ESTIMATION OF THE CO2 EMISSIONS IN PRODUCING HMA AND WMA IN JAPAN

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ABSTRACT

In general pavement repair works in Japan, which consist of material production, transportation, construction and disposal, CO_2 emissions during the material production account for about 60% of the total emissions from the whole stages, and about 60% of the emissions during production occurs during the preparation of hot asphalt mixture. Therefore, reducing emissions during this stage should effectively reduce the CO_2 emissions from paving works.

In this study, CO_2 emissions during the preparation of hot mix asphalt were investigated by interviewing asphalt plants in Japan and determining the fuel consumptions. The amount of CO_2 emitted for producing warm mix asphalt additives was also estimated to clarify the effects of warm mix asphalt technologies on reducing CO_2 emissions. The study showed that warm mix asphalt technologies reduce CO_2 emissions by about 10% even taking the emissions from the production of additives into account.

1. INTRODUCTION

CO_2 emissions in Japan in 2008 were 1,280 million tons (converted into CO_2) [1], a 1.6% increase from 1990, which is the reference year in the Kyoto Protocol. Therefore, further actions must be taken and technologies developed in order to create a low-carbon society, and paving technologies that can reduce CO_2 emissions must be developed.

The Guidebook on Environment-friendly Paving Technologies [2] cites lowering the temperature of hot mix asphalt (HMA), cold mix asphalt, recycling, and long-life pavement as paving technologies that reduce CO_2 emissions. In order to develop new low-carbon paving technologies and improve existing technologies into low-carbon ones, it is necessary to quantify the CO_2 emissions of the technologies.

According to our researches [3], the CO_2 emissions during the production of materials accounted for about 60% of the total emissions from ordinary pavement repair works (milling and overlaying), which consist of material production, transport, construction and disposal (Fig. 1). Of the emissions during material production, about 60% are emitted during the preparation of hot mix asphalt, so reducing the emissions during this stage should effectively reduce the CO_2 emissions from paving works.

The amount of CO_2 emitted during the production of hot mix asphalt is examined from the fuel consumption at asphalt plants (AP), of which a large percentage is used to dry and heat aggregates [3]. Recently, warm mix asphalt (WMA) technologies, which can reduce the fuel consumption at asphalt plants, are expected to reduce the CO_2 emissions.

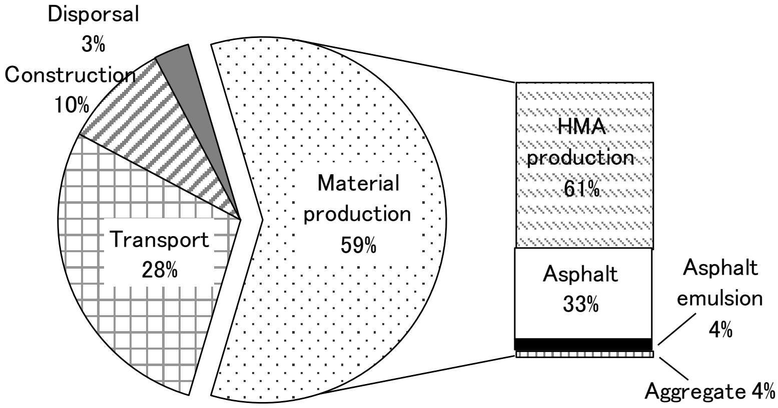
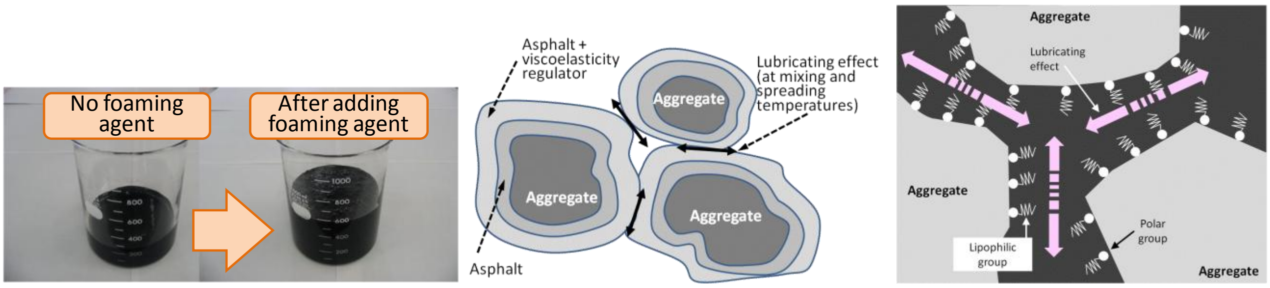


Figure 1 - Percentage of CO_2 emissions during milling and overlaying new asphalt mixture [3]

Warm mix asphalt technologies lower the temperature at which hot mix asphalt is produced by adding additives (Fig. 2). This approach has been reported to lower the temperature by 30°C compared to ordinary hot mix asphalt (160°C) and thus reduce the fuel consumption by about 15% [4]. However, CO_2 emissions during the production of additives are not known, and actual CO_2 emissions during the production of ordinary hot mix asphalt at plants have not been fully clarified either.

In this study, we interviewed asphalt plants in Japan on fuel consumption to clarify the CO_2 emissions during the production of ordinary hot mix asphalt, and then calculated the additional CO_2 emissions in producing warm mix asphalt additives. We determined the CO_2 emissions during the production of ordinary hot mix asphalt and warm mix asphalt and also estimated the emissions reduction resulting from shorter duration of traffic restrictions, which is a secondary effect of warm mix asphalt technologies.



a) Foaming agent
b) Schematic illustration of viscoelasticity regulator
c) Schematic illustration of lubricator

Figure 2 - Kinds of warm mix asphalt additives

2. OVERVIEW OF THE INVESTIGATION AND ESTIMATION CONDITIONS

2.1 Actual fuel consumption involved in the production of hot mix asphalt

To clarify the actual fuel consumption during the production of hot mix asphalt, we interviewed asphalt plants. Asphalt plants keep records of the amount of hot mix asphalt, recycled aggregate and fuel consumed. Fuels used at asphalt plants are electric power, diesel oil, and fuel oil. The electric power is used to run the plants, diesel oil is consumed by machines for moving aggregates within the mixing plant, and fuel oil is used by driers for heating aggregates.

In practice, it is difficult to record the fuel consumptions for producing hot mix asphalt using new aggregates ("new hot mix asphalt") and recycled aggregates ("recycled hot mix asphalt") separately at asphalt plants because new aggregates, which are heated exclusively in "V" driers, are not only used for producing new hot mix asphalt but are also added to recycled hot mix asphalt.

Therefore, we estimated the fuel consumption involved in the production of recycled hot mix asphalt from the fuel consumption of "R" driers, which are exclusively used for heating recycled aggregates, and the total amount of recycled aggregates used. The flow of materials in hot mix asphalt production is shown in Fig. 3.

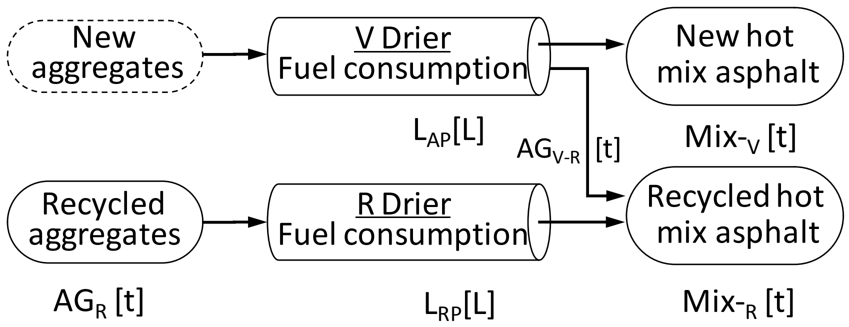


Figure 3 - Flow of materials in hot mix asphalt production

This study first estimated the fuel consumption $L_{mix\text{-}V}$ [L] involved in the production of hot mix asphalt that contained only new aggregates (new hot mix asphalt).

The fuel consumption L_{AP} [L] by a V drier includes the fuel for heating aggregates for new hot mix asphalt and that for recycled hot mix asphalt, which need to be separated. The amount $AG_{V\text{-}R}$ [t] of new aggregates added into recycled hot mix asphalt was estimated by subtracting the amount AG_R [t] of recycled aggregates used from the amount $Mix_{\text{-}R}$[t] of recycled hot mix asphalt produced.

$$AG_{V\text{-}R} = Mix_{\text{-}R} - AG_R \quad (1)$$

where $AG_{V\text{-}R}$: New aggregates used for recycled hot mix asphalt [t]

$Mix_{\text{-}R}$: Recycled hot mix asphalt [t]

AG_R : Amount of recycled aggregates used [t]

Therefore, the fuel consumption $L_{mix\text{-}V}$ [L] for producing new hot mix asphalt is given by:

$$L_{mix\text{-}V} = L_{AP} \cdot Mix_{\text{-}V} / (Mix_{\text{-}V} + AG_{V\text{-}R}) \quad (2)$$

$L_{mix\text{-}V}$: Fuel consumption for the production of new hot mix asphalt [L]

L_{AP} : Fuel consumed by V drier [L]

$Mix_{\text{-}V}$: Production of new hot mix asphalt [t]

Dividing the fuel consumption by the amount of new hot mix asphalt produced [t] gives the fuel consumption for producing 1 ton of new hot mix asphalt.

On the other hand, the fuel consumption $L_{mix\text{-}R}$ [L] for producing recycled hot mix asphalt is the sum of the fuel consumed L_{RP} [L] by the R drier and the difference between the total fuel consumption of the V drier and the fuel consumed $L_{mix\text{-}V}$ [L] for producing new hot mix asphalt.

$$L_{mix-R} = L_{RP} + L_{AP} - L_{mix-V} \quad (3)$$

L_{mix-R} : Fuel consumption for the production of recycled hot mix asphalt [L]

L_{RP} : Fuel consumed by R drier [L]

Dividing this by the amount of recycled hot mix asphalt produced [t] gives the fuel consumption [L] for producing 1 ton of recycled hot mix asphalt.

2.2 Unit CO_2 emissions of warm mix asphalt technologies

The manufacturers of warm mix asphalt about the present state of the technologies were interviewed. Questions included the kind of additives, mix ratios, difference in heating temperature and the amount of CO_2 emitted during the production of additives.

2.3 Calculation of CO_2 emissions

The amount of CO_2 emitted at an asphalt plant during the production of ordinary hot mix asphalt and warm mix asphalt were estimated. The unit CO_2 emission for producing one ton of hot mix asphalt was determined using the calculated fuel consumption (the amounts of fuel oil, electric power and diesel oil consumed) at the asphalt plant described above. The amount of CO_2 emitted can be calculated by multiplying the mass (the mass of hot mix asphalt in this case) and the unit CO_2 emission.

Reductions in CO_2 emissions by using warm mix asphalt were estimated by calculating the reduction in fuel oil consumption by lowering the temperature and adding the CO_2 emissions during the production of warm mix asphalt additives.

2.4 CO_2 emissions reduction by shorter duration of traffic restrictions

Because WMA technologies are able to produce asphalt mixture by lower temperature, the paving temperature using WMA became lower than general HMA. Thus WMA shorten the time of the duration of traffic restrictions and mitigate traffic congestion [2]. Therefore this estimated the CO_2 emission reductions resulting from shorter duration of traffic restrictions.

The amount of CO_2 emitted from automobiles varies depending on the mean travelling speed of the vehicle [5)]. Here, the speeds of vehicles were assumed to differ between when traffic restrictions are imposed or not imposed. The speed was assumed to be 40 km/h when traffic restrictions are not imposed and 10 km/h when restrictions are imposed. The CO_2 emission factors of vehicles are shown in Table 1.

Table 1 - CO_2 emission factors for each type of vehicle [5]
(Expected value for year 2010)

Travelling speed (km/h)	Compact car	Truck
	(g-CO_2/km vehicle)	
10	308.5	1345.5
40	151.7	835.5

The amount of CO_2 emitted from vehicles is determined by multiplying the traffic volume and distance by the emission factors.

CO_2 emitted from automobiles = EFiv・TRi・T・K (4)

whereEFiv: Unit CO_2 emission [g-CO_2 / (km・vehicle)] for vehicle type i at mean speed v [km/h]

TRi : Day traffic volume of vehicle type i [number of vehicles / (day・direction)]

T : Time [days]

K : Distance [km]

Distance (K) denotes the distance that the vehicle drives at an average speed. In this calculation, it was the distance until the mean speed of the vehicle changes due to traffic restrictions and was assumed to be the distance of traffic congestion.

According to Table 1, the CO_2 emissions from cars and trucks are reduced by 50% and 40%, respectively, by increasing the travelling speed from 10 km/h to 40 km/h. From the equation above, CO_2 emissions are expected to increase proportionally with traffic volume, time and congestion distance.

The effect of shortening the duration of traffic restrictions on CO_2 emissions was estimated using the following equation.

Difference in CO_2 emission = CO_2 emission during traffic restriction − CO_2 emission during normal traffic (5)

Table 2 shows the case used for estimating the CO_2 emission reductions by shortening the duration of traffic restrictions.

Table 2 Cases calculated

<table>
<tr><th colspan="2">Case</th><th colspan="4">Set value</th></tr>
<tr><td colspan="2">Difference in hours of opening the road section</td><td colspan="2">30</td><td colspan="2">60</td></tr>
<tr><td colspan="2">Traffic volume (number of vehicles /(day direction))</td><td colspan="2">N4</td><td colspan="2">N6</td></tr>
<tr><td rowspan="2"></td><td>Compact car</td><td colspan="2">911</td><td colspan="2">9.111</td></tr>
<tr><td>Truck</td><td colspan="2">200</td><td colspan="2">2,000</td></tr>
<tr><td colspan="2">Distance (km)</td><td>0.5</td><td colspan="2">1.0</td><td>1.5</td></tr>
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The difference in traffic restriction time has been reported to be 35 to 50 minutes [6] and 30 minutes to 1 hour [7]. Based on the data, the difference in restriction time was assumed to be 30 minutes and 1 hour in this study.

The traffic volume was assumed to be those of Classes N4 and N6 of Japanese Pavement Design; Class N4 assumes 200 trucks per day per direction, and Class N6 assumes 2,000 trucks per day per direction. The number of compact cars was estimated based on the statistic [8] that the percentage of trucks on general national highways is 18% of all vehicles on the highways.

The congestion distances of 0.5 km, 1.0 km and 1.5 km were assumed because there were no data on congestion distance caused by paving works.

3. ESTIMATED THE AMOUNT OF ENVIRONMENTAL LOADS

3.1 Fuel consumption involved in producing hot mix asphalt

Through interviews, valid answers were obtained from 29 asphalt plants in Japan: 4 in Tohoku, 2 in Hokushinetsu, 8 in Kanto, 3 in Tokai, 1 in Kinki, 3 in Chugoku, 3 in Shikoku and 5 in Kyushu region. Their annual production of hot mix asphalt ranged from 20 thousand to 180 thousand tons as shown in Fig. 4 and was about 100 thousand tons on average. The hot mix asphalt production and fuel consumption values are summarized in Table 3.

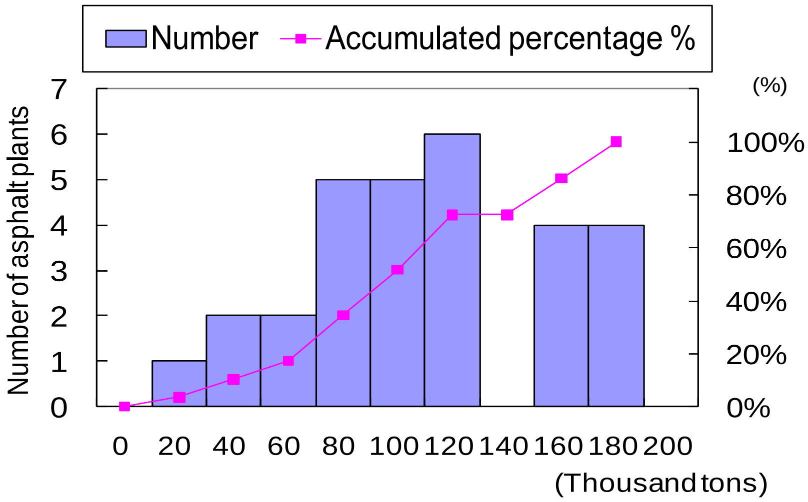

Figure 4 - Number of plants for each hot mix asphalt production class

Table 3 - Overview of hot mix asphalt production and fuel consumption

Item	Unit	Total	Item	Unit	Total
Hot mix asphalt production	Thousand tons	2,977	New asphalt mix	Thousand tons	795
			Recycled asphalt mix	Thousand tons	2,182
Fuel oil consumption	Thousand L	27,859	Amount of recycled aggregates used	Thousand tons	1,170
Power consumption*1	Thousand kWh	31,485	Fuel oil consumption by V drier	Thousand L	15,449
Diesel oil consumption*1	Thousand L	770	Fuel oil consumption by R drier *2	Thousand L	12,410

*1: Valid answers for electric power and diesel oil consumptions were obtained from 30 and 33 plants, respectively, and the amounts of asphalt mix produced using the fuels were 3,034,068 t and 3,275,811 t, respectively.
*2: In some plants, the fuel oil consumption by R driers includes the fuel consumed by deodorizing furnaces.

Figure 5 shows the relationships between the annual hot mix asphalt production and the consumptions of diesel oil, electric power and fuel oil at each asphalt plant. All showed correlations with the production of hot mix asphalt. Electric power and fuel oil consumptions were almost linearly correlated with the production amount. The consumption of diesel oil was slightly less correlated than the others possibly due to the small areas of the plants and machine arrangements within; larger facilities showed better production efficiencies and better power approximation. The electric power and fuel oil consumptions per ton of hot mix asphalt were 10 kWh and 0.23 L, respectively.

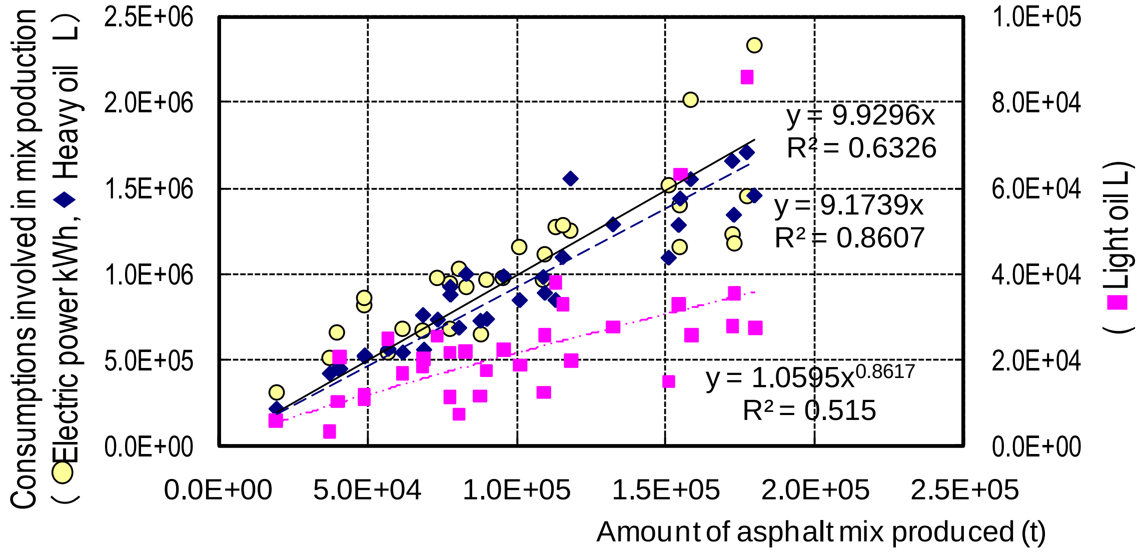

Figure 5 - Relationship between annual hot mix asphalt production and the consumptions of diesel oil, electric power and fuel oil

Figure 6 shows the stated amounts of fuel oil consumed during production of hot mix asphalt. For hot mix asphalt as a whole, 7.2 to 13.2 L (mean: 9.4 L) of fuel oil was consumed for producing 1 ton of asphalt mix. The value was the same as the mean national value of 9.4 L in the statistics [9] of the Japan Asphalt Mixture Association. The fuel oil consumptions for new hot mix asphalt and recycled hot mix asphalt were 5.6 to 12.8 L (mean: 8.4 L) and 7.4 to 14.2 L (mean: 9.7 L), respectively.

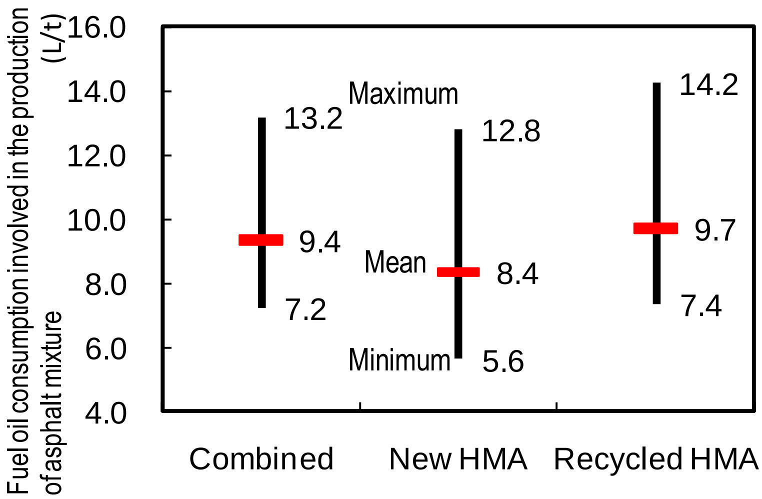

Figure 6 - Fuel oil consumption involved in the production of hot mix asphalt

3.2 Unit CO_2 emissions of warm mix asphalt technologies

Through the interviews, answers were obtained for eight technologies, which are outlined in Table 4. There were five technologies that used foaming additives and three that used viscoelasticity regulators. The cost is 1.07 to 1.22 times larger than that of hot mix asphalt.

For the three technologies that used foaming additives, unit CO_2 emission values were available for the production of the additives. Of these three, two involved lowering the temperature by 30°C, and the other involved lowering the temperature by 50°C. The CO_2 emission ranges are shown in Table 5.

There was no data available on the material composition and unit CO_2 emissions of viscoelasticity regulators. The unit CO_2 emission for producing viscoelasticity regulators was therefore assumed to be the value for asphalt cement because the regulators are petroleum products and have the same composition as asphalt. All products produced by refining petroleum are assumed to be equivalent when the unit of environmental load of asphalt. In this study, the unit of CO_2 emission of viscoelasticity regulator uses same unit as asphalt [10].

Table 4 - Types of warm mix asphalt (Results of interviews)

Type of additive	Temperature reduction	Mix ratio (to As content)
Foaming agent (5 technologies)	20°C to 50°C	2.0 to 7.2%
Viscoelasticity regulator (3 technologies)	30°C	3%, 3.6%*

*: Inner percentage for those that are replaced with asphalt

Table 5 - Unit CO_2 emissions for producing warm mix asphalt additives

Item (unit)		CO_2 emission (kg-CO_2)	Notes
Foaming agent	kg	1.28–6.82 × 10^{-1}	Interview results
Viscoelasticity regulator	kg	2.48 × 10^{-1}	Unit environment load of asphalt production substituted

3.3 Estimation of CO_2 emissions

The unit CO_2 emissions producing new hot mix asphalt were calculated from actual fuel consumptions (fuel oil, electric power and diesel oil) at asphalt plants. The calculated values are shown in Table 6. The unit CO_2 emissions were also calculated for asphalt mixes that used warm mix asphalt technologies (lowering the temperature by 30°C and 50°C) by assuming that the fuel oil consumption was reduced to 84% and 73%, respectively, based on previous calculations [4]. The warm mix asphalt technologies were estimated to reduce CO_2 emissions to 87% for lowering temperature by 30°C and 78% for lowering temperature by 50°C, respectively.

These are showing the amount of CO2 emissions of HMA during production, not amount of the CO2 emissions in the entire HMA. It is necessary to calculate CO2 in the whole HMA to add manufacturing and the transportation of the raw aggregate and asphalt.

Table 6 - Unit CO_2 emissions producing new hot mix asphalt

			CO_2 (kg)				
Basic unit CO2 emissions	Electric power (per kWh)		4.46E-01				
	Fuel oil (per L)		2.83E+00				
	Diesel oil (per L)		2.72E+00				
Unit during production		Consumption per 1t	CO_2 (kg)	-30℃	CO_2 (kg)	-50℃	CO_2 (kg)
Producing HMA	Electric power	10 kWh	4.46E+00	10 kWh	4.46E+00	10 kWh	4.46E+00
	Fuel oil	8.4 L	2.38E+01	7.06 L	2.00E+01	6.13 L	1.74E+01
	Diesel oil	0.23 L	6.26E-01	0.23 L	6.26E-01	0.23 L	6.26E-01
	Total (= Unit emissions: unit/t)		2.89E+01	—	2.51E+01	—	2.24E+01
			Reduction ratio:		87%		78%

The reductions in CO_2 emissions by using warm mix technologies were calculated using the unit CO_2 emissions producing three foaming agents and one viscoelasticity regulator shown in Table 5. The Fig.6 shows the ratio which CO_2 emissions of producing ordinary hot mix asphalt as standard (100%).

Use of any warm mix technology involves additional CO_2 emissions for producing additives. As shown in Fig. 7, the CO_2 emitted when producing additives needs to be added. However, the increase was only 0.9% to 2.7% of the emissions comparing producing ordinary new hot mix asphalt. The resultant total CO_2 emissions during production of hot mix asphalt were found to be reduced by 10% to 20% by using warm mix asphalt technologies.

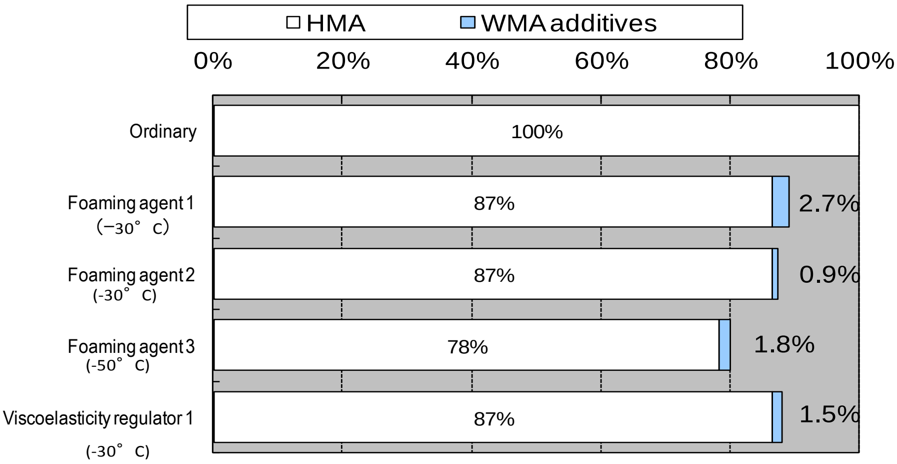

Figure 7 - Effect of warm mix asphalt technologies on reducing CO_2 emissions

3.4 CO_2 emissions reduction by shortening the duration of traffic restrictions

Figure 8 plots the changes in CO_2 emissions by shortening the duration of traffic restrictions, which were estimated for each traffic volume and congestion distance using Equation (5). In all cases, CO_2 emissions were 44% lower during ordinary service than during traffic restrictions because the mean travelling speed increased from 10 km/h to 40 km/h. According to the figure, CO_2 emissions are reduced more for works that require longer traffic restrictions, are executed on road sections with larger traffic volume, and cause congestion on longer road sections.

The largest reduction of 153 kg-CO_2 was estimated for a highway section of traffic volume N6, congestion distance of 1.5 km, and traffic restriction time shortened by 60 minutes.

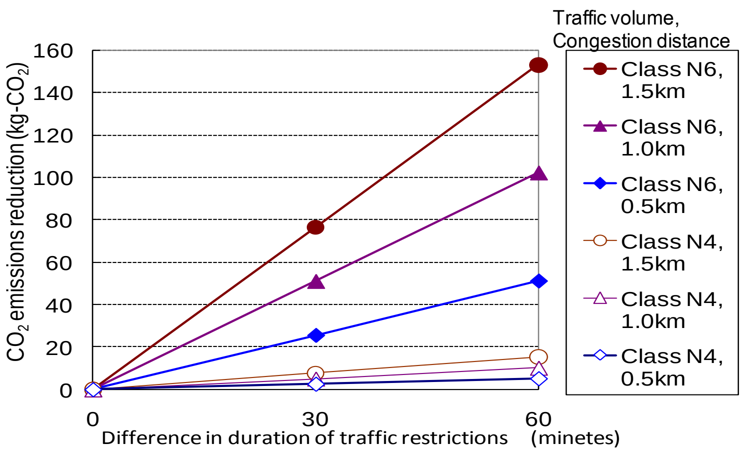

Figure 8 - Changes in CO_2 emissions by difference in duration of traffic restrictions

4. SUMMARY

The results of this study are summarized below.

1) The actual fuel consumptions at about 30 asphalt plants in Japan were surveyed. To produce one ton of hot mix asphalt, 10 kWh/t of electric power and 0.23 L/t of diesel oil were consumed. The consumption of fuel oil was 9.4 L/t on average, 8.4 L/t for producing new hot mix asphalt and 9.7 L/t for producing recycled hot mix asphalt.

2) The unit CO_2 emissions producing warm mix asphalt additives (foaming type) were 0.128 to 0.682 kg-CO_2/kg. Lowering the temperature at which asphalt mix is produced by 30°C to 50°C by using warm mix asphalt technologies can reduce the CO_2 emissions by about 10 to 20% compared to the level emitted in producing ordinary new hot mix asphalt.

3) Shortening the duration of traffic restrictions by using warm mix asphalt technologies would result in a 44% reduction of CO_2 emissions due to the difference in mean vehicle travelling speed with and without traffic restrictions. Emissions of 153 kg-CO_2 would be reduced by shortening the traffic restrictions by 60 minutes on a highway with heavy traffic where the restrictions cause congestion over a distance of 1.5 km.

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