Research on the terminal blend rubberized asphalt with high-volume of rubber crumbs and its gap graded mixture

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***ABSTRACT**. The terminal blend rubberized asphalt which could be made by wet process in factory and used in gap graded mix was studied. The paper researched the terminal blend rubberized asphalt and its gap graded mixture via mix design and laboratory test. The results indicated that the gap graded terminal blend rubberized asphalt mixture has similar moisture stability and poor performance at low temperature to that of asphalt-rubber or SBS modified asphalt mixture, while the gap graded terminal blend rubberized asphalt mixture has excellent anti-rutting performance. The amount of the terminal blend rubberized asphalt is similar to SBS modified asphalt and less than the asphalt-rubber made by wet process on site in the gap graded mixture. The performances of the gap graded terminal blend rubberized asphalt mixture without cellulose fiber meet the requirements of SBS modified asphalt SMA. So with the use of the terminal blend rubberized asphalt in SMA, the cost of the mix would be decreased while the cellulose fiber is omitted. Meanwhile, the costs of the gap graded terminal blend rubberized asphalt mixture are significantly lower than asphalt-rubber mixtures. Compared to the asphalt-rubber, the terminal blend rubberized asphalt has excellent energy saving too. So the terminal blend rubberized asphalt mixture has good application foreground after verification by engineering.*

***KEYWORDS**: The terminal blend rubberized asphalt, Gap graded, Pavement performance, Economic analysis, Energy consumption analysis*

1. Introduction

The production and application of asphalt-rubber not only solve the pollution of the waste tires efficiently, but also improve the performance of the mixture obviously [1]. Many researches and applications have showed that the asphalt-rubber mixtures have good performances of anti-rutting, crack resistance and moisture stability, and the better performances of anti-fatigue and anti-aging than other modified asphalt mixtures. The asphalt-rubber mixtures provide the highways a surface with little maintenance, smooth ride and less noise, the quality of the pavement have been improved and its service life is increased [2,3,4]. In China, the asphalt-rubber is mainly produced by wet process on site, and the technology is relatively mature, but there are also some problems in the production of asphalt-rubber by wet process on site [5,6], such as the weak storage stability and ease of segregation, the high cost caused by the large asphalt-rubber dosage and the limited production on site lack of special equipments.

With the development of asphalt-rubber, aim at the insufficiency of the traditional asphalt-rubber produced by wet process on site, a new asphalt-rubber named terminal blend rubberized asphalt abbr., TBRA which is produced by wet process in the factory has been developed and applied to projects initially. The rubber content in the TBRA is in the range of 18% to 22%, and usually more than 20%. The TBRA has the different technical process and formula from the traditional asphalt-rubber. Due to the change of different physical and chemical properties, the type of the mixture which the TBRA used in is different from the asphalt-rubber, and the design method and index need to be restudied. According to the characteristics of the TBRA, in this paper the mix design of the gap graded mixture as well as the pavement performance and explores the characteristics of the gap-graded TBRA mixture and its application feasibility was investigated.

2. Production Process of the TBRA

The modification mechanism of the TBRA is the same with that of the traditional asphalt-rubber, that is, the asphalt-rubber has the interactions of swelling and degradation etc [4] during the preparation, mixing and application. However, the production process of asphalt-rubber manufactured by the factory wet process differs from the field wet production process of the asphalt-rubber. The production of the TBRA adopts primarily the multiple colloid processes to mill the rubber powder as fine as possible, thus achieving the equidensite existence of the rubber powder and the base asphalt and the long-term storage stability. The detailed production flow is shown in Fig.1. First, heat some of the base asphalt in the high-temperature tank to a certain temperature; then transmit the heated base asphalt and rubber powder jointly to the reaction kettle for agitation and development; after the initial development of the base asphalt and rubber powder, the initially-developed asphalt-rubber, through the grinding effect of colloid mill, is pumped to other reaction kettles for continuous development; through the circulation among several reaction kettles, the asphalt-rubber has realized the multiple colloid mill process and the continuous production of the asphalt-rubber as well. Pump the fully-developed asphalt-rubber into the tank of finished product, and add the stabilizer in atmospheric temperature as needed to realize the long-term storage stability of TBRA. And arrange the ex-factory sales of the asphalt in the tank of the finished product as required.

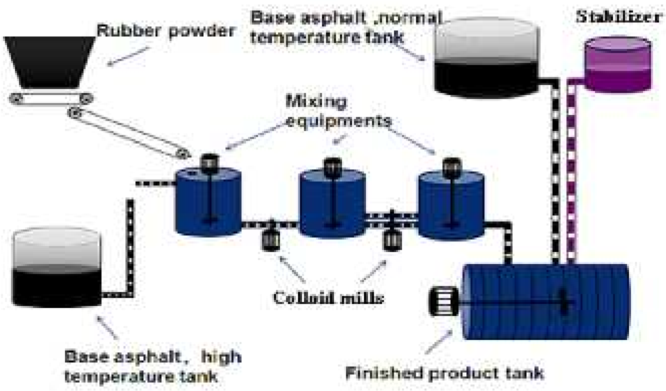

Figure.1 *The production process of the TBRA*

3. Mix Design

3.1 Raw materials

（1）The TBRA

Table.1 shows the basic properties of the TBRA used in this study as well as the test methods specifications used to evaluate them. According to the Table.1, the properties of the TBRA meet the technical Criteria of SBS modified asphalt except segregation of storage stability, and the TBRA can reach to the requirements of PG76-28 and has excellent performance at high and low temperature.

Item	Unit	Results	Technical Criteria	Test method
Penetration（25℃，100g，5s）	0.1mm	56	50-80	T0604-2000
Penetration index PI	—	-0.1	-0.2~+1.0	T0604-2000
Ductility（15℃，5cm/min）	cm	60	≮30	T0605-1993
Softening Point TR&B	℃	89	≮60	T0606-2000
Dynamic viscosity（60 ℃）		＞13000	≮800	T0625-2000
Kinematic viscosity（135 ℃）	Pa·s	7.15	≯3.0	T0625-2000
Dynamic viscosity（160 ℃）		3.075	/	T0625-2000
Dynamic viscosity（177 ℃）		1.3	/	T0625-2000
Density		1.047	/	T0603-1993
Flexibility Resume（25℃）	%	99	≮70	T0662-2000
Segregation of storage stability，deviation of Soft point after 48h	℃	2.8	≯2.5	T0661-2000
PG		PG76-28		AASHTO M320

Table.1 *Test results of the TBRA*

（2）Aggregate

The properties of the aggregates used in this study are presented in Table.2. This table also exhibits the technical criteria used to evaluate those properties. According to Table.2, each index of the aggregates can meet the technical Criteria.

Item	Unit	Sample 1 (0-3mm)	Sample 2 (3-5mm)	Sample 3 (5-10mm)	Sample 4 >(10mm)	Technical Criteria
Apparent relative density	/	2.945	2.930	2.915	2.913	≥2.6
Bulk relative density	/	2.808	2.844	2.857	2.860	/
Water absorption ratio	%	1.65	1.03	0.67	0.64	≤2.0
Powder density	t/m^3	2.711				≥2.50
Powder hydrophilic coefficient	/	0.7				＜1
Plasticity index of powder	/	2				＜4
Adhesion of coarse aggregate and SBS modified asphalt	level	5				≥3

Table.2 *The technical parameters of the aggregates (basalt)*

3.2. Selection of mixture gradation

According to the gradation specifications of SMA13 in *Technical Specifications for Construction of Highway Asphalt Pavements（JTG F40-2004）*, the coarse , medium and fine three gradations have been chosen(Gradation A, Gradation B and Gradation C). The compositions of the three gradations and the curves are presented in Table.3 and Figure.2, respectively.

Type	Mass percentage (%) of passing the following square meshes (mm) (%)								
	13.2	9.5	4.75	2.36	1.18	0.6	0.3	0.15	0.075
Gradation A	96.9	55.2	23.3	17.9	16.5	15.1	13.9	13.3	11.3
Gradation B	97.1	57.6	26.1	20.6	18.4	16.3	14.3	13.5	11.3
Gradation C	97.2	59.9	29.1	23.4	20.3	17.5	14.8	13.7	11.4

Table.3 *The gradations of the gap graded TBRA mixture*

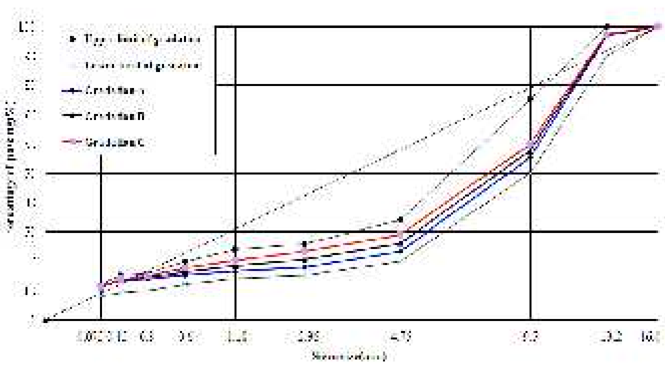

Figure.2 *Curves of the three gradations of the gap graded TBRA mixture*

3.3. Volume index of mixture

According to the usual asphalt content in SMA, the asphalt-aggregate ratio of 6.2% and cement content of 2% by weight are determined to make Marshall samples by both two sides compacted 75 times. The results of Marshall Test are presented in Table.4 and Table.5. According to the results, the VV of the medium gradation is close to the requirements of projects and technical criteria, and the volumetric properties of the mixture meet the technical criteria, so the medium gradation and the asphalt-aggregate ratio of 6.2% are determined to study the pavement performance of the gap graded TBRA mixture.

Type of gradation	Gap graded TBRA mixture
Coarse	5.1
Medium	4.0
Fine	3.4

Table.4 *The VV of the Marshall samples*

Type	Asphalt aggregate ratio（%）	Bulk relative density	Maximum theoretical relative density	VV (%)	VMA （%）	VFA （%）
Gap graded TBRA mixture	6.2	2.517	2.622	4.0	16.9	76.3
Technical Criteria of SMA13	/	/	/	3~4.5	≥16.5	75~85

Table.5 *The volumetric properties of the mixture*

4. Research on the performance of the gap graded TBRA mixture

4.1. Performance tests of gap graded-TBRA mixture

The mixture performance tests are conducted according to the determined mixture gradation and asphalt-aggregate ratio, including Schellenberg Binder Drainage test, Cantabro test, test of high/low temperature performance, moisture stability performance and fatigue resistance performance of the gap-graded TBRA mixture. All of the tests are according to *Standard Test Methods of Bitumen and Bituminous Mixture for Highway Engineering (JTG E20-2011).* Test results are presented in Table 6.

Item	Unit	Results	Technical Criteria
Schellenberg Binder Drainage test	%	0.06	≤0.10
Cantabro test	%	9	≤15
Residual Stability	%	87.8	≮85
TSR	%	82.8	≮80
Dynamic stability	Passes/mm	7292	≮3000
Failure Strain	με	2757.8	≮2500
Fatigue life(400με)	cycles	16071	/

Table.6 *Test results of the gap graded TBRA mixture*

According to Table.6, the performances of the gap graded TBRA mixture can meet the requirements of SMA13 in *Technical Specifications for Construction of Highway Asphalt Pavements（JTG F40-2004）*, so it is feasible for the TBRA to replace SBS modified asphalt as binder in SMA at the low dosage of asphalt.

4.2. Comparison study on the pavement performance

At present, the researches and applications of the asphalt-rubber can be divided into two types of gap graded mixture. One is increasing the VMA of the mixture, this gap graded mixture has smaller dosage of fine aggregate and larger dosage of asphalt-rubber (usually asphalt-aggregate ratio of 8.0%), Arizona in the U.S and Jiangsu province in China are as the representative of this type. The other is using the gradation of SMA, and adjusts local gradation on the basis of SMA. It may use larger dosage of asphalt-rubber, the asphalt-aggregate ratio is about 8.0% and Texas in the U.S is as the representative, smaller asphalt-aggregate ratio(about asphalt-aggregate ratio of 6.0%) may be also used, and Beijing is as the representative. Some researches and applications have showed the excellent performance of the two mixtures. The technical criteria of gradation of SMA13 in *JTG F40-2004* and the gradations of asphalt-rubber mixture used by Jiangsu province and Beijing are presented in Table 7. This paper has summarized some achievements of asphalt-rubber mixture in recent years and divided them into two types as the above classification, as shown in Table 8. Compared to the two type asphalt-rubber mixtures and SMA13, the performance characteristics of the gap graded TBRA mixture will be studied.

	Mass percentage (%) of passing the following square meshes (mm) (%)									
	16	13.2	9.5	4.75	2.36	1.18	0.6	0.3	0.15	0.075
Beijing	100	95	65.6	30.0	23.5	18.4	14.5	11.4	8.9	7.0
Jiangsu	100	100~90	65~45	32~12	18~8	/	/	/	/	3~0
technical criteria	100	100~90	75~50	34~20	26~15	24~14	20~12	16~10	15~9	12~8

Table.7 *The technical criteria of gradation of SMA13 and the gradations of asphalt-rubber mixture used in Jiangsu and Beijing*

Type	The Dosage of asphalt rubber	Gradation	VMA
Gap graded mixture Ⅰ	About 7.41%	Smaller dosages of fine aggregate and powder, AR-AC13S	⩾20%
Gap graded mixture Ⅱ	About 5.66%	The gradation of SMA13	⩾16%

Table.8 *The classification of the asphalt-rubber gap graded mixture*

4.2.1. Moisture stability

In China moisture stability test is Marshall Immersion Test or Freeze-Thaw Splitting Test. The results of Immersion Marshall Test and Freeze-Thaw Splitting Test are adopted to compare the moisture stability of various asphalt mixtures. The test results are shown in Fig.3 and Fig.4.

Figure.3 *The comparison of Residual Stability*

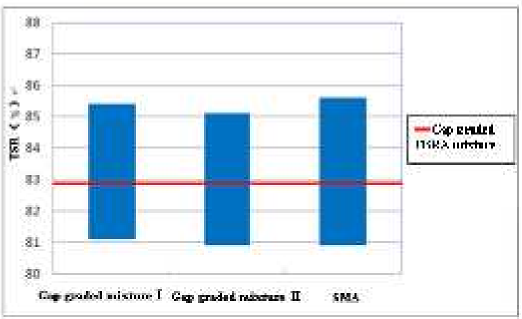

Figure.4 *The comparison of TSR*

According to Fig.3, the residual stability of the gap graded TBRA mixture is less than that of gap graded mixture and SMA, and located in the middle/upper position in the residual stability zone of the gap graded mixture . Generally, asphalt-rubber has great viscosity, but the large amount of rubber powders reduce the adhesion of asphalt, and cause the asphalt rubber poor moisture stability [8]. The gap graded mixture I has a greater dosage of asphalt of about 7.41% than that of about 5.84% in the gap graded TBRA mixture and the gap graded mixture , so the residual stability of the gap graded mixture is higher because of the thicker thickness of asphalt film. As shown in Fig.4, the TSR of the gap graded TBRA mixture is located in the TSR zone of the other three mixtures. All of the four mixtures have the similar value of TSR.

When considering the results of the residual stability and the TSR, conclusion could be drawn that the moisture stability of the gap graded TBRA mixture is similar to that of traditional asphalt-rubber mixture and SMA. The moisture stability can reach to the technical criteria, but close to the lower limit, this is consistent with the test road, so the cement should be added as anti-stripping agent to improve the moisture stability of the gap graded TBRA mixture.

4.2.2. Low temperature performance

Beam bending tests in T0715 are done at -10℃. The test can measure mechanical properties of hot mixture asphalt when beam (250mm×30mm×35mm) is flexural failure under -10℃ and 50mm/min of loading speed. The samples are put in the environmental preservation box to ensure the temperature of samples is -10℃. The failure strain is used to describe the performance of materials at low temperature. The higher the failure strain, the better the crack resistance. The results are shown in Fig.5.

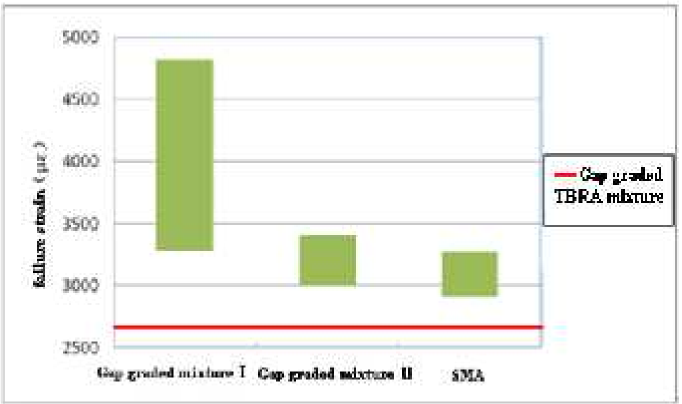

Figure 5. *The comparison of failure strain*

As shown in Fig.5, the low temperature performance of the gap graded TBRA mixture is slightly inferior to the other three mixtures. The low temperature performance of mixture mainly depends on the property of the asphalt binder and the dosage of the asphalt. The gap graded mixture Ⅰ has excellent low temperature performance because of the larger dosage of the asphalt. Due to the large content and fine rubber powder particle of rubber powder mixed in the TBRA, the free asphalt is reduced after the full swelling of rubber powder, which is adverse to the deformation of mixture. At the meantime, the large rubber powder content may result in the failure of forming the semi-solid continuous phase in the TBRA and the reduction of adhesivity. Therefore, the low temperature performance of the gap-graded TBRA mixture is inferior to the gap-graded mixture and SBS modified asphalt SMA with the similar gradation and dosage of the asphalt, but it still meets the specification requirements.

4.2.3. High temperature performance

The high temperature performance is measured by dynamic stability which is the total passes for every 1mm rutting with tire pressure of 0.7MPa and temperature of 60℃. The results of test and collections are showed in Figure 6.

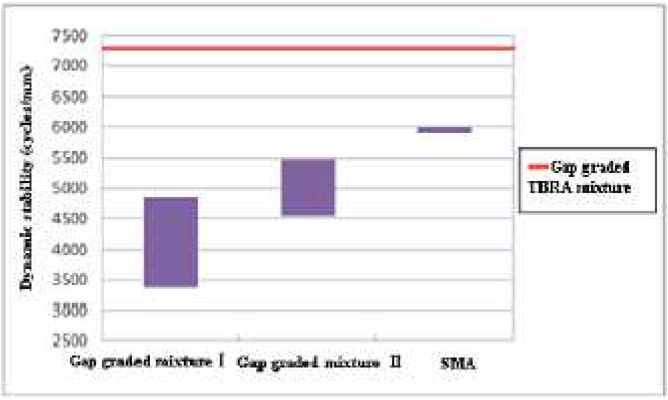

Figure.6 *The comparison of dynimic stability*

According to the Fig.6, the dynamic stability of the gap graded TBRA mixture is much higher than the other two gap graded mixtures and SMA. The dynamic stability of mixture mainly depends on the skeleton of the mixture and type of the binder. The VMA and dosage of asphalt of the gap graded mixture I are both higher than the other three mixtures, so the gap graded mixture I has smaller dynamic stability. The gap graded TBRA mixture has similar gradation and dosage of asphalt to the gap graded mixture and SMA, and the main difference is the type of the binder. Due to the larger rubber powder, the asphalt-rubber has greater elasticity, and the gap graded mixture is hard to be compacted[8]. In addition, the VMA is filled with the better mastic network formed by the TBRA binder and fine aggregates and the small amount of cement.

5. Economic and energy consumption analysis

According to the above-mentioned studies, the performances of the gap-graded TBRA mixture completely meet the technical specifications. To fully demonstrate the application prospect of the TBRA, this chapter will analyze the characteristics of the gap-graded terminal blend rubberized asphalt mixture from the perspective of economical efficiency and energy consumption.

5.1. Economic analysis

Currently, the domestic prices of the terminal blend rubberized asphalt and other modified asphalts are shown in Table 9.

Type of asphalt	Price (Euro/t)	Price changing to base asphalt (Euro/t)
Base asphalt	564.3	----
SBS modified asphalt	714.78	+150.48
Asphalt-rubber	727.32	+163.02
TBRA	639.54	+75.24

Table.9 *The prices of asphalts*

The dosage of TBRA in the gap graded mixture is close to or the same with the asphalt-rubber in gap graded mixture Ⅱ and SBS modified asphalt in SMA, so the dosage of TBRA is the same with the asphalt-rubber and SBS modified asphalt during the economic analysis in this chapter, and the asphalt-aggregate ratio is 6.1% in these cases, while the asphalt-aggregate ratio in the gap graded mixture Ⅰ is 7.41%.. Without considering the production costs of the asphalt mixture, from the perspective of the material costs, the costs of all mixtures per thousand tons are shown in Fig.7.

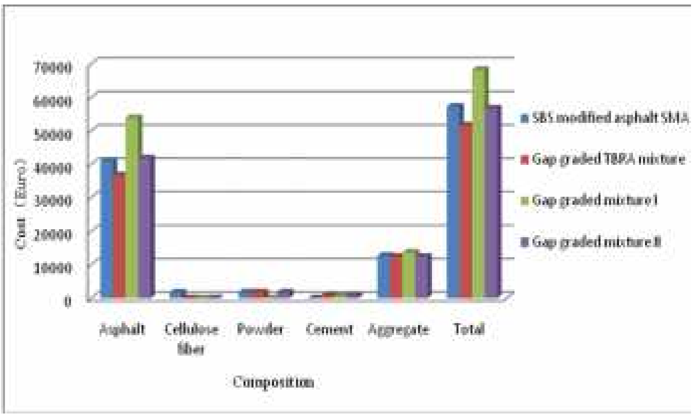

Figure 7. *The cost comparison between the four mixtures(1000T)*

According to Fig.7, the main difference in the costs of the four mixtures lies in the asphalt. Since the price of the terminal blend rubberized asphalt is lower than SBS modified asphalt and asphalt-rubber, and the gap-graded terminal blend rubberized asphalt mixture is not mixed with fiber, the cost of the gap-graded terminal blend rubberized asphalt mixture is significantly lower than SBS modified asphalt SMA by 5.32 Euro as well as gap graded mixture I by 15.85 Euro and gap graded mixture II by 4.14 Euro per ton. Therefore, it is of obvious economic efficiency. At the mean time, the TBRA replaces SBS modified asphalt to use in SMA, which avoids the interference of mixed fiber upon production of asphalt mixture and reduces the production procedures. Therefore, it is of significant economic benefit.

5.2 Energy consumption analysis

5.2.1. Energy consumption of asphalt production

During the production of modified asphalt, the asphalt-rubber adopts the production technology of high-speed shearing in the high-temperature condition, which involves the relatively high temperature environment during the production process, such as the preheating of base asphalt (about 160℃), high-speed mixing (about 190℃) and high-temperature swelling (about 180℃). At the meantime, the high-speed shearing involves more electric power consumption. However, the TBRA adopts primarily the production technology of colloid mill, which requires the relatively high temperature environment just in the preheating of base asphalt (30-40% base asphalt heated to 175-185℃, and 60-70% base asphalt to 150℃) and the colloid milling (180℃), and the electric power consumption of colloid milling is significantly lower than the high-speed mixing process. As for the production mode, the energy utilization rate of the intensification production of TBRA is higher than open production on site. According to the actual measurement, the above energy consumption is converted to the electric and fuel consumption. As shown is Table 10, during the production stage of modified asphalt, the electric consumption and fuel consumption of TBRA is respectively 30% and 40% of consumptions of asphalt-rubber by wet-process on site. Therefore, the production of TBRA is of superior efficiency in energy saving.

Type of asphalt	Electric Consumption(kw・h/t)	Fuel Consumption（kg/t）
Asphalt-rubber by wet-process on site	12~15	15~20
TBRA	3.5~5	6~8

Table.10 *Energy Consumption of TBRA and asphalt-rubber in production process*

5.2.2. Analysis of Energy Consumption in Mixture Production

According to the production characteristics of asphalt mixture, the energy consumption of mixture during the production lies primarily on storage of asphalt in the high-temperature insulation and the heating mixing of mixture. This section will make a quantitative comparison for the energy consumption of the two links through theoretical calculation.

1. Storage of the asphalt

The storage temperature of the asphalt-rubber made by wet-process on site is about 15℃ higher than that of the TBRA. Supporting the TBRA and asphalt-rubber has the same arrival temperature, to reach the required storage temperature, the asphalt-rubber each ton should consume 2.01×10^4 kJ more energy which can be calculated by the formula that 1000kg×15℃×1.34 KJ/（kg•℃）=2.01×104 kJ.

2. Mixture mixing

During the production of mixture, the energy consumption lies primarily on the thermal energy consumption to raise the aggregate temperature and the mechanical energy needed to mix the mixture, provided respectively by fuel and electric power.

（1）Fuel consumption

In reference to the energy consumption calculation method of warm mix asphalt and according to parameters in Reference [9], the parameters for calculating are presented in Table 11.the thermal energy consumptions of the gap-graded TBRA mixture, the gap-graded mixture I and the gap-graded mixture II are calculated, and the thermal energy consumptions of the three mixtures are summarized in Table 12.

Item	Specific heat capacity[J·(kg·K)^1]		Diesel heat(J)	Diesel combustion efficiency(%)	Aggregate temperature before heating(℃)	Water content in aggregate(%)	Heat exchange rate of roller(%)
	Aggregate	Water					
Value	920	4190	42.5×10^6	90	25	4	60

Note, all the water in aggregate is evaporated at 130 ℃.

Table.11 *Parameters for calculating the energy in the process of heating aggregates.*

Mixture Type	Asphalt-aggregate ratio（%）	Temperature（ ）		Energy Needed by Aggregate Heating Process（J）		Total Heat Needed by Aggregate Heating Process（J）	Fuel Quantity Needed by Aggregate Heating Process（kg）
		Discharge	Aggregate	Heat Absorption of aggregate	Moisture Evaporation		
Gap-graded TBRA mixture	6	170~180	190	1.43×10^8	1.66×10^7	1.60×10^8	6.97
Gap-graded mixture I	8	175~185	210	1.58×10^8	1.63×10^7	1.74×10^8	7.58
Gap-graded mixture II	6	175~185	205	1.56×10^8	1.66×10^7	1.69×10^8	7.54

Table.12 *Energy Consumption of Three Mixtures*

The Analysis of energy needed by aggregate heating process was as follows.

Energy consumption needed by aggregate heating process E_h included heating absorption of aggregate E_{ha} and moisture evaporation E_{hw}. According to the energy formula that $E=mc(t_2-t_1)$, the E_h of 1t weight of SMA13 during the heating process could be calculated as follows.

$$
\begin{aligned}
E_{\mathrm{h}} &= E_{ha}+E_{hw} \\
&= 920\times943.4\times(190-25)+4190\times943.4\times0.04\times(130-25) \\
&= 1.43\times10^8+1.66\times107 \\
&= 1.60\times10^8\mathrm{J}
\end{aligned}
$$

According to the parameter listed in the Table.11, the fuel quantity of TBRA mixture SMA13 aggregate during heating process (m_h) could be calculated as follows.

$$m_h=1.60\times10^8\div(42.5\times106)\div60\%\div90\%\approx6.97\mathrm{kg}$$

With the same way, the energy consumption and fuel quantity of mixture I and II could be calculated.

According to Table 12, the heat energy saving ratio of the gap-graded TBRA mixture is as follows:

Compared with the gap-graded mixture I,

$$\text{Energy saving ratio}=(7.58-6.97)\div 7.58\times 100\%=8.05\%$$

Compared with the gap-graded mixture II,

$$\text{Energy saving ratio}=(7.54-6.97)\div 7.54\times 100\%=7.56\%$$

Therefore, the gap-graded TBRA mixture has much better fuel energy saving effect compared with the gap-graded rubber asphalt mixture.

（2）Electric power consumption

During the mixture production, both the viscosity and asphalt-aggregate ratio of the TBRA are lower than the asphalt-rubber, so the mixing time of TBRA mixture is less than the traditional asphalt-rubber by saving about 5~10s in each time. If the mixing power of the mixing building is fixed, the mechanical energy consumption of the factory rubber asphalt mixture is in proportion to the mixing time.

The mixing time of both the gap-graded mixture I and the gap-graded mixture II is about 60s, so the energy saving ratio of the gap-graded TBRA mixture in the mechanical energy consumption is as follows:

$$5\div 60\times 100\%=8.33\%$$

Therefore, the gap-graded TBRA mixture has much better energy saving effect than the gap-graded rubber asphalt mixture.

Since the viscosity of the TBRA is lower than the traditional asphalt-rubber, the energy consumption of the TBRA mixture in transport, paving and rolling stages will be lower than the asphalt-rubber. It is difficult to forecast and calculate effectively the energy consumption during these stages, so is the quantization of the energy saving effect of the TBRA in such stages.

To sum up, the TBRA has much better energy saving effect than asphalt-rubber concerning the asphalt production, insulation and the mixing, transport, paving and rolling stages of asphalt mixture as well. The specific energy consumption to product a ton of mixture is shown in Table 13 and Fig.8.

<table>
<tr><th colspan="2" rowspan="2">Type of Energy Consumption</th><th colspan="2">Gap-graded TBRA mixture</th><th colspan="2">Gap-graded mixture I</th><th colspan="2">Gap-graded mixture II</th></tr>
<tr><th>Consumption（kg）</th><th>Energy Consumption</th><th>Consumption（kg）</th><th>Energy Consumption</th><th>Consumption（kg）</th><th>Energy Consumption</th></tr>
<tr><td rowspan="2">Asphalt production</td><td>Electric power</td><td rowspan="2">56.6</td><td>0.48 kw・h</td><td rowspan="2">74.1</td><td>0.96 kw・h</td><td rowspan="2">56.6</td><td>0.74 kw・h</td></tr>
<tr><td>Fuel</td><td>0.40kg</td><td>1.33kg</td><td>1.0kg</td></tr>
<tr><td>Asphalt heat insulation in mixture production</td><td>Electric power</td><td>56.6</td><td>----</td><td>74.1</td><td>0.41 kw・h</td><td>56.6</td><td>0.32 kw・h</td></tr>
<tr><td rowspan="2">Mixing of mixture</td><td>Electric power</td><td rowspan="2">1000</td><td>1.83 kw・h</td><td rowspan="2">1000</td><td>2 kw・h</td><td rowspan="2">1000</td><td>2 kw・h</td></tr>
<tr><td>Fuel</td><td>6.97kg</td><td>7.58kg</td><td>7.54kg</td></tr>
<tr><td rowspan="2">Total</td><td>Electric power（kw・h）</td><td colspan="2">2.31</td><td colspan="2">3.37</td><td colspan="2">3.06</td></tr>
<tr><td>Fuel（kg）</td><td colspan="2">7.37</td><td colspan="2">8.91</td><td colspan="2">8.54</td></tr>
</table>

Table.13 *Energy Consuming Analysis for a Ton of Mixture*

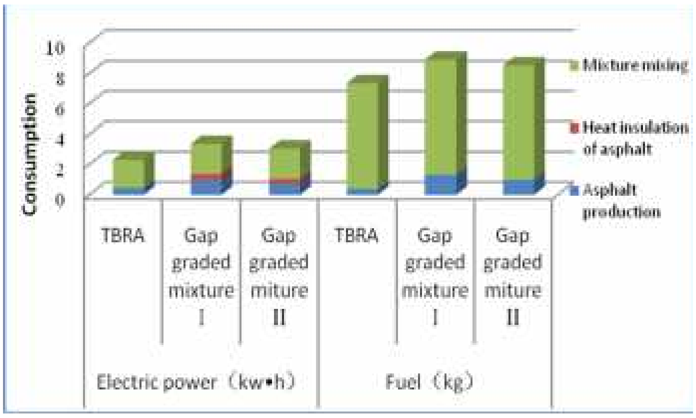

Figure.8 *Energy Consumption Analysis of a Ton of Mixture*

6. Engineering Application

The traffic of one section of the provincial highway of 239 is very heavy in Jiangsu Province, the section has been repaired several times in recent ten years, partial section have to rebuild the pavement by paving the cement concrete surface. The test road of the TBRA adopted double layer structure with 5cm thickness per layer. In order to ensure uniform mixing , the mix time of the gap graded TBRA mixture was extended 15s.The temperature control of each link is presented in Table 14.

Content	Temperature(℃)
Temperature of the mixture on leaving the plant	175~185℃
Temperature of the mixture on arriving the site	No less than 170℃
Temperature of paving	No less than 160℃
Temperature of initial compaction	No less than 150℃
Temperature of final compaction	No less than 110℃

Table.14 *The temperature control of each link*

According to the construction process, the gap graded TBRA mixture had the advantage of convenient construction, and the degree of compaction met the technical criteria, the test results for water permeability were no seepage.

7. Conclusions

The mix design and research show that all the pavement performance of the mixture reach to the technical criteria of SMA13 with the common asphalt dosage of 5.66% in SMA. The moisture stability and low temperature performance of the gap graded TBRA mixture are slightly lower than SBS modified asphalt SMA with the similar asphalt dosage and gap graded asphalt-rubber mixture with asphalt-rubber dosage of 7.41%, but the anti-rutting performance is optimal. With the similar asphalt dosage and gradation, the gap graded TBRA mixture has better moisture stability and anti-rutting performance, while the low temperature performance is inferior to asphalt-rubber. Economic analysis shows that the cost of the gap graded TBRA mixture is lower than that of SBS modified asphalt SMA and the gap graded asphalt-rubber mixture, and the energy consumptions of the production of the TBRA and its gap graded mixture are less than that of the asphalt-rubber. In addition, the gap graded TBRA mixture had the advantage of convenient construction, if the long-term performance still good, the gap graded TBRA mixture will be an effective choice to the heavy traffic, and be applied widely in the future construction.

8. Acknowledge

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