# Application of Epoxy Asphalt Mixture to the Binder Course in Orthotropic Steel Deck Pavement

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ABSTRACT: A orthotropic steel deck experiences a large degree of local deformation when subjected to wheel loads and is sensitive to air temperature. Accordingly, a pavement installed on one is subjected to very demanding conditions.

In the past, mastic asphalt mixtures were used in the construction of the binder course for a orthotropic steel deck to ensure that has properties such as being watertight and compactable. In recent years, however, stone-mastic mixtures have been employed as an alternative in an increasing number of cases because it enables construction to be performed without the use of special construction machinery. However, depending on the site and serviceability conditions, problems have sometimes been experienced with regard to the bond of the stone-mastic mixture to the orthotropic steel deck, and there have been reports of damage occurring soon after a pavement had gone into service.

To address this, we have developed an epoxy asphalt mixture that satisfies the performance requirements for a binder course mixture such as the need for it to adhere to the orthotropic steel deck. To confirm the efficacy of this mixture, we performed a laboratory evaluation and conducted a trial construction as an on-site verification.

This article describes the basic properties of the epoxy asphalt mixture, a laboratory evaluation to investigate its application to a orthotropic steel deck, and a trial construction aimed mainly at confirming the feasibility of constructing a pavement with this mixture and the initial serviceability of a pavement constructed using this mixture.

KEY WORDS: Urban expressway, orthotropic steel deck pavement, epoxy asphalt, adhesive strength.

## 1 OUTLINE

The pavement design standard used by Nagoya Expressway Public Corporation stipulates use of mastic asphalt mixtures (MAM) as a standard material for the mixture to be applied to the binder course of the steel deck.

But MAM is poor in rutting resistance and can cause flow rutting particularly at places where the vehicle speed decreases due to congestion or start and stop of vehicles is repeated, and another mixture with higher durability is required at such places.

We developed the NEW epoxy asphalt mixture (EAM) and we used on a trial basis for new construction of the Kiyosu Route, Nagoya Expressway No. 6 for the purpose of improving durability of pavement at the off-ramp section.

This report summarizes the outline of the trial application of EAM.

## 2 EPOXY ASPHALT MIXTURE FOR THE BINDER COURSE OF ORTHOTROPIC STEEL DECK PAVEMENT

### 2.1 Introduction

EAM is a mixture composed of composite binders of petroleum asphalt and epoxy resin. It is also mentioned in Nagoya Expressway Public Corporation's pavement design standard (hereinafter "PDS"), where it is called "thermosetting asphalt mixture."

EAM has the following major characteristics:

- ○ It has high rutting resistance compared with MAM or other general asphalt mixtures.
- ○ It has deflection following performance and fatigue resistance almost equal to that of MAM and is therefore extremely suitable for use in orthotropic steel deck pavement.
- ○ Unlike MAM, EAM requires no special construction machinery or transport vehicles, and can be applied by following the same procedure as that used to lay down ordinary asphalt paving.

### 2.2 Proposed EAM

The newly developed type of EAM used in our trial construction (EAM for trial construction) has slightly different specifications from those specified in the PDS (thermosetting asphalt mixture). Table 1 compares the specifications of the two types of EAM.

Table 1: Comparison of thermosetting asphalt mixture and EAM for trial construction

| Item | Thermosetting asphalt mixture | EAM for trial construction |
|---|---|---|
| Shape of epoxy resin | Base compound and curing agent both liquid at room temperature | Base compound: Solid (candy-like)<br>Curing agent: semi-solid (wax-like) |
| Usable time of mixture | About 2 hours in general | 3 hours at least (from mix finish to initial rolling) |
| Occurrence of initial strength | Slow (curing necessary until it is opened to traffic) | Quick (openable to traffic when the temperature lowers below 50°C after paving) |
| Additive amount of epoxy resin | Asphalt 70: epoxy resin 30 | Asphalt 85: epoxy resin 15 |
| Mixture production process | Complicated<br>Heat epoxy resin to around 60°C (viscosity lowering) → Mix main compound and curing agent → Charge | Simplified<br>Manually charge the previously weighed main compound and curing agent. |

### 2.1.1 Shape of Epoxy Resin

While the type of epoxy resin specified in PDS is liquid at room temperature, the one used in our trial construction is solid in appearance, as shown in Figure 1.

Figure 1: Appearance of solid epoxy resin (left: base compound; right: curing agent)

2.2.2 Improvement of Initial Strength Occurrence and Reduction in Additive Amount

Since “thermosetting asphalt mixture” takes a longer time to show its initial strength, there are concerns that it may cause initial rutting, meaning that it will take longer before the road can be opened to traffic.

Table 2: Comparison of initial strength (dynamic stability)

| Test condition (curing) | Dynamic stability (times/mm) | | |
|---|---|---|---|
| | Thermosetting asphalt mixture (30% addition) | EAM for test construction (15% addition) | (Control) MAM |
| 3 hours | 131 | 6,300 | — |
| 6 hours | 203 | — | — |
| 3 days | 1,800 | — | 315 (2 days) |
| 7 days | 12,600 | 10,500 | — |

Source: Ishibashi et al., 1990

It was also necessary to set the ratio of the added epoxy resin to the total amount of binder to about 30% in order to obtain the initial strength necessary for the road to be opened to traffic.

“EAM for trial construction” contained solidified epoxy resin, which allowed us to reduce the additive amount to 15% to help bring out the characteristics of the thermal plastic resin, and ultimately achieve an early occurrence of the initial strength (see Table 2).

2.2.3 Simplification of the Mixture Production Process

Epoxy resins of “thermosetting asphalt mixture” are liquid and too viscous to handle. The complexity of the production process, such as the need to heat the resin to about 60°C in producing the mixture, is one of the problems that face conventional epoxy resins. When a solid epoxy resin is used, its mixture production process is simplified to a level equal to that of a general solid modifying agent or plant-based fiber, thereby remarkably improving the constructibility.

3 PROPERTIES OF EPOXY ASPHALT MIXTURE FOR TRIAL CONSTURACTION

3.1 Rutting Resistance

The wheel tracking test results for ten kinds of mixtures including “EAM for trial construction” are shown in Figure 2. The figure shows that “EAM for trial construction” has a dynamic stability of 21,000 (times/mm), which is higher than that of any other mixtures, indicating that it has a significantly higher rutting resistance than MAM, whose dynamic stability is 300 (times/mm).

The product names of watertight SMA and surface course SMA in the figure indicate that the mixture is produced with the emphasis on water-tightness and rutting resistance respectively. Both SMAs are added to fiber-reinforced materials at a volumetric ratio of 0.3% to the mixture weight. To allow comparison with general materials, coarse-graded and dense-graded asphalts were chosen from straight asphalts.

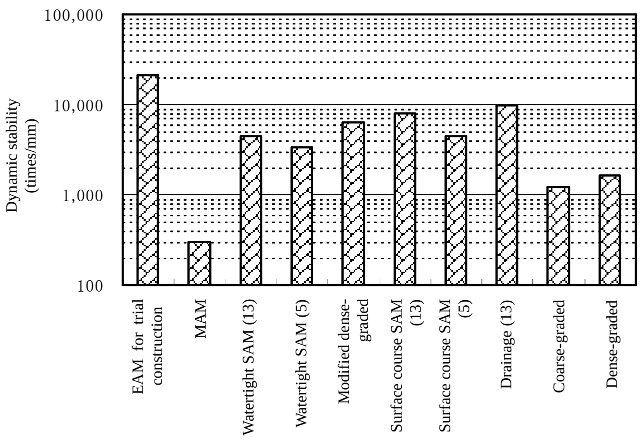


Figure 2: Wheel tracking test results

3.2 Deflection Following Performance and Fatigue Resistance

The bending fracture strain determined from the bending test results for each mixture is shown in Figure 3.

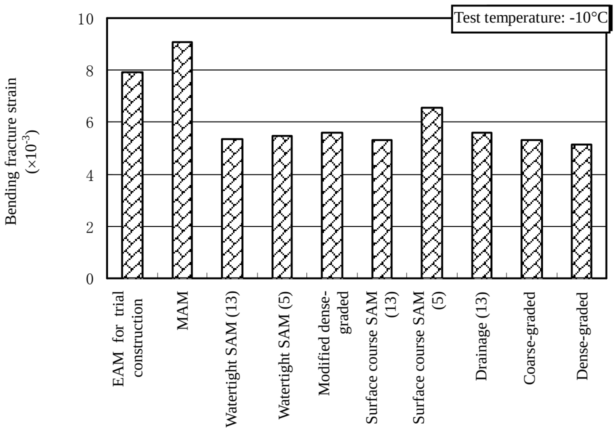


Figure 3: Bending test results

The bending fracture strain of “EAM for trial construction” is the highest after MAM. According to the PDS, the bending fracture strain of “thermosetting asphalt mixture” should be $5.0 \times 10^{-3}$ or higher (or $8.0 \times 10^{-3}$ or higher for MAM). Considering this standard, it is apparent that “EAM for trial construction” has a sufficient deflection following performance as a mixture for a orthotropic steel deck pavement.

The bending fatigue test results for each mixture are shown in Figure 4.

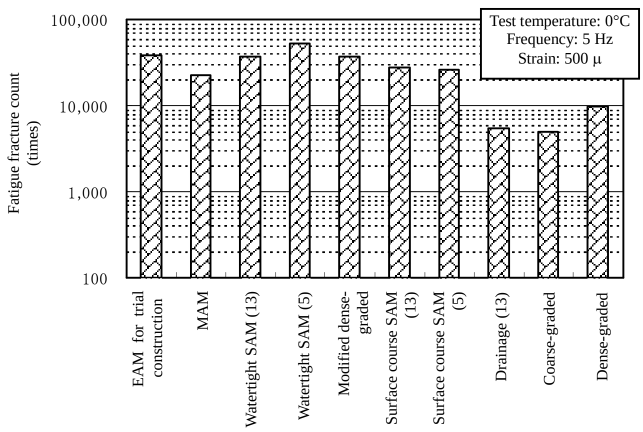


Figure 4: Bending fatigue test results

The fatigue fracture count of “EAM for trial construction” is larger than that of MAM, and the EAM has a fatigue resistance almost equal to SMA. The fatigue fracture count of the drainage asphalt (13), coarse-graded asphalt and dense-graded asphalt is small, indicating that these mixtures have an inferior failure resistance.

## 3.3 Bonding to Orthotropic Steel Decks

The bond strengths of the mixtures, used for the binder course of orthotropic steel deck paving, to orthotropic steel decks are compared in Figure 5. Both mixtures were provided with an adhesive course, and all the materials were provided with a watertight course except for MAM.

The results were obtained at a test temperature of 20°C, and they all satisfy the standard level for the 23°C test temperature as specified in the Waterproofing Handbook for Highway Bridge Slabs (Japan Road Association), or 0.6 N/mm$^2$ or higher. This indicates that “EAM for trial construction” has an adhesiveness to orthotropic steel decks that is equal to or higher than that of MAM.

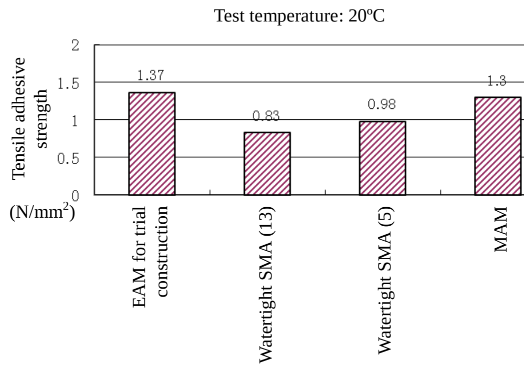


Figure 5: Bonding the mixtures to orthotropic steel decks

## 4 CONSTRUCTION

### 4.1 Application Site

The trial construction site was the Meidocho off-ramp section of the Kiyosu Route, Nagoya Expressway No. 6. The off-ramp section was selected for the following reasons:

- As the longitudinal grade is large (8%), we expected that MAM, when applied, would cause a run-off.
- Since we expect vehicles to often stop at that part after that section returns to service, the pavement, if done with MAM, may cause rutting.

The work involved applying “EAM for trial construction” to the binder course for the orthotropic steel deck to a thickness of 35 mm with an application area of 614 $m^2$.

### 4.2 Work procedure

The work procedure of the trial construction work is shown in Figure 6.

The adhesive course on the orthotropic steel decks, a waterproofing coating was also applied to improve the impermeability of the slab and the bonding of “EAM for trial construction” to the orthotropic steel decks.

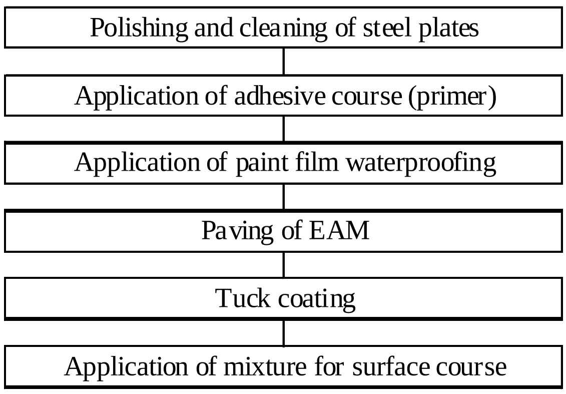


Figure 6: Work procedure

### 4.3 Mix Proportion of “EAM for trial construction” and Its Properties

The aggregate mix proportion and combined grading of “EAM for trial construction” are shown in Table 3, while the properties of the mixture are shown in Table 4. The standard values in the table are based on the PDS.

Table 3: Mix proportion of "EAM for trial construction"

| | | | |
|---|---|---|---|
| Aggregate mix proportion | No. 7 crushed stone | 46.0 | |
| | Coarse sand | 9.5 | |
| | Fine sand | 33.5 | |
| | Stone powder | 11.0 | |
| | Total | 100.0 | |
| Aggregate composite grading | Nominal size of sieve (mm) | Composite grading (%) | Target grading range (%) |
| | 13.2 | 100.0 | 100 |
| | 4.75 | 96.9 | 95 to 100 |
| | 2.36 | 58.1 | 45 to 65 |
| | 0.6 | 43.9 | 40 to 60 |
| | 0.3 | 28.3 | 20 to 45 |
| | 0.15 | 17.2 | 10 to 25 |
| | 0.075 | 11.1 | 8 to 13 |
| Amount of binder (%) | Total amount | 7.6 | |
| | St. 60/80 | 6.3 | |
| | Epoxy resin | 1.3 | |

## 4.4 Paving of "EAM for trial construction"

Since it is thin surfacing (t = 35 mm) and the temperature of mixtures is likely to decrease because of the pavement on the bridge surface, paving was conducted while carrying out careful and strict temperature control. The measurements of the mixture temperature and the number of rolling coverage satisfy the target values in either item as shown in Table 5. The time it took from shipment to the start of initial rolling was within 3 hours, which is the target for all dump trucks.

Table 4: Properties of "EAM for trial construction"

| Test item | Unit | Example of property | Standard or target | Curing condition, etc. |
|---|---|---|---|---|
| Marshall density | $g/cm^3$ | 2.395 | — | |
| Void ratio | % | 2.6 | 2 to 5 | |
| Saturation | % | 84.8 | 75 to 90 | |
| Marshall stability | kN | 40.39 | 19.6 or higher | Note 1 |
| Flow value | 1/100 cm | 25 | 80 or higher | Note 1 |
| Dynamic stability | time/mm | 6,300 | – | Note 2 |
| | | 10,500 | 5,000 or higher | Note 1 |
| Bending fracture strain | — | $7.14\times10^{-3}$ | $5.0\times10^{-3}$ or higher | Note 1 |
| Coefficient of permeability | cm/s | $4.56\times10^{-8}$ | $1.0\times10^{-6}$ or under | Note 1, 150 kPa in hydrostatic pressure |
| Note 1: Test conducted after 7 days of curing at 25°C<br>Note 2: Test conducted after 3 hours of curing at 60°C | | | | |

Table 5: Mixture temperature and the number of rolling coverage

| Management item | Description | Measurement timing | Unit | Target | Measurement result |
|---|---|---|---|---|---|
| Mixture temperature | Temperature at shipment | Immediately after mixing finish | °C | 155 to 175 | 165 to 170 |
| | Temperature at arrival | Before unloading | | 150 to 170 | 160 to 165 |
| | Spreading temperature | Immediately after passing of finisher | | 145 to 165 | 150 to 155 |
| | Initial rolling temperature | Upon rolling start | | 130 to 150 | 130 to 145 |
| | Secondary rolling temperature | Upon rolling start | | 100 to 120 | 100 to 115 |
| | Finish rolling temperature | Upon rolling start | | 70 or more | 75 to 85 |
| No. of rolling coverage | No. of initial rolling | – | times | 6 or more | 9 to 13 |
| | No. of secondary rolling | – | | 4 or more | 7 to 11 |
| | No. of finish rolling | – | | 4 or more | 5 to 7 |

As “EAM for trial construction” has a very fine grading and the epoxy resin is low in viscosity in a high-temperature state, “EAM for trial construction” is likely to cause hair-cracking during the initial rolling. In particular, there are concerns that hair-cracking may occur at places where the gradient is high.

As a solution, the following method of rolling was introduced for the trial construction.

(1) A compact steel roller (2.5 t) was used for the initial rolling.
(2) After the initial roiling, further rolling was conducted with a compact tire roller (3 t) as soon as possible to prevent the occurrence of hair-cracking.
(3) Lastly, finish rolling was conducted with a large tire roller (15 t).

The rolling work is shown in Figures 7 and 8.

Figure 7: Spreading with 3.75m width

Figure 8: Rolling by a compact tire roller(3t)

4.5 Confirmation of Bonding

One of the factors that determine the durability of a orthotropic steel deck pavement is the bond between the binder course and orthotropic steel decks. To confirm the adhesive strength, the adhesive strength test was conducted at the trial application site after paving.

It is known that the adhesive strength varies depending on the temperature. Therefore, an adhesive strength test with different temperatures was conducted on specimens produced during test mixing to prepare a temperature vs. adhesive strength curve in advance, and the test was conducted on “EAM for trial construction” after application. Adhesiveness was then evaluated by checking whether the measured value under the road surface temperature at the time of testing was on this curve.

The results of the adhesive strength tests conducted during the test mixing and trial application work are shown in Figure 9. The target values shown in Figure 9 are taken from the Waterproofing Handbook for Highway Bridge Slabs.

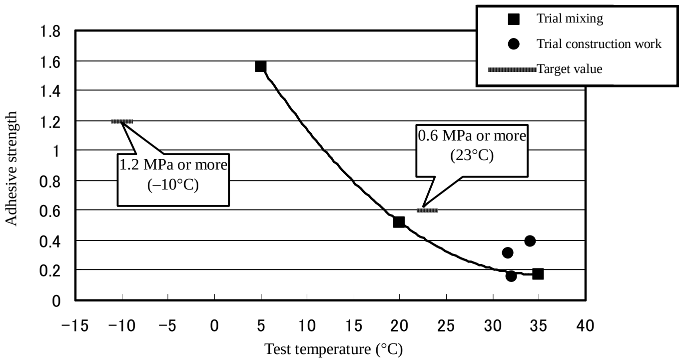


Figure 9: Adhesive strength test results

When the data are converted to temperatures of –10°C and 23°C, the values in the figure almost satisfy the target values. We then judged that an adhesive strength greater than the initially planned was achieved since all fracture points were located within “EAM for trial construction”.

## 5 FOLLOW-UP SURVEY RESULTS

Since the construction work was conducted as a trial application of EAM, a follow-up survey was to be conducted three times, or six months, one year and two years after opening the work site. Table 6 shows the follow-up survey results after the passage of one year. As the subject of evaluation is the mixture applied to the binder course, five evaluation items as shown in the table were used.

Satisfactory results, which fully comply with the allowable level, were achieved as shown in the table 6.

Table 6: Follow-up survey results

| Check item | Survey result | | Tolerance (target) |
|---|---|---|---|
| | 6 months later | 1 year later | |
| Cracking (visual check) | No cracking | No cracking | 20% or less |
| Rutting | 0 mm | 0 mm | 25 mm or less |
| Surface smoothness | 1.62 mm | 1.60 mm | 3.5 mm or less |
| Adhesion strength | | 1.10 MPa (20.2°C) | 0.6 Mpa or more (23°C) |
| Core density | 96.70% | — | Not less than 96.5% of the standard density (average over three) |

## 6 COMPARISON BETWEEN MAM AND EAM FOR TRIAL CONSTRUCTION

In a laboratory test and trial application, we confirmed that a proposed epoxy asphalt mixture that uses epoxy resin, the subject of our research, is fully applicable as a mixture for the binder course of orthotropic steel decks. The proposed “EAM for trial construction” was compared with MAM, generally used in the conventional method, in terms of characteristics such as constructibility and performance, as shown in Table 7. This comparison demonstrates that “EAM for trial construction” is fully capable of serving as an alternative to MAM for applications to the binder course of orthotropic steel deck pavement.

Table 7: Applicability comparison between MAM and “EAM for trial construction”

| Item | | MAM | EAM for test construction | Required performance of the mixture for steel plate deck binder |
|---|---|---|---|---|
| Construction machine | | Special machines necessary such as guss finisher, cooker, etc. | Executed with asphalt finisher, roller, or generally used equipment | — |
| Execution site | In terms of construction | Run-off of mixture feared at steep slope part | No particularly unsuited places | — |
| | In terms of service | Unsuitable to places where congestion or speed reduction is | No particularly unsuited places | — |
| Work volume | | 640 $m^2$/day | 1,900 $m^2$/ day | — |
| Rutting resistance (dynamic stability) | | About 300 to 500 times/mm Flow deformation is great when loading speed is low | 10,500 to 63,000 times/mm | MAM: 300 times/mm or more Epoxy asphalt: 5000 times/mm or more * 1 |
| Flexibility (bending fracture strain) | | Excellent | Almost equal to MAM | MAM: $8 \times 10^{-3}$ or more<br>EAM: $5 \times 10^{-3}$ or more * 1 |
| Watertightness | | Very excellent (impervious) | Almost equal to impermeability of $1\times 10^{-7}$ cm/s or less | EAM: $1 \times 10^{-6}$ cm/s or less * 1 |
| Adhesion with steel plate (adhesive strength) | | Excellent | Equal to or higher than MAM | 0.6 N/$mm^2$ or more (23°C)<br>1.2 N/$mm^2$ or more (–10°C) *2 |
| Repair | | Unsuited to small-scale repair | Impossible for small-scale repair | — |

* 1: Nagoya Expressway Public Corporation’s pavement design standard

* 2: Waterproofing Handbook for Highway Bridge Slabs (Japan Road Association, 2007)

## 7 CONCLUSION

This paper demonstrates that the epoxy asphalt mixture has high durability and exhibits excellent bonding properties with orthotropic steel decks. It also has excellent initial serviceability. We will continue to conduct follow-up surveys at the trial construction sites to verify its long-term performance.

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