Warm Mix Asphalt / Low temperature asphalt

**Warm mix asphalt on the Easing Sydney’s Congestion Program. A success story of collaboration, sustainability and innovation**

*Carlos Solis Navarro*
*AECOM, Ground Engineering Discipline Lead for the ESC Program Office, CEng MICE*

Abstract

Australia’s population reached 25 million on 8 August 2018 and Sydney’s population is projected to double from the current 4 million to 8 million by 2060. This increase in population is placing additional demand on the State Governments and Roads Agencies to supply their customers with the infrastructure required to support this growth. Since its inception in 2016, the Roads and Maritime Services (RMS) Easing Sydney’s Congestion (ESC) Program in New South Wales has been delivering significant improvements to increase capacity specifically at major intersections thereby reducing Sydney’s congestion. The vision of the program is “making the customers’ journeys better by delivering high benefit programs and projects through low impact and smart solutions”. The Program is proving to be an example of the benefits of collaboration between Public and Private Sector under a consultant Partnership Agreement. Moreover, the ESC program has become a platform for innovation in achieving more sustainable pavements through the use of warm mix asphalt on each project. This paper describes the challenging conditions to deliver urban projects on the Sydney network, key issues encountered during design and specification and an initial assessment of the performance of the warm mix asphalt used on these projects.

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## 1. INTRODUCTION

The population of Sydney is forecast to grow by 200% to reach 8 million by 2060 [1] and by 2056 New South Wales (NSW) will have more than 12 million residents. Currently, Sydney's road network serves 93% of passenger journey and 86% of port freight movements [2].

Although significant investment in infrastructure has tried to meet this demand, traffic on key corridors has grown by 50% during the last 20 years with congestion experienced throughout the day. Sustained congestion reduces the efficiency of commuter journeys, freight movement and business travel, affecting not only economic growth but also people's quality of life.

To assist in alleviating the existing congestion, increased road network capacity is required. Infrastructure NSW in its 2014 State Infrastructure Strategy Update recommended that in addition to major road and rail projects, making the most of the existing network would contribute to relieve this growing problem. A program of investment in congestion hotspots (Pinch Points), clearways and Smart Motorways across the city was included in its recommendations as key opportunities.

The Easing Sydney's Congestion (ESC) Program Office was the Roads and Maritime Services' (RMS) response to this recommendation. The Program includes several initiatives such as the Pinch Point, Clearways and Bus Priority Infrastructure Sub-Programs. Figure 1 illustrates the sub-structure and funding of the Program [3].

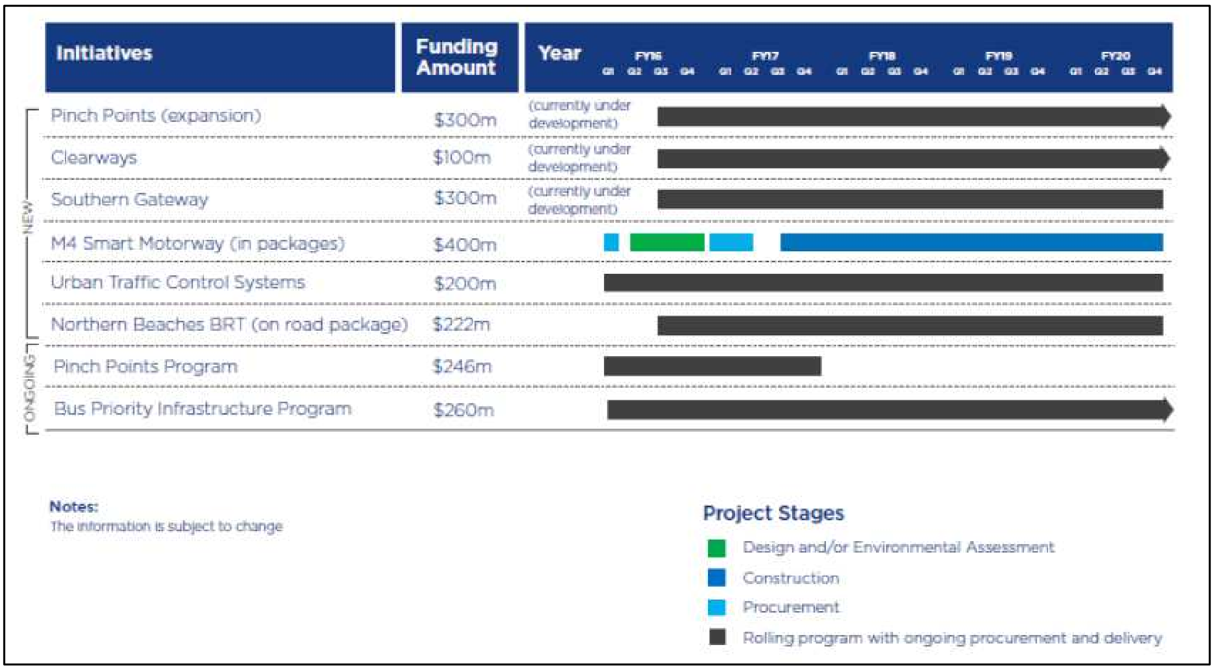



**Figure 1: ESC sub-program structure**

The Program commenced in 2016 and is being delivered under a partnership agreement between RMS and AECOM as lead consultant partner. This type of agreement was sought to create a framework in which projects can evolve and progress throughout the lifecycle with enhanced collaborative behaviors between both parties. This in turn would decrease procurement times and costs which would enable to provide a quicker outcome for customers.

In June 2018, the partnership agreement was extended for another two years. As a result, the vision of the Program was renewed to the following:

"Making the customers' journeys better by delivering high benefit programs and projects through low impact and smart solutions".

From the above vision, it was derived that one goal was to find solutions to the congestion problems whilst minimizing disruption to customers. Given that pavements are one of the main construction elements of the projects, efficient and quick construction methods were sought.

Warm mix asphalt was identified as one technology that would contribute to delivering projects in more efficient and sustainable method. Warm mixes are those whose modified manufacturing procedures allow their mixing, working and compaction at a lower temperature than conventional hot mixes [4].

The principle area of efficiency gain is with regards to construction programme savings. This is due to the material reaching a surface temperature appropriate for opening to traffic or for the next lift to be paved earlier than hot mix asphalt alternatives. As such the focus of efficiency is productivity [5]. In addition, the United States experience reports an average fuel saving of 23% and a general reduction of emissions [6].

This article presents the implementation of this technology on the ESC Program from design to delivery. It also describes key issues encountered during specification and mix design nomination. It should be noted that construction contracts are delivered under RMS GC/21 contracts, in which collaboration between Client and Contractor is part of the contractual philosophy.

## 2. LITERATURE REVIEW

Warm mix asphalt is not a newcomer for the asphalt industry. Since 1956, when Dr. Ladis H. Csanyi, professor at Iowa State University, realized the potential of foamed bitumen for use as a soil binder, a significant number of trials, case studies and papers have contributed to developing the current warm mix technologies [7].

The original process consisted of injecting steam into hot bitumen. In 1968, Mobil Oil Australia, which had acquired the patent rights for Csanyi's invention, modified the original process by adding cold water rather than steam into the hot bitumen. The bitumen foaming process then became more practical [8]. A warm asphalt mix process (WAM) was developed in Europe and was reported by Harrison and Christodulaki at the First World of Asphalt Pavements Conference in Sydney, 2000 and by Koenders et al [9] at the Eurobitume congress in the same year. Their work resulted in the development of WAM Foam®, Warm Asphalt Mix with foamed bitumen.

At the Eurobitume congress in 2004, Barthel et al [10] introduced the use of a synthetic zeolite additive to produce warm mix asphalt. This technology attracted National Center for Asphalt Technology (NCAT) attention in North America which published various reports about the use of Sasobit™, a synthetic wax, and Aspha-min®, a synthetic zeolite and Evotherm®, an asphalt emulsion, in warm mix asphalt between 2005 and 2006 [11], [12] and [13].

## 3. DESIGN PHASE

The design and construction of pavements in urban areas can be more challenging than design and construction in less built up areas. The design of pavements in urban areas needs to cater for limited construction space and the need for rapid construction time to mitigate disruption to road users.

From overseas experience, in particular from the UK, it was reported that warm mixes could increase shift output by 20% and a reduction in material costs [5]. In addition, safety and environmental benefits are achieved due to the reduced manufacturing temperature.

Considering the above, it was decided to specify warm mix asphalt with 20 mm nominal sized aggregate as the default asphalt basecourse mix (AC20) for each project on the Program. It was acknowledged that no real efficiencies would be gained from those projects in which deep lifts (more than 2 layers laid per shift) were not required. However, warm mixes were still specified to promote the uptake of warm mix and to promote a greener and safer pavement industry. This in turn would contribute to support the United Nations Sustainable Development Goal No.9: "Build resilient infrastructure, promote sustainable industrialization and foster innovation".

The below sub-sections describe four projects in which warm mixes were utilized.

### 3.1 Princes Highway upgrade in Kirawee

The project consists of the upgrade of 1.5 km of the Princess Highway corridor between Acacia Road and Kingsway in Kirawee. The project is part of the Gateway to the South Pinch Point Program with an estimated construction cost of circa $35M.

The main pavement works consist of widenings both into the verge and median to provide three lanes in each direction plus dedicated right and left turn lanes at the intersections. Figure 2 illustrates works at the intersection with Oak Road as an example. In addition, several sections were treated with heavy patching due to the change in vertical levels and to rectify the distressed condition of the existing pavement.

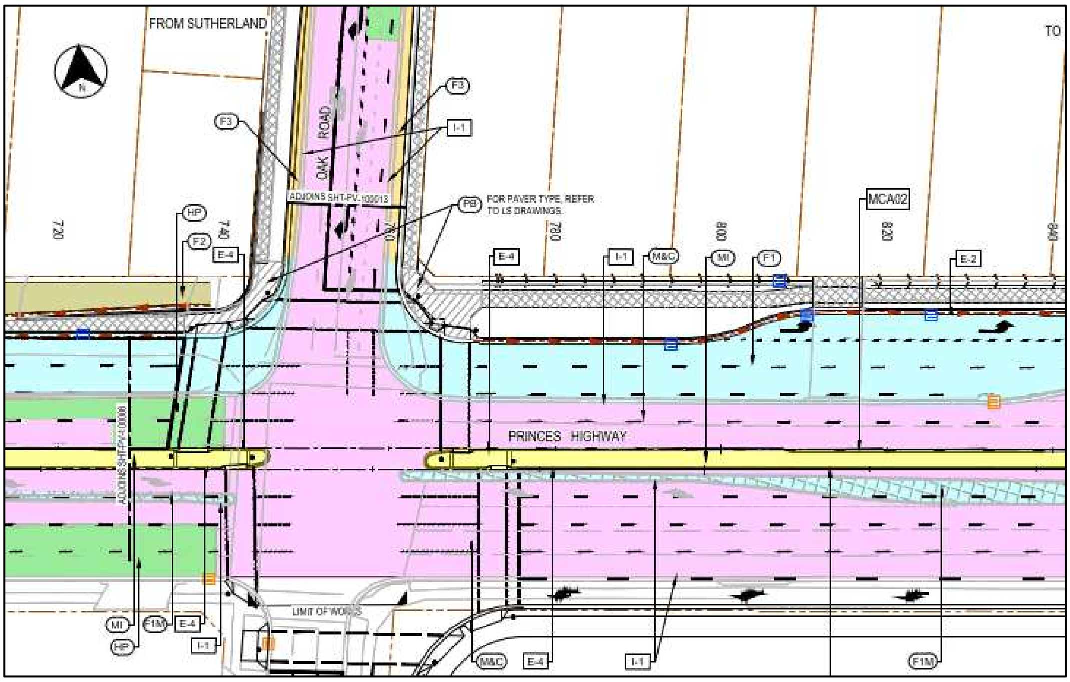



**Figure 2: Princes Highway works at Oak Road intersection**

For the works described above, the pavement profiles consist of 315 mm of asphalt (50 mm wearing course plus 265 mm AC20 basecourse i.e. pavement type F1) over the selected material zone for the widening into the verge and median and 300 mm asphalt (50 mm wearing course plus 250 mm AC20 basecourse i.e. pavement type HP) for the heavy patching.

Since the basecourse was to be laid as three layers, warm mix asphalt was specified to optimize shift outputs. Most of the heavy patching sections were scheduled for night shifts, and therefore warm mixes were also specified to enable opening to traffic without the risk of early rutting due to heat retention. The heavy patching sections were planned to be built as three 100 mm thick layers, and therefore the top 50 mm was used as a sacrificial layer to be milled off during the final milling and re-sheeting.

### 3.2 Stacey Street upgrade in Bankstown

The project consists of the upgrade of 420 m of the Stacey Street corridor between Macauley Avenue and Salvia Avenue in Bankstown. The project is part of the Gateway to the South Pinch Point Program with an estimated construction cost of circa $4M.

The main pavement works consists of widenings into both verges and heavy patching to reinstate existing pavement structure after adjustment of the vertical alignment. Similar to the Princes Highway project, warm mixes were specified to maximize output and enable heavy patching sections to be built over night-shifts and to be opened to traffic the following morning. Figure 3 illustrates a section of the works.

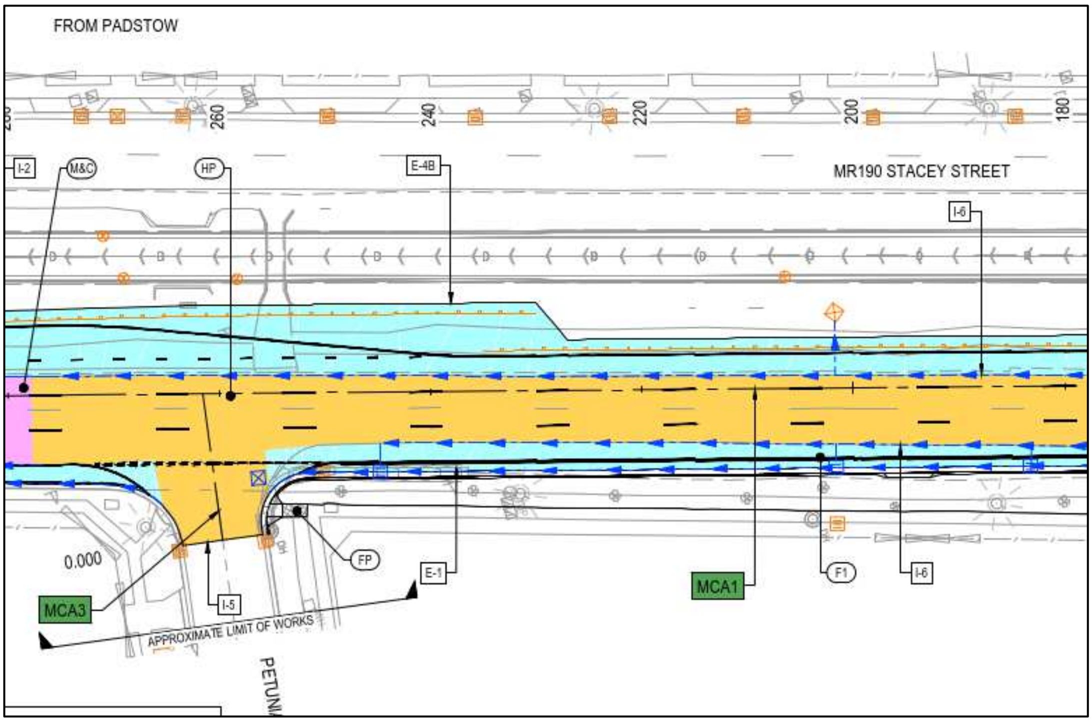



**Figure 3: Stacey Street works**

### 3.3 Cumberland Highway upgrade in Greystanes

The project consists of the upgrade of Cumberland Highway at the intersection with Merrylands Road. The project is part of the Urban Roads Pinch Point Program with an estimated construction cost of circa $10M.

The main pavement works consist of widening into both verges and medians to provide the intersection layout illustrated in Figure 4. The existing pavement structure in Cumberland Highway is asphalt over lean-mix concrete with full depth asphalt in Merrylands Road. Although warm mixes were better suited for the deep lift works at Merrylands Road in terms of productivity efficiencies, it was still specified across the entire project for consistency.


**Figure 4: Cumberland Highway works at Merrylands Road intersection**

### 3.4 Intersection improvement at Narellan Road and Appin Road in Campbelltown

This project is part of the Urban Roads Pinch Point Program with an estimated construction cost of circa $3.5M. The scope of works (illustrated in Figure 5) and existing pavement structure (asphalt over lean-mix concrete) were similar to the Cumberland Highways project and consequently  leant itself to the use of warm mixes.

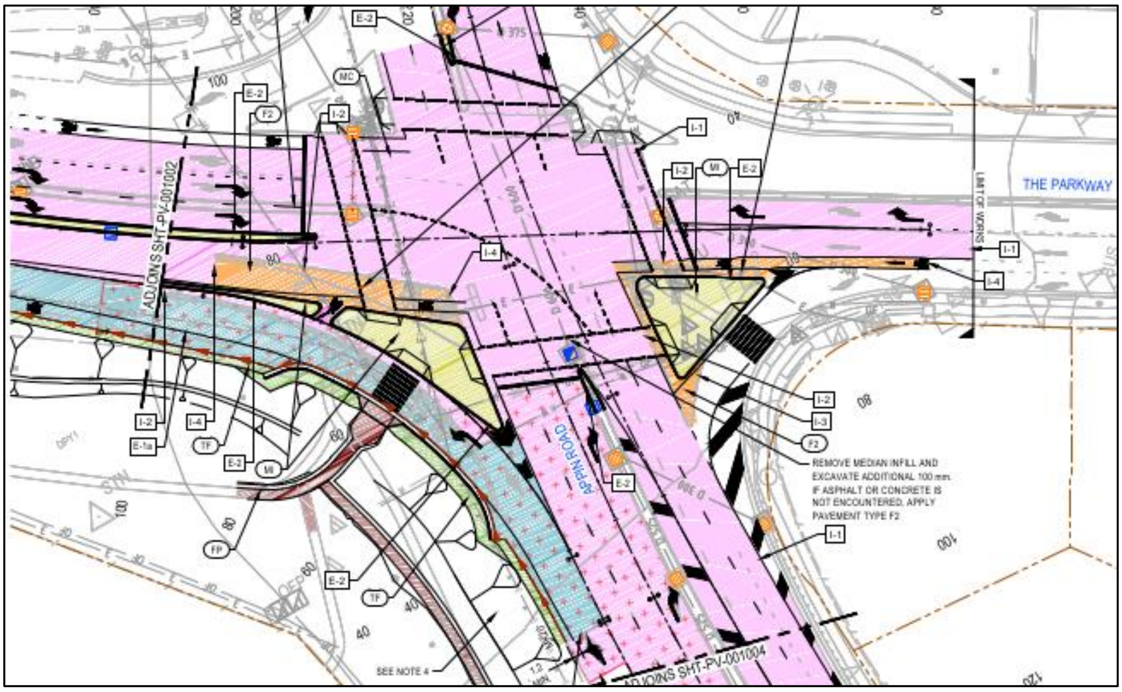



**Figure 5: Works at the intersection between Narellan Road and Appin Road**

## 4. SPECIFICATION AND NOMINATED MIX DESIGN

### 3.1 Specification

The use of warm mix asphalt additive is included as an option in the RMS QA Specification R116, Heavy Duty Dense Graded Asphalt. This can be used either to reduce the asphalt manufacturing temperature and/or improve workability during the pavement and compaction operations [14].

Clauses 2.1 and 2.2 of the aforementioned specification contain the requirements and proportions of constituent materials used in the manufacture of asphalt. Regarding additives to be used in warm mix asphalt, three types are accepted as illustrated in Figure 6.

**Table R116.4 – Maximum Proportion of Additive in Warm Mix Asphalt**

| Additive | Maximum Proportion |
|---|---|
| Wax | 2.0% by mass of binder |
| Surfactants | Nominated by Contractor |
| Water (either directly, or in the form of water containing crystals) | 0.06% by mass of the total mix |

**Figure 6: Additive and proportions for warm mix asphalt**

For the submission of the nominated mix design, Clause 2.3 requires that the contractor provides test results and evidence that additive is designed, supplied and has proven performance for the purpose.

Considering that the above requirements would suffice for the correct implementation of the warm mixes and with the aim to leave the selection of the additive open to the supplier, it was only included in a reference to warm mix asphalt on the drawings and in Annexure R116/A. Figure 7 shows an example extracted from the Princes Highway project.

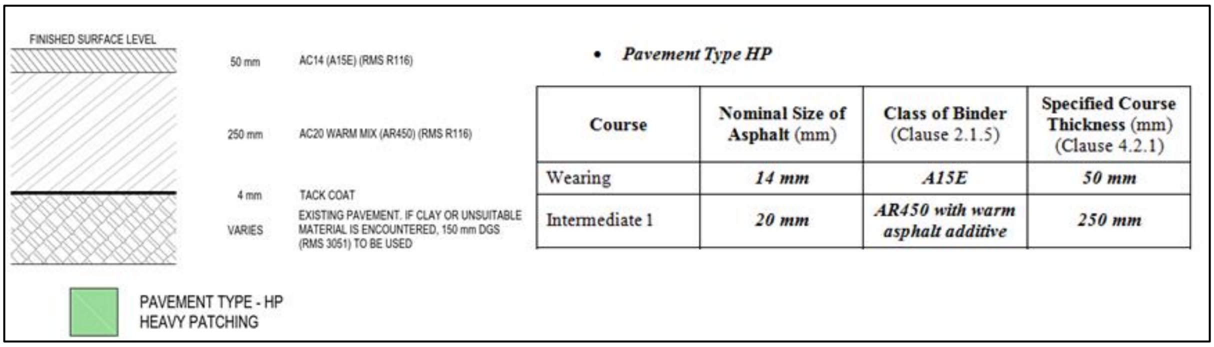



**Figure 7: Specification of warm mix for heavy patching**

## 4.2 Nominated mix design

Once the contracts were awarded, the contractors submitted their nominated mix designs as provided by the suppliers. Although the initial submissions included warm mix additive, as summarized in Table 1, the compaction temperature for the Gyropac tests as per AS2891.2.2 was still 150 °C, and therefore the intent was to manufacture the mixes as hot mixes. After consultation with the suppliers, they all reported that the common use of the warm mix additive was for aiding compaction and long haul rather than manufacturing at lower temperatures.

**Table 1: Additive used per project**

| Project | Supplier mix identifier/ Supplier | Additive/ Type | Proportion |
|---|---|---|---|
| Princes Highway | 01-09113[A]/ State Asphalt | Sasobit/wax | 1.5% |
| Stacey Street | 01-09113[B]/ State Asphalt | Sasobit and Evotherm/ Wax and Surfactant | 1.5% and 0.5% |
| Cumberland Highway | 109334.02/ Downer | Foamed water | N/A |
| Narellan Road | 01-09113[A]/ State Asphalt | Sasobit/wax | 1.5% |

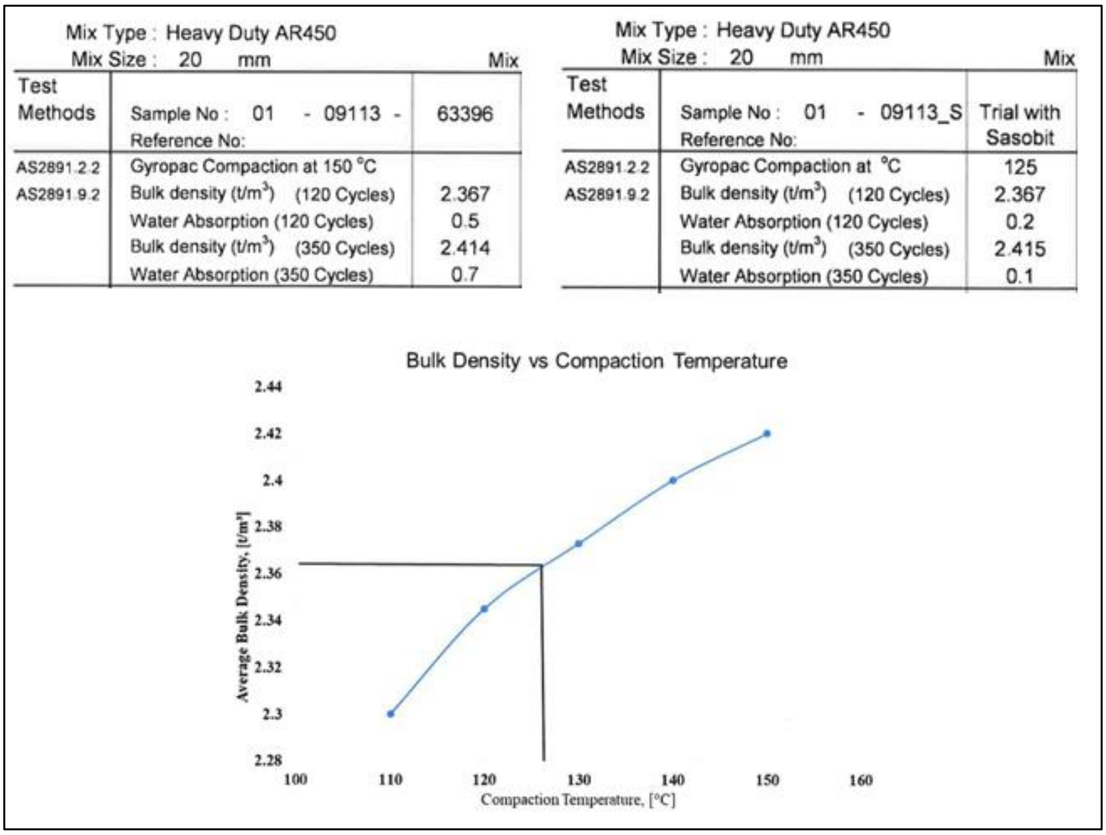
A: 01-9113 becomes 01-113SA when Sasobit is added

B: 01-9113 becomes 01-113SA when Sasobit is added and 01-113E when Evotherm is added

Discussions with the RMS Pavement Unit and the suppliers were held in which the intent of using warm mix asphalt for these projects was deliberated. After these, suppliers were instructed to observe the methodology included in Appendix B of AS/NZS 2891.2.2:2014 in order to calculate the adjusted compaction temperature for warm mixes manufactured at lower temperatures. This methodology consists of the following steps [15]:

A. Determine the reference asphalt bulk density of the asphalt mix using unmodified bitumen (without the warm mix additive) compacted at the standard temperature (150 °C).
B. Calculate the equivalent compaction temperature for the alternative asphalt mix (bitumen including warm mix additive) by determining the temperature at which the bulk density of the alternative mix is equal to the reference bulk density.
C. The results are then plotted to create a density/compaction curve.

Figure 8 shows for the process undertaken for the AC20 warm mix (supplier mix identifier 01-09113) used in the Stacey Street project.



Mix Type : Heavy Duty AR450
Mix Size : 20 mm

| Test Methods | Sample No : 01 - 09113 - Reference No: | Mix 63396 |
|---|---|---|
| AS2891.2.2 | Gyropac Compaction at 150 °C | |
| AS2891.9.2 | Bulk density (t/m³) (120 Cycles) | 2.367 |
| | Water Absorption (120 Cycles) | 0.5 |
| | Bulk density (t/m³) (350 Cycles) | 2.414 |
| | Water Absorption (350 Cycles) | 0.7 |

Mix Type : Heavy Duty AR450
Mix Size : 20 mm

| Test Methods | Sample No : 01 - 09113_S Reference No: | Mix Trial with Sasobit |
|---|---|---|
| AS2891.2.2 | Gyropac Compaction at °C | 125 |
| AS2891.9.2 | Bulk density (t/m³) (120 Cycles) | 2.367 |
| | Water Absorption (120 Cycles) | 0.2 |
| | Bulk density (t/m³) (350 Cycles) | 2.415 |
| | Water Absorption (350 Cycles) | 0.1 |



**Figure 8: Calculation of the equivalent compaction temperature of the mix 01-09113**

After this process, contractors submitted the minimum temperature for delivery and compaction as required in the Hold Point of Clause 3.8 of R116. Table 2 summarizes temperatures at different stages for the above asphalt mixes.

**Table 2: Minimum temperatures**

| Supplier mix identifier | Manufacture (°C) | At delivery (°C) | Minimum for compaction (°C) |
|---|---|---|---|
| 01-113SA | 150 | 130 | 115 |
| 01-113E | 150 | 130 | 115 |
| 109334.02 | 140 | 135 | 120 |

### 4.3 Additional testing

In addition to the required testing for determining the equivalent compaction temperatures, State Asphalt undertook viscosity tests in accordance with AS/NZS 2341 to binders with different proportions of additives at different temperatures. Table 3 and Table 4 summarise these results.

**Table 3: Viscosity test results for C450 binder with Sasobit**

| Binder | | C450 + 1% Sasobit | C450 + 1.25% Sasobit | C450 + 1.5% Sasobit |
|---|---|---|---|---|
| Viscosity (Pa.s), at | 90ºC | 11.2 | 9.6 | 8 |
| | 100ºC | 5.1 | 3.75 | 2.2 |
| | 120ºC | 1.4 | 0.982 | 0.837 |
| | 140ºC | 0.42 | 0.329 | 0.32 |
| | 150ºC | 0.228 | 0.215 | 0.202 |
| | 165ºC | 0.19 | 0.116 | 0.11 |

**Table 4: Viscosity test results for C450 binder with Evotherm**

| Binder | | C450 + 0.2% Evotherm | C450 + 0.35% Evotherm | C450 + 0.5% Evotherm |
|---|---|---|---|---|
| Viscosity (Pa.s), at | 90°C | 11.2 | 10.2 | 9.6 |
| | 100°C | 4.9 | 4.1 | 3.9 |
| | 120°C | 1.2 | 1.027 | 0.975 |
| | 140°C | 0.407 | 0.348 | 0.33 |
| | 150°C | 0.258 | 0.22 | 0.213 |
| | 165°C | 0.15 | 0.125 | 0.116 |

The above were compared against the indicative viscosity values for effective compaction (0.25-10 Pa.s) and optimum mixing (0.1-0.2 Pa.s) as per AUSTROADS and AAPA Pavement Work Tip 13 [16]. The associated temperatures for the viscosity results were in line with the results obtained from method AS/NZS 2891.2.2 and provided confidence that adequate in-situ compaction would be achieved at temperatures ranging from 110-120 °C.

## 5. DELIVERY

At the time of writing this paper, one project was completed; the intersection of Narellan Road and Appin Road, and a significant part of the main works were undertaken on the other projects. This enabled promotion of warm mix asphalt technologies between the site teams, their education in relation to the required testing for mix approval and assessment of the initial performance of the warm mixes.

Prior to moving on to describing key statistics around temperatures and compaction, it is worth highlighting the need for clear communication between site teams and supplier, so that, asphalt mixes are manufactured and delivered to the agreed warm mix temperatures rather than standard hot mix temperatures.

The below sub-sections describe main findings from the Princes Highway and Stacey Street projects in relation to the performance of warm mixes.

### 5.1 Princes Highway upgrade in Kirawee

This project was the first project in the ESC Program in which asphalt was manufactured at lower temperatures so therefore some sections were used as trial works for the implementation of the technology. As an example, in Oak Road, two 60 m long sections were treated with 300 mm thick AC20 laid in three layers, one section using the standard hot mixes and the other using warm mixes. Figure 9 and 10 show a minimal difference or slightly better performance of warm mix compared to hot mix asphalt.

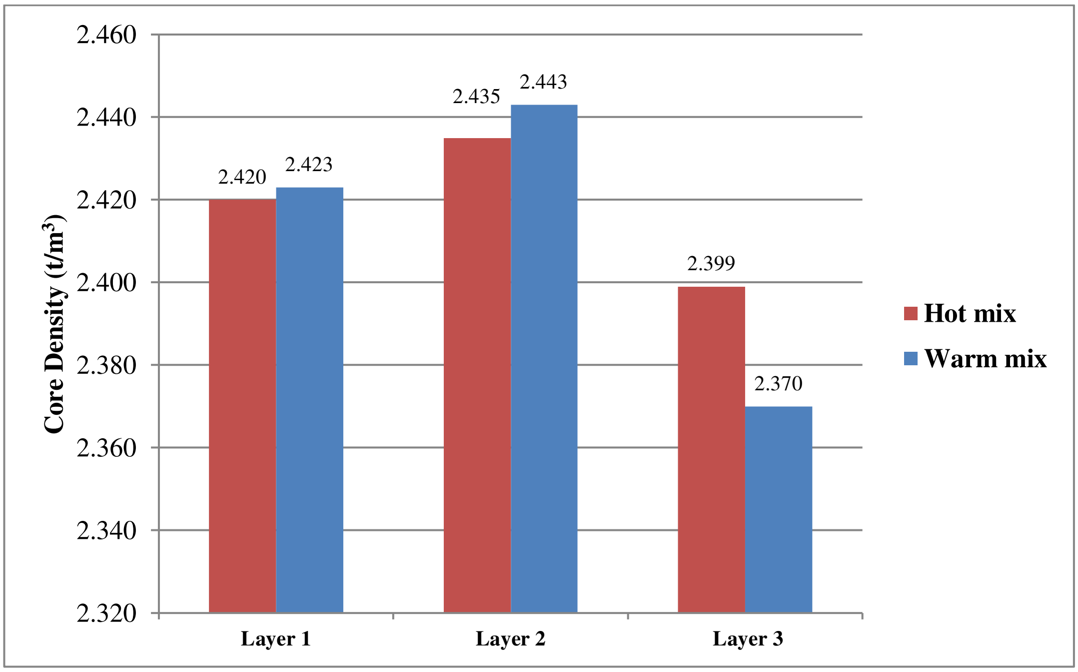



**Figure 9: Core density results**

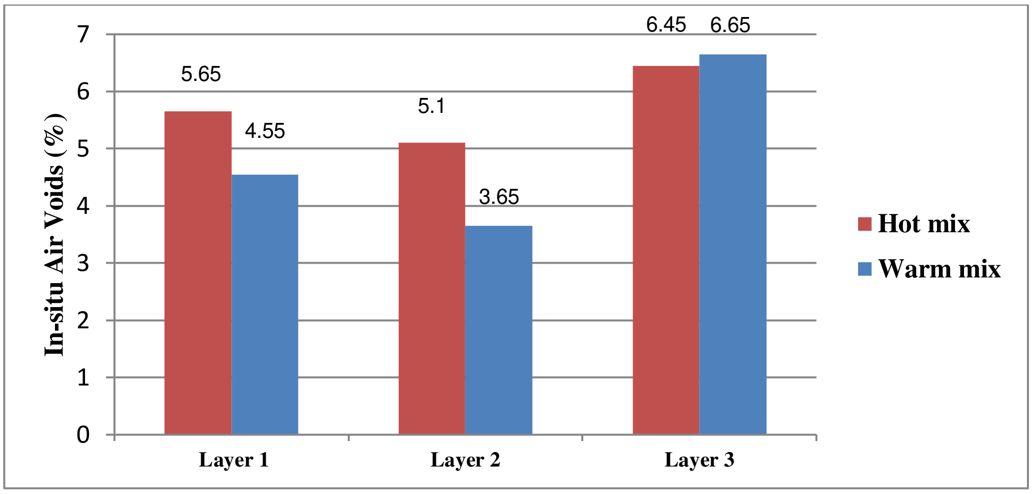



**Figure 10: In-situ air voids results**

After completing most of the widening works into the median and a number of heavy patching sections (circa 3,000 tonne), warm mixes were reported to be delivered in a consistent manner in terms of delivery temperatures (135 °C). Compaction results achieved were also uniform (average 5% in-situ air voids).

### 5.2 Stacey Street upgrade in Bankstown

Circa 250 tonne of warm mix have been laid up to date in the Stacey Street project during three night shifts. AC20 with Evotherm (01-113E) was used during the first shift to compare performance against AC20 with Sasobit (01-113SA) which was used for the subsequent two mixes. A small difference in characteristic air voids between the two mixes was reported, 6.3% for the 01-113E and 5.6% for 01-113SA.

In order to gather additional data of the workability of these mixes, the contractor was instructed to measure and record the temperature of the asphalt after laying and after compaction at two locations for each paving run. The measurements were taken at surface level using an infrared thermometer. These records, in conjunction, with the standard temperature measurements at delivery would provide an indication of the cooling rates. Figure 11 illustrates the asphalt cooling rates as measured on site for 100 mm compacted thickness. Although additional measurements need to be taken to formalize a conclusion, from these records, it can be derived that the average cooling rates of warm mixes were approximately 1.8 °C/minute for the 01-113E and 1.2 °C/minute for 01-113SA. For comparison purposes, the typical hot mix cooling curvature for a 75 mm compacted thickness layer as per AUSTROADS/AAPA Pavement Work Tip No.46 [17] is included in Figure 11. The cooling rate of a hot mix was estimated as 1.5 °C/minute.

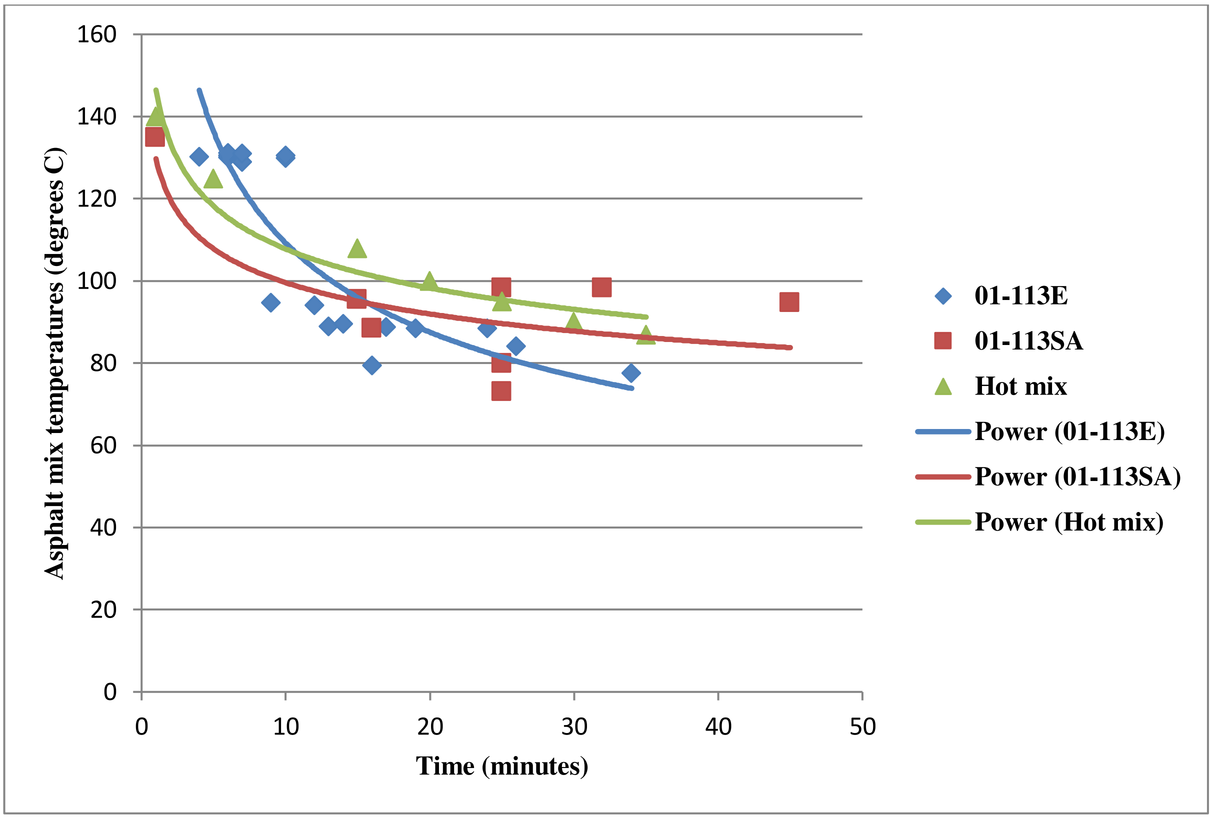



**Figure 11: Cooling rate for 100 mm compacted thickness**

## 6. CONCLUSION AND RECOMMENDATIONS

The ESC Program is responding to the challenge of extending the capacity of the existing network through smart solutions and low impact projects. This will enable to meet the growing capacity demand and alleviate congestion across the Sydney area.

For this Program to be a success, the delivery of these projects is to be efficient and the impact to customers reduced. The use of warm mix technologies is not only contributing to meeting the former goals but also enabling the Program to incorporate resource-efficient material and solutions. This in turn will lead to meet the Government Resource Efficiency Policy (GREP) [18] and United Nations Sustainable Development Goal No.9.

The initial implementation of warm mix technologies in the ESC Program has been satisfactory in terms of performance (in-situ air voids) of the mixes, ability to lay 300 mm thick asphalt basecourse over a night-shift and variety of additives utilized. Designers, contractors and suppliers are maturing in the use of these technologies and efficiencies can be achieved as the uptake of warm mix increases.

Finally, several recommendations and initiatives that are being adopted on the ESC Program are listed below. The aim of these is to ensure greater adoption of these technologies and a better understanding of the potential benefits in terms of construction programme savings, energy consumption savings and fume emissions reduction.

1. Contractual documentation (drawings and specifications) shall clearly instruct suppliers of reduced manufacturing temperature requirement and shall include reference to AS/NZS 2891.2.2 for calculation of the equivalent compaction temperatures.
2. Further data gathering from multiple sites to be able to report more robust conclusions. Data is to be linked to productivity data such as tonnes laid, time to compact, time on the road and time opened to traffic. All these data compared to hot mix asphalt would allow for efficiency benefits to be measured.
3. Trials with AC14 and warm mix are to be conducted.
4. Investigation of mechanisms to gather data to assess carbon footprint and energy consumption to be able to report benefits in these areas.

## 7. ACKNOWLEDGEMENTS

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The views, opinions, considerations expressed in this paper are strictly those of the author and do not necessarily reflect the views of the Roads and Maritime Services/ Transport for New South Wales.


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