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# Evaluation of plant-produced porous warm-mix asphalt mixture using LEADCAP additive

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**Abstract**: Warm-mix asphalt (WMA) technology was applied for asphalt mixture, plant-produced porous WMA using LEADCAP additive (porous WMA-LEADCAP) test section was built and compacted at 30 ℃ lower than porous hot-mix asphalt (porous HMA) test section. Marshall mix designs were conducted for porous WMA-LEADCAP mixture and porous HMA mixture in terms of Marshall stability, Cantabro loss and dynamic stability. The workability, compactablity and surface quality of porous WMA-LEADCAP pavement were investigated, and the engineering properties of plant-produced porous WMA-LEADCAP mixture and plant-produced porous HMA mixture were evaluated based on indirect tensile strength test and dynamic immersion test. Analysis result shows that LEADCAP additive does not affect polymer-modified asphalt in terms of penetration, softening point, viscosity, ductility, toughness and tenacity. Porous WMA-LEADCAP pavement has similar field density, permeability and smoothness compared with standard porous HMA pavement. Plant-produced porous WMA-LEADCAP mixture is equivalent to plant-produced porous HMA mixture in indirect tensile strength, toughness and stripping resistance. 4 tabs, 4 figs, 9 refs.

**Key words**: porous asphalt pavement; warm-mix asphalt; plant-produced type; indirect tensile strength; stripping resistance

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## 0 Introduction

One of the most dangerous problems on the road is hydroplaning. If rainwater cannot infiltrate into the ground where it falls, it will run off on pavements. Water on the road increases the risk of losing driving control due to the reduced friction of pavements. Porous asphalt pavement is a layer made of asphalt mixed with a high amount of interconnected air voids that drain out water quickly during a rainstorm. Generally, porous asphalt pavement is highly considered to improve driving control on wet surface condition, prevent visibility deterioration due to splash and spray, and reduce traffic noises[1]. In Japan, about 70% of expressway network system is paved with porous asphalt pavements since its introduction in the late 1980s, which has become the nation's defacto-standard in expressways and major highways by now. Warm-mix asphalt (WMA) technology is developed to allow asphalt mixtures to be produced and compacted at 30 ℃ lower than conventional hot-mix asphalt (HMA). Decreased production and application temperatures will provide several benefits, including reduced emissions, fumes, and odors, a cooler work environment, and evident

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energy savings[2].

However, current application of WMA technology has focused on conventional dense-graded asphalt pavement, rarely considered producing some mixtures, namely rubber asphalt mixture, stone mastic asphalt mixture and polymer-modified asphalt mixture. The main objectives of this study are to build porous WMA using LEADCAP additive (porous WMA-LEADCAP) test section, which is compacted at 30 ℃ low temperature compared to porous hot-mix asphalt (porous HMA) test section, investigate workability, compactablity and surface quality of porous WMA-LEADCAP pavement along with porous HMA pavement, and evaluate the engineering properties of plant-produced porous WMA-LEADCAP mixtures along with plant-produced porous HMA mixtures in terms of indirect tensile strength, toughness and stripping resistance. Marshall mix designs are conducted for porous WMA-LEADCAP and porous HMA mixtures in terms of Marshall stability, Cantabro loss and dynamic stability in the laboratory. The porous WMA-LEADCAP test section is constructed along with porous HMA test section to compare the workability, compactability and surface quality in the field. On the basis of the limited laboratory and field experiences, porous WMA-LEADCAP test section achieves a comparable density to a standard porous HMA test section. The porous WMA-LEADCAP mixture is also equivalent to a standard porous HMA mixture in the permeability, smoothness, strength, and stripping resistance. It is concluded that LEADCAP technology can be applied for porous warm-mix asphalt (WMA) pavement without the changes of volumetric characteristics and engineering properties.

## 1 Additive selection

Warm-mix asphalt (WMA) technology is available to decrease the production temperatures of asphalt mixture, improve the mixture workability at construction temperatures while reportedly maintaining or improving pavement performance. For this study, low energy and low carbon-dioxide asphalt pavement (LEADCAP) additive is selected and used in porous WMA mixture at significantly lower temperature than standard porous HMA mixture. The LEADCAP is an organic WMA additive, which has a wax-based composition including a crystal controller and an adhesion promoter. The crystal controller adjusts the wax crystallization at the low temperature, prevents the binder to show a brittle behavior, and the adhesion promoter acts as an effective bonding agent between aggregate and asphalt binder[3-4]. As a result, the LEADCAP additive would improve crack resistance at low temperature and enhance the moisture susceptibility of WMA mixture. This additive is typically added at the rates of 1.0% to 4.0% by weight of asphalt.

The LEADCAP additive melted in asphalt at 110 ℃ shows low viscosity because the molecular weight of wax is lower than that of average asphalt molecule. It behaves like lubricating oil during the mixing and compacting processes. As a result, it decreases the friction force between aggregates. Normal wax material is very stiff and brittle at low temperature under crystallization point. The asphalt mixture with normal wax-based WMA additive exhibits a high potential of cracking at low temperature. Crystal controller can adjust crystalline degree of wax material to avoid becoming too stiff and brittle at low temperature. The adhesion promoter is a metallic salt that has aggregate-philic part in one side and asphalt-philic part in other side. Aggregate-philic part of metallic adhesion promoter can fully coat the surface of aggregate to prevent the water invasion. Therefore, LEADCAP additive with adhesion promoter can resist the moisture damage. Lee et al evaluated moisture susceptibility and stripping resistance of WMA mixtures with LEADCAP additive and it was found that WMA mixtures with LEADCAP additive exhibited higher moisture resistance than a control HMA and other WMA mixtures[5]. Since 2010, in order to access the applicability of LEADCAP WMA additive to various asphalt mixtures, it has been applied to dense-graded asphalt mixtures in Portugal, Italy and Thailand, SBS polymer-modified porous asphalt mixture in Japan, and dense-graded asphalt mixture with reclaimed asphalt pavement (RAP) materials in the United States. It was examined that LEADCAP WMA additive can be used in various types of asphalt mixtures at significantly low temperature without any problems such as coating, segregation, mixing and compaction[6-7].

## 2 Properties of asphalt binder with/without additive

To compare the properties of PG 82-22 polymer-modified porous asphalt binders with/without LEADCAP additive, penetration, softening point, viscosity, ductility, toughness and tenacity are measured in Tab. 1. Based on the pavement works guideline of Japan road association (JRA), polymer-modified porous asphalt binders with/without 1.5% LEADCAP additive of asphalt weight are satisfied with JRA specification.

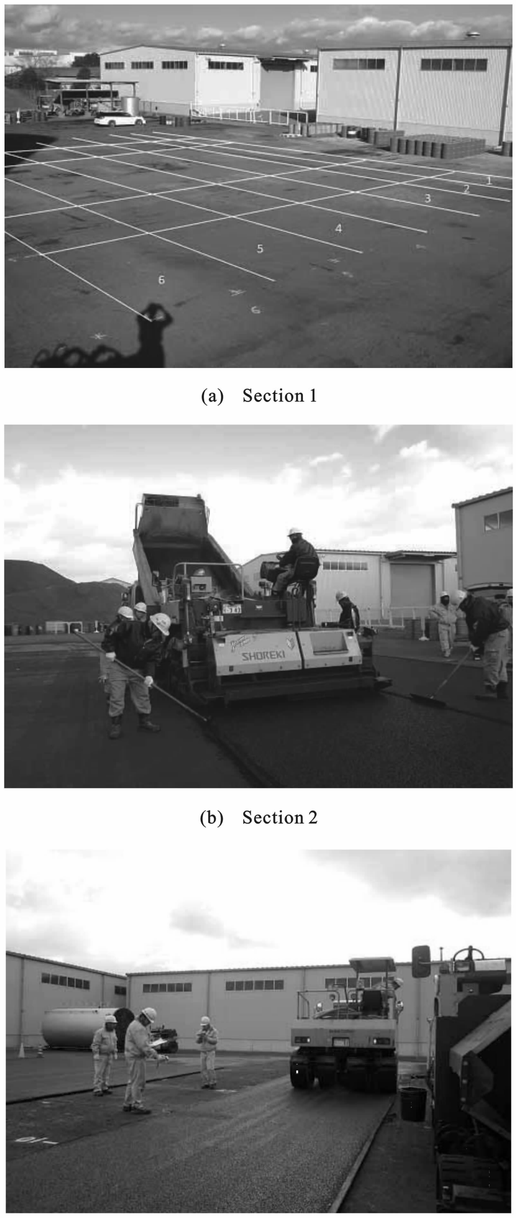
**Tab. 1 Test results of asphalt binders with/without additive**

| Parameter | Porous asphalt | Porous asphalt with LEADCAP additive | Target |
|---|---|---|---|
| Penetration/0.1 mm | 53 | 48 | ≥40 |
| Softening point/℃ | 93.0 | 91.5 | ≥80 |
| Viscosity(160 ℃)/(mPa·s) | 939 | 872 | |
| Ductility(15 ℃)/cm | 74 | 56 | ≥50 |
| Toughness/(N·m) | 20.0 | 20.1 | ≥20 |
| Tenacity/(N·m) | 11.6 | 11.4 | |

Penetration of polymer-modified porous asphalt with LEADCAP additive is slightly lower than that of polymer-modified porous asphalt without LEADCAP additive. However, the viscosity of polymer-modified porous asphalt with LEADCAP additive is obviously lower than that of polymer-modified porous asphalt without LEADCAP additive. It is postulated that LEADCAP additive does not affect penetration at 25 ℃ but affects viscosity at 160 ℃ because it is melted at 110 ℃.

## 3 Porous WMA test section

To investigate the workability and compactability of plant-produced porous WMA-LEADCAP mixtures, the porous WMA-LEADCAP test sections were built along with standard porous HMA test section in Himeji, on December 25th, 2011, as shown in Fig. 1.




(a) Section 1

(b) Section 2

(c) Section 3

Fig. 1 Porous WMA-LEADCAP test sections

### 3.1 Mix design results

Marshall mix designs are conducted for both standard porous HMA mixture and porous WMA-LEADCAP mixture. Mix design parameters used for both mixtures are same and only differences between those mixtures are mixing and compaction temperatures. The standard porous HMA mixtures are produced at 180 ℃ and compacted at 155 ℃ while the porous WMA-LEADCAP mixtures are produced at 150 ℃ and compacted at 125 ℃. As summarized in Tab. 2, both porous HMA and porous WMA-LEADCAP mixtures are satisfied with JRA specification.

### 3.2 Production and compaction temperatures

As shown in Fig. 2, at the same asphalt plant, the standard porous HMA mixture is produced at 184 ℃ and the porous WMA-LEADCAP mixture is produced at 154 ℃. Tab. 3 shows the temperature informations of standard porous HMA mixture and porous WMA-LEADCAP mixture. The production and compaction temperatures of porous WMA-LEADCAP mixture are selected at 30 ℃ lower temperature than typical porous HMA mixture, which is produced at 190 ℃ and compacted at 150 ℃ in Japan.

(a) Standard porous HMA mixture (b) Porous WMA-LEADCAP mixture

Fig. 2 Productions of standard porous HMA mixture and porous WMA-LEADCAP mixture

**Tab. 2 Mix design results**

| Design parameter | Porous HMA mixture | Porous WMA-LEADCAP mixture | Target |
|---|---|---|---|
| Marshall stability/kN | 6.00 | 5.11 | ≥3.5 |
| Marshall flow value/ 0.1 mm | 31 | 43 | |
| Cantabro loss at 20 ℃ (Standard)/% | 8.1 | 10.1 | ≤20 |
| Cantabro loss at 20 ℃ (Water immersion)/% | 8.3 | 13.3 | ≤20 |
| Dynamic stability (Cycle)/mm | 5 730 | 4 850 | ≥3 000 |

**Tab. 3 Temperature informations**

| Temperature/℃ | Porous HMA mixture | Porous WMA-LEADCAP mixture | Reduction |
|---|---|---|---|
| Production | 184 | 154 | −30 |
| Lay-down | 174 | 147 | −27 |
| Initial compaction | 148 | 118 | −30 |
| Ending compaction | 103 | 100 | −3 |

### 3.3 Field density and surface quality

To examine the compactability of porous WMA-LEADCAP test section, several samples are cored to measure their weights in air, water, and saturate surface conditions and calculate the field density. Porous WMA-LEADCAP pavement achieves 99% of the required relative density level for standard porous HMA pavement. It indicates that LEADCAP additive would be effective in producing and compacting porous WMA mixture that is comparable to standard porous HMA mixture. After the completion of compaction process, field permeability and smoothness are measured at both test sections, as summarized in Tab. 4. Permeabilities and smoothnesses of porous HMA and porous WMA-LEADCAP pavements are satisfied with JRA specification.

**Tab. 4 Permeability and smoothness**

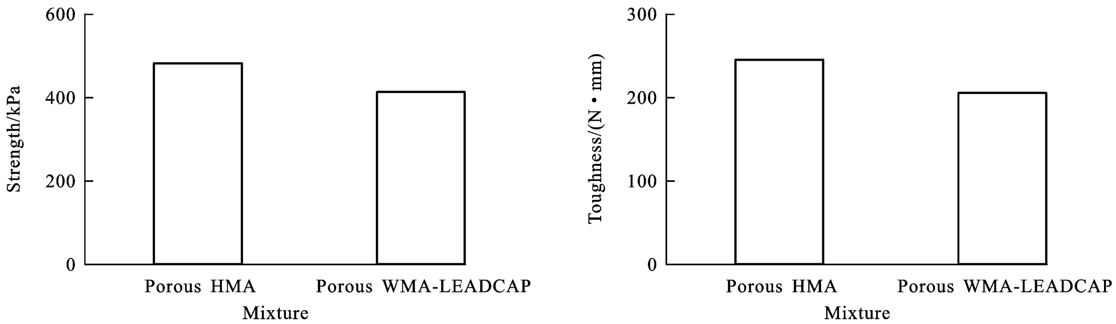
| Surface quality | Porous HMA mixture | Porous WMA-LEADCAP mixture | Target |
|---|---|---|---|
| Permeability ratio/ [mL·(15 s)$^{-1}$] | 1 192 | 1 230 | ≥1 000 |
| Smoothness/mm | 1.40 | 2.19 | ≤2.4 |

## 4 Evaluations of engineering properties

In order to evaluate the engineering properties of plant-produced porous WMA-LEADCAP mixture along with porous HMA mixture, indirect tensile strength test and dynamic immersion test are conducted to determine strength, toughness and stripping resistance.

### 4.1 Indirect tensile strength test

The indirect tensile strength test is performed on three test specimens for each mixture in accordance with ASTM D4123-82[8]. The Marshall compacted specimens are placed and cured in the oven at 25 ℃ for 2 h before the test. Fig. 3 shows the average indirect tensile strengths and toughnesses of standard porous HMA mixture and porous WMA-LEADCAP mixture along with their standard deviations. As can be seen from Fig. 3, the average indirect tensile strength of three porous WMA-LEADCAP specimens is 413 kPa whereas that of three porous HMA specimens is 483 kPa. Overall, the indirect tensile strength and toughness of porous WMA-LEADCAP mixture are slightly lower than those of standard porous HMA mixture.



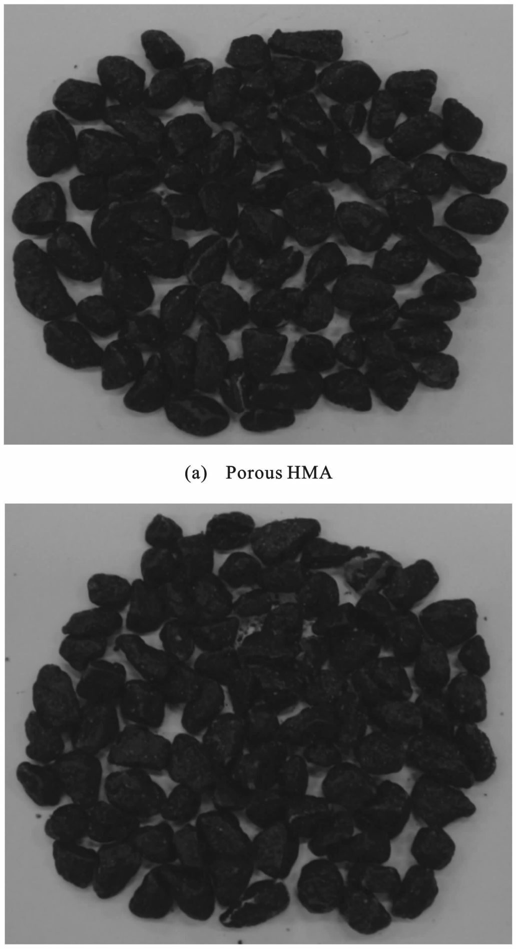

(a) Indirect tensile strength (b) Toughness

Fig. 3 Test results of porous HMA mixture and porous WMA-LEADCAP mixture

### 4.2 Dynamic immersion test

The dynamic immersion test following BS EN 12697-11: 2003 is performed to evaluate the stripping resistance of loose porous WMA-LEADCAP mixture along with loose porous HMA mixture[9]. The individual aggregates from the mixtures are placed in the pan at room temperature for 24 h. 115 g of aggregates are placed into a closed 250 mL glass vessel with 100 mL of distilled water. The glass vessel is carried out in a rotating device at the speed of 40 r • $min^{-1}$ at 25 ℃ for 24 h. After the completion of dynamic immersion test, the aggregates are dried in the oven at 60 ℃ for 24 h.

Stripping resistance is estimated by visual observation with individual particles of aggregates and percentage of asphalt stripped off the aggregates. As shown in Fig. 4, based on the visual observation, aggregates coated with polymer-modified porous WMA-LEADCAP are not stripped as well as polymer-modified porous HMA. The stripping caused by water in loose asphalt mixtures is determined as a loss of asphalt weight after the completion of dynamic immersion test. Percent weight loss of asphalt of porous WMA-LEADCAP mixture is 9.3% and that of



(a) Porous HMA

(b) Porous WMA-LEADCAP

Fig. 4 Visual observations of aggregate particles porous HMA mixture is 8.2%. It can be postulated that LEADCAP additive does not negatively affect asphalt/aggregate adhesion in polymer-modified porous warm-mix asphalt mixture at low mixing and compaction temperatures.

## 5 Conclusions

Typically, standard porous hot-mix asphalt mixture is produced at temperatures between 180 ℃ and 190 ℃ to ensure that aggregate is dry, the asphalt binder coats the aggregate, and the mixture has a suitable workability. A number of new warm-mix asphalt processes and products are available to reduce the temperature at which the asphalt mixtures are produced and compacted, apparently without compromising the performance of the pavement.

In this paper, the use of LEADCAP additive is investigated for the plant-produced porous warm-mix asphalt mixture along with standard porous HMA mixture. On the basis of laboratory and field experiences, the following conclusions are derived.

(1) LEADCAP additive does not affect polymer-modified asphalt in terms of penetration, softening point, viscosity, ductility, toughness and tenacity.

(2) Porous WMA-LEADCAP pavement exhibits a similar field density, permeability, smoothness compared with standard porous HMA pavement.

(3) Plant-produced porous WMA-LEADCAP mixture is equivalent to plant-produced porous HMA mixture in indirect tensile strength, toughness and stripping resistance.

(4) Overall, LEADCAP additive is effective in the production and compaction of porous WMA mixture at 30 ℃ lower than standard porous HMA mixture.

(5) Further researches are necessary to investigate long-term field performance in actual pavement under real loading and environmental condition.

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