engineering proceedings

Proceeding Paper

Development of Plant-Mix-Type Modified Mixture with Excellent Flexibility and Stress Relaxation Properties for Ensuring High Resistance to Cracking †

Nhat Thanh Tran * and Masashige Aoki

Institute of Research and Development, Taisei Rotec Corporation, Kamiya Kounosu, Saitama 1456, Japan; masashige_aoki@taiseirotec.co.jp
* Correspondence: tran_thanh_nhat@taiseirotec.co.jp

† Presented at the Second International Conference on Maintenance and Rehabilitation of Constructed Infrastructure Facilities, Honolulu, HI, USA, 16–19 August 2023.

Abstract: Over the past few years, in order to extend the service life of pavements, the authors developed a special asphalt mixture that adequately prevents the ingress of water from the foundation layer of the asphalt into the top layers. The highly flexible mixture with a premix-type modified asphalt has been applied on a road, and the mixture showed excellent cracking performance in serviceability. Since the highly flexible mixture uses a premix-type modified asphalt that is transported by an asphalt tanker truck, it is difficult to manufacture in small quantities for responding to small-scale and emergency constructions. In order to deal with this difficulty, the present study developed a plant-mix-type modified asphalt mixture using a special additive at the plant. The laboratory tests and field evaluation results indicated that both the premix-type asphalt mixture and the plant-mix-type modified asphalt mixture exhibited excellent flexibility and stress relaxation properties.

Keywords: asphalt mixture; premix; plant-mix; reflection cracks; low-temperature cracking; flexibility; stress relaxation

Citation: Tran, N.T.; Aoki, M. Development of Plant-Mix-Type Modified Mixture with Excellent Flexibility and Stress Relaxation Properties for Ensuring High Resistance to Cracking. *Eng. Proc.* **2023**, *36*, 20. https://doi.org/10.3390/engproc2023036020

Academic Editor: Hosin (David) Lee

Published: 4 July 2023

1. Introduction

An increase in the traffic volume of heavy vehicles may increase cracks in the asphalt layer, resulting in allowing water to ingress from the foundation layer to the asphalt layer. This also weakens the foundation layer and subgrade, thereby reducing the rutting resistance, cracking resistance, and interlayer adhesion of the pavement [1,2]. In Japan, there are large differences in temperatures and rainfall among the four seasons, potentially leading to rainwater infiltration, rutting in summer, and cracking in winter. Therefore, the authors have developed a special asphalt mixture using a premix-type asphalt binder, which effectively prevents reflection cracks and has high resistance to low-temperature cracking and rutting. The highly flexible mixture has been applied in the field, and the mixture shows excellent cracking resistance on construction sites [3]. However, because the highly flexible mixture uses a premix-type modified asphalt binder that is transported by an asphalt tanker truck, it is challenging to produce small quantities to supply for small-scale and emergency constructions.

The main objective of this study was to develop a plant-mix-type modified asphalt mixture by mixing special additives when the mixture is manufactured at the plant. This study also presented the laboratory test results and field evaluation results of the premix-type asphalt mixture and the plant-mix-type modified asphalt mixture that exhibited excellent flexibility and stress relaxation properties.

2. Concept Development of the Special Asphalt Binder

In order to design the properties of the asphalt binder, the various types of binder tests and asphalt mixture tests were investigated based on the common causes of cracks in asphalt pavement [3]. Styrene-butadiene-styrene (SBS) and special petroleum resin were used together to modify the premixed asphalt [3]. The special process oils were also applied to improve the ductile performance of the butadiene in SBS [3]. By using these materials, it is possible to achieve a mixture that has both high cracking resistance and rutting resistance [3].

The plant-mix-type additive, which is added to polymer-modified asphalt type II (PMA II), is a resin that has high flexibility and stress relaxation. Because the gel in the additive shows extremely high viscosity, the plant-mix-type additive is wrapped in hot-melt resin, making this additive easier to convey, weigh, and store in a plant. The shape of the plant-mix-type additive is shown in Figure 1.

Figure 1. The shape of plant-mix-type additive.

3. Experimental Work, Results and Discussion

3.1. Characterization Tests of Asphalt Binder

The plant-mix-type modified asphalt binder (plant-mix binder) was prepared by adding the plant-mix-type additive into the PMA II. Table 1 shows the results of the asphalt binder test for each type of binder. The penetration index (PI) values of plant-mix binder and premix binder, which indicates the temperature sensitivity of the asphalt binder, were higher than that of the PMA II. This means there is little change in performance between low and high temperatures for the highly flexible mixture. In addition, the viscosity of the plant-mix binder and premix binder is higher than that of the PMA II at 60 °C, thereby ensuring a high rutting resistance of the highly flexible mixture. Furthermore, the results of the fragility point, bending test, and $|G^*|\sin\delta$ indicated the highly flexible mixture may have high resistance to fatigue cracking and low-temperature cracking.

Table 1. The binder test results of plant-mix binder, premix binder, and PMA II.

Properties		Plant-Mix Binder	Premix Binder	PMA II
Penetration	1/10 mm	146	135	54
Penetration index PI		8.9	9.3	1.6
Viscosity at 60 °C	Pa·s	7320	9670	2574
Fragility point	°C	−30	−34	−14
Fracture energy (−20 °C)	$\times 10^{-3}$ MPa	1583	1028	157
Fracture toughness (−20 °C)	MPa	40	32	270
Dynamic shear $|G^*|\sin\delta$ (25 °C) *	10^5 Pa	0.9	0.6	9.5

* The DSR test was conducted using 8 mm plates, 10 rad/s, 1% strain, and 1 mm samples.

3.2. Characterization Tests of Asphalt Mixture

Table 2 presents the characteristics of aggregate gradation investigated in this study. The aggregate gradation was typically designed to investigate a dense-graded mixture (13F) with a 12.5 mm nominal maximum particle size. In the design, the asphalt content (5.4%) of the highly flexible mixture (plant-mix binder and premix binder) and the PAM II mixture was determined in accordance with the Japanese pavement construction handbook [4], which was the same as the common protocol for asphalt mixtures. As shown in Table 3, the resistance to cracking at low temperature, fatigue, and rutting of these mixtures were evaluated in the laboratory by three-point bending beam (TPBB) test [5,6], four-point bending fatigue (FPBF) test [5], and wheel tracking test (WTT) [5,7].

Table 2. The aggregate gradation for all asphalt mixtures.

Sieve size (mm)	19.0	13.2	4.75	2.36	0.600	0.300	0.075
Criteria (%)	100	95~100	52~72	40~60	25~45	16~33	8~13
Percent passing (%)	100	99.8	71.3	54.3	33.3	20.6	8.0

Table 3. Tests and evaluations in the laboratory.

Evaluation	Test	Standard
Cracking resistance	TPBB test (−15 °C~15 °C, 6.25 × 10^{-3} 1/s strain rate)	JRA-B005
Fatigue resistance	FPBF test (5 °C, 5 Hz, 400 µm)	JRA-B018T
Rutting resistance	WTT (60 °C, 686 N, 42 cycles/min)	JRA-B003

Figure 2 shows the relationships of temperature with tension stress and tension strain of the TPBB test. The results shown in Figure 2a indicated that the brittleness temperature of the plant-mix flexible mixture, the premix flexible mixture, and the PMA II mixture were −10 °C, −15 °C or less, and 5 °C, respectively. This means that under the same loading, the highly flexible mixtures have lower failure temperatures than those of the PMA II mixture. Therefore, the highly flexible mixtures showed ductile performance in a wide temperature range on the low-temperature side. In addition, the results shown in Figure 2b illustrated that the tension strain values of the highly flexible mixtures tended to be more than twice higher than those of the PMA II mixture at the brittle region. Therefore, the highly flexible mixtures potentially showed excellent flexibility at low temperatures.

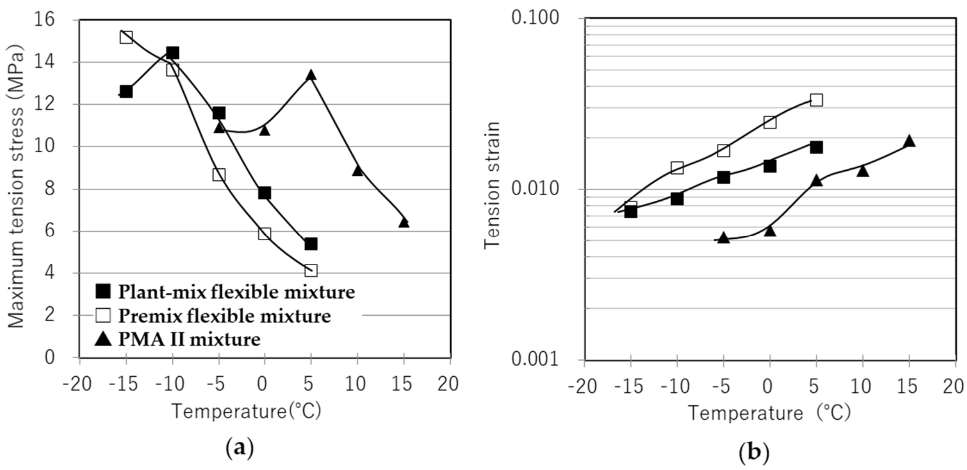

Figure 2. Relationships of temperature with tension stress (**a**) and tension strain (**b**) of TPBB test.

The results of FPBF test demonstrated that the number of cycles to failure of the plant-mix flexible mixture, the premix flexible mixture, and the PMA II mixture were 770,000 cycles, 830,000 cycles, and 14,000 cycles, respectively. There was no significant difference in the results between the plant-mix flexible mixture and the premix flexible mixture. The results also indicated that the fatigue resistance of the highly flexible mixtures was more than 50 times higher than that of the PMA II mixture.

The results of WTT showed that the dynamic stability (DS) values (which indicates the passing wheel load per 1.0 mm of rut depth [7]) of the plant-mix flexible mixture and the premix flexible mixture were greater than or equal to 6000 cycles/mm, which were the same as the results obtained from the PMA II mixture.

4. Plant Results and Discussion

Figure 3 shows the mixing steps of the plant-mix-type modified asphalt binder for the flexible mixture at the plant. The FPBF test results demonstrated that the number of cycles to failure of the plant-mix flexible mixture produced at the plant was more than 1 million cycles (the test was set up to stop at 1 million cycles), which was higher than the result obtained from the laboratory mentioned in Section 3.2. In addition, the WTT results indicated that the DS values of the plant-mix flexible mixture were greater than or equal to 6000 cycles/mm, which were the same as the results obtained from the laboratory.

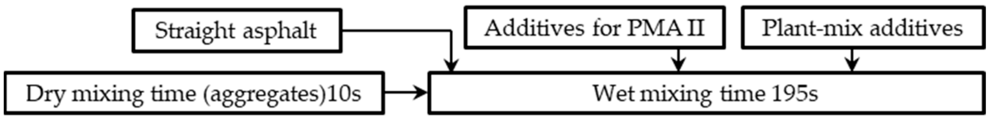

Figure 3. Mixing process of the plant-mix flexible mixture in the plant.

5. Field Test Section for Validation of the Plant-Mix Flexible Mixture

In 2003, the present study applied the premix flexible mixture to construct a national highway in cold regions. After 18 years, the crack growth rate of the premix flexible mixture on construction sites was ten times lower than that of the PMA II mixture, indicating the excellent cracking resistance of the premix flexible mixture [8].

Since 2019, the plant-mix flexible asphalt mixture has been also manufactured in small quantities (about 20 tons) for responding to small-scale and emergency constructions. As shown in Figure 4, after 2 years, the cracking and rutting performance of the test sections in Ishikawa Prefecture Japan were monitored. The results demonstrated that rutting and cracking did not occur in the test sections.

Figure 4. Views of the test section in Ishikawa Prefecture ((**a**) 2019 and (**b**) 2021).

6. Conclusions

The findings of the present study can be summarized as follows:

- The present study developed a premix flexible mixture and a plant-mix flexible mixture that have both high cracking resistance and high rutting resistance.
- Using the plant-mix flexible asphalt mixture is an effective solution for manufacturing a highly flexible asphalt mixture in small quantities that is able to respond to small-scale and emergency constructions.

Author Contributions: Conceptualization, N.T.T. and M.A.; methodology, N.T.T. and M.A.; formal analysis, N.T.T.; investigation, N.T.T. and M.A.; data curation, N.T.T. and M.A.; writing—original draft preparation, N.T.T.; writing—review and editing, N.T.T. and M.A.; visualization, M.A.; supervision, M.A. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: No new data were created or analyzed in this study. Data sharing is not applicable to this article.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Japanese Ministry of Land, Infrastructure, Transport and Tourism. *Pavement Inspection Guidelines*; MILT: Tokyo, Japan, 2016.
2. Takahashi, S.; Ono, Y.; Sato, M. Project for detailed instructions on asphalt pavement. *Pavement* **2016**, *51*, 13–19.
3. Konno, M.; Otomo, N.; Isayama, H.; Kokufuda, Y. Development of asphalt binder with high rutting resistance and high cracking resistance. *Road Constr.* **2017**, *765*, 63–69.
4. Japan Road Association. *Pavement Construction Handbook*; Japan Road Association: Tokyo, Japan, 2006.
5. Japan Road Association. *Pavement Handbook and Test Method Handbook*; Japan Road Association: Tokyo, Japan, 2019; Volume 3.
6. Tran, N.T.; Takahashi, O. A comparative analysis of the fracture performance of wearing course mixtures under different geometries, compactions, and aggregate gradations. *Int. J. Pavement Eng.* **2020**, *21*, 1703–1715. [CrossRef]
7. Tran, N.T.; Takahashi, O. A comprehensive evaluation of the effects of aggregate gradation on the shear strength properties of wearing course mixtures. *Int. J. Pavement Eng.* **2021**, *22*, 550–559. [CrossRef]
8. Karaki, K.; Kizawa, S.; Okajima, H. Long-term performance of specially modified asphalt mixture with excellent cracking resistance. In Proceedings of the 34th Japan Road Conference, Tokyo, Japan, 4–5 November 2021. Paper 3018.