Development of Warm-Mix-Asphalt Mixture Using Paper Sludge Ash

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ABSTRACT: The low emission such as carbon dioxide is also demanded for the road pavement industry. In this paper, the warm-mix-asphalt mixture that can decrease the temperature at the construction of asphalt pavement is reported. The main material of the warm-mix-asphalt mixture developed by author is artificial zeolite. The artificial zeolite is converted from the paper sludge ash or the fly ash by chemical processing. The artificial zeolite has fine pores and generates the micro bubbles in asphalt. It paid attention to this characteristic, treatment as the warm-mix-asphalt mixture is performed to the artificial zeolite. Use to the use of this mixture, it is confirmed to be able to decrease the mixing temperature of the asphalt mixture at 30°C by the laboratory experiment. Moreover the property changes of asphalt with the warm-mix-asphalt mixture are investigated. And by paving the actual road experimentally, the present study reports that there is no problem for manufacturing and the construction work of the asphalt using the warm-mix-asphalt mixture.

KEY WORDS: energy conservation, carbon-dioxide emissions, environmental, artificial zeolite, effective use for industrial another waste.

1 INTRODUCTION

Recently, amid calls for prevention of global warming, efforts to preserve and improve the global environment are being made worldwide based on the Kyoto Protocol. The asphalt pavement industry in Japan also has its self-help aim of reducing CO_2 emission. Normal asphalt mixtures consume fuel such as fossil fuel to be produced by being heated to 160–180°C. Although there is a technology for producing warm-mix asphalt mixtures, which reduces environmental load, the quality of asphalt pavement has not yet been established(Barthel, 2004). However, this technology for producing warm-mix-asphalt mixture may reduce energy consumption, such as fossil fuel, for heating and may dramatically reduce environmental load. Hence, we will establish the warm-mix technology, which forms fine foam in the asphalt by adding zeolite to the asphalt heated to about 130°C, by focusing on the crystalline void and ion-exchange capacity among chemical and physical characteristics of zeolite. In this study, research and development were carried out on an add-in warm-mix material whose major component was an artificial zeolite that can be produced by converting the paper sludge ash (Hereafter, it is designated as PS ash) discharged from the paper manufacturing industry (Henmi, 2003). Moreover, a laboratory experiment was performed on the technology for producing warm-mix-asphalt mixtures by the prototype add-in warm-mix material. The results of the experiment are described below.

2 MATERIAL OF MIDDLE TEMPERATURE

2.1 Artificial Zeolite of P S Ash

As for the artificial zeolites used in this study, we chose materials that contain zeolites obtained by alkali-treating the PS sludge ash. Based on the result of a fundamental experiment, as for the zeolites contained in the artificial zeolites, we chose to study about three types: faujasite; phillipsite (NaP1); and zeolite A, and those artificial zeolites have two kinds of cations. We chose these types of artificial zeolites, because they can be effectively produced by converting the PS ash. Six kinds of an artificial zeolite are shown below.

a) Zeolite A-Na
b) Zeolite A-Ca
c) Faujasite -Na
d) Faujasite -Ca
e) NaP1-Na
f) NaP1-Ca

2.2 Improvement of Form Performance of Artificial Zeolite

(1) Theoretical Analysis
Although foam formation occurs in asphalt because of physical micro voids in the artificial zeolite, since the forming time was short, we chose to study about foaming aids in order to improve the artificial zeolite. We studied about adsorption behavior of water molecules and ethanol by a theoretical analysis by the molecular orbital method(Matsue, 1992). Figure 1 shows the result of adsorbability of water molecules and ethanol. According to the result of the analysis, forms of adsorption are almost the same among the target types of artificial zeolites (Faujasite, Zeolite A, and NaP1). Therefore, according to the adsorbability in the analysis result of FS, the optimal foaming aid is considered to be water. Moreover, as for the type of the artificial zeolite, since adsorbabilities of both water molecules and ethanol are smaller in Na type than in Ca type, Na type is considered better suited for the main component of the warm-mix material.

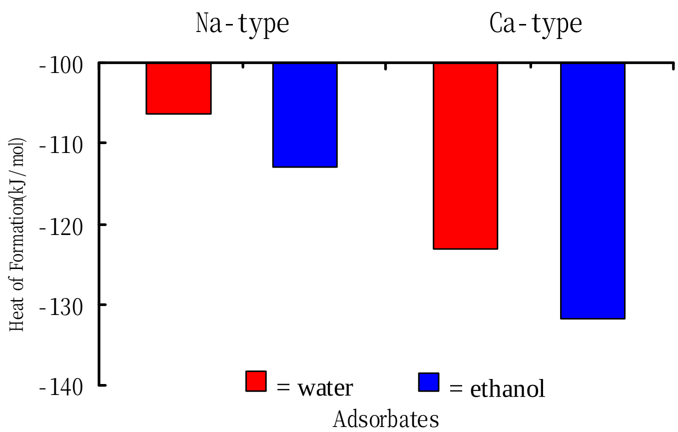

Figure 1: adsorption energy

(2) Thermal Analysis

With the analysis result and an experiment for confirming foam formation in mind, calculation of foam formation and support for each type was performed by heat analysis and the synthetic zeolite. The aimed foaming aids were water, methanol, ethanol, and isopropyl alcohol. The Ca-zeolite was obtained by washing the Na-zeolite by 1M solution of $CaCl_2$.

Table 1 shows the result of the analysis. Based on the result of the heat analysis, it is considered that NaP1-Na type, which released the supported water at a lower temperature, is considered the best suited for warm-mixing of asphalt.

Table 1: thermal analysis result

type	discharge temperature(°C)			
	water	methanol	ethanol	iso-propyl alcohol
type-A-Na	138.6	136.5	141.3	141.5
type-A-Ca	190.8	192.3	189.5	198.5
faujasite-Na	128.9	137.7	130.1	135.1
faujasite-Ca	142.2	147.3	152.1	150.4
NaP1-Na	121.5	111.2	105.6	137.6
NaP1-Ca	127.9	132.4	106.7	122.5

(3) Form Experiment

To validate the results obtained by the theoretical and heat analyses, we performed a foaming experiment of asphalt. The procedure for containing water in the synthetic zeolite is as follows.

a) synthetic zeolite is heated at 200°C
b) Return it at the normal temperature
c) An impregnation in water for 24 hours
d) The one inclusion having soaked it strained in the furnace paper
e) Preservation for 24hours in constant of 20°C and 50%R.H.

Table 2 shows the result of the foaming experiment, and Figure 2 shows an example of foaming situations. According to the result of the foaming experiment, foaming time was longer in Faujasite-Na type and Zeolite A-Na type. Moreover, according to the result of a visual observation, amount of foam was large in the order Zelite A, Faujasite, NaP1. However, to lower the normal mixing temperature of 160°C by warm-mixing-asphalt mixture, piecing together the results of the theoretical and heating analyses, NaP1-Na type is considered suitable for the warm-mix material. Hence, we chose the Na-artificial zeolite with its zeolite seed of NaP1 as the object of the prototype warm-mix material.

Table 2: foam experiment result

type	foam duration time(min)	
	water	ethanol
type-A-Na	80	95
type-A-Ca	34	60
faujasite-Na	58	132
faujasite-Ca	58	72
NaP1-Na	57	92
NaP1-Ca	15	58

Figure 2: foam experiment (30min example)

(4) Trial Manufacture of Warm-Mix Material

(a) Conversion Manufacturing of Artificial Zeolite

The zeolites used in the above mentioned theoretical analysis, heat analysis, and foaming experiment were synthetic zeolites. However, for the prototype warm-mix material, we chose to use NaP1-Na artificial zeolite derived from PS ash. We used an artificial zeolite with its zeolite content of about 30% and ion-exchange capacity, which is used for performance evaluation of zeolite, of 200, and its water content was adjusted to 30% to use it as the main component.

(b) Foam-Enhancing Agent (Surfactant)

According to the result of the foaming experiment, amount of foam and foaming time need to be increased. Hence, to improve foamability of the warm-mix material, as a means to increase and strengthen the adsorptive retention of water, which is a promoter, on the artificial zeolite, we searched for a foam-enhancing agent.

As foam-enhancing agents, we chose to use anionic, nonionic, and cationic surfactants, and as an effect of the surfactant alone, amount of foam and foaming time of asphalt, also under the conditions of A-2 shown in Table 3, were measured. Table 3 shows the types of warm-mix materials that were processed and produced. The measurement results of the amount of foam and foaming time showed that the amount of foam was improved to the maximum 1.4 times in the case of the anionic surfactant and the same asphalt volume ratio, and that the foaming duration was improved to 120 min. Figure 3 shows the measurement result of the amount of foam and elapsed time.

Table 3: material-type of middle temperature

NO. of type	surfactant	additive rate (%)
A-1	anionic	5
A-2	anionic	50
B	nonionic	5
C	cationic	5
Z	zeolite only	0

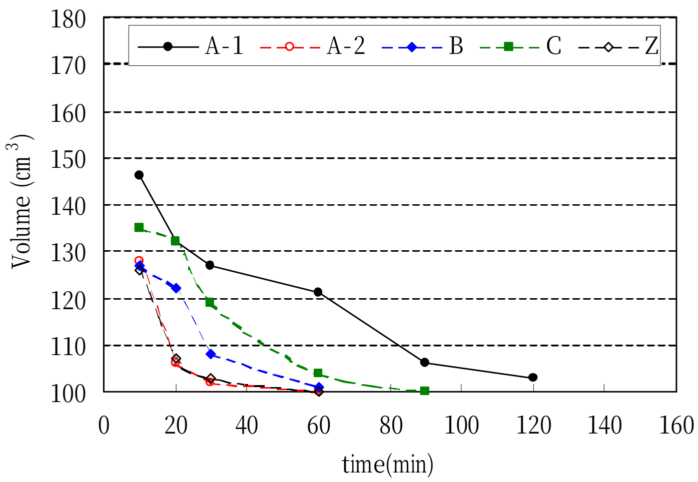

Figure 3: amount of foam-elapsed time

3 INDOOR EXPERIMENT OF ASPHALT MIXTURE

3.1 Indoor Mixture Experiment

The addition experiment condition to the asphalt mixture is shown below.

a) 160°C in mixture temperature (normal, TEST NO.1)
b) 130°C in mixture temperature (normal, TEST NO.2)
c) 90°C in mixture temperature (normal, TEST NO.3)
d) 130°C in mixture temperature (A-1, post-addition ,TEST NO.4)
e) 130°C in mixture temperature (A-1, pre-addition, TEST NO.5)
f) 130°C in mixture temperature (A-2, post-addition , TSET NO.6)
g) 130°C in mixture temperature (B, post-addition , TEST NO.7)
h) 130°C in mixture temperature (C, post-addition , TEST NO.8)
i) 130°C in mixture temperature (Z, post-addition , TEST NO.9)

The addition method was decided by the trial and error in a preliminary experiment. The list of experimental conditions and the list of the mechanical properties are shown in Table 4. Figure 4 shows the density by the Marshall test specimen and the Marshall stability level of each warm-mix material.

Table 4: Experimental conditions and mechanical properties

TEST NO.	type		mixing temperature (°C)	compaction temperatuer (°C)	additive rate (%)	density (g/cm^3)	void ratio (%)	saturation fraction (%)	stabilit ylevel (kN)	flow value (1/100mm)
1	standard	---	160	150	0	2.320	4.8	73.6	9.82	40
2	standard	---	130	120	0	2.309	5.3	71.7	7.82	36
3	standard	---	130	90	0	2.273	6.7	66.3	5.58	35
4	A-1	pre-addition	130	120	4	2.281	6.2	68.0	8.02	35
5	A-1	post-addition	130	120	4	2.326	4.4	75.4	9.08	37
6	A-2	post-addition	130	120	4	2.342	3.7	78.6	7.79	35
7	B	post-addition	130	120	4	2.311	5.0	72.8	7.59	40
8	C	post-addition	130	120	4	2.319	4.7	74.0	7.67	36
9	Z	post-addition	130	120	4	2.311	5.0	72.8	7.63	36

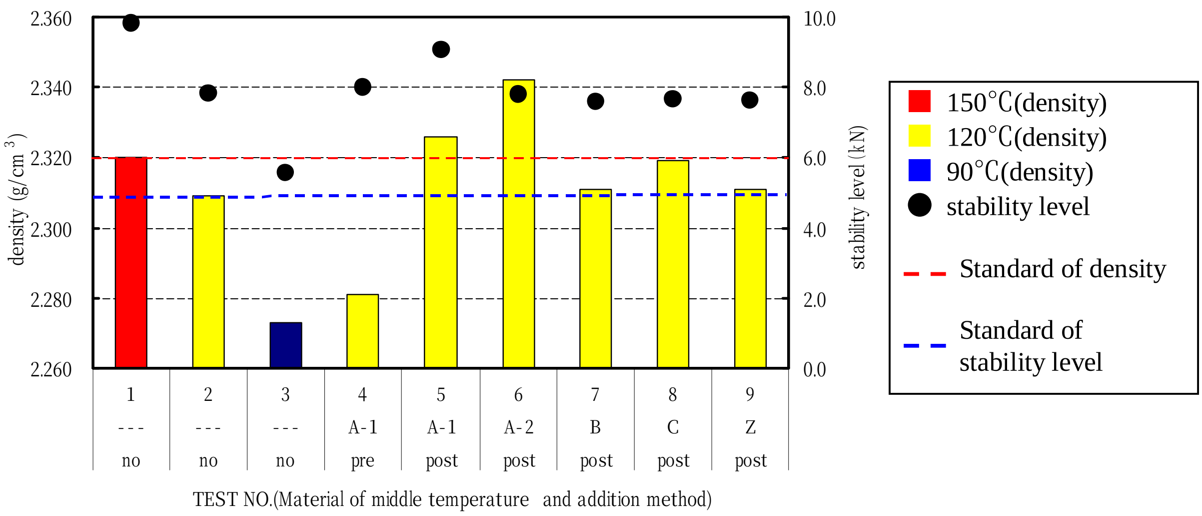

Figure 4: density and stability level – warm-mix material

As shown Figure 4, when the surface-active agent of anion (A) and cation (C) are used as a foam-enhancing agent, the density of asphalt mixture is almost the same compared with that without the foam-enhancing agent (Test No.1). The density of asphalt mixture without the foam-enhancing agent decreases with the decrease of compaction temperature. The densities of the asphalt mixtures for which the foam-enhancing agent of the nonion (B) and zeolite (Z) are used are almost the same as the asphalt mixture of same compaction temperature (No.2) though it is smaller than No.1.

With regard to an effect of the foam-enhancing agent on the warm-mix material, we compared the two percentages (5% and 50%) of the foam-enhancing agent. As for density, in the case of the addition percentage of 50%, the same degree of density as the normal mixture, which is more than 0.02 g/cm^3 higher than that in the case of 5%, could be obtained. This mixture is easier to solidify. As for the Marshall stability, although the result of the addition percentage 50% was 1 kN lower than that in the case of 5%, both of them surpassed the standard of 4.9 kN. As for the difference in density depending on the addition method, when adding to asphalt (pre-foaming), the density was 0.04 g/cm^3 lower than when adding to the mixture (post-addition). This density seems insufficient.

Next, as for the relationship between the type of the warm-mix material and the Marshall stability, as shown in Figure 4, A-1 (5%, post-addition) was about 1.0 kN and the others were more than 2.0 kN, which means that the stability decreased compared to the normal mixture.

3.2 Consideration of Indoor Mixture Experiment Result

From the addition experiment result of the asphalt mixture, the anion (A) surfactant agent is effective for the foam-enhancing agent because the soil compaction density and the stability at the same level as the normal asphalt mixture are obtained.

Moreover, the stability of the asphalt mixture decreases when the additive ratio of the surfactant agent is 50%, although the density increases by the addition of 50% of the surfactant agent. It is consider that the surfactant agent excessively added influences asphalt mixture.

When adding the warm-mix material by pre-foaming, since the foam retentivity of asphalt itself is weak, the foam soon disappears and little effect of foam formation can be obtained. However, when adding to the mixture to which asphalt has been added, since the foam retentivity of the mixture is strong, it is considered that the effect of foam formation of the warm-mix material sustains. Therefore, as for the addition method of the warm-mix material, “post-addition,” in which the material is added to the mixture after adding asphalt, is effective.

4 TRIAL CONSTRUCTION OF WARM-MIX-ASPHALT MIXTURE

4.1 Manufacturing Condition of Asphalt Mixture

Under the production conditions and with the types of mixtures shown in Table 4, we performed an actual-size mixing experiment. Producing the warm-mix mixture by setting the conditions about production of the asphalt mixture, we confirmed its production temperature, state of mixing, and physical properties. By conducting a temporary paving in a plant with the mixture that was mixed and produced at a medium temperature (30°C lower than usual), we also confirmed its handling ability, paved surface, and finishing state.

4.2 Mix Method of Warm-Mix-Asphalt Mixture and Mixture Time

The Procedure of the manufacturing of the asphalt mixture is shown in Figure 5. After the aggregate is turned on to the mixer, Dry Mixing is done for five seconds, and jets asphalt. After Wet Mixing of 15 seconds, the warm-mix material packed into the bag is turned on in the mixer, and Wet Mixing is continued for 25 seconds. The asphalt exhausted from the mixer is loaded into the track, and transported to the examination site.

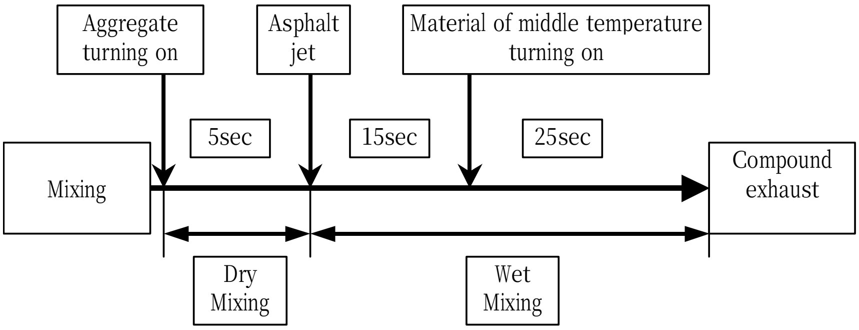

Figure 5: Manufacturing condition of asphalt mixture

Table 5: Result of a measurement

TEST NO.	compound type	additive rate (%)	mixing temperature (°C)	Standard density (g/cm^3)	Cutting core density (g/cm^3)	Degree of compaction (%)	Fuel use (l/10min)
K1	Reproducing granularity	0	165	2.331	2.291	98.3	106
K2	Reproducing granularity	4	132	2.315	2.280	98.5	80
R1	granularity	0	185	2.325	2.302	99.0	121
R2	granularity	4	155	2.307	2.280	98.8	101

4.3 Result of Trial Construction

Table 5 shows the mixing temperature, density and compaction degree the asphalt mixture with warm-mix material manufactured at the plant.

4.4 Examination Concerning Manufacturing

As for mixing temperature of the Reproducing close granularity ASC, both of the two types of the warm-mix mixture (R2 and R3) could be produced at around the target temperature, 30°C lower than the normal mixture (R1). As for the state of the mixtures, each material underwent no separation of materials, and the coating state of the asphalt was good; it was exactly same as the normal mixture. As for the situation of the temporary paving, although both the handling ability and finishing state were good, we considered this as a reference evaluation, since the conditions such as transportation were different from the actual paving.

The quantity consumed of the fuel for heating was carried out by the method of measuring the amount (liter) of the fuel that flowed in ten minutes. The mixing temperature of both reproducing close granularity ASC and close granularity ASC (reforming) decrease by about 30°C by using the warm-mix material. As a result, the fuel use for every ten minutes is saved by about 20 liters.

4.5 Confirmation and Examination Concerning

It was cloudy in the weather at the trail pavement construction, and it was 4-6°C, and humidity was 50-80%.

The state of the asphalt mixture like the state of the film and the aggregate separation, etc. is excellent in all asphalt mixture. It was able to confirm that it was steady about the working efficiency (handled).

4.6 Density of Cutting Core Specimen

As shown in Table 5, the density in the core taken out from in each experimental pavement working area is 98.3-99.0% of a high degree of compaction against a standard density. The adverse effect of the addition of the warm-mix material on the density of the pavement is not admitted.

4.7 Consideration of Examination Pavement

The temperature in this experimental pavement work was 4 – 6 °C, and it is a little bad conditions. However, for the asphalt mixture using warm-mix material, the state of asphalt mixture and the working performance just like a usual asphalt mixture were able to be secured. Furthermore, the density of the core specimen and the finish of the surface of pavement are excellent. Therefore, the pavement using asphalt mixture with warm-mix material has the same performance as the pavement using usual asphalt mixture.

From measurement on consumption of heating fuel, the fuel used for heating was able to be reduced by about 20 liters per 10 minutes, when the mix temperature of the asphalt mixture was decreased by using the warm-mix material at about 30°C. It roughly becomes a reduction in 20% if it converts it into the amount of the consumption reduction of the fuel (crude petroleum) for the heating used for the asphalt mixture manufacturing of the experimental pavement construction.

5 CONCLUSIONS

The present study is a fundamental study that examined the warm-mix-asphalt mixture that the main material is an artificial zeolite converted from paper sludge ash. The results obtained by this study are summarized as follows:

(1) NaP1-Na type of artificial zeolite is suitable for the main material of the warm-mix-asphalt mixture because of the results of analysis by the molecular orbital method on the adsorption of the ethanol and water.
(2) From differential thermal analysis and Derivative Thermogravimetry on zeolite, a suitable zeolite for the warm-mix-asphalt mixture is NaP1-Na type of artificial zeolite as well as the result of the analysis of the adsorption character.
(3) The foaming performance of the artificial zeolite in asphalt is improved by using the artificial zeolite adsorbed water compared with the artificial zeolite adsorbed the ethanol.
(4) From the manufacturing experiment at the real plant, it is confirmed to be able to construct asphalt pavement by adding the warm-mix-asphalt mixture developed in this study under the condition of decreasing at 30°C more than a usual mixing temperature.

As challenges for the future, the pavability and performance need to be evaluated by a test paving. Moreover, CO_2 emission including the production of the warm-mix material and the production of the artificial zeolite also needs to be evaluated. Furthermore, based on the fact that this is a technology that can reduce the time of traffic restriction because of the construction, we would like to continue the research with the aim of evaluating the reduction of the environmental load through the entire construction.

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