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Optimum Road Pavement from the Viewpoint of CO_2 Emission Reduction

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ABSTRACT

The main objective of this study is to determine the amount of CO_2 emission starting from the production of surface materials, maintenance, removal, and disposal to the recycle process on three types of pavements. The three pavements were asphalt, interlocking block, and cement concrete pavement. This study was done in order to promote CO_2 emissions reduction in the future. By comparing the amount of CO_2 emission per 100 m^2 of pavement in 100 years after new construction, it was found that the smallest amount of CO_2 emissions for asphaltic pavements was produced from the pavement under the dynamic loads of 250 heavy trucks with a capacity of 20 tons in one direction per day, later called as 250 traffic loads. While for interlocking block pavement, the smallest amount of CO_2 emissions was generated from the pavement with over 250 traffic loads.

INTRODUCTION

Environmental problems are serious at present all over the world. Efforts for environmental impact reduction are practiced in various fields, and in civil engineering field is no exception. Especially for greenhouse gases, the aim that 60~80% of them has to be reduced by 2050 was put up at the Touyako summit in Hokkaido in May 2008. More than 90% of greenhouse gases that are emitted in Japan are CO_2 [Daily-ondanka.com], and huge amounts of CO_2 are emitted because the scales of civil infrastructures are so large; therefore, civil engineers need to make considerable effort to reduce it. The same applies to road pavements, there is a strong possibility that the amount of CO_2 emissions depends on the type of pavement. Therefore, in order to promote CO_2 emission reductions, the purpose of this study is to evaluate the CO_2 emissions starting from the production of surface materials, maintenance, removal, and disposal to the recycle process quantitatively for three types of pavements: asphalt, interlocking blocks, and cement concrete pavements.

RESEARCH METHODOLOGY

Inventory data associated with the construction of asphalt, interlocking blocks, and cement concrete pavements were prepared [Japan Society of Civil Engineers 2004]. These inventory data depended on various parameters in the process of pavement construction. Using these data, the amounts of CO_2 emissions from new pavement construction and from mending activities on the surface layer of pavement for each pavement were evaluated. Finally using these data, the amount of CO_2 emissions for each pavement was evaluated and then compared with each other for long-term point of view.

ASSUMPTIONS IN CALCULATING THE CO_2 EMISSIONS

In this study, the CO_2 emissions for three types of pavements: asphalt, interlocking blocks, and cement concrete pavements were evaluated by classification of traffic loads. This traffic loads were classified by the number of heavy trucks with a capacity of 20 tons moving in one direction per day [Japan Road Association 1990]. The classification is shown in Table 1.

Table 1. The Classification of Traffic Loads

Traffic loads (The number of heavy trucks in one direction per day)	Less than 100 traffic loads
	100~250 traffic loads
	250~1000 traffic loads
	1000~3000 traffic loads
	More than 3000 traffic loads

The structures of each type of pavements are shown in Figs.1 [Japan Road Association 1990], 2 [Japan Interlocking Block Pavement Engineering Association 2007], and 3 [Japan Road Association 1991].

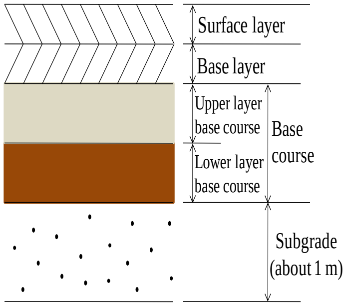

Fig. 1. Structure of asphaltic pavement

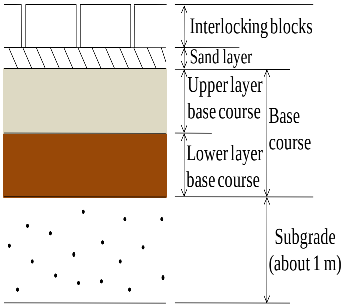

Fig. 2. Structure of interlocking block pavement

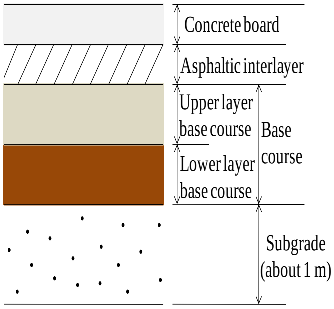

Fig. 3. Structure of cement concrete pavement

Crusher-run stone was used as material for the lower layer base course, while for the upper layer of the base course consisted of pulverized and bituminous treatment rocks [Japan Road Association 1990]. High-density asphalt mixture and recycled high-density asphalt mixture were used as materials for the asphaltic interlayer. Besides, Table 2 shows the design of thickness for each pavement by classification of traffic loads [Japan Road Association 1990, Japan Interlocking Block Pavement Engineering Association 2007, and Japan Road Association 1991]. A high-density asphalt mixture was used as the pavement material in new asphaltic pavement. A recycled high-density asphalt mixture was used for mending the surface layer of the asphaltic pavement [Amano 1998].

Values for the mix proportions of high-density asphalt mixture and recycled high-density asphalt mixture were quoted from data in the reference [Amano 1998]. The typically mix proportions of cement concrete and interlocking block used in Japan were provided by some companies. Table 3 and 4 show the mix proportions of cement concrete and interlocking block pavements, respectively, which were used for this study.

Table 2. The Design Thickness for Each Pavement by Classification of Traffic Loads

Paving material	Traffic loads (The number of heavy trucks in one direction per day)	Surface and base layer (cm)	Block layer (cm)		Asphaltic interlayer (cm)	Upper layer base course (cm)		Lower layer base course
			Block	Sand		Pulverized rocks	Bituminous treatment rocks	Crusher-run
High-density asphalt mixture	Less than 100	5	—	—	—	—	15	15
	100~250	5	—	—	—	—	20	25
	250~1000	10	—	—	—	—	15	35
	1000~3000	10	—	—	—	8	20	35
	More than 3000	15	—	—	—	11	25	35
Interlocking block	Less than 100	—	8	2	—	5	—	12
	100~250	—	8	2	—	8	—	23
	250~1000	—	8	2	—	10	15	19
	1000~3000	—	8	2	—	15	25	29
	More than 3000	—	10	2	—	20	30	38
Cement concrete	Less than 100	15	—	—	—	—	25	25
	100~250	20	—	—	—	—	25	25
	250~1000	25	—	—	—	—	20	25
	1000~3000	28	—	—	4	—	10	25
	More than 3000	30	—	—	4	—	10	25

Table 3. Mix Proportion of Cement Concrete

Density (kg/m^3)				Mass per unit volume (t/m^3)
Water	Cement	Fine aggregate	Course aggregate	
126	300	709	1243	2.38

Table 4. Mix Proportion of Interlocking Block

Density (kg/m^3)				Mass per unit volume (t/m^3)
Water	Cement	Fine aggregate	Course aggregate	
110	350	870	1000	2.33

In addition, the design thickness shown in Table 2 is the thickness after compaction, and it is necessary to calculate actual usage by using adjustment formula. So Table 5 was used to calculate the amount of base course material, asphalt mixture and cement concrete [Construction Research Institute 2007].

Table 5. Adjustment Formula of Materials

Name of material	Adjustment formula	Adjustment coefficient (K)
Base course material	Usage (m^3) = Design usage (m^3) ×(1+K)	K = 0.27
Asphaltic mixture	Usage (t) = Design dimensions (m^2) ×Thickness of asphaltic pavement (m) × density after compaction (t/m^3) × (1+K)	K = 0.07
Cement concrete	Usage (m^3) = Design dimensions (m^2) × Thickness of concrete block (m) × (1+K)	K = 0.04

Next, Fig. 4 illustrates the whole process of pavement construction. In this figure, production of materials means it of cement, aggregate, and straight asphalt and so on, while production of pavement materials means it of asphalt mixture, interlocking block, and cement concrete.

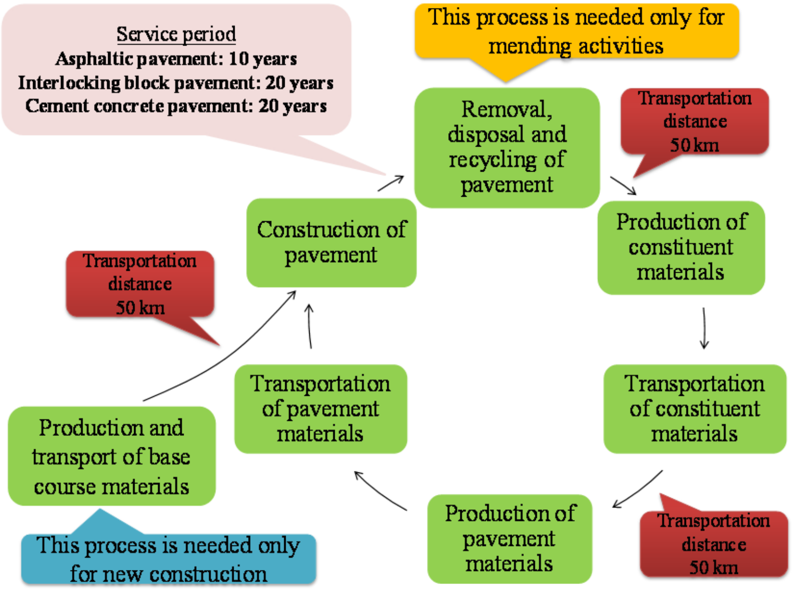

Fig. 4. The Whole Process of Pavement Construction

Since data of the distance between production plants to construction site has not been obtained until this moment, 50 km was assumed to be the distance for all types of pavement. Also, the same distance was assumed for the distance from the construction site to the recycled asphalt mixture plant. All of the high-density asphalt mixture was assumed to be recycled for mending activities. Interlocking blocks were assumed to be reusable at about a 30% rate. These assumptions appertain to recycle were based on the results of hearing to a Japanese road company. Since it was difficult to reuse the cement concrete as pavement material, it was assumed that it was discarded at the end of the service period. A 10-year service period of asphaltic pavement and a 20-year period for interlocking blocks and cement concrete pavement were assumed for the calculations of CO_2 emissions. These values of service period were quoted from the guideline for each type of pavement [Japan Interlocking Block Pavement Engineering Association 2007, Japan Road Association 1991, Japan Road Association 1990].

In addition, Table 6 shows inventory data used in this study. These inventory data were quoted from a reference [Japan Society of Civil Engineers 2004] or calculated by using performance of construction equipments [JCMA 2007].

Table 6. Inventory Data Used in This Study

Materials and equipments	Unit (*)	Inventory of CO_2 emission (kg-CO_2/*)
High-density asphaltic mixture	t	104.2
Recycled high-density asphaltic mixture	t	54.8
Cement	t	766.6
Fine aggregate	t	3.7
Coarse aggregate	t	2.9
Sand	t	3.7
Steel bar	t	1213
bituminous treatment rocks	t	41.2
Pulverized rocks	t	4.3
Crusher-run	t	4.3
Asphalt emulsion	ℓ	0.164
Distributed machine	m^2	0.25
		0.304
Macadam roller	h	15.97
Tire roller	h	18.74
Road cutter	m^2	1.334
		1.617
Backhoe	m^3	7.9
Road sweeper	h	31.6

Materials and equipments	Unit (*)	Inventory of CO_2 emission (kg-CO_2/*)
20 t diesel truck	t· km	0.0714
10-t dump truck	t· km	0.117
Ready mixed concrete plant	t	7.68
Asphalt finisher	m^2	0.578
		0.700
Spreader	m^2	0.15
Concrete finisher	m^2	0.15
Concrete leveller	m^2	0.08
Steam curing	m^3	38.5
Vibration roller	h	1.592
Vibration compacter	h	2.38
Agitator truck	m^3· km	0.253

RESULTS AND CONCLUSIONS

Figs. 5, 6, and 7 show the amounts of CO_2 emissions based on the traffic loads for each new pavement construction while Figs. 8, 9, and 10 show the amounts of CO_2 emissions based on the traffic loads for each pavement from mending activities on the surface layer.

CO_2 emissions from the production of the surface layer and base course material, as well as from its transportation activities, were responsible for about 70-80% of the total amount of CO_2 emissions from each pavement. The amount of CO_2 emissions per 100 m^2 of pavement for the cement concrete pavement was the highest with all traffic loads. Especially, there were large differences in the production of surface materials. The proportion of CO_2 emissions caused by the production of materials in asphaltic pavement was smaller than that in other types of pavement. The use of cement as the raw material for concrete was responsible for this difference in the amount of CO_2 emissions.

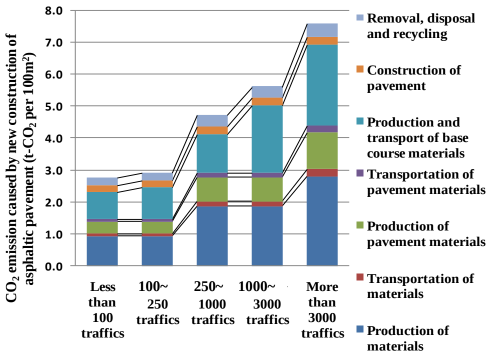

Fig. 5. The Amount of CO_2 Emissions from a New Asphaltic Pavement Construction.

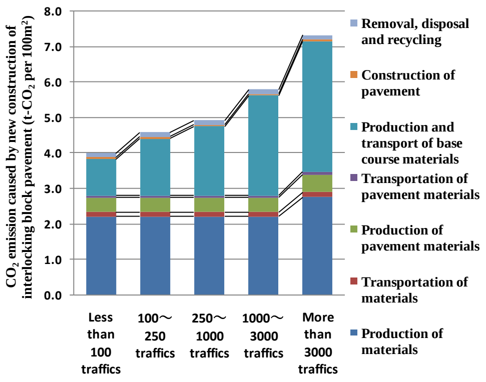

Fig. 6. The Amount of CO_2 Emissions from a New Interlocking Block Pavement Construction.

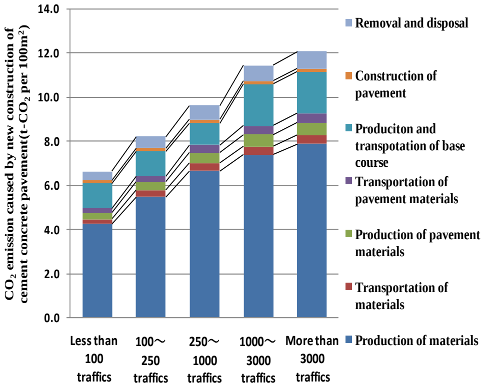

Fig. 7. The Amount of CO_2 Emissions from a New Cement Concrete Pavement Construction.

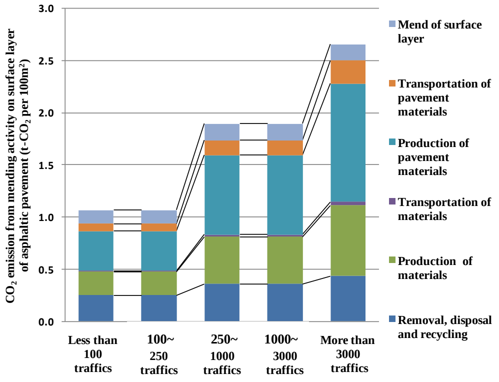

Fig. 8. CO_2 Emissions from Mending Activities on the Surface Layer of Asphaltic Pavement

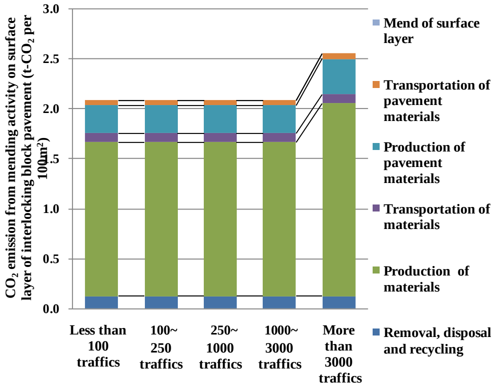

Fig. 9. CO_2 Emissions from Mending Activities on the Surface Layer of Interlocking Block Pavement.

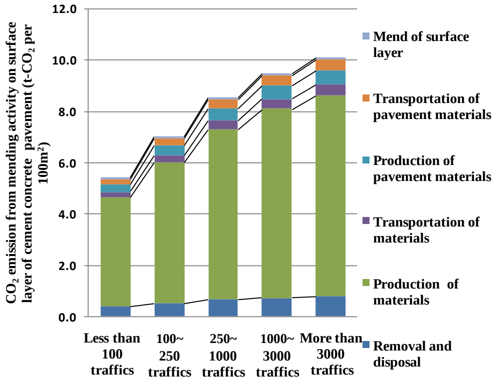

Fig. 10. CO_2 Emission from Mending Activity on Surface Layer of Cement Concrete Pavement.

On the contrary, the amount of CO_2 emissions in asphaltic pavement with more than 3,000 traffic loads was larger than that in interlocking block pavement. In asphaltic pavement, the thickness of a surface layer increased with increases in traffic loads, while in interlocking block pavement, the thickness of interlocking blocks was constant regardless of the increases in traffic loads. This was the cause for the higher CO_2 emissions in asphaltic pavement compared to that in interlocking block pavement.

For mending activities, the amount of CO_2 emissions from asphaltic and interlocking block pavements was 50-60% lower, compared to that for the new pavement construction. It is because these pavements were reusable from recycled pavement materials. In cement concrete pavement, however, the amount of CO_2 emissions only decreased by 20%. The difficulty of reusing cement concrete was the reason why the emissions were still high from this type of pavement. In addition, in interlocking blocks and cement concrete pavements, the amount of CO_2 emissions generated from the surface material production accounted for about 80% of total CO_2 emissions. On the other hand, in asphaltic pavement, the amount of CO_2 emissions generated from the production of base course pavement only accounted for about 40%. This was due to the use of recycled asphalt mixture which emitted low amounts of CO_2 for mending the surface layer in asphaltic pavement.

Fig.11 shows the amount of CO_2 emissions per 100 m^2 of pavement for the next 100 years after a pavement construction.

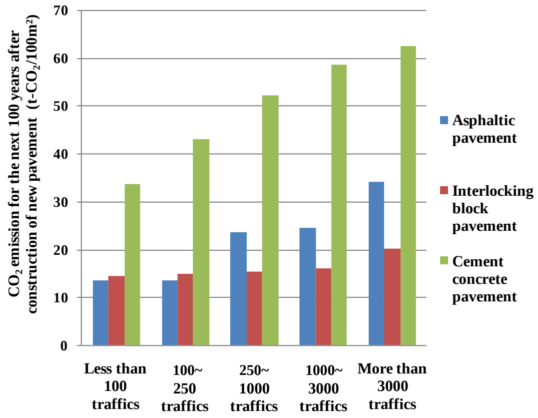

Fig. 11. CO_2 Emissions per 100 m^2 of Pavement for the Next 100 Years after New Pavement Construction.

By comparing the results of CO_2 emissions for 100 years after new construction with different traffic loads, the smallest amount of emissions in asphaltic pavement was produced from pavement with under 250 traffic loads. In the case of interlocking block pavement, the smallest ones were generated from pavement with more than 250 traffic loads. The differences in service periods and the thicknesses of the surface layers, which increase with the increase in traffic loads, were the main reason for this condition.

CONCLUSIONS

The following conclusions were reached:

- Considering the amount of CO_2 emissions from new pavement construction, the emissions generated from the production of the surface layer and the base course materials, as well as from its transportation, were responsible for about 70-80% of the total CO_2 emissions.

- As a result of mending the surface layer of pavement, the amount of CO_2 emissions generated from the production of pavement materials in asphaltic pavement accounted for a high proportion in total CO_2 emissions while in interlocking pavement and cement concrete pavements, the amount of CO_2 emissions generated from the production of surface materials accounted for a high proportion in total CO_2 emissions.
- By comparing the amount of CO_2 emissions per 100 m^2 from each pavement for the next 100 years after new construction, it was found that the smallest amount of CO_2 emissions from asphaltic pavement were produced with pavement under 250 traffic loads. In the case of interlocking block pavement, however, the smallest one was generated from pavement with more than 250 traffic loads.

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