Development and Practice of Warm Mix Asphalt Technology in Japan

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ABSTRACT: Japan has been made efforts to accomplish the goal of emission reduction of greenhouse gas, as well as foreign countries. Pavement engineers have been made efforts to develop the environmental conservation technology in the field of pavement construction. In Japan, hot mix asphalt has been produced by about fifty millions ton a year with disadvantage of large amount of fuel consumption in mixing process. To reduce fuel consumption and carbon dioxide emission occurred during the mixing process, the warm mix asphalt technology with exclusive special additives was developed which decreased the mixture manufacturing temperature by 30 degrees Celsius than that of conventional hot mix asphalt. Today, there are several types of additives to reduce carbon dioxide emission and furthermore give other useful effects. This paper describes mechanism of each warm mix asphalt technology with three types of additives such as foaming type, viscoelasticity adjustment type, and surfactant type. Additionally, it introduces the in-situ practical examples of these technologies applied in Japan.

KEY WORDS: Warm mix asphalt, CO_2 reduction, early traffic opening, cold weather paving.

1 INTRODUCTION

In recent years, environmental problems, especially the action to the reduction of the carbon dioxide (CO_2) emission for the arresting global warming becomes more and more important. In Japan, the CO_2 emission from the field of civil works is about 10% of the CO_2 emission of all industry. The emission of the road works occupies the high ratio with about 25% in the field of civil works (Japan road association 2005).

In the pavement engineering, research and development for environmental load reduction is performed positively including the reduction of the CO_2 emission. The warm mix asphalt (WMA) technology to decrease temperature of manufacturing and to pave the hot mix asphalt (HMA) as one of environmental load reduction was developed and practically used in the field. This technology can 1) reduce the CO_2 emission in the mixture manufacturing, 2) expect the early traffic opening in the pavement repairing, and 3) attempt the improvement of paving in cold weather and the bridge deck pavement by providing a high compaction effect, and applying the mixture manufacturing at conventional temperature.

This paper describes the concept of some WMA technologies developed until today. Additionally, it introduces the in-situ practical examples of the applied technology for the reduction of the CO_2 emission, for the early traffic opening, and for the improvement of paving in cold weather.

2 CONCEPT OF WMA TECHNOLOGY

2.1 Mechanism of WMA Technology

There are several processes of WMA technology. Each technology requires selecting proper exclusive special additive in order to achieve the benefits of WMA technology. Three major types of special additives are foaming type, viscoelasticity adjustment type, and surfactant type. Because their mechanics are different, proper selection is necessary for the purpose of use.

Foaming Type

The special additive of foaming type consists of a mineral included water of crystallization and an adjustment agent to maintain foaming. By using the steam generated from water of crystallization during mixture manufacturing and combining an adjustment agent with the additive, the micro-foams such as mousse occurs. The micro-foams are dispersed in asphalt mortar in order to improve the mixing ability of mixture manufacturing even at the lower mixing temperature than normal mixing temperature. As a result, they act as ball bearings to have the better compaction ability. Figure 1 shows the concept of the mechanism of foaming type.

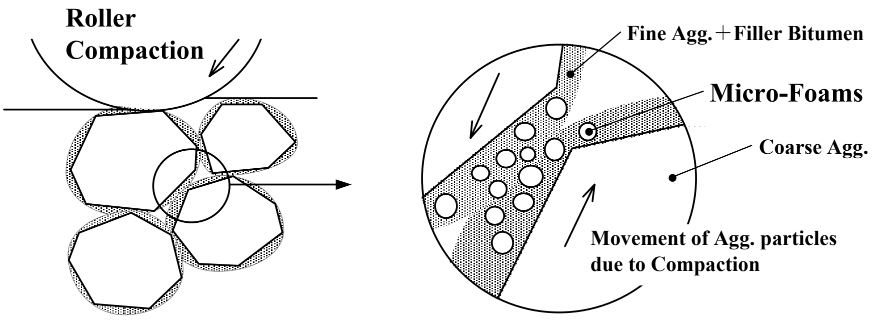

Figure 1 : Concept of the mechanism of foaming type

Viscoelasticity Adjustment Type

The special additive of the viscoelasticity improvement type whose a melting point is about 100 degrees Celsius shows a liquid property in the temperature more than the melting point and suddenly solidify when it cools down and act as a solid. For such a reason, workability of hot mix asphalt improves so that asphalt viscosity lowers in the temperature range of mixture manufacturing and paving. On the other hand, rutting resistance property improves so that asphalt viscosity becomes higher in the service temperature range. Figure 2 shows the concept of the mechanism of viscoelasticity adjustment type.

Other type of the viscoelasticity adjustment is the special additive with the composition that is similar to asphalt. The additive decreases the consistency of the manufacturing temperature range and the paving temperature range of HMA. However, it does not fall the consistency of the service temperature range. Therefore, HMA fall only manufacturing and paving temperature with having maintained the durability. Figure 3 shows the concept of the consistency type of viscoelasticity adjustment.

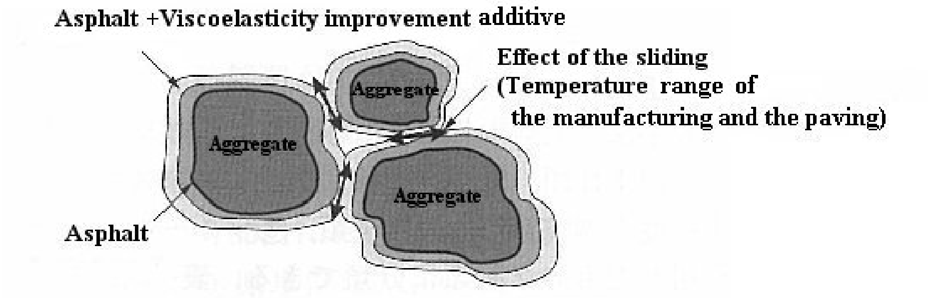

Figure 2 : Concept of the mechanism of viscoelasticity adjustment type

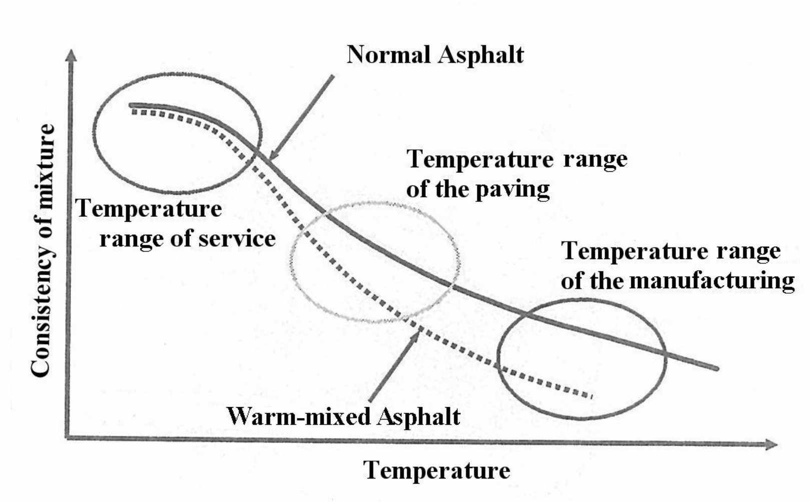

Figure 3 : Concept of the consistency type of viscoelasticity adjustment

Surfactant Type

Some surfactant decreases interfacial tension and improves lubricity. In this special additive, the most appropriate surfactant for asphalt is selected. As shown in Figure 4, this additive adsorbs onto interface of asphalt and aggregate, then, improves the mixing ability and the compaction ability by the effect of the lubricant. This additive has few influences on asphalt consistency.

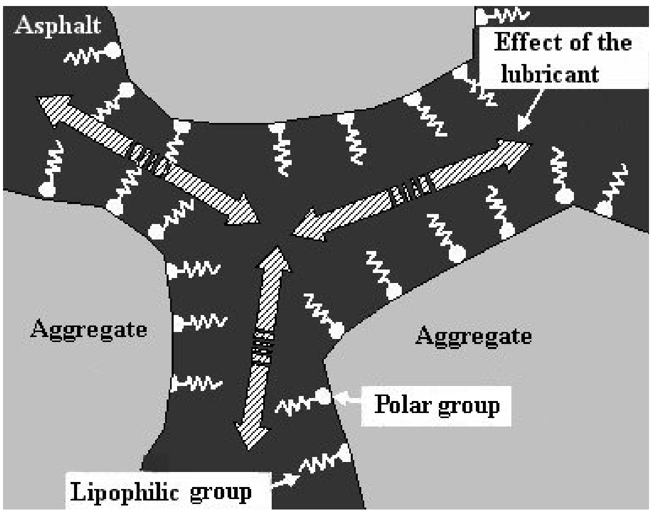

Figure 4 : Concept of the mechanism of surfactant type

2.2 Effect of application

The major effects of WMA technology are as follows.

Reduction of CO_2 Emission

The WMA mixture decreases fuel consumption because it can lower mixing temperature than normal mixing temperature, and can reduce a CO_2 emission of the mixture manufacturing.
In addition, the WMA technology can simplify the equipment of compaction for the paving because the WMA mixture has the higher compaction ability at normal temperature, and reduces CO_2 emission of the paving by decreasing fuel consumption of equipment for compaction.

Early Traffic Opening

In repair construction under the traffic control, it can shorten the period of road restriction because the temperature of the WMA mixture is lower than HMA mixture. As the result, It also can expect the mitigation of the traffic jam. Furthermore, in the paving of thick layer or construction in summer season, it can prevent pavement from initial rutting.

Improvement of Paving in Cold Weather

The WMA technology can attempt the improvement of paving in cold weather and extend permission time for the paving because the WMA mixture has the higher compaction ability at normal temperature. In addition, it is effective to obtain the required degree of compaction for the bridge deck pavement and the thin surfacing that is concerned about a sudden temperature fall after spreading asphalt mixture.

3 APPLICATION EXAMPLE OF REDUCTION OF THE CO_2 EMISSION

This chapter introduces the example that examined the effect of CO_2 reduction of mixture manufacturing by the plant and by the simplified compaction equipment of the paving at normal temperature.

CO_2 Reduction of Manufacturing

First example was examined the effect of CO_2 reduction by the calculated CO_2 emission from fuel consumption in the plant when it used HMA mixture and WMA mixture decreased 30 degrees Celsius than HMA mixture for the construction of a 5cm thick milling and overlay project.
Table 1 shows the calculated results of the CO_2 emission in the manufacture of those mixtures (Shiga and Akita 1999). As shown in the table, the WMA mixture was reduced 14.6% of the CO_2 emission in comparison with the HMA mixture.

Table 1 : Calculated results of the CO_2 emission in the manufacture of mixtures

Mixture type	Construction site	Paving day	Fuel consumption (liter)	CO_2 emission (t)	Manufacture of mixture (t)	CO_2 emission per ton of mixture (kg-CO_2/t)	
						Calculation	Average
Conventional HMA	Site A	2.26 AM	1,395	3.143	145	21.67	22.53
		3.24 AM	1,650	3.717	160	23.23	
	Site B	3.1 AM	1,379	3.107	137	22.68	
	Total		4,424	9.967	442	—	—
WMA	Site A	2.26 PM	1,512	3.406	185	18.41	19.24 (-14.6%)
		3.24 PM	1,064	2.397	120	19.97	
	Site B	3.1 PM	1,201	2.706	140	19.33	
	Total		3,777	8.509	445	—	—

Second example was examined the effect of CO_2 reduction by the calculated CO_2 emission from consumption of heavy oil in the plant when it used HMA mixture and WMA mixture which decreased 30 degrees Celsius and 50 degrees Celsius than HMA mixture for the construction of a 5cm (a part of section : 20cm) thick milling and overlay project. Table 2 shows the calculated results of the CO_2 emission in the manufacture of those mixtures (Ichioka et al.2001). As shown in the table, the WMA mixture was reduced 20.1% of the CO_2 emission when it decreased 30 degrees Celsius, and 32.0% of the CO_2 emission when it decreased 50 degrees Celsius in comparison with the HMA mixture.

Table 2 : Amount consumption of heavy oil and reduction rate of the CO_2 emission

Condition	Mixing temperature (℃)	Manufacture of mixture (ton)	Heavy oil consumption per ton of mixture (liter/ton)	CO_2 emission per ton of mixture (kg-C/ton)	CO_2 reduction (%)
1	160	443	7.5	5.52	0.0
2	130	243	6.0	4.41	20.1
3	110	63	5.1	3.75	32.0

Note Moisture content : 4% Basic unit of CO2 emission : 0.7357kg-C/litre

In addition, the WMA mixture and the HMA mixture were obtained the same degree of compaction in each paving.

CO_2 Reduction of Paving

This example was examined the effect of CO_2 reduction by the calculated CO_2 emission from the fuel consumption of simplified equipment for compaction of the paving when WMA mixture was manufactured at normal temperature using the higher compaction ability. Table 3 shows the calculated results of the CO_2 emission in the paving (Yoshinaka et al.1998). As shown in the table, the paving using WMA mixture was able to reduce about 53% of CO_2 reduction when the equipment for compaction simplified to one of 4ton combined roller from the combination of macadam roller and pneumatic tire roller. In addition, the WMA mixture was obtained the same degree of compaction in each combination of equipment for compaction.

Table 3 : Calculated results of the CO_2 emission in the paving of equipment combination

Apparatus	Trial calculation		Combination	
	Fuel consumption per hour (liter/hour)	CO_2 emission per hour (kg-CO_2/hour)	Nomal	Simplification
Asphalt paver	5.5	15.7	○	○
Macadam roller	5.8	16.6	○	
Pneumatic tire roller	7.2	20.6	○	
4 ton combined roller	3.2	9.1		○
	Total fuel consumption（liter/hour)		18.5	8.7
	Total CO_2 emission (kg-CO_2/hour)		52.9	24.8

4 APPLICATION EXAMPLE OF EARLY TRAFFIC OPENING

This chapter introduces the example that applied WMA mixture as a purpose of the early traffic opening in the repair construction of the road and airport runway. In addition, in this example, it links with the reduction of the CO_2 emission of the mixture manufacturing.

Repair Construction of Road Pavement

The repair construction of 14cm milling and overlay was conducted in two sections, one was a typical section using HMA mixture with the normal temperature conditions as a control, and another was WMA section with decreased 30 degrees Celsius from HMA mixture. The overlay was a 4cm thick of surface layer and 10cm thick of binder layer.
This example was examined, for the purpose of early traffic opening, by measuring the temperature inside the pavement with the thermocouples from the beginning of construction. Figure 5 shows the measured results of inside temperature change with time (Kobayashi et al.1997). As shown in the figure, there was a time difference until inside temperature dropped to 60 degrees Celsius of surface layer between the HMA and the WMA was about 70 minutes in about 30 degrees Celsius of ambient temperature. The WMA technology was effective to shorten the curing time and as a result the traffic opening became early and no initial rutting was found at this stage.

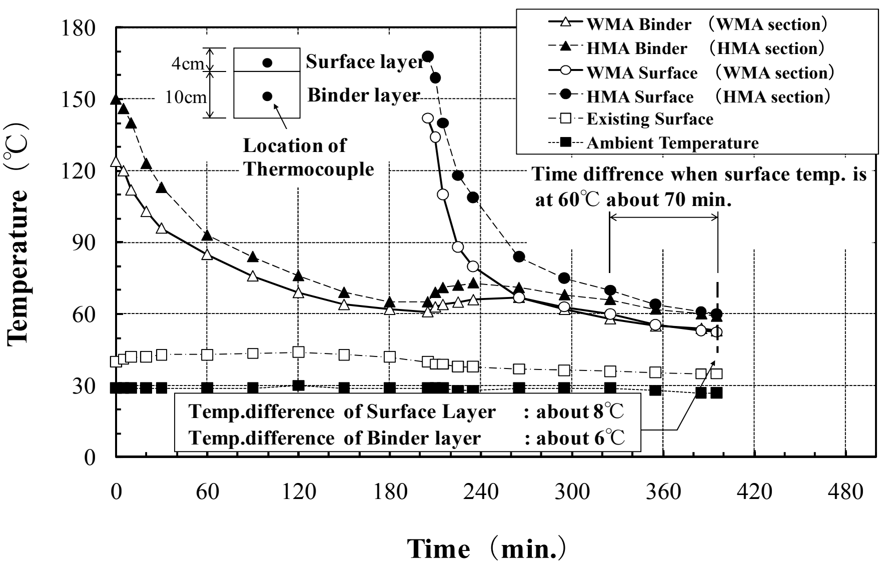

Figure 5 : Pavement temperature drop with time

Repair Construction of Airport Runway

The repair construction was full-scale milling and overlay of average thickness 16cm and replacing of the lane form of total thickness 42cm in the pavement of Airport Runway, and WMA technology was applied to all asphalt mixture for the overlay. In addition, it was the first construction in Japan which executed the paving under the strict time limitation in the night aiming at the early opening in the next morning. The WMA mixtures used the large stone mixture with decreased 30 degrees Celsius by the thicklift method for base course and dense asphalt mixture with decreased 30 and 50 degrees Celsius for surface layer or binder layer. Particularly the WMA mixture with decreased 50 degrees Celsius was applied at the lane track and the runway end where the tire of a heavy airplane of the load condition contacted. By splashing water to cool WMA mixture, the temperature at the opening of the service achieved 50 degrees Celsius lower. In addition, the atmosphere temperature was around 15 degrees Celsius.
This example was examined, for the purpose of early opening, by measuring the temperature inside the pavement with the thermocouples from the construction completion. Figure 6 shows the measured results of inside temperature change with time (Ikegami et al.2003). As shown in the figure, the WMA mixture with decreased 50 degrees Celsius was able to be lower temperature of the pavement surface than specified of 50 degrees Celsius at the opening of the service. In addition, the degree of compaction and the surface smoothness satisfy the specifications in both WMA mixtures.

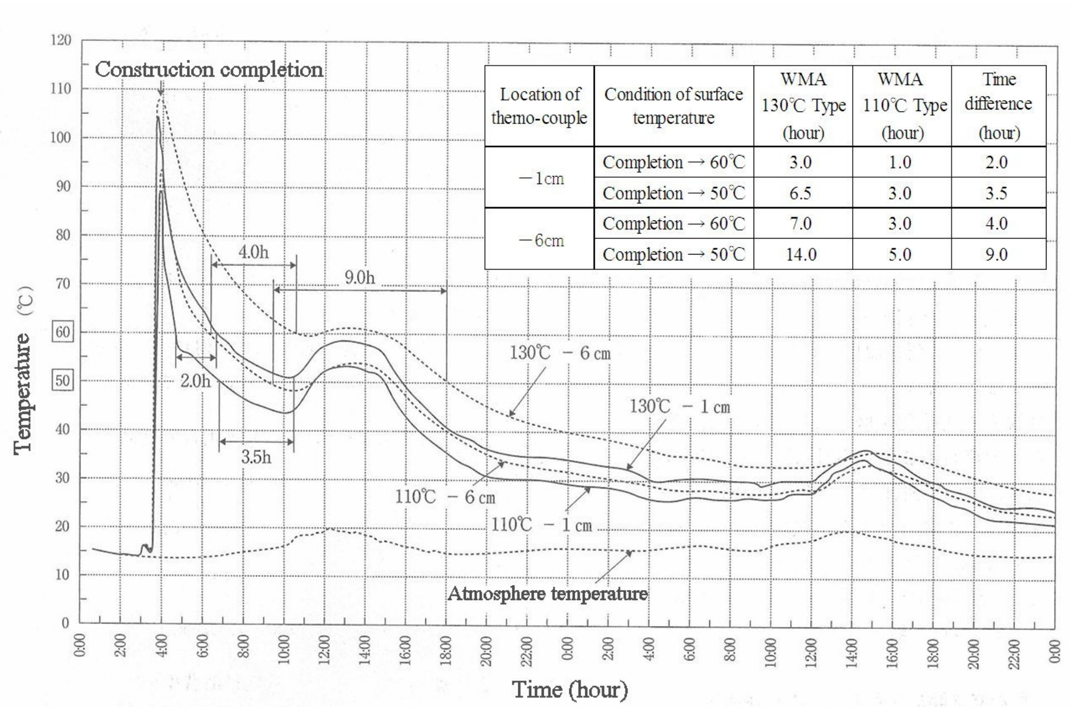

Figure 6 : Pavement temperature drop with time in pavement of airport

5 APPLICATION EXAMPLE OF IMPROVEMENT OF PAVING IN COLD WEATHER

The degree of compaction in the paving is very important in the cold weather. So far, it has been made hauling temperature a little high and devised compaction work as general correspondence. This chapter introduces the example of the paving in the cold weather that uses the effect of higher compaction ability which applies WMA technology at normal manufacturing temperature.

First example was applied WMA technology for the stone mastic asphalt mixture of the 5mm top that used for the intermediate course of the composite pavement, and aimed to obtain the required degree of compaction in the thin layer of 3cm. Table 4 shows the measured temperature of the WMA mixture in the paving (Ebisawa et al.2000). The WMA mixture was accepted a sudden temperature fall right after spreading in the paving, but the workability did not deteriorate and the compaction degree of cored samples was provided the good result of 98.7%.

Table 4 : Results of measured temperature of WMA mixture

Item	Temperature (℃)
Hauling	175-185
Spreading	160-170
Compaction starting	116-135
Atmosphere	About 5

Second example was applied WMA technology for the porous asphalt mixture that the temperature management of the winter season was difficult in the paving, and examined the required quality. Figure 7 shows the results that the spreading temperature of the porous asphalt mixture compared winter season with autumn season (Hidaka 2007). As shown in the figure, the spreading temperature in the winter season was the case that cannot exceed temperature of the standard temperature of 140 degrees Celsius or more for the required quality. However, the compaction ability of the porous asphalt mixture was improved because it applied WMA technology, and it was able to obtain the required quality that the temperature of initial compaction was higher than around 130 degrees Celsius.

Based on this examination, the manual of the construction in winter for porous asphalt pavement which applied WMA technology was published.

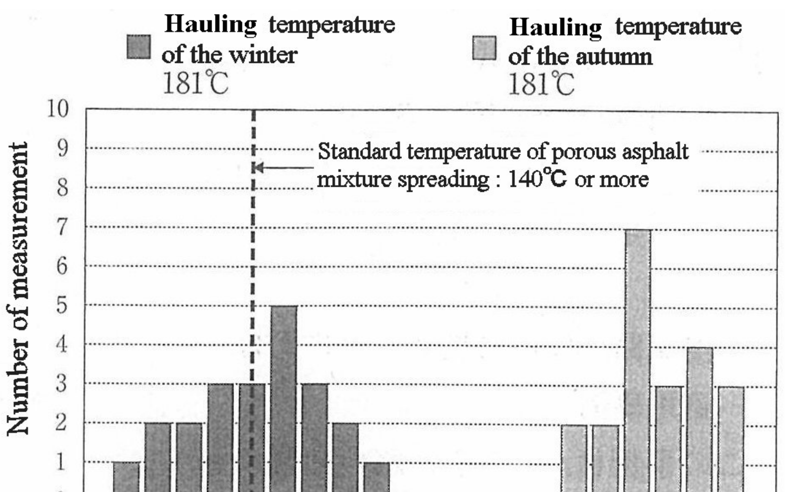

Figure 7 : Comparison of the spreading temperature between winter and autumn

6 ACTUAL RESULTS

In Japan, the actual results used the WMA technology for are about 3,000,000square meters according to the investigation of Japan Road Contractors Association in June, 2009.
Figure 8 shows the number of construction for every application purpose. As shown in the figure, the number of construction for decreasing the mixture manufacturing temperature is total 40%, and the number of the mixture manufacturing temperature at normal temperature is total 60%.
The WMA technology is applied in a wide use. However the number construction for the application purpose that reduces a CO_2 emission in still few present conditions.

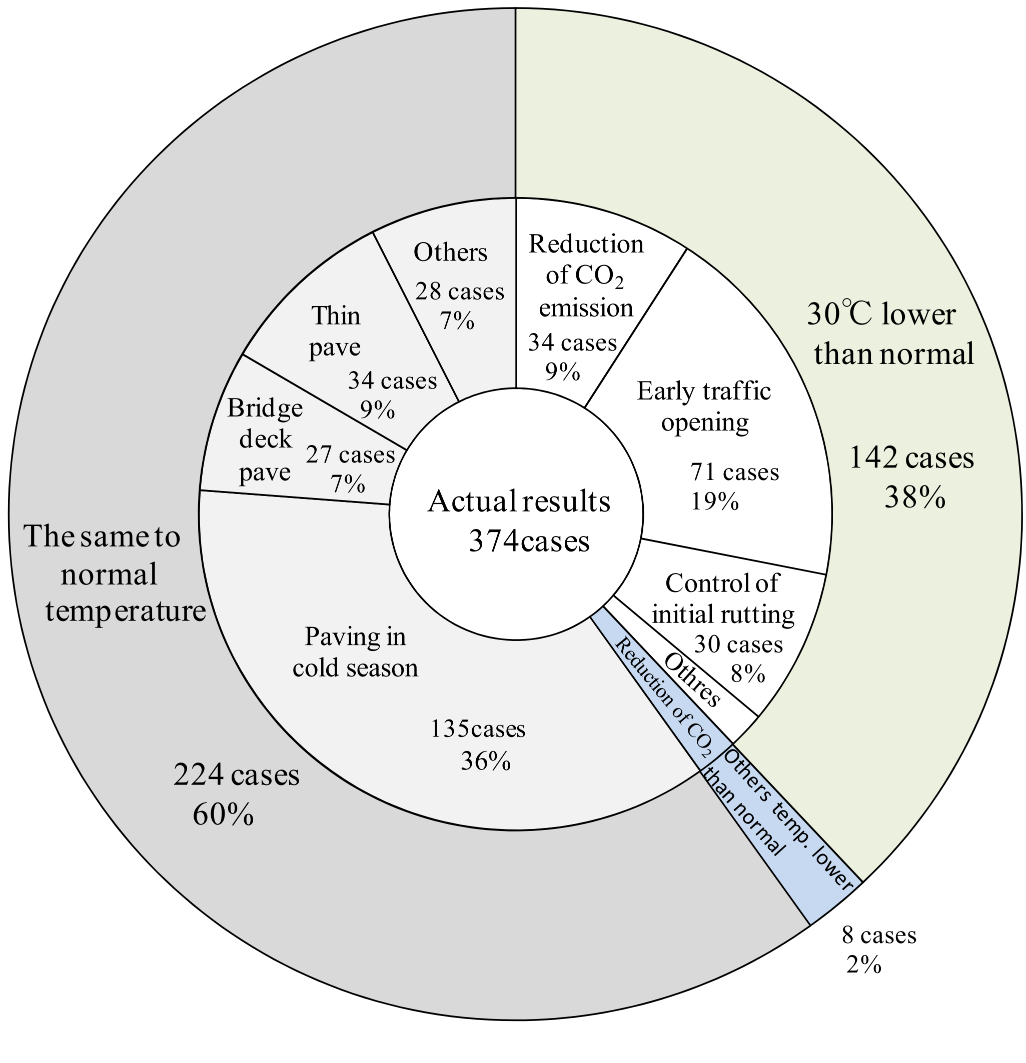

Figure 8 : Construction number of every application purpose

7 CONCLUSIONS

The measures to the global warming are urgent problems, and it is necessary for the action from the field of pavement for the realization of the low carbon society to be able to advance more. The WMA technology which we introduced this paper is effective to reduce a CO_2 emission of the hot mix asphalt manufacture. The CO_2 emission is able to reduce about 15%

which decreased the mixture manufacturing temperature by 30 degrees Celsius than that of conventional HMA mixture in the plant. It can expect that the CO_2 emission reduces about 150,000ton at all of the quantity of manufacture in the year of the HMA mixture in Japan. In addition, the quantity of annual manufacture of the HMA mixture in Japan is about 54,000,000ton by 2007 years. We expect that The WMA technology is utilized from the viewpoint of global warming restraint more than before.

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