Technical Paper

ISSN 1996-6814 Int. J. Pavement Res. Technol. 6(4):423-430

Assessment of CO_2 Emission Reduction in Road Construction Using Recycled Concrete Materials

Kuang-Yi Wei[1+], Jyh-Dong Lin[2], and I-Hung Yu[3]

Abstract: Climatic change is a grave threat for human life. After the industrial revolution, the rapid increase in atmospheric greenhouse gases, most notably carbon dioxide (CO_2), is primarily responsible for global warming over the past 50 years. Particularly, the high emission of CO_2 in civil works becomes a critical issue for urban development and construction due to its high energy demand and fuel consumption. Therefore, it is important to make the effort to reduce the CO_2 emission from each quality construction project.

Based on product-category rules (PCR), two major road construction materials, asphalt concrete and cement concrete, were studied in this paper. Carbon footprints of the studied materials were examined through the cradle-to-gate life cycle assessment (LCA) from raw material mining and transportation to factory manufacturing.

Our results showed that the primary factor controlling the CO_2 emission factor of recycled concrete is the proportion of recycled materials in the mixture of cement and fine-grained aggregates. The amount of CO_2 emission of road construction using recycled asphalt concrete was 4.533 kg CO_2 less than those using normal asphalt concrete.

DOI:10.6135/ijprt.org.tw/2013.6(4).423

Key words*: Asphalt concrete; Carbon Footprint; Concrete; Reduce Carbon Emissions.*

Introduction

Over the past half a century, the earth's temperature has risen yearly and carbon dioxide concentration in the atmosphere continued to rise. The succession of various natural disasters is all related to the overuse of the earth's resources [1]. In this time of climatic changes, reducing carbon emission is a common goal all the countries in the world strive for. The great energy consumption of asphalt concrete, cement, reinforcing steel, concrete and other bulk engineering materials in the manufacturing industry causes a lot of greenhouse gas emission. Asphalt concrete and cement concrete are still the main materials involved in pavement engineering, so reducing the carbon emission of these two materials will have crucial influences on the carbon emission in road engineering construction [2]. This study leads the preparation of recycled and reused concrete materials of the road engineering in the project according to the concrete code in Taiwan, carries out carbon footprint calculation and example verification, and constructs the carbon emission standards tried out by the road engineering in Taiwan.

Concrete Products Evaluation Model Preparation

The concrete product evaluation model is divided into the raw materials stage, factory production energy consumption stage, product transport stage, and so on according to the Product Category Rules (PCR), then the emission of the products at various stages is calculated and finally the unit carbon emission could be concluded through totaling [3]. The raw materials stage could be categorized into raw materials production and transport, while the factory production is calculated through two parts, which are the part for coordinating the design and the production process stage, respectively. Finally, the product transport stage is calculated through the motor freight investigation report and investigation results [4].

Research Object

Among various concrete products, the study mainly has the two major products of cement concrete and asphalt concrete as the research object. For the cement concrete part, traditional concrete and self-compacting concrete (SCC) is the research object, while the asphalt concrete is categorized into normal hot mix asphalt concrete and hot mix recycling asphalt concrete.

Data Source

In recent years, the greenhouse gas inventory of the industry has been promoted gradually at home to coordinate with the international trend. However, the domestic civil construction industry has no public industry database at present, so the study collects data from various types of manufacturers in the product system and compares with the same industry abroad. The categories of the manufacturers that provide data are shown in Table 1. The fuel and power usage carbon emission factor during the carbon emission calculation process adopt the data announced by the Bureau of Energy. During the research period, the national power emission factor is 0.612kg-CO_2e/ degree, the heavy oil emission factor is 3.11kg- CO_2/L, and the diesel oil emission factor is 2.61kg-CO_2/L [5].

[1] Judong Township Office, Hsinchu County, Taiwan.
[2] Department of Civil Engineering, National Central University, Jhongli, Taoyuan, Taiwan 32001..
[3] Hsinchu Science Park Administration, Hsinchu, Taiwan 300.
[+] Corresponding Author: E-mail weiky0500@yahoo.com.tw
Note: Submitted January 24, 2013, Year; Revised June 26, 2013; Accepted June 27, 2013.

Table 1. Information About Manufacturers Providing Various Types of Data.

LCA Stage	Manufacturer Type	Number of Manufacturers
Raw Material Mining	Sand Mining Dealer	4
Raw Material Processing	Sand Processing Dealer	4
Raw Material Transport	Transport Dealer	4
Design of Product Mix	Ready-mix and Asphalt Concrete Factory	4,5
Product Manufacturing	Ready-mix and Asphalt Concrete Factory	4,5
Product Transport	Transport Dealer	1

Table 2. Survey of Energy Consumption from Sandstone Materials Mining in Taiwan.

Survey Data	A1	A2	A3	A4	B1	B2	B3	B4
Production Stage	Mining				Processing			
Unit Carbon Emission (kg/m^3)	0.407	0.428	0.46	0.495	3.949	4.163	3.305	2.626
Total Carbon Emission (kg)	5844				630223			
Total Output (m^3)	13400				175000			
Unit Average Carbon Emission (kg CO_2-e /m^3)	0.436				3.601			
Unit Average Carbon Emission (CO_2-e kg/T)	0.218				1.8			

Research Hypothesis

This study will face various uncertainties and other situations in the real environment during the benefit evaluation of energy saving and carbon emission reduction, which will influence the evaluation. Therefore, several hypotheses and restrictions shall be made during the calculation process to eliminate the uncertainties. During the benefit calculation process of concrete energy-saving and carbon emission reduction, the study will adopt foreign data as the reference value for verification, choose domestic representative manufacturers as the respondents, and average the calculated data to make them more comprehensive. As the mining uncertainties are too great, the raw materials production site is similar to Taiwan, whose raw materials carbon emission factor is chosen as the foundation of raw material production stage.

Owing to the technology, equipment, factory site, types, depreciation, and other different factors in the production process for the same type of concrete manufacturers, the computed results would be influenced, so the above factors are excluded from the range of study. The study ignores the factors with less influence during the computation process, so as to favor the process computation.

As the raw materials acquisition of the factory itself has a certain regionalism, and the feed manufacturer of the factory belongs to the property of cooperation, the raw material products transport distance could be regarded as the actual distance between the manufacturer and the factory. As the products transport distance of different manufacturers vary greatly, the product transport part not only utilizes basic inquiries, but also hypothesizes the computation with the transport related data in the motor transport survey report. Various raw materials' proportion in mix design products would be based on the mix design procedures. As a result, the difference range among the proportions won't be great; the upper and lower limit and mean value of various proportions could be obtained through statistics, so as to obtain the carbon emission interval of the raw materials of the product under the mix design. The others will be computed through the representative matching.

Table 3. Carbon Emission Coefficient of the Coal Fly Ash.

Material Name	Unit	kg CO_2-e	Country
Coal Fly Ash	T	0	Taiwan
Dry Pulverised Fuel Ash, PFA	T	4	-

Coefficient Collection and Computation at the Raw Material Stage

Inventory of Carbon Emission from Aggregates

As for the concrete products, the primary ingredient is the aggregate. At present, there is no announced value for the carbon emission of aggregates at home, so the data collected abroad is sorted out and the carbon emission coefficient range of aggregates is 1 CO_2-e kg/T to 7 CO_2-e kg/T [6].

However, the statistical result from investigating domestic aggregates manufacturers is shown in Table 2. The statistics of the mining part is mainly made under the complete operation procedures of river mining, including water conservation construction, measuring and mapping, topsoil removal, excavation, transport, weighing, discharge and so on, and the statistics are mainly made of the energy consumed by mining machines and the material yield obtained from the excavation. After the raw material mining is completed, the processing stage comprises sand transport, charging, screening, crushing, washing, discharging, yarding, and other procedures and the same investigation is made on the energy consumed by processing machines and the material yield after the processing.

Through the survey results from the manufacturers, it is concluded that the energy consumption at the sandstone materials mining stage is about 0.4 to 0.5 CO_2-e kg/m^3, and then the unit carbon emission of the domestic manufacturers' sandstone materials mining energy consumption is computed within 0.218 CO_2-e kg/T through weighted average and unit conversion. The unit carbon emission of the sandstone materials processing is 1.800 CO_2-e kg/T.

Inventory of Carbon Emission from Cement

The production process of the cement industry comprises four stages, which are raw material mining, raw material grinding, clinker sintering, and cement grinding. Various raw materials are placed into the powder with specific fineness and proper and uniform ingredients, which is the raw batch, and the power consumed during the grinding process accounts for 20% of the plant's total power. Then the cement sintering process produces the largest amount of greenhouse gas emission, and the power consumed at the cement grinding stage accounts for 40% of the plant's total power. As for the cement industry, the ingredient proportions of various cement products are different, and the processing differs to some degree. As such, the carbon emission coefficient is influenced relative to the cement itself. Thus, the life cycle assessment (LCA) boundary setting of the Product Category Rule on the cement is only limited to the process until the clinker sintering, and the essay also integrates the carbon emission coefficients of clinkers in different countries for the reference., These coefficients tend to be similar according to inventory results. Therefore, having clinkers as the key setting could serve as one inventory principle. As mentioned above, owing to the differences in the ingredients' proportion and posterior stage of the production process, the greenhouse gas emission of cement products varies greatly. For the cement product itself, more than half of the greenhouse gas emission is from cement clinker production; the cement carbon emission coefficient range in all the countries is 650 to 930 kg CO_2-e/T, whose mean value is about 810 kg CO_2-e/T, and the Bureau of Energy, Ministry of Economic Affairs has the carbon emission 880 CO_2-e kg/T as the standard [7].

Inventory of Carbon Emission from Coal Fly Ash

Coal fly ash, which belongs to pozzolanic materials, is the by-products from the operation of thermal power plants. The coal fly ash itself is not produced by consuming energy. The Energy Audit Management Guidance Plan of the Bureau of Energy, Ministry of Economic Affairs mentions that as the coal fly ash could be utilized directly without the processing, the carbon emission of its materials production is zero, while the carbon emission collected abroad is also close to zero. Therefore, in the computation process for this study, the carbon emission of the coal fly ash raw material production is zero.

Inventory of Carbon Emission from Water-quenching Blast Furnace Slag

At present, most of the water-quenching blast furnace slag used at home is produced from the water-quenching blast furnace, which is supplied by CHC Resources Corporation. The blast furnace is the by-product from the iron-smelting process in steel works, so it does not need to consume energy during the materials production process. However, the materials shall be ground before the use until the designated grain size is reached, so the energy consumption during the grinding process of the blast furnace shall be computed. Aiming at the condition that the unit amount of water-quenching blast furnace slag is used to replace cement, after the variance calculation of the production energy consumption and carbon emission, the carbon emission difference for one ton is 827.8 kg CO_2-e. The difference in the carbon dioxide emission is mainly caused by the raw material itself. By contrast, the water quenching blast furnace slag only needs to consume the energy during the grinding process. In addition, the carbon emission of cement is much higher, so the use of water quenching blast furnace slag as the pozzolanic material could effectively reduce carbon dioxide emission. The carbon emission coefficient will have CHC Resources Corporation, which is the biggest representative manufacturer in Taiwan, as the computation basis and it is computed that the coefficient is 52.2kg CO_2-e/T [8].

Inventory of Carbon Emission from Asphalt Cement

According to the survey results, the asphalt cement used by asphalt concrete manufacturers is mainly supplied by CPC Corporation, whose oil refineries are located in Kaohsiung, Taoyuan and Ta-Lin, respectively. After the crude oil refining, the asphalt cement is purchased by manufacturers and then transported back to asphalt concrete factories; other types of asphalt cement shall be remade by asphalt plants. By collecting foreign coefficients, it is found that the unit carbon emission is 170 to 550 kg CO_2-e/T under foreign life cycle assessments [9], and the life cycle assessment made in cycle

Table 4. Comparison of Carbon Dioxide Emission between Unit Water Quenching Blast Furnace Slag and Cement

Product	Limestone (kg)	Fuel Coal (kg)	Electric Power (Degree)	Carbon Dioxide Emission (kg CO_2-e/T)
Water Quenching Blast Furnace Slag	0	14	70	52.2
Normal Cement	1,200	110	110	880
Difference	-1,200	-96	-40	-827.8

Table 5. Carbon Emission Coefficient of Asphalt Cement.

Material Name	Unit	kg CO_2-e	Country
Bitumen, Feedstock (Alcorn)	T	171	New Zealand
Bitumen, Feedstock (Alcorn)	T	138	New Zealand
Bitumen, Feedstock (Gabi)	T	305	New Zealand
Bitumen, Feedstock (Gabi)	T	178	New Zealand
Asphalt	T	248	Japan
Bitumen	T	430 - 550	UK
Bitumen	T	280	-

assessments [9], and the life cycle assessment made in England is the most complete, where the unit carbon emission of asphalt cement is 430~550kg CO_2-e/T.

Inventory of Carbon Emission from Mineral Filler

The mineral filler could use completely dry lime, limestone powder, or cement, which could improve the asphalt softening point, enhance the stability, and reduce void content. This study discusses the lime. The lime production mainly comprises the processes of ore preparation, lime burning, and hydration reaction, while the carbon emission coefficient of the lime is 740 kg CO_2-e/T per unit.

Inventory of Carbon Emission from Reclaimed Asphalt Pavement

Reclaimed asphalt pavement has become a kind of effective recycled material in all countries, and the sole difference is in the appending proportion. As the reclaimed asphalt pavement itself belongs to recycled aggregates, its carbon dioxide emission is bound to have the reduction effect. As for the reclaimed asphalt pavement, the carbon emission does not have a certain definition. The differences in the distance and construction method after the recovery during the processes of in-place recycling, transport, and blending after returning to the factory would cause the difference in the computation [10].

According to the survey results about domestic manufacturers as shown in Table 6, the unit carbon emission of the reclaimed asphalt pavement is computed based on the power and diesel consumed during the pavement scratching process. It is then weighted and averaged based on the output to get the unit carbon emission of reclaimed asphalt concrete pavement, which is 1.74kg CO_2-e/T.

Computation at the Raw Materials Transport Stage

According to the motor freight investigation report made by the Ministry of Transportation and Communications, the mean transport distance of sandstones at the raw materials transport stage could be computed as 44.05 km, with a mean transport distance of cement at 64.20 km and a mean transport distance of asphalt cement at 41.14 km. The study will compute the carbon emission at the raw materials stage and transport stage based on the motor freight investigation report and the mean transport distance in the survey results, respectively. The computation results at the raw materials transport stage of cement concrete and asphalt concrete are as shown in Table 8 [11].

Carbon Emission Computation at the Plant Production Stage

The plant production energy consumption stage is mainly composed of mix design and production energy consumption [12]. The product mix design shall adjust the ingredient proportion according to different engineering properties and work requirements, so as to conform to the construction specifications, national standards and in-place construction requirements. As such, the final actual construction situation for the same type of products may be matched by many different proportions. If the proportion of various products is clarified clearly, it is unable to conform to the actual situation on the spot, which will hinder the computation process. Therefore, the proportion of various ingredients in the product is the important item to be considered.

The production energy consumption stage is operated according to the product process mainly coordinating with the engineering requirements. If there is no demand of the products at present, the plant won’t manufacture the products, so the product process of the civil construction industry is not a regular operation. This is unfavorable to the production process inventory and monitoring. As for the present industrial characteristics, there are numerous machines and tools in the production process and there is no specific monitoring mode for the operation efficiency of the machines and tools. The energy consumption control in the plant is mostly in the form of the general electric meter. Other than the independent electric meter monitoring for each machine, which causes the uneasy execution of the inventory, the machines and tools in the plant cannot operate simultaneously during the production process. Parts of functional machines require specific starting conditions, so the energy consumption at the production stage shall be defined more explicitly.

Table 6. Carbon Emission Computation of Reclaimed Asphalt Pavement

	Power (Degree)	Diesel (L)	Output (T)	Unit Carbon Emission (kg CO_2-e/T)	Weighted Average (kg CO_2-e/T)
Manufacturer A	9600	120	4000	1.56	
Manufacturer B	-	1000	960	2.68	1.74
Manufacturer C	8200	350	3500	1.69	

Table 7. Raw Materials Transport Distance Data Sorted out by Investigating Manufacturers.

Manufacturer	Ready-mix Plant				Mean	Asphalt Plant					Mean
	A	B	C	D	Value	A	B	C	D	E	Value
Cement/ Asphalt	30.4	122	49.9	117	79.83	17.8	13.9	37.8	38.1	9.6	23.44
Sandstone 1	10	19.8	11.8	15.4	14.25	10	40.9	35.2	43.1	33.7	32.58
Fly ash / Sandstone 2	82	34	145	124	96.25	45	15.7	23.7	42.5	36.2	32.62
Blast Furnace Slag /Limestone Powder	116	112	142	39.5	102.38	200	58.5	83.8	130	300	154.46

Table 8. Carbon Emission of Cement Concrete and Asphalt Concrete at the Raw Materials Transport Stage.

Raw Materials Type		Mean Transport Distance (km)	Mean Fuel Consumption (L/km)	Diesel Coefficient eCO_2-kg/L	Carrying Capacity of Transport Tools (T)	Carbon Emission kg CO_2-e/T
Sandstone	10	44.05	0.8	2.61	24	3.83
		14.25	0.8	2.61	24	1.24
Cement	10	64.2	0.8	2.61	24	5.59
		79.83	0.8	2.61	24	6.95
Fly Ash		96.25	0.8	2.61	24	8.37
Blast Furnace Alag		102.38	0.8	2.61	24	8.91
Raw Materials Type		Mean Transport Distance (km)	Mean Fuel Consumption (L/km)	Diesel Coefficient eCO_2-kg/L	Carrying Capacity of Transport Tools (T)	Carbon Emission kg CO_2-e/T
Sandstone	10	44.05	0.8	2.61	24	3.83
		32.58	0.8	2.61	24	2.83
		33.62	0.8	2.61	24	2.92
Asphalt	10	41.14	0.8	2.61	24	3.58
		23.44	0.8	2.61	24	2.04
Limestone Powder		154.46	0.8	2.61	24	13.44

Data source: 10

Table 9. Production Energy Consumption Computation of the Asphalt Concrete Plant

Product Type	Heavy Oil Usage Amount (L)	Power Consumption (Degree)	Carbon Emission （kg CO_2-e/T）
Normal Asphalt Concrete	12	7.48	41.90
Recycled Asphalt Concrete	12	11.19	44.17

Energy Consumption Stage Computation of the Cement Concrete Plant

After investigating the cement concrete plants, it is known that all the machines in the plant have no independent electric meter for verification, while the mixing control room has the current value as the adjustment standard for control mixing. Therefore, the study plans to utilize the consumed electric degree and the output of all the products within the unit time as the data collection targets, hoping to estimate the consumed electric degree required by different concrete product mixing. Due to the limited data collection, the following hypothesis shall be made before the computation: the biggest difference during the mixing process of various types of concrete is the mixing time. However, the data about the consumed electric degree obtained by investigating the plants is the energy consumption in the whole plant. Compared with other energy consumption in the office and so on, the biggest energy consumption in the ready-mix plant is the energy consumed during the mixing process, so the hypothesis of other energy consumption by the office and working staff could be ignored.

From the computation results of the study, it could be seen that the difference in the mixing energy consumed by various strengths of concrete products is not great. It is preliminarily judged that the concrete products of much higher strength contain much more cementing materials according to the concrete strength power consumption, which probably causes the mixing machines to require greater energy consumption. Secondly, it is estimated that owing to the self-compacting property, the slump flow of the self-compacting concrete itself is much greater, so the mixing will not easily cause energy consumption.

Energy Consumption Stage Computation of the Asphalt Concrete Plant

The energy consumption in the asphalt concrete plant is also divided into mix design and production energy consumption. According to the mix design results, statistics are respectively made of various raw materials in normal asphalt concrete and recycled asphalt concrete. The statistical results of the study integrate the mix design results of several asphalt concretes and set the upper and lower limit for the blending quantity of various raw materials, so as to compute the raw material interval of normal and recycled asphalt concrete and then calculate the carbon emission interval of asphalt concrete products.

The production energy consumption in the asphalt concrete plant utilizes the daily output and the energy consumed on that day in the asphalt concrete plant for statistics. Then, the electric power and heavy oil consumed during each ton of normal and recycled asphalt concrete production and the carbon emission of the asphalt concrete products could be calculated. According to the statistical analysis results of the production energy consumption data collected from asphalt concrete manufacturers, the heavy oil quantity and electric degree consumed during various asphalt concrete production process could be calculated, and then it is concluded that the carbon emission during normal asphalt concrete production process and recycled asphalt concrete production process is 41.90kg-CO_2e/T and 44.17 kg-CO_2e /T, respectively, based on the power carbon emission coefficient 0.612kg-CO_2e/ degree and heavy oil carbon emission coefficient 3.11 kg-CO_2e/L announced by the Bureau of Energy in 2011.

Carbon Reduction Efficiency Evaluation of Concrete Products

Table 10. Concrete Product Raw Material Coefficient

	Production Stage	Transport Stage	Carbon Emission of Raw Materials (kg CO_2-e/T)
Sandstone	2.02	3.83	5.85
Cement	880	5.59	885.59
Fly Ash	0	8.37	8.37
Blast Furnace Slag	52.2	8.91	61.11
Asphalt	490	3.58	493.58
Limestone Powder	740	13.44	753.44
Recycled Asphalt Pavement	1.74	-	1.74

Table 11. Carbon Emission Computation of OPC and SCC under the Design Strength of 350 kgf/cm2.

	Raw Material Stage				Production Stage		Carbon Emission at the Transport Stage	Product Carbon Emission (kg CO_2-e/m^3)
Raw Material Type	Aggregates	Cement	Blast Furnace Slag	Fly Ash	Power	Fuel Consumption		
Carbon Emission Coefficient	5.85	885.59	61.11	8.37	0.612	2.61		
OPC	882+815	450	0	0	1.747	0	4.87	414.38
SCC	878+848	230	110	110	1.144	0	4.87	227.00
Carbon Reduction Amount (kg CO_2-e/m^3)								187.38

The carbon emission of the concrete product raw material is collected and calculated in the study; the raw material coefficient is the total of the product stage and transport stage, respectively, as shown in Table 10, and various concrete product raw materials are obtained for further calculation. As the distance variation of the recycled asphalt pavement at the recycling site during the transport stage is too great, and most of the recycled asphalt pavement is reused by reducing asphalt on site, getting processed in the plant and transported to the site, the carbon emission of the recycled asphalt pavement certainly will be much less than that of directly transporting for discarding. The transport stage of the recycled asphalt pavement is temporarily not listed in the calculation process.

Carbon Reduction Efficiency of Self-compacting Concrete

Compare the unit carbon emission of the same strength of ordinary Portland cement concrete (OPC) and self-compacting concrete (SCC) and it could be known the higher the strength, the greater the product carbon emission difference. If the carbon reduction amount of the works is taken into account, self-compacting concrete could be adopted to replace ordinary Portland cement. Under the same mix design principle, if the design strength is 350 kgf/cm^2, the product carbon emission difference between OPC and SCC is calculated, and it is shown that each ton of SCC saves 187 kg CO_2-e/m^3 more than OPC under the design strength of 350 kgf/cm^2.

Carbon Reduction Efficiency of Recycled Asphalt Concrete

The mix design computation results of ordinary asphalt concrete products are as shown in Table 12, which shows that the upper carbon emission limit of the ordinary concrete is 50.262 kg CO_2-e/T and the lower limit is 47.547 kg CO_2-e/T. It also shows that the upper limit of recycled asphalt concrete is 43.928 kg CO_2-e/T and the lower limit is 40.275 kg CO_2-e/T. Integrate the above raw materials and the transport, production process, and product transport stage as shown in Table 13, and it is known that the unit carbon emission interval of ordinary asphalt concrete product is 96.817~99.532 kg CO_2-e/T, that of the recycled asphalt concrete product is 91.815 to 95.468 kg CO_2-e/T, and each ton of recycled asphalt concrete could reduce 4.533 kg CO_2-e more than ordinary

Table 12. Carbon Emission of Asphalt Concrete Mix Design Results.

Raw Material Type	Ordinary Asphalt Concrete	Recycled Asphalt Concrete
Eighth Aggregates	3.13%	0.00%
Sixth Aggregates	6.31%	19.73%
Third Aggregates	18.44%	16.40%
Second Aggregates	26.44%	17.07%
Natural Sand	43.50%	18.13%
Filling Material	2.25%	1.67%
Recycled Asphalt Pavement	-	27.00%
Upper Limit of the Fuel Capacity	5.59%	5.41%
Lower Limit of the Fuel Capacity	5.04%	4.67%
Upper Limit of the Unit Carbon Emission (kg CO_2-e/T)	50.262	43.928
Lower Limit of the Unit Carbon Emission (kg CO_2-e/T)	47.547	40.275

Table 13. Carbon Emission Computation of Asphalt Concrete.

	Ordinary Asphalt Concrete	Recycled Asphalt Concrete
Upper Limit of the Unit Carbon Emission (kg CO_2-e/T)	50.262	43.928
Lower Limit of the Unit Carbon Emission (kg CO_2-e/T)	47.547	40.275
Heavy Oil usage (L)	12	12
Power Usage (Degree)	7.48	11.19
Product Transport Avg. (kg CO_2-e/T)	7.37	7.37
Upper Limit of the Product Carbon Emission (kg CO_2-e/T)	99.532	95.468
Lower Limit of the Product Carbon Emission (kg CO_2-e/T)	96.817	91.815

asphalt concrete on average.

The computation results show that the addition of recycled asphalt pavement in recycled asphalt concrete could reduce the usage of natural aggregates and lower the amount of asphalt cement usage. The usage of recycled asphalt pavement in the raw material part could decrease the carbon emission of asphalt concrete products. Because more machines are used during the production process of recycled asphalt concrete than in ordinary asphalt concrete, the energy consumed and carbon dioxide emission at the plant production stage is much more than ordinary asphalt concrete. However, as for the overall life cycle of asphalt concrete products, the carbon emission of recycled asphalt concrete products is still less than that of ordinary asphalt concrete products.

Conclusions

I. As for concrete products, the carbon emission computation results of cement concrete products and asphalt concrete products at various stages show that the greatest factor influencing the carbon emission at various production stages of products is the raw material proportion of the mix design result.

II. As for the cement concrete product research results, the study points out that the greatest influence factor for the carbon emission of products is the cement material proportion in the product. Under the precondition of the same design strength and no influence on the engineering property, if the cement material replacement quantity could be improved, the highest carbon reduction efficiency could be reached.

III. The asphalt concrete product research results point out that though recycled asphalt concrete itself uses more machines in the production process than ordinary asphalt concrete, the replacement of recycled asphalt pavement in the raw material could lead to much greater carbon reduction effect. Therefore, as for the overall production carbon emission, the carbon emission of each ton of recycled asphalt concrete is still 4.533 kg CO_2-e/T less than that of ordinary asphalt concrete.

Suggestions

I. Concerning the unit carbon emission computation of the products, the study makes evaluations mainly with the coefficients obtained from the survey data. Though the computation results contain regionalism and are very close to foreign data, the national inventory shall be made on the civil construction industry and establish a correct database, so as to make the data usage more representative.

II. The carbon emission and carbon trading system has already taken shape in European and American countries, and the unit carbon emission has its economic value. At present, the study only concerns the environmental conservation and has not considered the economic benefit. In the future, overall considerations could be made regarding the engineering carbon emission and unit price of the materials, so as to conduct optimization calculation and choose the most effective construction method.

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