ABSTRACT

Mastic asphalt for use as pavement quality surfacing is an ‘old’ product in the sense that it has been around for some time. It can be demonstrated that the product, when appropriately designed, can withstand heavy traffic loading over long periods. It requires minimal attention and maintains sufficient flexibility to be able to absorb movements of the substrate and base structure, subjected to a broad band of temperature fluctuations, such as may occur on bridge decks, and particularly steel decks.

INTRODUCTION

Mastic asphalt as a product for use in pavement surfacing has been around for some time. As early as the 1700s when natural rock asphalt (limestone impregnated with about 5 – 15% bitumen) was discovered in France and Switzerland, where it was mined, ground and heated to form a paste like material. This was then placed in position with a wooden float and provided both a durable and waterproof layer. Because it was found to be so long lasting, the use of mastic asphalt was further developed. Particularly during the 1800s when it was discovered that a natural occurring bitumen located in a ‘lake’ in Trinidad, West Indies\(^1\) could be added to, (and eventually replace), the rock asphalt, as well as enhancing the durable properties of the mix. It was during this period that the refinement of adding stone to the paste (or epuré) was found to provide greater stability to the mix.

![Figure 1 - Mastic asphalt being laid in 1929 on a bridge over the White Nile in Khartoum.](image)
In more than 30 years the method of application had not changed much. In fact it had not changed much from that used when applied in the 1700 and 1800s.

It was not until 1980, with the surfacing of the Humber Bridge in England, that the method of laying pavement quality mastic asphalt by machine was widely adopted\(^{(2)}\).

The Material

In most asphalt paving mixtures the bitumen content is devised so as to provide a content of voids after compaction, (measured by volume of the mix). The percentage of the contrived voids may vary depending on factors associated with the type of material, the proposed use and current conventional thinking. These voids might range from anything between 2% to 20%. With mastic asphalt however the aim is that within the mineral structure of the mix there should be a minimum of voids and any voids that do remain are filled with bitumen.

A typical material content for mastic asphalt to be used for pavement surfacing is:-

<table>
<thead>
<tr>
<th>Material</th>
<th>Percentage</th>
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<tbody>
<tr>
<td>Total bitumen in the mix</td>
<td>8%</td>
</tr>
<tr>
<td>Fine limestone rock</td>
<td>46%</td>
</tr>
<tr>
<td>Coarse aggregate</td>
<td>46%</td>
</tr>
</tbody>
</table>
A TALE OF TWO BRIDGES

Whilst mastic asphalt is used for any pavement requiring high stability and durability, it is ideally suited for the surfacing of bridge decks in general and steel suspension bridges in particular.

This is because of an amalgam of eclectic properties, such as:-

i) Water impermeable, affording protection to the steel deck against corrosion.

ii) Flexible, able to follow the deformation of the steel deck without fracture.

iii) Stable, resistant to plastic flow and permanent deformation at high temperatures.

iv) Durable, ideal in situations (such as on bridges), where maintenance work is difficult and where there is generally no convenient alternative route.

v) High stiffness, allowing a thin layer, limiting the dead load element on the deck.

The Process of Design, Manufacturing & Laying

The design, manufacturing and laying process is illustrated here by highlighting operations associated with the recent laying of mastic asphalt surfacing on two large steel suspension bridges. One in the Hong Kong SAR, (the Tsing Ma Bridge, in 1997) and the other in Mainland China, (the Jiangyin Bridge, in 1999, which crosses the Yangtze River 150kms up stream from Shanghai).
The Tsing Ma Bridge in Hong Kong forms a major link in the expressway and railway connection between the island of Hong Kong, and the new airport at Chek Lap Kok which was opened in July 1998. The bridge has a span of 1377m with two 3-lane carriageways on the upper deck and two railway tracks on the lower deck, together with, at the same level, two sheltered single-lane carriageways for maintenance access and for the diversion of traffic during high winds.

The upper deck carriageway of approximately 60,000m² was surfaced with a nominal 37mm of machine laid pavement quality mastic asphalt over a sprayed synthetic (acrylic) resin waterproof membrane system. The specification for the mastic asphalt was essentially a recipe mix based broadly on a British Standard with some modifications, principally the modification of the asphaltic cement from a 50/50 to a 70/30 TLA/bitumen blend\(^3\).

The Jiangyin Bridge provides the only fixed crossing of the Yangtze over a 350Km stretch of the river between Shanghai and Nanking. It is not only in a local context commercially important, linking north and south Jiangsu Province, but it also forms a part of the planned north-south coastal trunk road connecting Heilongjiang province in the north of China with Hainan province in the south.

The Jiangyin Bridge is perhaps more interesting as an illustration because the surfacing system was supplied on a design and construct basis.

The suspension bridge, (the longest in Mainland China and fourth longest in the world), has a span of 1385m with 14m wide, dual 3 lane carriageway, a 1.5m central reservation and two 2.2m wide maintenance lane/footways hung either side off the
main cross section girder. The area of the main carriageway is approximately 41,000m² with a mastic asphalt surface of nominal 48mm thickness and the maintenance lane/footway of 6,000m² with a 28mm thickness of mastic asphalt.

**Figure 8 - Cross-section of the Jiangyin Bridge**

*Design:*

The specification for the main carriageway required a design of the surfacing system which provided for an incremental Traffic Loading to year 2017 with a speed limitation of 100km/hr. It also called for a design that would be durable for 15 years and accommodate a range of temperature movement from +70°C to -15°C. In addition the composite material was to show no sign of softening at 70°C.

Whilst the intent of the specification with respect to the design was obviously one of performance compliance, it did also contain some recipe elements. In this context, the specification did not actually dictate the specific mix composition, but it made it difficult to deviate that much, by prescribing certain material characteristics.

For example:
The bitumen to be 60/70 penetration (at 25°C).
The mineral matter content of the asphaltic cement to be in the range 18%-27% by weight.(4) The soluble bitumen content within the range 14% - 16% (excluding coarse aggregate).
The grading envelope of the fine aggregate limestone rock defined.
The size and grading of the coarse aggregate stipulated.

However previous experience, gained by using materials on the Tsing Ma Bridge project two years earlier, was used to establish a range of mixes that would be likely to fit the recipe part of the specification as well as satisfy the performance criteria.

A comprehensive technical appraisal was devised which had three stages(5).

First, it included conducting a series of laboratory tests on a range of materials to assess their suitability and compliance with the specification and their compliance with...
appropriate performance criteria. This was not only on those materials for the mastic asphalt surface layer, but also for the complete surface system which included a rubberised bitumen waterproofing underlay and a bitumen based primer suitable for the underlay’s adhesion to the steel deck. From the results obtained from these tests a number of materials were selected for further evaluation.

The second stage of the evaluation process comprised a programme of testing the complete surfacing system. This was to ascertain the compatibility of all the components comprising the system, their ability to perform over a temperature range of +70°C to -15°C and the adhesion and compatibility with the underlying paint system on the steel plate deck. The tests undertaken checked tensile adhesion and shear resistance over a range of temperatures (-10°C to +40°C). Also tests to check for any potential for heat degradation of the binder in the mix after reheating of the epuré and tests for water absorption and freeze-thaw\(^\text{(6)}\).

The final stage of the technical examination process entailed assessing the optimum design that would best meet all of the stated environmental and traffic conditions extended over a period of 15 years.

This part of the design process comprised a finite element (FE) analysis of the surfaced steel deck to assess the capability of the proposed mastic asphalt surfacing system through a range of temperature conditions under localised vehicle wheel load effects. As well as an interpretation of the FE analysis to assess the projected life of the surfacing, utilising given temperature and traffic data and incorporating the laboratory determined properties for a range of specific surfacing/waterproofing combinations.

The FE analysis of the behaviour of the steel deck and the surfacing system used a LUSAS model which produced a three dimensional FE section of the bridge. The model allowed for composite action between the deck and the mastic asphalt. The results of the analysis were then used to verify that local deck behaviour, (as distinct to overall) would not unduly stress the surfacing and cause premature failure.

Based on this comprehensive design programme, the composite mix proposal comprised:

<table>
<thead>
<tr>
<th>Material</th>
<th>Composition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Adhesive primer</td>
<td>Bostik 9225 (bitumen modified with rubber &amp; resin).</td>
</tr>
<tr>
<td>Rubberised bitumen underlay</td>
<td>A mix of filler &amp; Caribit polymer modified binder, (hot applied).</td>
</tr>
<tr>
<td>Mastic asphalt</td>
<td>Fine aggregate&lt;br&gt;Coarse aggregate&lt;br&gt;Asphaltic Cement (70 %Trinidad Lake Asphalt &amp; 30%, 60/70 penetration bitumen)&lt;br&gt;Roadstone chippings precoated with approximately 2% bitumen.</td>
</tr>
</tbody>
</table>

As a comparison, the surfacing system adopted for the Forth Bridge in Scotland laid in 1964\(^\text{(7)}\) was:

<table>
<thead>
<tr>
<th>Material</th>
<th>Composition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Adhesive primer</td>
<td>Bostik 1255</td>
</tr>
</tbody>
</table>

6
Rubberised bitumen underlay  Filler, bitumen and crumb-rubber.

Mastic asphalt
Fine aggregate
Coarse aggregate
Asphaltic Cement (50% Trinidad Lake Asphalt & 50%, 60/70 penetration bitumen).
Pre-coated roadstone chippings.

This is a clear example that illustrates there has been little fundamental change in the product that was used more than 35 years ago, from the one currently used. However, because of the progress in performance related design testing, we now know why it has been successful in the past.

Manufacture:

There are basically two methods used for producing mastic asphalt, but both revolve around first mixing the mastic epuré, (that is the asphaltic cement, and fine limestone) and then adding the stone. It is this adding of the stone, or rather the timing of the adding of the stone, that is the fundamental difference. Fundamental in the sense that whilst in the end both methods produce the same product for laying, the particular method adopted greatly influences the logistics of the total production process. The decision on what method is used may, out of necessity, have to be based on considerations associated with situation or circumstance (such as size of site area available, location, time allocated for the laying operation etc.). Or it may simply be an optional choice and primarily based on cost considerations.

One method was used for the manufacture of the mastic asphalt for the Tsing Ma Bridge project in Hong Kong and the other for the mastic asphalt on the Jiangyin Bridge in Mainland China.

Both process methods require a custom designed production unit.
With either method, the function of the mixer, (which in this case has a capacity to mix about 20 tonnes of epuré), is to accurately combine and mix the bitumen, the Trinidad Lake Asphalt (TLA) and the fine limestone which forms the mastic epuré. The mixer unit is mounted on calibrated load cells (to within $\pm\frac{3}{2}\%$), to allow accurate measurement of the mass of each material. It also has a thermostatic temperature control which maintains the mixture during the mixing process at between 170°C and 210°C.

The sequence of mixing involves the total quantity of hot bitumen being first pumped into the mixing chamber. This is then followed by portions of the TLA, (previously broken down into easily manageable pieces from the 230Kg cardboard barrels it has been shipped in), and corresponding portions of fine limestone\textsuperscript{(6)}, (directly dispensed from the 1 tonne bags in which the material was shipped).
When the final bag of limestone is added, a proportional reconciliation of each material against the cumulative weight is undertaken to determine if any further increments of bitumen, TLA, or fine aggregate is required to achieve the precise blend specified. (The plum pudding recipe concept).

The mixed épuré (which is at a temperature of around 200ºC) is discharged into dedicated mixer/transporter units of total capacity of 11 tonnes.

Essentially a mobile cooker/boiler, fitted with internal paddle/agitators, (much the same as for ready mixed concrete) but with a means of heating (either by gas or oil).

It is at this stage where the two methods deviate. In the case of the Tsing Ma Bridge project, hot stone is then discharged from an aggregate storage hopper into the
mixer/transporter which has already been approximately half loaded with hot mastic epuré. The transporter however first being weighed, (by site weighbridge), to ascertain the exact quantity of stone required to be added to the epuré in order to meet the criteria of the specified mix proportions. The composite mastic asphalt is then thoroughly mixed and the temperature brought to about 200°C before being transported to the site for immediately laying.

In the case of the Jiangyin Bridge project the mastic epuré is similarly mixed in the mixer unit, still in Hong Kong but now located on a plant site. However, after mixing and dispensing into the cooker/boiler, the epuré is then directly discharged into steel moulds each of about 1 tonne capacity. After the material is cooled the moulds are struck, (generally the next day), and the blocks of material transferred onto pallets ready for ease of loading for shipment to the site in Mainland China.

![Figure 12 - Steel moulds filled with hot poured epuré.](image1)

![Figure 13 - Cooled epuré blocks stacked on pallets](image2)

To arrive at the same stage of readiness to lay the mastic material, as on the Tsing Ma Bridge Project, the Jiangyin Bridge Project required further on site operations.

The mastic epuré blocks, having been shipped from Hong Kong and unloaded on site, were broken into smaller pieces, fed into the mobile cooker/transporters, (of which there were 10No), and melted down. After weighing the epuré in each of the cookers, dried hot aggregate is discharged into each in the proportions that ensure the specified overall material content is satisfied. The temperature of the mastic asphalt was brought to 200°C and then transported to the bridge deck for laying.
The process adopted on the Jiangyin Bridge project is similar to that conventionally used in producing mastic asphalt. That is mixing the bitumen, TLA and fine limestone and discharging to form blocks, remelting the blocks when required and then adding the stone, (preferably pre-heated).

Needless to say, with both methods, a rigid quality control system is in place to monitor and check quality at every juncture of the process. In the case of the Tsing Ma project this meant one comprehensive site laboratory to cope with the testing both for the manufacture and the laying process. For Jiangyin project, two laboratories were required, one for testing the raw materials and mixed epuré at the production unit, the other on site for the testing of the production process of mastic asphalt and the laying.

**Laying:**

Whilst the manufacturing of the material for the Tsing Ma Bridge and Jiangyin Bridge projects differed, the laying processes for the mastic asphalt surface were very similar.

However, the underlaying waterproof membrane was different. For Tsing Ma Bridge, apart from the protective zinc metal coating on the steel deck, there followed a 5 coat (3mm total thickness), sprayed methylacrylate (‘Eliminator’ type) waterproofing membrane. This work was carried out by others under a separate subcontract to the mastic. For Jiangyin Bridge the zinc coating on the steel deck was overlaid with a bitumen based adhesive primer and a 2mm layer of hot applied rubberised bitumen compound. This operation, along with the mastic asphalt, formed a part of the same surfacing contract.
As mentioned, apart from the waterproofing underlay, the sequence of operations for the laying of mastic asphalt for both projects was similar.

Before any laying, a level survey of the bridge deck was carried out and a finished surface 'best fit' profile was arrived at, which encompassed the consideration of factors such as the running surface, cross profile and the overall thickness.

Steel side restraint formers were then placed and set to the agreed profile thickness.

The mastic asphalt is poured from the cookers in front of the purpose made laying machine, which runs along the top of the forms, acting similar to the rails used as part of a conventional concrete train, with a spreader and automatic leveler fitted to the laying machine. No vibration is used.

Some handwork attention is required behind the machine to ensure that the joint of the freshly laid mastic aligns with the previously laid adjacent lane. In this respect, the laying machine is fitted on each side with an infra red heater unit that heats up the edge of the adjacent lane so that the material can be integrated with the fresh hot mastic being laid.
Bitumen coated stone chippings, which enhance skid resistance, are spread on the surface of the mastic immediately behind the laying by means of a mechanical purpose made chip spreader. The chipping machine is pre-calibrated to ensure the rate of spread of the chippings is uniform and in accordance with specified requirements. (Usually in the order of 1 tonne to every 110m² of surface area).\(^{(10)}\)

**Figure 18 - The mechanical chip spreader in action.**

The coated chippings are then ‘settled’ into the surface by hand rolling and then as the material cools, embedded by means of a small roller.

**Figure 19 - Hand rolling and embedding chippings into the surface.**

**SUMMARY**

Whilst pavement quality mastic asphalt is an ‘old’ product in the sense that it has been around for some time, it competes with the current state of the black art bituminous surfacing products on the same terms in being able to provide a durable, hard wearing cost effect surface. Once the design characteristics appropriate to a specific project have been established, the material works well. It has been found to be most effective when the asphaltic cement content of the mix is modified by adding TLA. It is particularly well suited for use where movement of the substrate is considered likely (eg: on bridge decks, reclaimed land etc), and where the opportunity for regular maintenance work is limited.

The two examples of the Tsing Ma Bridge in Hong Kong and the Jiangyin Bridge across the Yangtze in China are an illustration of recent major projects in East Asia.
adopting the use of pavement quality mastic asphalt. Both projects were high profile. The Tsing Ma Bridge was opened by Margaret Thatcher in April 1997 and the Jia ngyin Bridge by Jiang Zemin in September 1999.

![Image](212x480 to 369x705)

**Figure 20** - The finished surface of the Tsing Ma Bridge

![Image](178x298 to 403x455)

**Figure 21** - The finished surface of the Jiangyin Bridge

The product has a reassuring feel about it. It has been shown that it continues to work, virtually without attention, for more than 20 years. For the ultra sceptical, which unfortunately is the category most of us are compelled to fall into nowadays, seeing that it works is believing.

NOTES

1. Trinidad Lake Asphalt (TLA) occurs naturally in a 100 acre ‘lake’ located on the island of Trinidad in the West Indies. The lake was originally discovered in 1595 by Sir Walter Raleigh. TLA was first commercially shipped to Europe in the mid 1800s. The ‘skimmed’ crude asphalt from the lake is a uniform emulsion of bitumen, gas, water, sand and clay. It originates from a deep lying oil sand bed that contains both asphalitic petroleum and a natural gas under a high pressure. As the petroleum and gas rise to the surface they come in contact with colloidal
clay and silica paste. The gas, water and surface vegetable matter are removed by a simple refining process and converted to the material known as TLA. Estimates indicate that the deposits in the lake are of the order of 10m tonnes. ‘Blended Asphalt Proves Out For Heavy Duty Pavement’. Grimaldi & Yue Sun Chen, NEW YORK PUBLIC WORKS, September 1987.

2. This refers to machine laid on bridge decks in England. In his paper, ‘Mechanically Laid Mastic Asphalt in Germany’, Dipl.Ing. R. Pohmann, states that ‘Mastic asphalt was mechanically laid for the first time in the year 1953 on a street in Berlin’ He does not elaborate on what type of mechanical laying that entailed but as the paper was written in 1966 (and shows a machine laying operation) it was certainly before 1980. However he does explain that the German term ‘Gussaphalt’ is roughly translated in English as ‘Mastic Asphalt’. Gussaphalt is a similar product but is not the same as Mastic asphalt. The paper was presented at the FIFTH WORLD MEETING OF THE INTERNATIONAL ROAD FEDERATION, September 1966.


4. Because the mineral matter (ash) content in the TLA is consistent at 36-37%, then the specified ash content, (18% to 27%), in effect dictates the range of the TLA content that can be used in the mix. (eg: 50% of 36% =18% and 73% of 37%=27%). Thus the allowable range of TLA content in the asphaltic cement is limited to not less than 50% and not more than 73%).

5. The three stages needed to adequately address the specification criteria : viz: ‘Ensure that the materials selected are fully compatible and have a proven record of suitability for the purpose and condition’. ‘In accordance with the temperature conditions, loading and traffic capacity and actual conditions of asphaltic cement, fine and coarse aggregate and performance procedures to test and select the asphalt mixture’. ‘Prior to use, make various verification tests for the asphalt mixture, such as tension in bending, anti-fatigue properties, high temperature creep and adhesive force between surfacing and the steel deck’.

6. The results of these additional tests are worth recording here because although they are not tests regularly undertaken on mastic asphalt they have some significance as an indication of the overall ‘resilience’ of the product. Heat degradation of binder: Essentially a check on whether the re-heating of the epurè blocks (to a temperature of 210°C), causes any degradation in the bitumen. That is comparing the effect of the two different methods of mastic asphalt production in this respect. (See main text under ‘Manufacture’)

<table>
<thead>
<tr>
<th>Sample</th>
<th>Penetration (d_{mm})</th>
<th>Softening point (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Binder recovered from continuously mixed mastic asphalt</td>
<td>14</td>
<td>69</td>
</tr>
<tr>
<td>Binder recovered from remixed epure + added coarse aggregate</td>
<td>12</td>
<td>72</td>
</tr>
</tbody>
</table>
**Water Absorption:** The determined mean water saturation rate on 3 samples was 0.07%. Water saturation is equivalent to water absorption and the results are very low.

**Freeze-thaw Splitting Test:** 4 standard mix samples were tested unconditioned and 4 samples tested after freeze thaw conditioning. The determined freezing-thawing splitting tensile test ratio (conditioned to unconditioned) was 84%. The Strategic Highways Research Program (SHRP) indicate a minimum tensile test strength ratio of 80%.


8. As mentioned previously, the grading and content of the fine limestone was specified, as was its minimum calcium carbonate content (at least 85% by mass). The mineral content (ash) of the TLA is a consistent 36-37% and influences the fine aggregate content in the epuré. The mineral matter in the asphaltic cement was also specified (18 –27%). See also note 4 above.

9. Fixed datum levels on bridge decks, and particularly steel decks, are not practical because the level at a particular point can vary. Factors such as temperature and wind and its direction will affect a datum level. This concept can also be related to certain areas of reclaimed land where tidal movement can influence a point level relative to a datum depending on when or at what state is the tide.

10. The method for calibrating the rate of spread of the chipping machine is carried out on site prior to each operation (usually each day of laying) of spreading the pre-coated aggregate (PCCs). A tray of uniform surface area (preferably 1 or 1.5m²) is placed in front of the mechanical spreader. The spreader is then passed over the tray, distributing the PCCs on to the tray as it goes. The tray with the PCCs is then weighed to confirm, or otherwise, the correct rate of spread. The machine can be immediately adjusted to either increase or decrease the rate of spread if the tested rate is found to be nonconforming.