INVESTIGATION AND ANALYSIS ON THE TWO-YEAR ENERGY CONSUMPTION ON ASPHALT PAVEMENT IN LU'AN CITY IN CHINA

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ABSTRACT

In order to establish a database of energy consumption emissions on asphalt pavement in China, a two-year energy consumption investigation on the life cycle of asphalt pavement is conducted in this study, covering relevant areas of Lu'an City, Anhui Province. The investigation involves four stages closely related to the emissions including aggregate production stage, asphalt mixture production stage, asphalt mixture transportation stage and construction stage. The results show that the asphalt mixture production accounts for the largest proportion of the energy consumption and is far more than other stages. Besides, the type of the mixing plant has a significant effect on the energy consumption. The results of the type 1000 and type 3000 are 508.378 MJ/t and 295.756 MJ/t respectively. Compared to the mixture production, the energy consumptions of other stages are much less. For example, the energy consumption of the aggregate production is 8.959 MJ/t, the asphalt mixture transportation 0.835 MJ/t.KM and the asphalt mixture construction 37.171 MJ/t. stage. Within the statistical cycle of this study, the energy consumption of one ton of asphalt mixture from raw material production stage to construction stage is about 680 MJ. The energy consumption level of the investigated area in this study is essentially representative of the national average in central China.

INTRODUCTION

Nowadays, global warming is considered as a very serious problem on the earth. The problem has resulted in studies focusing on the reduction on energy consumptions and green-house gas (GHG) emissions of pavements constructions as well as other human activities. Typically, an LCA model of pavement consists of the following components: material, construction, use, maintenance and rehabilitation (M&R), and end of life (EOL). This growing interest in the topic is reflected in the number of studies published recently.

Overseas, Thenoux *(1)* studied three different structural pavement rehabilitation alternatives and compared them using an energy consumption methodology: Asphalt overlay; Reconstruction; Cold in place recycling with foamed asphalt. Huang *(2)* described the development of an LCA model for pavement construction and maintenance that accommodates recycling and up-to-date research findings. Wang *(3)* developed a pavement LCA model to evaluate energy usage and greenhouse gas (GHG) emissions from pavement rehabilitation strategies. Kucukvar *(4)* developed an ecologically-based hybrid life cycle assessment model which is used to evaluate the resource consumption and atmospheric emissions of continuously reinforced concrete and a hot mix asphalt pavement. Yu *(5)* developed a life cycle assessment model which is built to estimate the environmental implications of pavements using material, distribution, construction, congestion, usage, and end of life modules.

However, life cycle assessment (LCA) for pavement is still at an immature stage in China. Currently, total life cycle research on asphalt pavement in China focuses on aspects such as life cycle energy consumption evaluation methods and models etc. However, the collection of data on energy consumption emissions is not frequently carried out. Pan *(6)* put forward the list of life cycle energy consumption on highways and the evaluation methods. Nevertheless, reference materials at home and abroad were cited for the energy consumptions during the phases, for example, the energy consumptions of raw materials such as asphalt, concrete, aggregate and steel etc. and the oil consumption of construction machinery was obtained by calculating the motor power and working hours. Yang *(7)* studied that the oil consumptions of transport vehicles were obtained by calculating the actual shipment distance and oil consumption per kilometer. In the research of Yang *(8)*, relevant data at home and abroad were mainly cited for the data of oil consumption per kilometer. For example, data from European Bitumen Association were cited for the energy consumption of asphalt production and the energy consumptions at aggregate production phase, asphalt mixture production phase and construction phase were obtained by theoretical calculation.

On the aspect of acquisition for energy consumption data , there are three methods to acquire the unit energy consumption: 1) Querying for data, you can directly cite for the literature data at home and abroad, for example the energy consumption of asphalt production; 2) Theory method, the energy consumption of transport vehicle and construction energy consumption can be obtained by multiplying the power of transport vehicle or construction machinery by working hours; 3) Field measurement method, as it takes to much work and time to field measure the energy consumption and it is comparatively harder to implement more often than not, relevant researches are specific to a specific engineering project or a specific phase of a specific engineering project and only some short-term data acquisition work can be done with this method. Therefore, the first two methods are mainly adopted for acquiring energy consumption data currently in China.

The main purpose of our research program is to present the asphalt pavement life cycle energy consumption and GHG emission database for the transportation industry in China. This paper presents some preliminary research results of the program, that is, two-year's energy consumption data (from 2011 to 2012) collected in Lu'an, Anhui province.

CASE INFORMATION

Case Description

The energy consumption investigation is conducted in Lu'an City, Anhui Province, China and Lu'an City is located in the west of Anhui Province, Dabie Mountain area. The investigation was conducted to Lu'an

Highway Traffic Industrial Co., Ltd., which is a subordinate enterprise of the Bureau of Public Road in Lu'an City. And also it is the largest enterprise to produce and construct asphalt mixture in Lu'an City. The statistics lasts for two years, from 2011 to 2012.

System Boundary

The LCA model of asphalt pavement consists of the following stages: material production, construction, use, maintenance and rehabilitation (M&R), and end of life (EOL). In this paper, only the first two stages were discussed: from material production to asphalt pavement construction. The two stages include raw materials production, raw materials transportation, asphalt mixture production, asphalt mixture transportation and field construction.

Conversion Coefficient

The main energies involve the statistical cycle in this paper are diesel fuel, fuel oil and electricity. Refer to China National Standard *(9)*, the average referential coefficients of lower heating values of the above mentioned energies are shown in Table 1. Data in Table 1 are used as the standard for the following energy calculation.

Table 1: Average Referential Coefficient of Low Calorific Values of the Energies *(9)*

Energy	Diesel Fuel	Fuel Oil	Electricity
Average calorific	42.652MJ/kg	41.816MJ/kg	3.6MJ/KWh

INVESTIGATION OF ENERGY CONSUMPTION

Raw Material Production Stage

Raw materials of the asphalt pavement engineering in the statistical cycle in this paper mainly include bitumen and aggregate. Because bitumen is one of the many petroleum products made from crude oil, and refining crude oil is a complex procedure, proper allocation of the environmental flows from the entire crude oil acquisition through refining process to asphalt production is difficult. Multiple data sources of bitumen production that applies the life cycle assessment to pavements have been published. Table 2 demonstrates that there is greater variation among data sources for asphalt production. This could result from the difference in technology used in different regions, or may be due to different system boundaries defined in different data sources.

Table 2: Energy Consumption per Mass of Bitumen Production

Source material	Stripple *(10)*	Athena *(11)*	*EcoInvent (12)*	USLCI *(13)*	Häkkinen *(14)*	Eurobitume *(15)*
Energy consumption (MJ/t)	2,890	5,320	9,000	10,500	6,000	4,900

At present, no systematic life cycle assessment has been done to bitumen materials in China and there has been no approved standard for energy consumption allocation during the asphalt production phase. Therefore, there exist no standard asphalt production energy consumption values. In this paper, the energy consumption during the asphalt producing phase of European Bitumen Association is directly adopted, namely, the energy consumption of asphalt production is 4,900 MJ/t. Lu'an City is located in

Dabie Mountain area and it is good for aggregate production. The aggregate required for pavement construction is produced locally. The aggregate production and total energy consumptions in 2011 and 2012 are listed in Table 3.

Table 3: Energy Consumption of Aggregate Production

Statistical Cycle	Aggregate (t)	Electricity (KWh)	Diesel Fuel (kg)	Energy Consumption (MJ)
2011	420,000	589,860	37,360	3,716,975
2012	407,000	548,367	40,270	3,691,717
Total	827,000	1,138,227	77,630	7,408,692
Unit energy consumption	1	1.376	0.094	8.959

Asphalt Mixture Production Stage

The fuels used in asphalt mixture mixing plant heating and drying system are diesel fuel, heavy oil, coal and natural gas etc. As the energy consumptions in different countries and districts are different, the use conditions for fuels of asphalt mixture mixing plants are also different. At present in China, the main fuel of asphalt mixture mixing plant is heavy oil. Recently, some mixing plants also use natural gas as the fuel. The range of using natural gas, however, is relatively small. Besides, electrical equipment is one of the main types of equipment used during asphalt mixture production. Electricity consumption is one of the main energy consumptions during the asphalt mixture production stage. Lu'an Highway Traffic Industrial Co., Ltd. owns a type 1000 asphalt mixing plant and a type 3000 asphalt mixing plant. The information of the mixing plants is shown in Table 4. The total production and total energy consumption of asphalt mixture produced by this company in 2011 and 2012 are shown in Table 5 and Table 6.

Table 4: Asphalt Mixing Plant

Brand	Model	Purchase Date
XUETAO	AMP1000	August, 2006
LINTEC	CSD3000	March, 2010

Table 5: Energy Consumption of Asphalt Mixture production –Plant AMP1000

Statistical Cycle	Asphalt Mixture (t)	Electricity (KWh)	Diesel Fuel (kg)	Fuel Oil (kg)	Energy Consumption (MJ)
Year 2011	26,937	105,030	80,180	232,270	13,510,548
Year 2012	22,333	82,920	46,830	221,000	11,537,241
Total	49,270	187,950	127,010	453,270	25,047,789
Unit energy consumption	1	3.815	2.578	9.200	508.378

Table 6: Energy Consumption of Asphalt Mixture production Plant - CSD3000

Statistical Cycle	Asphalt Mixture (t)	Electricity (KWh)	Diesel Fuel (kg)	Fuel Oil (kg)	Energy Consumption (MJ)
Year 2011	112,513	344,280	71,310	660,980	31,920,462
Year 2012	175,445	469,630	94,980	1,136,000	53,244,731
Total	287,958	813,910	166,290	1,796,980	85,165,193
Unit energy consumption	1	2.868	0.588	6.175	295.756

The factors influencing the energy consumption of mixing plants include production mode (continuous production, intermittent production), service life of the mixing plant and water content in aggregate etc. It can be seen from Table 5 and Table 6 that the unit energy consumptions of type 1000 mixing plant and type 3000 mixing plant are 508.378 MJ/t and 295.756 MJ/t respectively, which are obviously different. The production efficiency of type1000 mixing plant is lower and it is usually used for minor works such as maintenance and repair etc. And it is usually of intermittent production. However, the production efficiency of type 3000 mixing plant is higher and it is usually used for large-scale projects such as new-built projects as well as rehabilitation and expansion projects. And most of them are of continuous production. Moreover, the serviced life of type 1000 mixing plant is longer than that of type 3000 mixing plant. This is the main reason why there exists a great difference between the two mixing plants.

Transportation Stage

The energy consumption for asphalt mixture transportation is mainly generated in the process of transporting the mixed asphalt mixture from the mixing plant to the construction site. The energy consumption in this process mainly involves the load capacity of the transport vehicle, total volume of the asphalt mixture transported, shipment distance and the traffic conditions. Generally speaking, the smaller the load capacity is, the more the total volume of the asphalt mixture will be; and the longer the shipment distance is, the larger the fuel consumption during the process of transporting asphalt mixture will be.

In the actual production process, the output of asphalt mixture is closely related with quantities and it is hard to artificially reduce the output. Therefore, under the condition that the output, namely the shipping quantity of the asphalt mixture is fixed, auto dumpers with larger load capacities are generally adopted for transporting asphalt mixture currently. The full load capacity of heavy load trucks in this district is 35 tones in general. Energy consumption of asphalt mixture transportation is shown in Table 7.

Table 7: Energy Consumption of Asphalt Mixture Transportation

Statistical Cycle	Asphalt Mixture (t)	Total Volume (ton/km)	Avg. Haul Distance (km)	Diesel Fuel (kg)	Energy Consumption (MJ)
Year 2011	139,450	9,126,942	65.45	190,370	8,119,661
Year 2012	197,778	10,167,293	51.41	187,300	7,988,720
Total	337,228	19,294,235	—	377,670	16,108,381
Unit energy consumption (per ton of asphalt)	1	—	—	1.120	47.767
Unit energy consumption (ton per km)	—	1	—	0.020	0.835

Notes: a. the factors influencing transportation energy consumption are distance of the project, road condition and serviced life of the vehicle etc.
b. As the main engineering projects in year 2011 were located at mountainous areas, the energy consumption in 2011 is greater than that in the year 2012.

Field Construction Stage

The energy consumption of construction equipment is mainly generated in the asphalt mixture paving and rolling processes. The energy consumption in these processes mainly involves the types of construction machinery and construction technology. Asphalt pavement construction machineries include pavers, double drum rollers, rubber tire rollers etc. Please refer to Table 8 for information of main equipment. The construction volumes and total energy consumptions of asphalt mixture of this company in 2011 and 2012 are shown in Table 9.

Table 8: Construction Vehicles

Construction Vehicles	Brand	Model	Purchase Date
Paver	SANY	TLU-90Ⅱ	July, 2007
Paver	XCMG	RP602	September, 2009
Paver	VOLVO	VOLVO-ABG	August, 2010
Double drum roller	DYNAPAC	CC522	July, 2007
Double drum roller	DYNAPAC	CC624	January, 2011
Rubber tire roller	XCMG	XP261	September, 2008
Rubber tire roller	XCMG	XP302	March, 2009

Table 9: Energy Consumption of Field Construction

Statistical Cycle	Asphalt Mixture (t)	Diesel Fuel (kg)	Energy Consumption (MJ)
Year 2011	139,450	145,390	6,201,174
Year 2012	197,778	148,500	6,333,822
Total	337,228	293,890	12,534,996
Unit energy consumption	1	0.871	37.171

Notes: a. as the engineering projects are numerous and of various sizes, the quantities of pavement equipment used are different (the quantity for major project is large and that for minor projects is small). Therefore, annual summary filling method is adopted here.
b. As the main engineering projects in year 2011 were located in mountainous areas, the energy consumption in 2011 is greater than that in the year 2012.

RESULTS AND DISCUSSION

Subentry Energy Consumption Statistics

The micro statistical data for the two-year asphalt mixture production, transportation and construction in Lu'an Traffic Industrial Co., Ltd. are presented in this paper. The aggregate is produced by a local aggregate production enterprise in Lu'an City. Except for Lu'an Traffic Industrial Co., Ltd., it also supplies aggregate for other local enterprises. Therefore, the total production of aggregate in these two years is larger than the total consumption of aggregate for producing asphalt mixture. In calculation, the bitumen aggregate ratio takes 4.5%. The total production of asphalt mixture in these two years as well as the total consumptions of asphalt and aggregate calculated in accordance with total production of asphalt mixture and bitumen aggregate ratio is given in Table 10.

Table 10: Material Consumption

Statistical Cycle	Asphalt Mixture	Bitumen	Aggregate
Bitumen aggregate ratio	1	0.045	0.955
2011	139,450	6,275	133,175
2012	197,778	8,900	188,878
Total	337,228	15,175	322,053

The statistical stages include raw material stage (including asphalt and aggregate), asphalt mixture production stage (including type 1000 and type 3000), asphalt mixture transportation stage and construction stage. Among them, energy consumption of asphalt transportation is not counted. Unit energy consumption of aggregate transportation is the unit energy consumption of asphalt mixture. The transportation distance is the distance between the aggregate factory and the asphalt mixing plant. The transportation distance in this district is as far as 50 kilometers. The energy consumption statistics during each stage are given in Table 11 and Figure 1.

Table 11: Subentry Energy Consumption Statistics of the Asphalt Pavement

Statistics Stage		Unit Energy Consumption	Material Consumption (t)	Subentry Energy Consumption (MJ)	Energy Consumption Ratio (%)	Energy Consumption Ratio (%)
Raw material stage	Bitumen	4,900MJ/t[a]	15,175[b]	74,357,500	32.39	32.39
	Aggregate production	8.959MJ/t	322,053[b]	2,885,273	1.26	7.12
	Aggregate transportation	0.835MJ/t.KM [c]	322,053[b]	13,445,713 [d]	5.86	
Asphalt mixture production stage	AMP1000	508.378MJ/t	49,270	25,047,789	10.91	48.01
	CSD3000	295.756MJ/t	287,958	85,165,193	37.10	
Asphalt mixture transportation stage		0.835 MJ/t.KM	337,228	16,108,381	7.02	7.02
Field construction stage		37.171MJ/t	337,228	12,534,996	5.46	5.46
Total		—	—	229,544,845	100.00	100.00
Total energy consumption per ton of asphalt mixture		—	1	680.681	—	—

Notes: a. Reference data; b. calculated data; c. Energy consumption data for referential asphalt transportation; d. the haul distance is 50 kilometers.

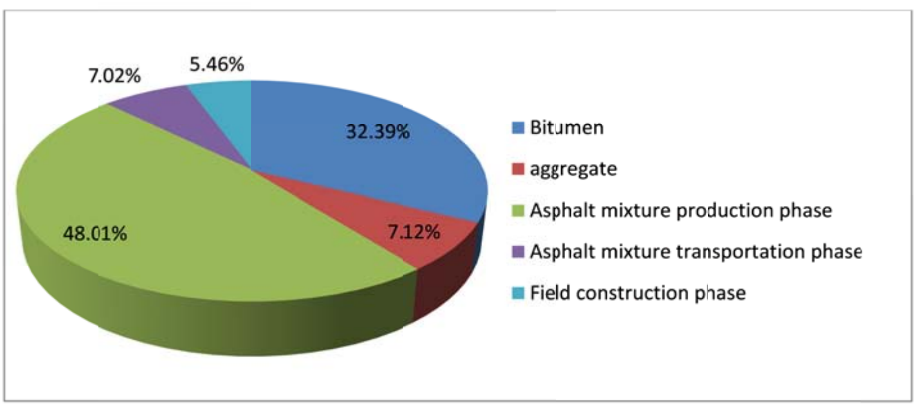

Figure 1: Subentry energy consumption statistics of the asphalt pavement.

Discussion

The proportions of energy consumptions in production of asphalt, aggregate and asphalt mixture, transportation and construction of asphalt mixture are 32.39%, 7.12%, 48.01%, 7.02% and 5.46% respectively.

Energy is mainly consumed in raw material phase and asphalt mixture production phase. During the raw material production phase, energy is mainly consumed for asphalt production, taking up 32.39%. However, asphalt is produced in oil refinery and the energy consumption in production is not controlled by the highway industry.

During the controllable phases in this industry, asphalt mixture production phase consumes most of the energy. Main factors influencing the energy consumption of mixing plant are as follows: type of fuel, condition of the mixing plant, type of mixing plant, water content in aggregate and discharge temperature of the asphalt mixture. Therefore, the main energy saving goal for asphalt pavement production is to improve the production efficiency of mixing plant and decrease the energy consumption of mixing plant. As a result, it is necessary to take some technical and management measures to reduce energy consumption emissions. In China, these technical measures include: 1) adopt new types of asphalt mixtures, such as warm asphalt mixture and recycled asphalt mixture etc.; 2） reduce water content in aggregate; 3) adopt the method of continuous production; 4) use mixing plants with high efficiency such as type 3000, type 4000 and type 5000 in large engineering projects; 5) adopt alternative energy, adopting natural gas to replace fuel oil etc.

Factors influencing energy consumption during material transportation phase include road condition, vehicle condition, haul distance etc. Lu’an city is located at mountain areas and the construction site is for away from the mixing plant. Therefore, energy consumption of material transportation increases comparing with plain regions.

The construction phase includes two inseparable processes: mixture paving and rolling. In this paper, therefore, the energy consumptions in these two processes are calculated together. The factors influencing the energy consumption in construction phase include type of mixture, thickness of structural layer and construction procedures etc., which are not discussed in detail in this paper.

CONCLUSIONS AND FUTURE WORK

In order to establish the basic database of energy consumption emissions on asphalt pavement in China, the two-year engineering energy consumption in the largest asphalt mixture production and construction enterprise in Lu’an City is analyzed in this paper. Moreover, the energy consumption data in this district basically reflect the macroscopic energy consumption data on asphalt pavement in central China. During the statistical cycle in this paper, the energy consumption of one ton of asphalt mixture from raw material production stage to the end of construction stage is about 680 MJ.

However, we still have some future work to do, which includes 1) counting in the energy consumption of the full life cycle of asphalt pavement, including the repair and maintenance phase; 2) conducting investigation and research on micro energy consumption data in other districts in China; 3) counting gas emission in the asphalt pavement life cycle assessment system. With the aim of establishing a basic database of energy consumption and emission for asphalt pavement full life cycle, we are striving for having a good command of the whole energy consumption and emission on asphalt pavement in China, which provides a research basis for energy saving and emission reduction in the transportation industry in China.

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