A Study on Extension of the Transportation Time of Asphalt Mixture Using a Container

TERAUCHI Takahito, KAWABE Masaharu
Development Department, Section 4, Nikko Co., Ltd.

Abstract

The production of asphalt mixtures (hereinafter referred to as mixtures) has been decreasing in volume year by year, and accordingly, the asphalt plants (hereinafter referred to as APs) throughout the country have been decreasing in number. The number of APs is anticipated to further decrease (hereinafter referred to as consolidation) to improve the productivity of mixtures. The quality of the mixed materials is highly dependent on temperature. As the consolidation of APs progresses, unfortunately, mixtures become available in fewer regions due to the temperature drop during transportation with the current method of loading mixture onto dump trucks and transporting it to the paving site (hereinafter referred to as the "current method"). Therefore, technically, temperature retention of mixtures is an important factor in increasing the regions to supply them.

Tamura et al.[1] have investigated the temperature change of a mixture in the current method and reported (2021) that a mixture in a container exhibits a more significant drop in temperature at the bottom of a container, which is in contact with a dump truck bed, than at the surface exposed to the outside air. They also found that the development of a shipping container for the reduction of heat transfer both to the housing of the container and the outside air is effective for increasing the supply area of mixtures. Based on these findings, the authors have repeatedly produced and improved a prototype container (hereinafter referred to as container) that is coated with a special heat insulation material[(2)(3)]. In this paper, we study the heat retention properties of a mixture in the container.

1. Introduction

With the current method, the quality of mixtures generally starts to deteriorate due to temperature drop after 1.5 to 2 hours have passed, and such mixtures cannot be used for pavement anymore. For this reason, the APs have been constructed across the country to keep the transport time of mixtures within two hours. According to the "2022 Asphalt Mixture Statistics Annual Report[4]", however, the restraint of public investment has caused the production volume of mixtures to decrease from 70,000 kilotons in 2000 to 39,000 kilotons in 2022 by approximately 44%, and the number of APs has decreased from 1,500 to 1,000, in line with the decrease in production volume, by approximately 34% (see **FIG. 1**).

Furthermore, in recent years, more frequent and severe heavy rain disasters have been predicted due to the effects of global warming caused by greenhouse gases. The international community has been working to achieve net zero greenhouse gas emissions (carbon neutrality) by 2050[5)6)]. Of course, the road construction industry has also been making efforts

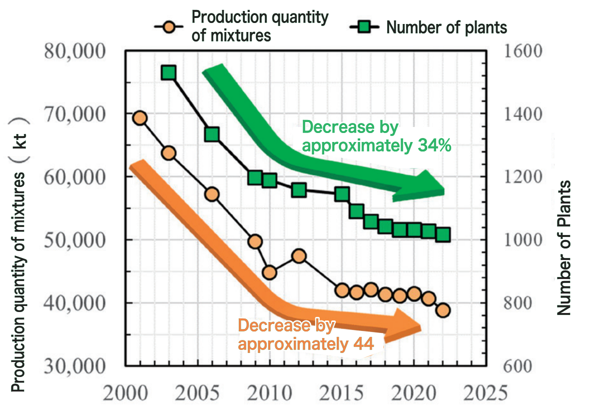


FIG. 1: Changes in Production Quantity of Mixtures and Number of Plants (Cited and edited from "2022 Asphalt Mixture Statistics Annual Report [4]")

toward carbon neutrality, and there is a need to improve the productivity of mixtures by reviewing the operations of the APs (hereinafter referred to as the AP innovation).

In addition, we have issues related to labor shortages, such as a reduction in drivers' working hours (according to the partial revision of standards for improving working hours, and the others of automobile drivers[7]) and a decrease in the number of factory workers. These issues may accelerate further consolidation of the APs for streamlining operations. As the consolidation of APs progresses, concerns arise that mixtures can be supplied to fewer regions. Accordingly, efforts have been made to develop technology that enables the effective transportation of mixtures over long distances.

The effective long-distance transportation of mixtures can be achieved through two approaches: one to ensure a constant quality even at low temperatures of the mixtures, and the other to reduce any drop in temperature of the mixtures. Examples of the former include foamed asphalt, which increases fluidity with a small amount of added water to asphalt and foaming. Examples of the latter include a heat-retaining sheet used in the current method and a container equipped with a heater. The authors have focused on the latter technology and have been working on it since 2021 to develop a container that achieves heat retention of the mixture for an extended period. We poured a mixture into the container and conducted a study on the heat retention properties of the mixture. In this paper, we provide an overview of the study.

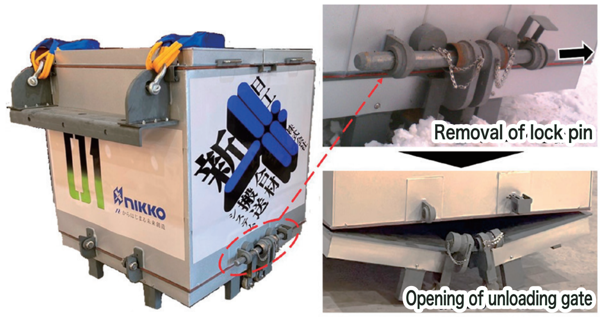


FIG. 2: Appearance of Container

Table 1　Specification of Container

Internal Capacity	1.73 m^3
Weight	964kg
Material	SS400

2. Test Overview

2.1 Specifications of the Container to be tested

FIG. 2 shows the appearance of the container tested, and **Table 1** shows its specifications. The container is made of structural rolled steel (SS400) with a special heat insulation material covering the exterior and a sheet metal is applied over the material for protection. The container is configured to receive a mixture through a port at the top and discharge it from a port at the bottom. The lid of the input port (hereinafter referred to as a loading gate) closes under its own weight. The lid of the discharge port (hereinafter referred to as an unloading gate) is configured so that, as shown in **FIG. 2**, when the lock pin is removed while the container is on the ground and then lifted, the unloading gate opens, allowing the mixture inside to be discharged through it.

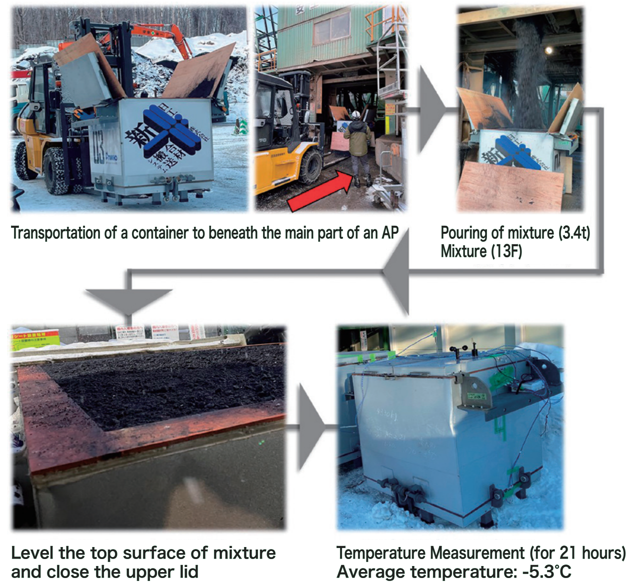


FIG. 3: Test Procedure

Table 2　Test Conditions

Date	2023/2/21～2023/2/22
Weather	Snow
Place	Sapporo-shi, Hokkaido
Environment	Outdoors (Stationary)
Average Temperature	−5.3°C
Mixture	Dense Graded Asphalt (13F) 50% Recycled
Temperature for Shipping	177°C
Mixture Quantity	3366kg

2.2 Test Conditions

A test was conducted during winter in a cold district in Japan where the temperature of a mixture drops significantly. The test procedure is listed below and in **FIG. 3**, and the test conditions are shown in **Table 2**.

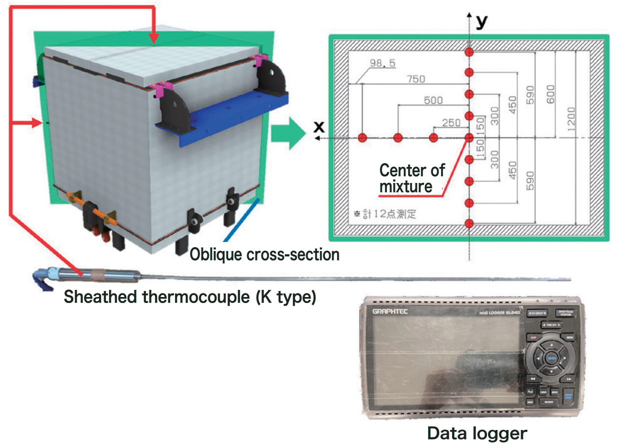


FIG. 4: Details of Measurement Points and Devices Used

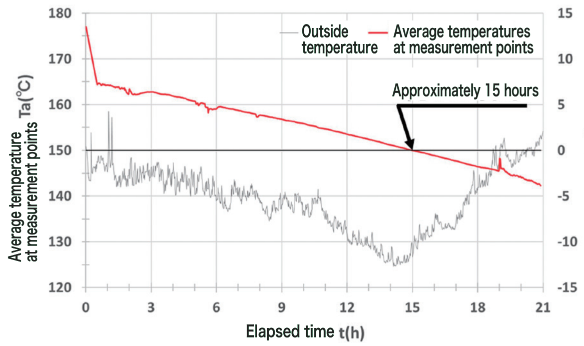


FIG. 5: Correlation between Average Temperatures at Measurement Points and Elapsed Time

[Test Procedure]

1. The container, with its loading gate open, was transported by a forklift to a position beneath the main part of an AP, specifically under the mixture discharging port of the AP.
2. A mixture was poured in to fill the container.
3. The surface of the mixture was leveled to be flush with the edges of the container.
4. The loading gate was closed, and the temperature of the mixture was measured for 21 hours using a sheathed thermocouple and a data logger which will be described later.

While the mixture was being kept warm in the container, the temperatures at twelve points inside the container and the outside temperature were measured with the sheathed thermocouple (K type) and recorded by the data logger. **FIG. 4** displays the twelve measurement points (hereinafter referred to as measurement points) along with the devices used. To precisely define the positional relationship of the measurement points, we designate a cross-section taken along a line connecting the opposite diagonals of a container in the vertical direction as an oblique

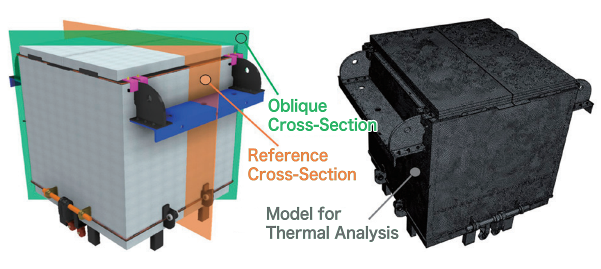


FIG. 6: 3D model and Defined Cross-Sections

cross-section. Regarding the insertion of the thermocouples, we define the horizontal direction as the x-axis and the vertical direction as the y-axis. In the x-axis, the thermocouple could only be inserted into the mixture at the corners of the container due to the specifications of the special insulation material applied to the container. As for the x-axis, the container has a structure axially symmetrical to the y-axis, thus the temperature distribution was expected to be axially symmetrical as well. Accordingly, in the x-axis, the temperatures were measured only in one direction from the center of the mixture. In contrast, in the y-axis, the dissipation behavior was expected to differ due to the difference in the structure of the container, and the temperatures were measured at upward and downward positions from the center of the mixture.

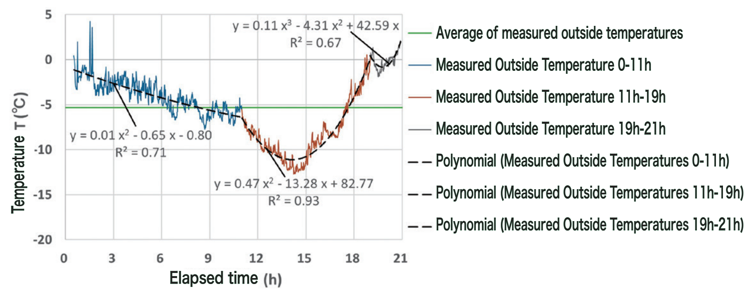


FIG. 7: Measured Outside Temperatures and Approximation Function

Table 3 Analysis Conditions

	Mixture	SS400	Special Heat Insulation Material
Density ρ [kg/m^3]	1947.9	7850	Various
Thickness l [mm]	600※	6	70
Specific Heat c [J/(kg・K)]	1280	473	Various
Thermal Conductivity λ [W/(m・K)]	1.25	51.6	Various
Initial Temperature T_0 [°C]	177	-0.8	-0.8

The thickness of mixture refers to the distance between the center of the mixture and a wall of the container.

3. Evaluation

As the heat retention time of the mixture is extended, the temperature inevitably drops at the contact interfaces between the mixture and the inner

$$\rho c \frac{\partial T}{\partial t} = \lambda \left(\frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2} + \frac{\partial^2 T}{\partial z^2} \right) \quad \cdots [\text{Equation 1}]$$

T : Temperature [°C]

t : Time [s]

$$\frac{\partial T}{\partial t} = \alpha \left(\frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2} + \frac{\partial^2 T}{\partial z^2} \right) \quad \cdots [\text{Equation 2}]$$

α : Thermal Diffusivity $[m^2/s]$ $\left(\alpha = \dfrac{\lambda}{c \cdot \rho}\right)$

walls of the container. However, at actual paving sites, the mixture is agitated by the screw of an asphalt finisher or similar equipment, resulting in almost uniform temperature distribution throughout the mixture.

Therefore, in this study, the time required for the average temperature of the "entire" mixture to reach

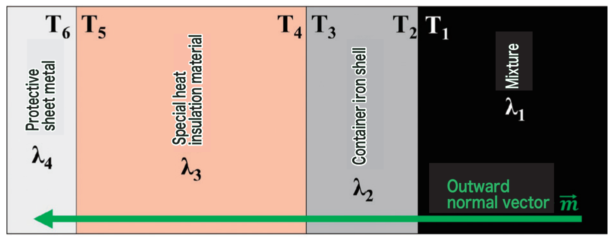


FIG. 8: Container Structure (Schematic diagram)

$$T_1 = T_2$$

$$T_3 = T_4$$

$$T_5 = T_6$$

$$\left.\begin{aligned} \lambda_1 \frac{\partial T_1}{\partial m} &= \lambda_2 \frac{\partial T_2}{\partial m} \\ \lambda_2 \frac{\partial T_3}{\partial m} &= \lambda_3 \frac{\partial T_4}{\partial m} \\ \lambda_3 \frac{\partial T_5}{\partial m} &= \lambda_4 \frac{\partial T_6}{\partial m} \end{aligned}\right\} \cdots [\text{Equation 3}]$$

$$h(T_7 - T_{Air})^{\frac{5}{4}} \quad \cdots [\text{Equation 4}]$$

h = Thermal Conductivity $[W/(m^2 \cdot K)]$

T_7 = Surface Temperature of Protective Sheet Metal $[K]$

T_{Air} = Temperature of Outside Air $[K]$

the temperature (hereinafter referred to as 150°C), at which mixtures are typically acceptable, is defined as the heat retention time.

3.1 Test Results

FIG. 5 shows the correlation between the average temperatures and the elapsed time at the measurement points depicted in **FIG. 4**.

FIG. 5 indicates that it took approximately 15 hours for the average temperatures at the

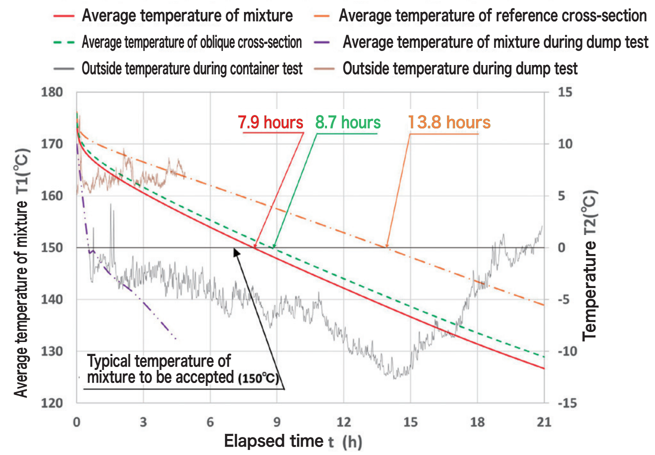
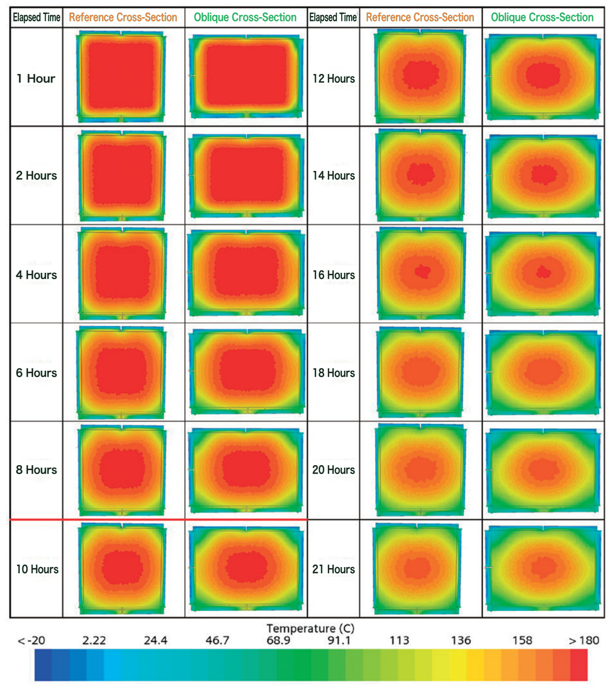


FIG. 9: Calculation Results of Average Temperatures of Mixture (Average Temperature of Mixture during Dump Test: Cited and Edited data from "Consideration on Temperature Characteristics of Asphalt Mixture during Transportation" [1])

Table 4 Temperature Distribution of Reference Cross-Section and Oblique Cross-Section over Elapsed Time



measurement points to reach 150°C.

However, the results do not precisely indicate the temperatures of the "entire" mixture as defined above. Specifically, the results do not reflect the temperatures at the corners of the container, where a significant temperature drop in the mixture is expected. Hence,

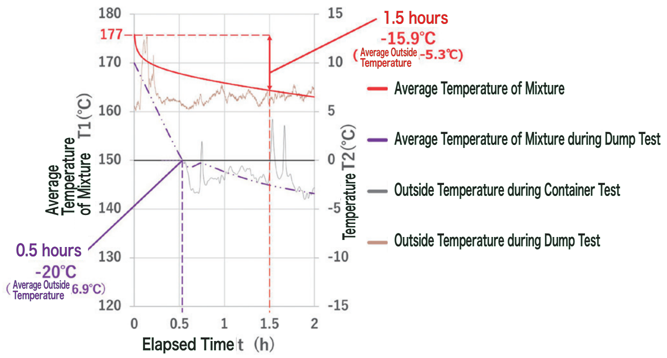


FIG. 10: Details of a Portion of Calculation Results of Average Temperature of Mixture

the overall average temperature of the "entire" mixture was calculated by supplementing the temperatures of the mixture at points other than the measurement points using a thermal analysis simulation, which will be described later.

3.2 Estimation of Possible Heat Retention Time Using Thermal Analysis

To calculate the overall average temperature of the mixture, a back analysis was performed on the test results using thermal fluid analysis software (STAR-CCM+ Ver. 18.02, manufactured by Siemens PLM Software Computational Dynamics Co., Ltd.).

3.2.1 Generation of a 3D Model

Initially, a 3D model mirroring the shape of the container was generated. In addition to the oblique cross-section outlined in **FIG. 4**, we established a vertical cross-section (hereinafter referred to as the reference cross-section) to investigate the temperature distribution within the mixture over time, as well as the correlation between the overall average temperature of the mixture and time. **FIG. 6** depicts these details.

3.2.2 Analysis Conditions

The outside temperature affects the temperature drop gradient of a mixture, and thus the outside

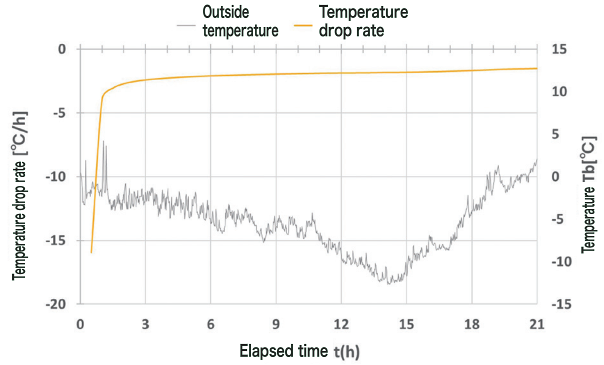


FIG. 11: Correlation between Elapsed Time and Temperature Drop Rate

$$\frac{T_t - T_{t-0.5}}{0.5}\ [℃/h] \quad \cdots \text{[Equation 5]}$$

T_t = Temperature after t hours have elapsed $(t = 0.5, 1, 1.5 \cdots)$ [℃]

$T_{t-0.5}$ = Temperature after (t - 0.5) hours have elapsed [℃]

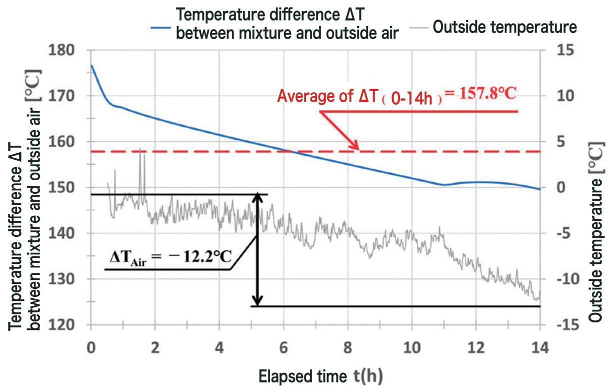


FIG. 12: Correlation between ΔT and ΔT_{Air}

$$\frac{\Delta T_{Air}}{\Delta T\ \text{Average}} \times 100 = \frac{12.2}{157.8} \times 100 \cong 7.7\% \quad \cdots \text{[Equation 6]}$$

temperature is an important factor in the test to study the heat retention of a mixture in the container. For this reason, an approximation function for the measured outside temperature was created such that the results of the inverse analysis would reproduce the test results as closely as possible, and implemented in the thermal analysis simulation. **FIG. 7** shows the

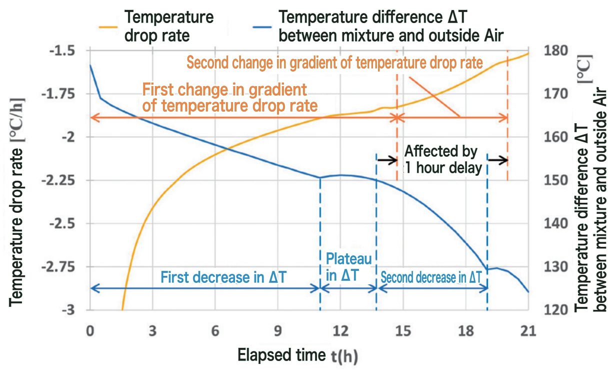


FIG. 13: Correlation 1 between Temperature Drop Rate and ΔT

Table 5 Correlation between Temperature of Mixture, Outside Temperature, and ΔT over Time

Elapsed Time	0 Hours	14 Hours	21 Hours
Temperature of Mixture	177℃	138.5℃	126.7℃
Outside Temperature	-0.8℃	-13℃	2.5℃
ΔT	177.8℃	151.5℃	124.2℃

correlation between the elapsed time and the measured outside temperatures, alongside the approximation function. **Table 3** presents the conditions used in thermal analysis simulation. The density of the mixture was calculated from the measured weight and the container capacity, and the initial temperature of the mixture was set to 177℃, which is the temperature for shipping while the initial temperature of the container was set to -0.8℃ based on a calculation using the approximation function. The special insulation material has a laminated structure, and its thermal conductivity, specific heat, and density were described as Various. The thickness of the material refers to the total thickness of the laminated layers. The thermal conductivity of the mixture was determined by conducting a thermal analysis simulation while keeping the specific heat and density of the mixture constant and varying the thermal conductivity value: the final value was adopted based on the approximation of the measured data at each measurement point with the results of the thermal analysis simulation.

Here, for a case where the thermal conductivity, specific heat, and density are constant, the differential equation for three-dimensional heat conduction in the orthogonal coordinate system of the x, y, and z axes is expressed in **Equation 1**. **Equation 2** represents a modification of **Equation 1**.

Equation 2 indicates that the larger the value of thermal diffusivity α (i.e., the larger the value of thermal conductivity λ, and the smaller the values of specific heat c and density ρ), the more remarkable the temperature change is.

Next, **FIG. 8** schematically illustrates the structure of the container used in the test, and **Equation 3** expresses a differential equation for the boundary conditions. Furthermore, **Equation 3** represents a case where different types of materials are in complete contact and the thermal resistance therebetween is not taken into account.

Equation 4 represents the heat transfer due to natural convection at the boundary between the protective sheet metal and the outside air in **FIG. 8**

3.2.3 Analysis Results

A back analysis was performed on the measurement points. **FIG. 9** shows the calculated results of the average changes in temperature of the entire mixture, the reference cross-section, and the oblique cross-section. In **FIG. 9**, the average temperature of the mixture during the dump test shown by the purple two-dot chain line was compiled from those in "Consideration On Temperature Characteristics of Asphalt Mixture During Transportation[1]", and the outside temperature during the dump test was the measured data of outside temperature in Hyogo Prefecture in January when the test was conducted. **Table 4** presents the temperature distributions in the reference cross-section and the oblique cross-section at each elapsed period of time determined by simulation. **Table 4** indicates that the temperature drop in the mixture was more significant in the upper part of the container than in the lower part.

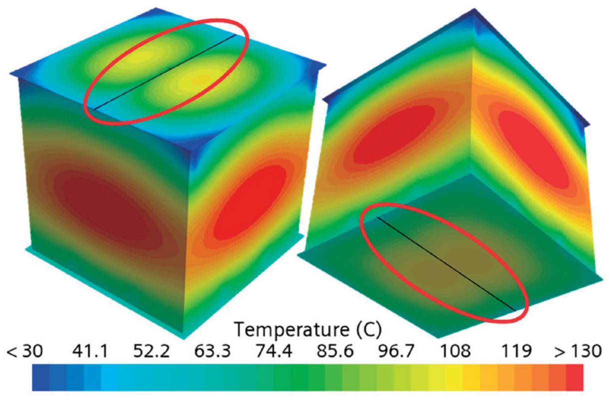


FIG. 14: Temperature Distribution on the mixture surfaces after 21 hours have elapsed

4. Discussion

4.1 Temperature Drop Immediately After Pouring of Mixture

FIG. 10 highlights a portion of the data in **FIG. 9**: the data within the range of 0 hours to 2 hours after the test started. This is to focus on the overall average temperature of the mixture, shown by the solid red line, immediately after pouring the mixture, and the average temperature of the mixture during the dump test, represented by the purple chain double-dashed line.

Calculating the temperature drop gradient from immediately after pouring the mixture to 0.5 hours, as displayed in **FIG. 10**, the overall average temperature of the mixture was -15.9℃/h and the average temperature of the dump test mixture was -45.5℃/h, both of which demonstrate a rapid drop in temperature. These rapid temperature drops were believed to occur because the purpose of the dump test was to figure out the temperature distribution and behavior of the mixture during transportation, no heat retention was performed "to roughly capture the behavior of temperature drop" (Tamura et al., 2021, p. 34[1]), and the heat was taken away by the dump truck bed of a large heat capacity. In addition, the sudden temperature drop immediately after pouring the mixture into the container (hereinafter referred to as the initial temperature drop) occurred possibly because the heat was conducted from the mixture to the steel plate that was at a temperature of -0.8°C, equal to that of the outside temperature at the start of temperature measurement. For these reasons, we can say that reduction of the heat conduction to the steel plate is effective, by preheating the container to reduce the temperature difference between the mixture and the outside air for example, in order to extend the heat retention time of the mixture.

4.2 Heat Retention Time and Temperature Drop Rate

FIG. 9 shows that, when the mixture was shipped at 177°C, the heat retention time of the container was 7.9 hours. As mentioned above, this is because, even though the initial temperature drop was seen immediately after the pouring of the mixture, the temperature drop thereafter was slowed. Here, the rate of change in temperature of the entire mixture over time is defined as the temperature drop rate, and the correlation therebetween is shown in **FIG. 11**. The temperature drop rate was calculated and plotted every 0.5 hours, and **Equation 5** expresses this calculation.

In **FIG. 11**, the temperature of the mixture decreased over time, with a slower temperature drop rate accordingly. The change in the outside temperature over time (hereinafter referred to as ΔTAir) was -12.2°C (decreasing from -0.8°C to -13°C) 14 hours after pouring the mixture. This change, amounting to 7.7% of the temperature difference (hereinafter referred to as ΔT) between the entire mixture and the outside air, is relatively small. Consequently, no significant change in the temperature drop rate was observed. **FIG. 12** and **Equation 6** provide details of these findings.

Next, to show in detail the change in the temperature drop rate due to ΔT, which did not show a significant change in **FIG. 11**, we focus on a specific portion of the data (i.e., the range with the temperature drop rate from -3 to -1.5°C/h) in **FIG. 11**. This allows **FIG. 13** to depict the correlation between the temperature drop rate and ΔT within the range.

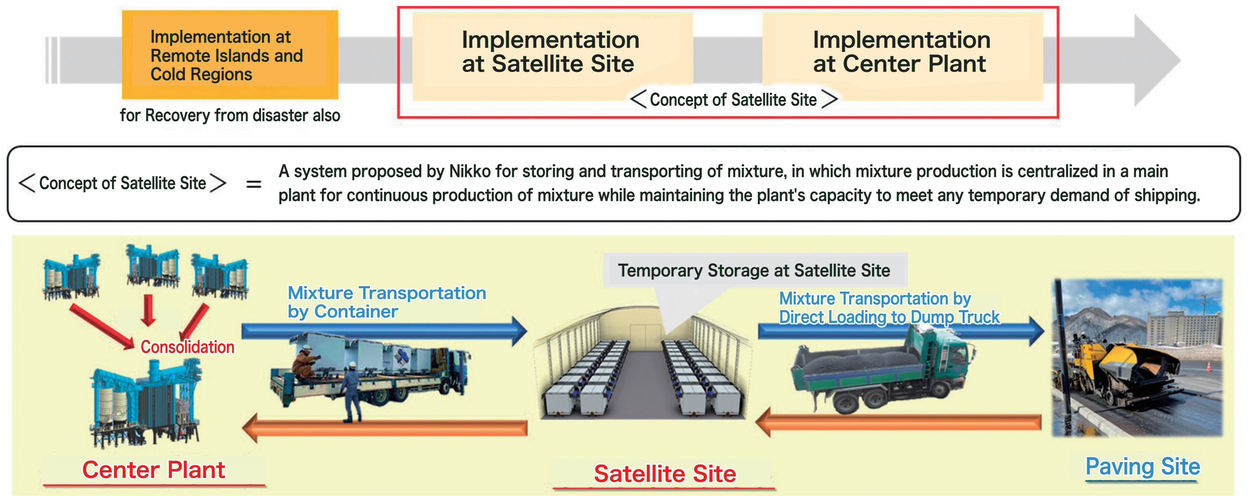


FIG. 15: Establishment of Mixture Storage- Transportation System

First, we describe the transition of ΔT. As described above, ΔTAir exhibited a small value relative to ΔT after 14 hours since the mixture was poured: this indicates that the influence of ΔTAir on ΔT is extremely small. Therefore, even if the outside temperature eventually dropped to -13°C, the temperature drop rate of the entire mixture was greater than that of the outside air, resulting in a consistent decrease in ΔT. Conversely, if the temperature drop rate of the outside air is greater, ΔT will increase. **Table 5** presents the summary.

Next, we describe the influence of ΔT on the temperature drop rate. It has been known that the temperature drop rate in a mixture is proportional to the heat dissipated per unit surface area of the container (hereinafter referred to as heat flux), and the heat flux, in turn, is proportional to the thermal conductivity and ΔT. These facts imply that the rate of temperature drop in a mixture is proportional to ΔT. Specifically, in **FIG. 13**, we can observe that the temperature drop rate in the mixture decreased in a circular curve from -3.0°C/h to -1.8°C/h in proportion to ΔT, over a span of 14 hours following the initial temperature drop when the mixture was poured into the container. We can observe then that the rate of temperature drop in the mixture gradually decreased from -1.8°C/h to -1.6°C/h until 19 hours had passed. These observations support the fact that the temperature drop rate in a mixture is proportional to ΔT. Furthermore, as ΔT relates to ΔTAir, the temperature drop rate in a mixture can be said to be influenced to a large extent by the outside temperature. However, during the second decrease in ΔT, despite an approximate 10°C increase in the outside temperature, the difference in the temperature drop rate was only 0.2°C/h, indicating a negligible effect. The effect was believed to be small, as described above, because of the following reasons. The influence of ΔTAir on ΔT was extremely small, and the area of the steel plate to be exposed to the outside air was small because of the special heat insulation material covering most of the container. In addition, the special heat insulation material of 70 mm was thick enough to mitigate the impact of the outside temperature to a small extent.

As described above, even in sub-zero environments, the influence of changes in outside temperature on the container was extremely small, and the mixture was kept warm in the container for 7.9 hours, which is approximately five times longer than the typical transportation time of 1.5 hours (see **FIG. 9**). These results suggest that the container can be an effective means for transporting a mixture over long distances.

4.3 Examination of Temperature Distribution across Cross-Section and Points of Heat Dissipation Locations

In **FIG. 9**, when comparing the average temperature of the reference cross-section shown by the orange dashed-dotted line, the average temperature of the oblique cross-section shown by the green dashed line, and the overall average temperature of the mixture shown by the red solid line, the highest temperature is found in the reference cross-section. This is followed by the oblique cross-section, and then the entire mixture. The reason why the temperature at the reference cross-section is the highest is believed to be due to the smallest heat dissipation area in the reference cross-section, which reduces the likelihood of heat dissipation from the mixture. In contrast, the reason for the lowest average temperature of the entire mixture is assumed to be the increased amount of heat dissipation due to the inability to install special insulation material in the gaps at the container loading and unloading gates of the container depicted in red circles in **FIG. 14**. The simulation results reflect this reason. Accordingly, it is considered that the influence of temperature drop due to the gaps between the loading and unloading gates of the container is limited for the mixture at the reference cross-section and the oblique cross-section.

Furthermore, based on the temperature distribution after 21 hours of elapsed time presented in **Table 4** and the temperature distribution on the mixture surface shown in **FIG. 14**, we can see that the decrease in temperature of the mixture began at the corners of the container, while the center of the mixture remained with unnoticeable changes in temperature. The reason for the small temperature drop at the center of the mixture can be attributed to its low thermal conductivity of the mixture. The mixture has a low thermal conductivity of 1.25W/(m•K) (see **Table 3**), similar to that of glass materials at room temperature (New Edition of Thermophysical Properties Handbook [8]). Under this situation, the center of the mixture can be presumed to be covered with its own heat insulation material of a 600 mm-thickness and a low thermal conductivity of 1.25W/(m•K) in addition to the 70 mm-thick special heat insulation material around the container. Therefore, no significant temperature drop was observed even after 21-hour heat retention.

Based on the above findings, ensuring a certain level of capacity for the container can be an approach to effectively extend the period of time for heat retention of the mixture inside. While the mixture inherently has some heat-insulating properties, the simulation results show that the mixture is required to have a thickness of 600 mm or more to optimally achieve the properties. Additionally, it is ideal to approximate the shape of the container to a sphere that minimizes the surface area for heat dissipation (specific surface area). The temperature of the mixture significantly dropped at the corners of the container. This drop can be attributed to several factors, including the large surface areas (specific surface areas) for heat dissipation, the thinner mixture itself as a heat insulation material, and the difficulty in applying the special heat insulation material to the corners.

We describe two specific approaches for reducing the heat dissipation area of the container as follows. First, as mentioned above, a change in the container's shape is possible to reduce the surface area (specific surface area) for heat dissipation. For example, in a cylindrical container, the surface area (specific surface area) for heat dissipation can be reduced compared to a rectangular container even of the same capacity, and heat dissipation becomes less likely to occur. Second, loading and unloading gates can be integrated. As described above, the tested container was configured to receive a mixture through the top and discharge it through the bottom, and the loading and unloading gates include some portions where the special heat insulation material cannot be applied. Accordingly, if both the pouring and discharge of a mixture can be conducted through a common gate, for example by installing a device to invert the container, the portions without the special heat insulation material can be reduced, thereby resulting in less heat dissipation from the container.

5. Summary

The results and discussion of this study are summarized below.

- ●The heat retention of a mixture is achievable for 7.9 hours by using the container having a special heat insulation material therearound, even in sub-zero environments.
- ●Immediately after the mixture is poured into the container, the temperature of the mixture drops rapidly due to heat transfer to the steel plate which is at the same temperature as the outside.
- ●In this test, the temperature drop in the mixture inside the container was small at the center and was noticeable at the corners.
- ●The mixture has a low thermal conductivity, and the surrounding mixture acts as a heat insulator for the center of the mixture.
- ●The temperature drop gradient of the mixture over time is affected by the outside temperature, but this effect can be reduced if the container surface is largely covered with a special heat insulation material.
- ●To extend the heat retention time of the mixture, it is assumed to be effective to secure a container capacity above a certain level and to reduce the container' s surface area (specific surface area) that contributes to heat dissipation.

6. Future Developments

We anticipate that carbon neutrality and a shortage of workers will drive innovation in APs and, ultimately, the consolidation of the APs in the future. We are concerned that there will be an increase in the number of regions where the current means cannot supply mixtures when the consolidation progresses.

Against the background, the authors have been working on developing a container capable of retaining the heat of a mixture for extended periods. The ultimate goal of this development is to establish a storage and transportation system of mixtures (see **FIG. 15**). The system aims to centralize mixture production in a main plant (the center plant in **FIG. 15**), and ensure continuous production of mixtures while maintaining the plant's capacity to meet any temporary demand of shipping. One objective of the system is to increase the regions around one AP where mixtures can be supplied by using the container for heat retention of the mixture. As a first step in establishing the system, one goal is to deploy the containers in cold regions and remote islands. For the

deployment, we are planning to collect information so that we are able to improve the container to have a structure for easier pouring, discharging and transportation of a mixture and to review the container' s capacity.

In addition, as previously mentioned, the use of the container is accompanied by a significant initial temperature drop in the mixture inside. Accordingly, to extend the period of temperature retention, the mixture should be prepared to be at a higher temperature for shipping. However, this process contradicts technologies aimed at reducing shipping temperatures to lower CO_2 emissions, such as mixtures under intermediate temperature conditions. Hence, we need to develop approaches for shipping mixtures within a conventional temperature range by reducing the initial temperature drop, possibly by preheating the container using waste heat.

We continue to improve the container by utilizing the sampling data and thermal analysis simulations obtained in this study.

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Authors

TERAUCHI Takahito
Development Department, Section 4, Nikko Co., Ltd.
(Joined in 2024)

KAWABE Masaharu
Development Department, Section 4, Nikko Co., Ltd.
(Joined in 2021)