMENS**.

STRAIGHT-RUN BITUMENS
VACUUM RESIDUES used as bitumens. **STEAM STRIPPING** may have been used in their production. **STRAIGHT REDUCED BITUMENS** refer to a bitumen produced to a specific target grade without blending with other bitumen grades to achieve the desired result.

THERMALLY CRACKED BITUMENS
Also known as Residues (petroleum), thermal cracked, vacuum: **BITUMENS** produced by thermal cracking, followed by vacuum distillation.

THERMOPLASTIC POLYMER (PLASTOMER)
A polymer type which exhibits stiffness and strength but does not recover substantially when deformed. Examples of this type of polymer used in **BITUMENS** are ethylene vinyl acetate, ethylene methacrylate, polyethylene, and atactic polypropylene.

TRINIDAD LAKE ASPHALT
A **NATURAL ASPHALT** obtained from the La Brea region of Trinidad.

VACUUM DISTILLATION
Distillation of **ATMOSPHERIC RESIDUUM** under vacuum.

VACUUM RESIDUUM
Residue obtained by **VACUUM DISTILLATION.**

VISCOSITY
Resistance to flow of a substance when a shearing stress is imposed on the substance. For **BITUMEN** products, test methods include vacuum-capillary, cone and plate, orifice-type and rotational viscometers. Measurements of viscosity at varying temperatures are used by technologists in all industry segments that utilise **BITUMEN** materials.

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