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Monitoring and Evaluation of Energy Consumption in the Whole Process of Asphalt Pavement Construction

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Abstract. According to the life cycle theory, the project analyzed the energy consumption of the entire asphalt pavement construction process, and clarified the energy consumption monitoring method of key nodes during the asphalt pavement construction period and the energy consumption boundary of each link during the construction period; the raw materials used for the asphalt pavement and each link during the construction period The energy consumption was compared and analyzed, the key nodes of energy consumption control during the asphalt pavement construction period were clarified, the energy consumption of different asphalt mixtures were compared and analyzed, and the asphalt pavement energy consumption evaluation system was established.

Keywords: asphalt pavement, construction period, energy consumption, evaluation system.

1. Introduction

As we all know, all aspects of asphalt pavement construction consume resources and energy, and produce greenhouse gas and harmful gas emissions. According to foreign survey data, the construction of a standard two-lane asphalt pavement with a length of 1km requires about7.0×10^6 MJ of energy, which is equivalent to 240 t of standard coal. The construction of asphalt pavement generates high energy consumption and large greenhouse gas emissions. Such environmental issues have increasingly attracted widespread attention at home and abroad.

Aiming at how to scientifically decompose the construction process of construction projects in asphalt pavement construction, systematically calculate the energy consumption of each link in the construction process, explore the establishment of energy consumption and emission evaluation indicators in the field of transportation engineering construction, and conduct accurate comprehensive evaluation of energy consumption and emission for each technology , The promotion and application of new energy-saving and emission-reduction technologies is a hot spot that scholars at home and abroad are thinking and exploring. European and American countries have carried out systematic calculation and analysis of road energy consumption index in the process of road construction, decomposed the pavement construction process, respectively considered the production and transportation of raw materials, mixture mixing, pavement paving and compaction and other construction links, and some organizations have also carried out analysis from the perspective of life cycle, including pavement maintenance, regeneration and reconstruction and other life cycle processes. An evaluation index system has been formed, some basic data have been established, and relevant calculation software has been compiled. Nevertheless, when we evaluate domestic related technologies, we cannot directly copy foreign data, because domestic and foreign construction techniques, construction equipment, raw materials and other aspects are different, and the final results must be quite different. Therefore, we must Combined with the specific domestic technology, carry out related investigations and studies to form an accurate and reliable local basic database.

This paper takes asphalt pavement construction as the research object, including raw material production and transportation, mixture mixing, transportation, paving, rolling and other construction links to investigate, combined with energy consumption evaluation indicators, calculate the energy consumption of each link of the construction, it is effective to lay the foundation for evaluating the energy consumption of each pavement structure of the highway project.

2. Design of Monitoring Method for Energy Consumption of Key Nodes During the Construction Period of Asphalt Pavement

2.1. Energy consumption acquisition method

After investigating basic road data such as engineering construction technology, energy consumption can be calculated directly from the parameters of mechanical equipment, operating vehicles, and frequency of use. According to the method of data source and the scope of application, there are three methods for quantitative calculation of energy consumption for new or expanded road construction projects: actual measurement method, theoretical method, and research method.

A flowchart of the three energy consumption calculation method shown in Fig.1 quantization, wherein the measurement method taking into account different production facilities equipment, the actual situation of the manufacturer, the device operation or the like, more accurate results, but this method is limited to specific engineering , The scope of application is limited. The theoretical method is based on the standard operating conditions of the production equipment and the average value of the process flow. In a specific situation, there may be errors such as overestimation or underestimation. However, this method fully considers the general situation of the industry and has a certain representativeness. , Especially in the absence of relevant domestic statistical data, it has good adaptability. Quota method is a set of systematic and complete quantitative system established by modern management technology, which is managed and improved by national authoritative departments. It has high authority, stability and effectiveness, but it is only applicable to the energy consumption calculation of mechanical equipment specified in quota.

This paper adopts the quantitative calculation method of energy consumption based on the basic principle of "quota method as the main method, theoretical method as the supplement, and measurement method as the supplement", so that the calculation results can truly express the energy consumption of pavement engineering, and provide basic data accumulation for subsequent research. The energy consumption monitoring measures of asphalt pavement construction period are shown in the table.

Table 1. Energy consumption monitoring measures during pavement construction

Serial number	Asphalt pavement construction equipment	Energy type	Energy consumption monitoring measures
1	transport vehicle	Fuel oil	Refueling details or vehicle fuel consumption meter
2	bulldozer	Fuel oil	Refueling details or vehicle fuel consumption meter
3	Asphalt heating tank	Fuel oil	Refueling details
4	burner	Fuel oil / natural gas / coal system gas	Oil / gas details
5	Coal gas equipment	Electricity + Fuel	Electric meter (current, voltage) + refueling details
6	Main equipment of mixing station	Electricity	Electricity meter (current, voltage)
7	Conventional paver	Fuel oil	Refueling details or vehicle fuel consumption meter
8	Large width paver	Fuel oil	Refueling details or vehicle fuel consumption meter
9	Steel wheel roller	Fuel oil	Refueling details or vehicle fuel consumption meter
10	Rubber roller	Fuel oil	Refueling details or vehicle fuel consumption meter
11	Conveyor belt	Electricity	Electricity meter (current, voltage)

2.2. Energy consumption conversion

In the energy consumption calculation process, the types of energy used by different equipment in the production of asphalt pavement raw materials or pavement construction are different, including solid coal, liquid gasoline, kerosene, diesel, and power sources. Different types of energy are not only different in units, The power effects produced are also different, and the corresponding emissions of various energy sources are also different. In quantification and evaluation, different energy sources need to be accumulated to obtain unified data, which represents its comprehensive energy consumption, otherwise the evaluation cannot be carried out.

China's GB/T 2589-2008 "General Principles of Comprehensive Energy Consumption Calculation" stipulates that the fuel energy actually consumed by an energy-using unit should be calculated based on its low (bit) calorific value and converted into the standard coal amount kgce . A fuel with a low (bit) calorific value equal to 29,307 kilojoules (kJ) is called 1 kilogram of standard coal (1kgce). The table summarizes the average low calorific value and converted standard coal coefficient of various mechanical equipment and common fuels of vehicles involved in the construction or reconstruction of several asphalt pavements.

Table 2. The calorific value of several energy sources and the conversion coefficient of standard coal

Energy name	Average low calorific value	Conversion factor of standard coal
raw coal	20908KJ/kg(5000kcal/kg)	0.7143kgce/kg
Washed coal	26344KJ/kg(6300kcal/kg)	0.9000kgce/kg
crude	41816KJ/kg(10000kcal/kg)	1.1572kgce/L
Fuel oil	41816KJ/kg(10000kcal/kg)	1.4286kgce/kg
gasoline	43070KJ/kg(10300kcal/kg)	1.4714kgce/kg
kerosene	43070KJ/kg(10300kcal/kg)	1.4714kgce/kg
Diesel oil	42652KJ/kg(10200kcal/kg)	1.2194kgce/L
Liquefied Petroleum Gas	50179KJ/kg(12000kcal/kg)	1.7143kgce/kg
Oilfield natural gas	38931KJ/kg(9310kcal/kg)	0.9541kgce/m 3
Electricity (equivalent value)	3600KJ/(kw.h)(860kcal/kw.h)	0.1229kgce/(kw·h)

3. Energy Consumption Assessment of Each Link During the Construction Period of the Asphalt Pavement

3.1. The boundaries of each link during the construction period of the asphalt pavement

3.1.1. Boundary of raw material energy consumption calculation. (1) Asphalt energy consumption calculation boundary: petroleum → atmospheric and vacuum residue → ordinary petroleum asphalt → modified asphalt / emulsified asphalt. The investigation and research results show that the atmospheric and vacuum residue production equipment consumes electricity and fossil fuels, and the solvent deasphalting production equipment, modified asphalt production equipment and emulsified asphalt production equipment consume electricity, therefore. In the asphalt production process, electricity and fossil fuels are mainly consumed. Fossil fuels generally include coal, fuel oil or fuel gas.

(2) Aggregate energy consumption calculation boundary: The aggregates used in asphalt mixtures include coarse aggregates and fine aggregates. The aggregate production process mainly includes stone mining → stone crushing (secondary or tertiary crushing) → stone Sieving. According to the technological process of aggregate production, the energy consumption of aggregate production includes chemical blasting of stone mining, electricity consumed by aggregate crushing, and the consumption of diesel, gasoline and other fuels for loaders and vehicles. The explosive needed for chemical blasting is to transform chemical potential into work done to the outside world.

(3) Boundary of energy consumption calculation of ore powder: the road project uses ore powder made from limestone. The production process of ore powder mainly includes the process of raw material processing and grinding. The production of ore powder usually uses limestone crushed stone with a smaller particle size after crushing, and then crushed by a high-efficiency hammer crusher, using high-efficiency screening and ultra-fine grinding, and sending the fine-grained crushed stone to the mill for grinding. Stored in the round warehouse, packed with a packaging machine and sent to the finished product warehouse for storage.

(4) Portland cement energy consumption calculation boundary: raw meal preparation → clinker calcination →Cement grinding. Lime-based raw materials, clay-based raw materials, and a small amount of calibration raw materials are crushed, mixed and ground according to a certain proportion, and mixed into raw materials with suitable composition and uniform quality, which is called the preparation of raw materials; Portland cement clinker calcined into cement kiln and partially fused to form calcium silicate as the main component is called clinker calcination; the clinker is grinded by adding appropriate amount of gypsum and sometimes an appropriate amount of mixed materials or additives to make cement, called cement grinding .

(5) Lime energy consumption calculation boundary: The production process of lime mainly includes raw material crushing and kiln calcination.

(6) Fly ash energy consumption calculation boundary: raw material transportation → grinding process.

(7) Boundary of energy consumption calculation for recycled aggregate: RAP asphalt mixture → transporting back to the mixing plant → crushing → screening. According to the processing flow of recycled aggregates, the main energy consumption in the processing of recycled aggregates is the power consumption of secondary screening equipment and the fuel consumption of loaders and transportation vehicles.

3.1.2. Boundary of energy consumption calculation of mixture. Asphalt pavement construction can be roughly divided into several links such as asphalt mixture production, transportation, and asphalt pavement construction.

Among them, the production of asphalt mixture can be further divided into three parts: asphalt production, mineral production and asphalt mixture mixing, and each link are present energy consumption and emissions. According to the life cycle analysis method, the energy consumption of each environment is calculated, and the sum can get the energy consumption of the asphalt mixture production stage. The analysis of the asphalt mixture construction phase is the same. After obtaining the energy consumption and emissions of the asphalt mixture production, transportation and asphalt pavement construction phases, the total energy consumption of the asphalt pavement construction can be obtained by summing again.

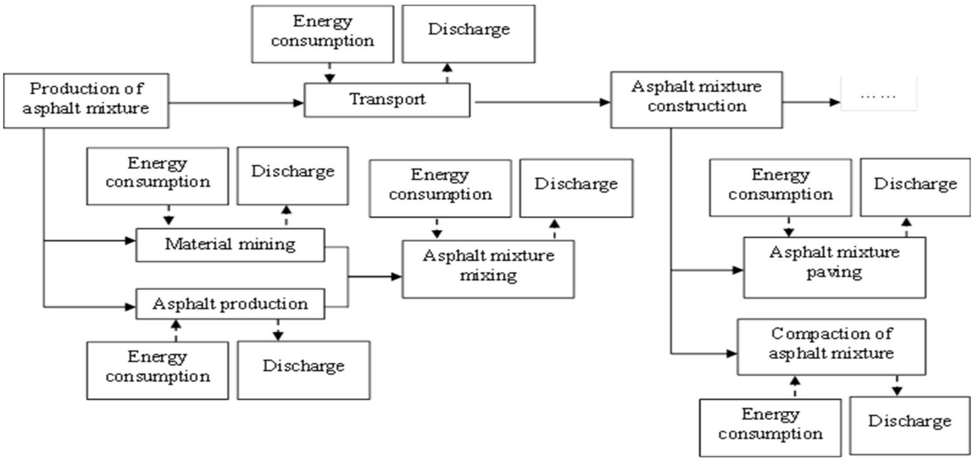

Figure 1. Asphalt pavement mixture construction energy consumption analysis diagram

3.2. Comparative analysis of energy consumption in each link of the asphalt pavement construction period

3.2.1. Comparative analysis of energy consumption of raw materials for pavement. A summary analysis of the energy consumption of each raw material combined with the survey and actual measurement results, as shown in the figure2:

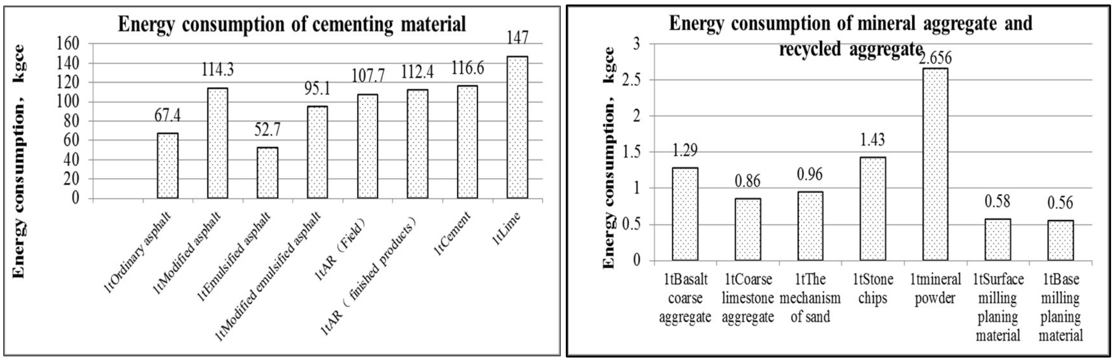

Figure 2. The energy consumption of various raw materials

(1) Cementing materials during the production period of raw materials are all energy-consuming materials, especially lime, cement, and modified asphalt. The order of energy consumption of raw materials (binders) from high to low is: lime> cement> SBS modified asphalt> rubber modified asphalt> modified emulsified asphalt> ordinary asphalt> emulsified asphalt.

(2) The order of energy consumption of mineral aggregate and recycled materials from high to low is: mineral powder> stone chips> basalt coarse aggregate> machine-made sand> limestone coarse aggregate> surface milling material> base milling material.

3.2.2. Comparative analysis on energy consumption of typical structure layer of asphalt mixture during construction period. Depending on the asphalt mixture construction of the project, the energy consumption of each link and the total energy consumption are shown in the table3.

Table 3. Energy consumption in each link of ordinary asphalt mixture

Construction process	Ordinary hot mix asphalt mixture			
	Modified asphalt AC-13	Modified asphalt AC-20	Ordinary asphalt AC-25	Modified asphalt SMA-13
Asphalt(MJ/t)	187.52	167.89	79.6	226.35
Aggregate(MJ/t)	30.25	30.36	30.48	30.02
Raw material transportation (150km) (MJ/t)	120.6	120.6	120.6	120.6
Mixture mixing(MJ/t)	334.99	334.99	307.80	336.67
Mixed material transportation (80km) (MJ/t)	64.32	64.32	64.32	64.32
Paving(MJ/t)	13.22	8.81	7.34	15.86
Rolling(MJ/t)	13.23	12.48	10.39	18.60
Total energy consumption (MJ/t)	786.4	761.72	640.75	834.69
Total energy consumption (Kgce)	26.83	25.99	21.86	28.48

The energy consumption of the upper layer SMA is 28.48 kgce , the energy consumption of modified asphalt AC-13 is 26.83 kgce , the energy consumption of modified asphalt AC-20 is 25.99kgce , and the energy consumption of ordinary asphalt AC-25 is 21.86kgce . The upper layer (SMA13) is 8.2% higher in energy consumption than the middle layer and 26% higher than the lower layer due to the addition of fibers, the use of modified asphalt, and the smaller particle size . Mixing time and mixing temperature will affect energy consumption. Different mixing plant energy consumption and emissions significantly different, indicating that mixing station equipment, coal product quality and management of large differences.

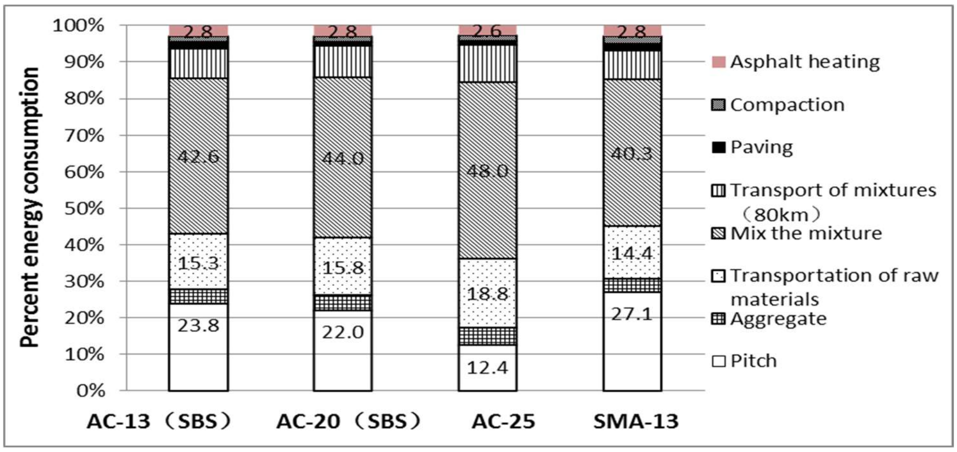

Figure 3. The proportion of energy consumption in each link

In all aspects of the asphalt surface construction period, the energy consumption of asphalt mixture mixing accounts for the largest proportion, accounting for 45% of the total energy consumption. Therefore, it is the key link to reduce energy consumption during asphalt mixture mixing. According to the investigation and analysis of this study, during the mixing process, the energy consumed by the heating of the aggregate is 90-98% of the mixing process. Therefore, the aggregate heating link of the mixing station is the key to energy saving and emission reduction in the mixing station. Choosing energy with high calorific value and low emission is an effective measure for energy saving and emission reduction. Among the three bidding sections, the construction units that consume a lot of energy during

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the mixing process, the coal selected is of poor quality, incomplete combustion, and low thermal efficiency.

4. Conclusion

(1) This chapter analyzes the method of obtaining energy consumption, and determines the quantitative calculation method of energy consumption based on the basic principle of "the quota method is the main, the theoretical method is the supplement, and the actual measurement method is the supplement " .

(2) Through the comparative analysis of energy consumption of raw materials for asphalt pavement:

①The order of energy consumption of raw materials (binder) is from high to low: lime> cement> SBS modified asphalt> rubber modified asphalt> modified emulsified asphalt> Ordinary bitumen>emulsified bitumen.

②The energy consumption of mineral aggregates and recycled materials is in descending order: mineral powder>stone chips>basalt coarse aggregate>machine-made sand>limestone coarse aggregate>surface RAP material>base RAP material.

(3) Through investigation, statistics, and on-site monitoring, a calculation model of energy consumption during highway construction was established, and a list of energy consumption during the entire construction period was proposed. The proportion of energy consumption of asphalt mixture mixing is the largest, accounting for about 45% of the total energy consumption. Asphalt mixture mixing is the key to reduce energy consumption. The energy consumption of the upper layer (SMA13) is 8.2% higher than that of the middle layer and 26% higher than that of the lower layer due to the addition of fiber, the use of modified asphalt and small particle size.

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