

Effect of production process parameters on high temperature stability of rubber asphalt mixture

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This study aims to improve the high-temperature stability of rubber asphalt mixtures. Single factor analysis was used to compare and analyze the results of rutting test before and after rubber asphalt equipment reformation and indoors. The influence rule of various production process parameters on high-temperature stability was determined and analyzed through gray correlation theory. The dynamic stability of rubber asphalt mixtures significantly improved after reformation. Prolonged mixing time benefitted mixing uniformity and swelling reactions. With increasing developing temperature and time, the dynamic stability first increased and then decreased. In actual production, the optimal temperature and time are 185-190°C and 1-1.5 h, respectively. Under horizontal axis stirring, the dynamic stability increased by 16% relative to that under vertical shaft stirring. The dynamic stability improved with increasing rubber powder content, and the optimal rubber powder content in terms of construction workability is 20-22%. Experimental results of mass production after reformation are consistent with the laboratory test results. The gray correlation analysis results show that rubber powder content, developing temperature, developing time, and stirring technique are key control parameters. Furthermore, control accuracy should be enhanced, and fluctuation should be reduced.

Keywords: Hybrid, Road engineering and materials, High temperature, Production process parameters, Rutting test, Dynamic stability, Gray relation

With the aggravation of global warming, extension of seasons with high temperatures, and aggravated phenomenon involving high speeds, heavy loads, mass flow¹, and channelization in modern transportation, various distresses related to high-temperature stability occur on asphalt pavement; the most prominent damage of which is rutting deformation, which greatly shortens the service life of asphalt pavement². Hence, improving the high-temperature performance of pavement and decreasing rutting deformation have become important issues that require immediate solutions in current highway construction.

Rubber asphalt mixtures are widely applied because of their improved performance at high and low temperatures than those of ordinary asphalt mixtures. Although rubber asphalt mixtures offer certain social and economic benefits, they suffer from decreased anti-sliding performance, floating of fine materials, and deterioration of high-temperature anti-rutting performance. Many scholars at home and abroad have conducted relevant studies. A previous

study used a dynamic shear rheometer and frequency scanning and revealed that increasing the rubber powder dosage decreased the temperature sensitivity of rubber asphalt mixtures^{3,4}. Single-factor analysis indicated that cementing materials, gradation, and aggregate ratio significantly influenced the high-temperature performance of rubber asphalt mixtures; in particular, decreasing the dosage of mineral powder and fine aggregates resulted in a highly satisfactory effect⁵. In the literature⁶, the influence degree on the high-temperature stability of rubber asphalt mixtures was analyzed by the Marshall characteristic value based on gray correlation entropy theory; the results provided a basis for the optimal design of mix proportions⁶. The high-temperature performance of rubber asphalt pavement was improved by optimizing aggregate gradation and rolling process parameters⁷. A rut testing machine was optimized, and the computation of duration and dynamic stability at different loading rates during the rutting test was illustrated⁸. The dry method, wet method, and laboratory production process of rubber asphalt mixtures were compared. Results showed that wet method significantly influenced dynamic stability and

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anti-rutting performance⁹. The above mentioned theories and tests related to the high-temperature stability of rubber asphalt mixtures mainly focused on the performance of component materials, with laboratory tests regarded as the priority on the basis of high-quality rubber asphalt performance^{10,12}. However, most rubber asphalt production equipment in China are self-developed by enterprises without uniform standards. Thus, the resulting diverse production processes and defects lead to significant differences in the preparation process of rubber asphalt. Consequently, the high-temperature performance of rubber asphalt mixtures varies. The present study explored the impact of the process parameters of rubber asphalt production equipment on the high-temperature stability of rubber asphalt mixtures. These parameters include mixing time in make-up tank, developing temperature, stirring technique of the developing tank, developing time, and rubber powder content. The results of the batch production of rubber asphalt, the rutting test on the rubber asphalt mixture, and the laboratory rutting test before and after equipment renovation were compared according to the construction engineering practices for rubber asphalt pavement in Shanxi province and on the basis of the technology optimization of multiple rubber asphalt production equipment^{13,14}. Gray relation theory was also adopted to analyze the key controlling factors to provide basis in standardizing the process parameters of rubber asphalt production equipment and their promotion and application in pavement construction.

Experimental Procedure

Comparison of equipment performance

Qualified rubber asphalt production equipment is the premise of ensuring the quality of rubber asphalt production and high-temperature performance of rubber asphalt mixtures. However, most rubber asphalt production equipment are self-developed by enterprises without uniform standards and thus suffer from certain defects. For example, some manufacturers simplify or even remove some key links to improve production efficiency, thereby causing discrepancies in batch processing and laboratory simulation tests of rubber asphalt. Such discrepancies render the laboratory test results unusable as references. In another example, matrix asphalt is aged before being put into production due to the absence of rapid heating devices. In addition, the low measurement accuracy of load weighting devices

for matrix asphalt and rubber powder and the obvious nonlinearity of measurements hamper the effective control of the mixing ratio during batch production (Fig. 1).

The aforementioned problems greatly affect the performance of rubber asphalt and its mixture. Therefore, this study provides technical support for the processing quality of rubber asphalt and its mixture on the basis of a field survey analysis of multiple rubber asphalt equipment used in highway pavement engineering in Shanxi Province. The study also explores technical renovation and optimization aimed at existing problems. The performance of rubber asphalt production equipment before and after technical renovation is presented in Table 1.

Materials

Sinopec 90# matrix asphalt of Zhenhai Ningbo and 30-mesh rubber powder of Xi'an Zhongxuan Rubber Company were selected for the test. The physical and chemical performance indices are given in Table 2.

The various aggregates used to produce asphalt mixture were all basalt, and the mineral powder was made of limestone obtained by grinding. The wood fiber was obtained from Beijing Tiancheng KenTeLai Co., Ltd. The various performance indices of the above-mentioned materials were certified by an entrusted party through tests, and all of them were found to meet the required highway construction specifications. To study the impact of the different production process parameters of rubber asphalt equipment on the high-temperature stability of rubber asphalt mixtures and ensure the comparability of the test results, we adopted the SMA-13 mixing ratio of pavement layers in Shanxi Province during the test for unification. The suggested a gradation is shown in

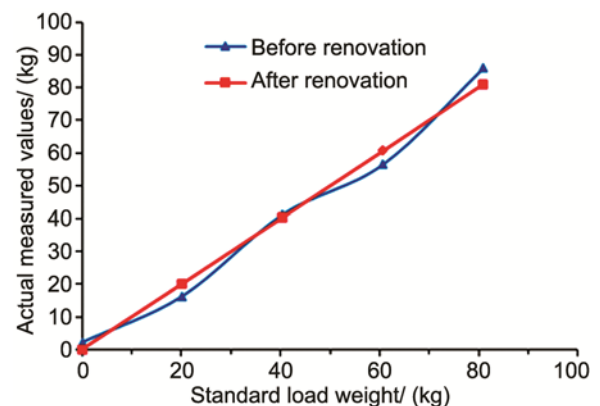


Fig. 1 — Comparison of measurements before and after equipment renovation

Fig. 2. The optimal rubber asphalt-aggregate ratio was set to 6.9% after the Marshall test.

Test methods

During the production of rubber asphalt, a reasonable selection of the mixing time of the make-up tank, developing temperature, stirring techniques of the developing tank, developing time, and rubber powder dosage can improve the production quality of rubber asphalt and thereby enhance the high-temperature performance of rubber asphalt mixtures¹⁵. In the present study, one parameter was changed while the other production parameters remained unchanged during the tests. The tests were conducted before and after the renovation of the rubber asphalt production equipment and in the laboratory. The increase in the mixing time of the make-up tank contributes to the adequate swelling reaction of the rubber powder and matrix asphalt under high

temperature. However, an excessively long make-up time decreases the production efficiency of the equipment. Hence, 5, 8, 11, 14 and 17 min were selected as the mixing times under the corresponding developing temperature of 185°C. Horizontal stirring

Table 2 — Physical and chemical performance indices of 30-mesh rubber powder

Test items	Specifications	Test results
Water content/%	< 1	0.60
Acetone extract	≤22	5.83
Metal content /%	< 0.05	0
Fiber content/%	< 1	0.02
Rubber hydrocarbon content /%	≥42	63
Carbon black content/%	≥28	28
Ash content/%	≤8	7.5
Qualitative analysis of natural rubber	/	Natural rubber

Table 1 — Performance comparison of rubber asphalt equipment before and after renovation

Item	Rapid heating of asphalt	Flowmeter of matrix asphalt	Measurement methods of rubber powder	Mixing time	Measurement nonlinearity
Before renovation	None	Mechanical type with low measurement accuracy	Volume measurement	0 min	Yes
After renovation	Yes	Electronic type with high accuracy	Double measurement of weight and volume	Adjustable	None
Item	Premix as per mixing ratio	Time of premixing inside make-up tank	Stirring technique	Temperature	
Before renovation	No	0 min	Vertical	Inaccurate	/
After renovation	Yes	8 min	Horizontal shaft type	Accurate	/

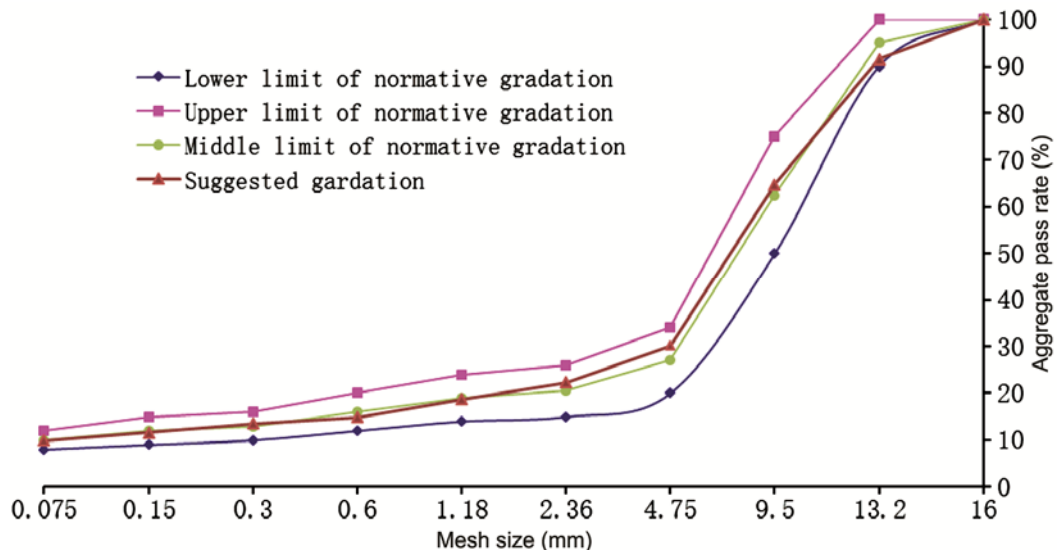


Fig. 2 — Mixing ratio of SMA-13 rubber asphalt mixture

was adopted inside the developing tank, with the developing time being 1.5 h and the rubber powder dosage being 20%. A proper developing temperature prevents the aging of matrix asphalt and contributes to the physical and chemical reactions between the rubber powder and the matrix asphalt. The mixing time of the make-up tank corresponding to the developing temperatures of 175°C, 180°C, 185°C, 190°C and 195°C was set to 8 min. Horizontal stirring was adopted inside the developing tank, with the developing time being 1.5 h and with the rubber powder dosage being 20%. A test was conducted on horizontal stirring and vertical stirring inside the developing tank; the parameters were 8 min of mixing inside the make-up tank, developing temperature of 185°C, developing time of 1.5 h, and rubber powder dosage of 20%.

An extended developing time can contribute to an adequate reaction between the rubber powder and the matrix asphalt. However, an excessively long developing time decreases rubber asphalt viscosity. Therefore, the following were set: 0.5, 1.0, 1.5, and 2.0 h of developing times; 8 min of mixing inside the make-up tank; horizontal stirring inside the developing tank; 20% rubber powder dosage; and developing temperature of 185°C. The key indices of the rubber asphalt changed obviously with the change in the rubber powder dosage. A high rubber powder dosage equates to a high rubber asphalt viscosity, which contributes to cementation between aggregates¹⁶. However, excessive rubber powder dosage induces the rubber asphalt to show solid phase characteristics, especially for coarse rubber particles, which hamper the flow performance of rubber asphalt and cause the flow to go against the coating between aggregates. Hence, the following parameters were set: 18%, 20%, 22%, and 24% of rubber powder dosage; mixing time of 8 min inside the make-up tank; horizontal stirring inside the developing tank; developing time of 1.5 h; and developing temperature of 185°C.

Results and Discussion

In this study, rubber asphalt was prepared by changing the various production process parameters and keeping the other test conditions unchanged to prepare and test the rut samples of rubber asphalt mixture. The test results are shown in Figs 3-6.

Mixing time inside the make-up tank

In Fig. 3, 0 min indicates the period before the renovation of the rubber asphalt equipment. At this point, the rubber powder and matrix asphalt inside the

make-up tank have not been premixed for a certain period before being continuously delivered to the developing tank. As shown in Fig. 3, the dynamic stability of the asphalt mixture made of non-premixed rubber asphalt was low and near normative minimum. This production process result was not in accordance with the laboratory process. When the mixing time inside the make-up tank was set to 5 min, the value of dynamic stability of the rubber asphalt mixture was also low, but it met the technical specification requirement. Nevertheless, the stability value was regarded as poorer than the values acquired under other mixing times. The rubber powder floated when put into the make-up tank due to its density, which was slightly lower than that of the matrix asphalt. A short mixing time cannot contribute to effective mixing and to the physical and chemical reactions of

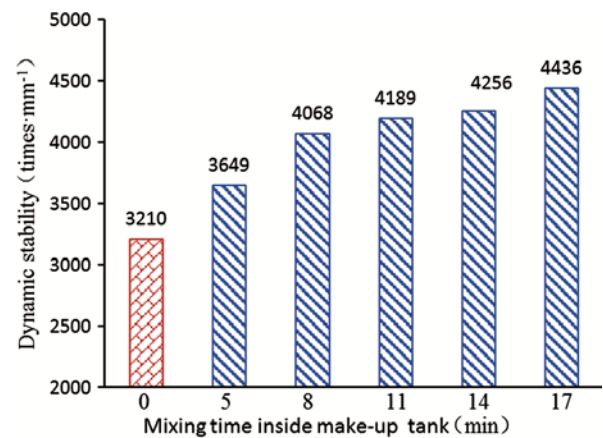


Fig. 3 — Impact of different mixing times on stability

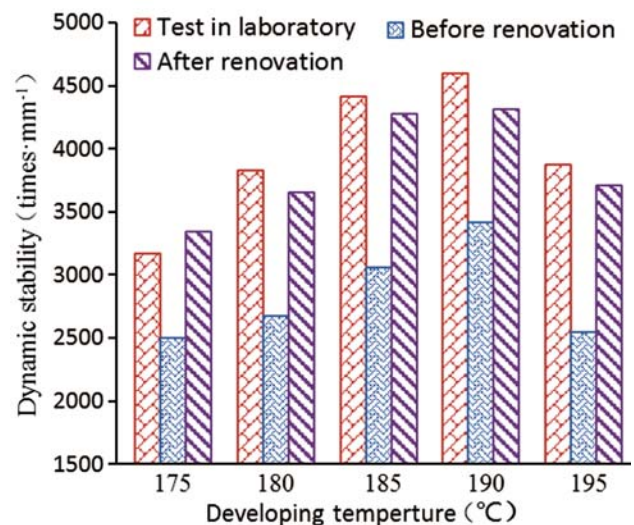


Fig. 4 — Impact of different developing dynamic temperatures on dynamic stability

rubber powder and matrix asphalt, especially when the rubber powder dosage is large. After putting multiple batches of such uneven premixed materials into the developing tank, the evenness worsened. Although premixed materials are still being mixed in the developing tank, the effect of stirring in small volumes is much worse than that of stirring at high rotation speeds inside the make-up tank.

The test results of various samples differed obviously because of the uneven distribution of rubber powder in the 25°C cone penetration test of rubber asphalt. When the mixing time was increased to 8 min, the dynamic stability of the mixture improved to a certain degree. When the mixing time was increased to 11 or 14 min, no obvious change in dynamic stability was observed. Although the dynamic stability improved again when the mixing time was increased to 17 min, excessive stirring causes a sharp reduction in production efficiency and increases construction cost. Thus, 8–11 min was set as the mixing time inside the make-up tank. The other performance indices of the mixture measured also met the technical requirements.

Developing temperature

As shown in Fig. 4, the dynamic stability of the rubber asphalt mixture produced by the equipment before renovation was lower than that after renovation and in the laboratory test. When the developing temperatures were 175°C, 185°C, and 195°C, the dynamic stability value fell below the lower limit of the specification requirement. Table 1 suggests that before the equipment was renovated, the temperature in the developing plant was highly inaccurate. In such a case, achieving good control of the developing process of rubber asphalt was difficult, and dynamic

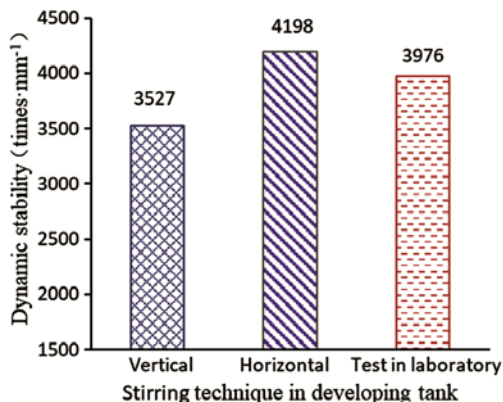


Fig. 5 — Influence of different stirring techniques on dynamic stability

stability became unstable. When the developing temperature was 175°C after the equipment renovation, the mixture showed the lowest dynamic stability (i.e., the worst high-temperature stability) because the matrix asphalt could not easily react to the rubber powder under a low temperature and the rubber powder was not fully dispersed and swollen.

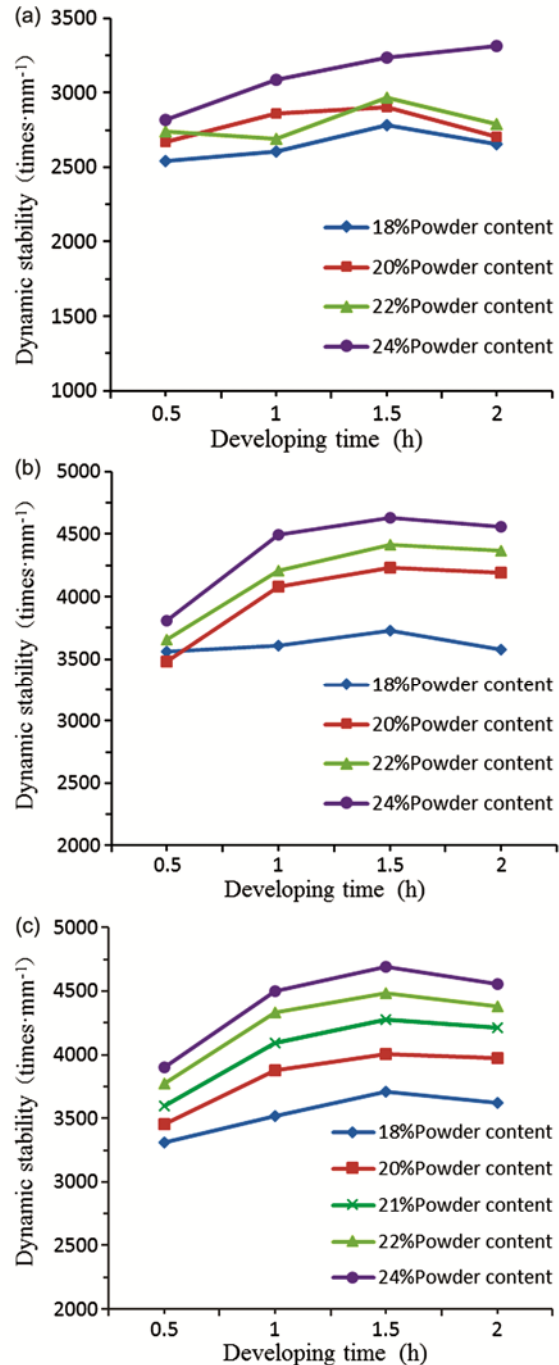


Fig. 6 — Influences of different developing time and mixing amount of rubber powder on dynamic stability

The 180°C Haake viscosity of the rubber asphalt was only 2 Pa·s, which is near the lower limit of the technical requirement. The rubber asphalt mixture produced under such circumstances could not meet the pavement requirements in highway construction.

Increasing the developing temperature improves the dynamic stability of the rubber asphalt mixture, which reaches its maximum when the temperature is 190°C, representing an increase of 21.8%. However, further increasing the developing temperature only causes the dynamic stability value to decline. Under long durations and high developing temperatures, the matrix asphalt and rubber powder fully react. However, the heavy aging of the matrix asphalt and the desulfuration and oxidation of the rubber powder decrease material properties, resulting in the decline of the dynamic stability value. Hence, a developing temperature range of 185°C-190°C in actual production is regarded as appropriate. In the present work, the rubber asphalt mixtures produced under ideal laboratory testing circumstances exhibited higher dynamic stability in comparison with those produced with the revised equipment. This result is explained by the precise temperature control during low production in the laboratory.

Stirring technique

Figure 5 shows that the dynamic stability of the rubber asphalt mixture produced by vertical stirring was 16% lower than that produced by horizontal stirring. Hence, the stirring technique in the developing process exerts a significant influence on the performance of the rubber asphalt and its mixture under high temperatures. This finding is explained as follows: Under horizontal stirring, the blades are drawn near the plant bottom and lay across the whole inner plant to produce a strong stirring force, which effectively and evenly mixes the rubber powder with the matrix asphalt and speeds up their reaction. However, because of the limits in motor capacity and stirring shaft strength, vertical stirring shows a weak force, particularly when the rubber powder dosage and the rubber asphalt viscosity are high; in this case, the floating of rubber particles becomes increasingly obvious. The preferred technique in field production is horizontal stirring, as proved in the laboratory testing results. In the laboratory testing, the relatively small amount of rubber asphalt caused the effect of the vertical glass rod stirring to be better than that of mass vertical stirring in the equipment before renovation. Thus, the dynamic stability of the rubber

asphalt mixture was high under vertical stirring but low under horizontal stirring.

Rubber powder dosage

The rutting test results of the equipment before renovation, the equipment after renovation, and the laboratory setup are shown in Figs 6(a), (b), and (c), respectively. When the rubber powder dosage was added, the dynamic stability of the mixture increased, although the increase was not linear. This change was caused by the increase in the rubber asphalt viscosity and the improvement of its coating and cohesive force in relation to the aggregates. In the two-phase system of the rubber asphalt, the properties of the rubber powder became particularly obvious, and its modification effect strengthened. As a result, the dynamic stability of the rubber asphalt mixture improved. From this perspective, the powder dosage could significantly change the high-temperature performance of the rubber asphalt surface.

However, the dynamic stability of the rubber asphalt mixture before the equipment renovation (Fig. 6a) was lower than that after renovation and under the laboratory setup. Moreover, it was lower than the 2800 times·mm⁻¹ specification value under the rubber powder dosages of 18%, 20%, and 22%. As shown in Table 1, before the equipment renovation, the measurement accuracy of the rubber powder and matrix asphalt was low, and the non-linear error was large, resulting in the large deviation of the practical blending ratio, which led to the low dynamic stability value of the rubber asphalt mixture.

Figure 6(b) shows that after the equipment renovation, all the dynamic stability values matched the design requirement, except for the one under the 18% rubber powder dosage. In terms of workability¹⁷ under the rubber powder dosages of 22% and 24%, the 180°C Haake viscosity of the rubber asphalt was over 3.8 Pa·s, which is near the upper limit of the technical requirement. Under such condition, pumping, paving, and compaction of the rubber asphalt mixture become difficult. Thus, in mass production, a rubber powder dosage of 20% is appropriate. From Fig. 6(c), we can see that the testing result is similar to that under the 21% of rubber powder dosage in the laboratory test. Hence, it can be taken as a revise to the results under the laboratory ideal testing circumstances. With the increase in the rubber powder dosage, the viscosity increased, but the mixing performance of the equipment became relatively poor. As the developing

time lengthened, the dynamic stability generally increased at first and then decreased, ultimately reaching the maximum value at 1.5 h. As the developing time continued further, the matrix asphalt aged, the rubber powder desulfurized, and the material properties changed under high temperature, thereby influencing the performance of the rubber asphalt mixture. Therefore, the recommended developing time is in the range of 1-1.5 h. However, in actual production, pumping premixed materials from the make-up tank to the developing tank requires a certain amount of time. Hence, the developing time is counted after the feeding to the developing tank has stopped. Otherwise, the real developing time is shorter than 0.5 h, at which point the test indices of the rubber asphalt mixture become poor.

Gray correlation theory

The gray correlation analysis method¹⁸ is widely used in impact factor analysis, risk analysis, load forecasting, and other fields. It can predict the dynamic development process of systems and encourage and guide system changes in the favorable direction on the basis of the quantitative analysis of the correlation coefficient and correlation degree on a variety of sub factors affecting system development trend. Although based on a mathematical theory, the method does not require a large number of samples or distinct data. It addresses the correlation of the

reference data sequence and the comparative data sequence according to the calculation of their geometric correlation degree. Similar geometric curves equate to a significantly close correlation^{19,20}.

Given the complex structures of rubber asphalt equipment, they are easily influenced by various internal and external factors under mass production. The control of operation parameters exerts different influence degrees on rubber asphalt and its mixture. The key factors can be determined via gray correlation analysis, and the results can provide references for actual production^{21,22}. We marked the data sequence composed of dynamic stability values as the reference sequence $x_0 = \{x_0(k) | k = 1, 2, \dots, n\}$ and the data sequence of the process parameters of the rubber asphalt production equipment as the comparative sequence $x_j = \{x_j(k) | k = 1, 2, \dots, m\}$, where n =the testing groups under various process parameter conditions and m =the number of process parameters. As a result of the differences in physical implications, data dimensions, and orders of magnitude of the influence factors, all the data dimensions should be normalized, as shown in Eq. (1).

$$x_{ij}' = x_{ij} / x_{0j}, j = 1, 2, \dots, n \quad \dots (1)$$

Among the data sequence in the normalized data dimension, x_{0j}' and x_{ij}' correspond to the values of j in

Table 3 — Rubber asphalt mixture dynamic stability under different production process parameters

factors	1*	2*	3*	4*	5*	6*	7*	8*	9*	10*
Dynamic stability, (times·mm ⁻¹)	3649	4068	4189	4256	4436	3542	4198	3345	3651	4279
Stirring time, (min)	5	8	11	14	17	8	8	8	8	8
Stirring way	2	2	2	2	2	1	2	2	2	2
Developing temperature, (°C)	180	180	180	180	180	180	180	175	180	185
Developing time, (h)	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
rubber powder dosage, (%)	20	20	20	20	20	20	20	20	20	20
factors	11*	12*	13*	14*	15*	16*	17*	18*	19*	20*
Dynamic stability, (times·mm ⁻¹)	4316	3706	3482	4079	4233	4190	3621	3678	4419	4628
Stirring time, (min)	8	8	8	8	8	8	8	8	8	8
Stirring way	2	2	2	2	2	2	2	2	2	2
Developing temperature,(°C)	190	195	180	180	180	180	180	180	180	180
Developing time, (h)	1.5	1.5	0.5	1	1.5	2	1.5	1.5	1.5	1.5
rubber powder dosage, (%)	20	20	20	20	20	20	18	20	22	24

Note: 1*-20*is the number of testing groups

Table 4 — Grey correlation degree under different production process parameters

Process parameter	Rubber powder dosage	Developing temperature	Stirring way	Developing time	Stirring time
Grey correlation Degree	0.91	0.86	0.84	0.83	0.62
Rank	1	2	3	4	5

the data sequences x_0' and x_i' , respectively. At this point, the gray correlation coefficient is marked as $r_j(x_j', x_0')$ and simplified as r_{ij} . Then, the calculation formula for the gray correlation coefficient is shown below is shown below; here,

$\min_{1 \leq i \leq n} \min_{1 \leq j \leq n} |x_{ij}' - x_{0j}'|$ is the minimum value of the deviation between the two magnitudes, and $\max_{1 \leq i \leq n} \max_{1 \leq j \leq n} |x_{ij}' - x_{0j}'|$ is the maximum value.

$$r_{ij} = \frac{\min_{1 \leq i \leq n} \min_{1 \leq j \leq n} |x_{ij}' - x_{oi}'| + \rho \max_{1 \leq i \leq n} \max_{1 \leq j \leq n} |x_{ij}' - x_{oi}'|}{\max_{1 \leq i \leq n} \max_{1 \leq j \leq n} |x_{ij}' - x_{oi}'| + \rho \min_{1 \leq i \leq n} \min_{1 \leq j \leq n} |x_{ij}' - x_{oi}'|} \quad \dots(2)$$

ρ is the resolution ratio coefficient, whose role is to mitigate the distortion caused by the large singular value in the calculation sequence, which is usually 0.5.

For the above system, the calculated correlation coefficient is the same as the number of testing groups; thus, the information is relatively sporadic. To clearly describe the general variation characteristics of the system, we can calculate the mean value of the correlation coefficients of the comparative data sequences, i.e., relevancy r_i .

$$r_i = \frac{1}{n} \sum_{i=1}^n r_{ij}, i = 1, 2, \dots, n \quad \dots (3)$$

Gray correlation degree of rubber asphalt mixture testing results

The various process parameters for rubber asphalt production and the corresponding rutting testing results are shown in Table 3. According to the calculation steps, the ranks are first transposed. Then, the data are non-dimensionalized by using Eq. (1). Thereafter, the gray correlation coefficients of various production process parameters are calculated by using Eq. (2). Finally, the gray correlation degree is calculated by using Eq. (3). The results are shown in Table 4.

Table 4 shows that the most important parameter that influences the dynamic stability of rubber asphalt mixture under high temperature is the rubber powder dosage, followed by the developing temperature, stirring technique in the developing tank, developing time, and

stirring time in the make-up tank. The process parameters, especially the rubber powder dosage, clearly play a key role in the stability of the rubber asphalt mixture under high temperature conditions.

A high rubber powder dosage equates to a smooth swelling process for the rubber powder and matrix asphalt. The modification degree of the matrix asphalt is further enhanced, and the rubber asphalt viscosity is increased. At the same time, the rubber asphalt is effectively coated with the aggregate, resulting in the improvement of the dynamic stability of the mixture and high-temperature stability. As proved by the test in the current work, in mass production, using horizontal stirring is more powerful and achieves better stirring effects in comparison with vertical stirring. Furthermore, strictly controlling the developing temperature and fluctuations of the developing time enhances the quality of the rubber asphalt and its mixture stability under high temperature conditions. Given these findings, the following parameters are preferable: rubber powder dosage within the range of 20%-22%, developing temperature of 185°C-190°C, horizontal stirring, and developing time of 1-1.5 h.

As the minor parameter, the stirring time in the make-up tank cannot be overlooked; the preferable period is 8-11 min.

Conclusions

The following conclusions can be derived from the results:

(i) The results of the rutting tests before and after equipment renovation and under the laboratory setup were compared. Under the same process parameters, the dynamic stability of the rubber asphalt mixture after the equipment renovation improved significantly in comparison with that before the equipment renovation. The production process of the revised equipment showed good agreement with that in the laboratory testing, and the testing results were fundamentally identical. These outcomes could serve as guidance in unifying the production process parameters in domestic rubber asphalt equipment.

(ii) When the stirring time in the make-up tank was 0 min, the stability of the rubber asphalt mixture approached the lower limit of the technical requirement. When the stirring time was 8-11 min, the premixing effect of the rubber powder and matrix asphalt, the dynamic stability of the mixture, and the production efficiency were ensured. Improving the

developing temperature obviously promoted the swelling of the rubber powder and matrix asphalt in the developing tank. Using horizontal stirring sped up the swelling reaction. When the developing temperature was 185°C-190°C, the rubber asphalt mixture achieved high-temperature stability.

(iii) As the developing time increased, the mixture stability first increased and then decreased. A prolonged developing time caused the rubber powder and matrix asphalt to change and ultimately decreased the dynamic stability. Therefore, the best developing time is 1-1.5 h, and it should be calculated after the feeding of the materials to the developing tank has stopped in practical production. Increasing rubber powder dosage enhances rubber asphalt viscosity and increases the coating and aggregation strength of the rubber asphalt. Consequently, the high-temperature stability of the mixture improves. The mass production testing indicates that the rubber powder dosage of 20%-22% is appropriate. This range ensures the degree of modification to the matrix asphalt and matches the workability requirement.

(iv) The result of the gray correlation analysis indicates that among the process parameters that influence rubber asphalt production, rubber powder dosage is the most important; its measurement should be precisely controlled in actual production. Horizontal stirring should also be adopted, and the fluctuations of developing temperature and time should be strictly controlled.

Acknowledgments

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