

## Influence Mechanism of Epoxy Resin and Curing Agent on High-Temperature Performance of Asphalt

(Mekanisme Pengaruh Resin Epoksi dan Agen Pengawetan pada Prestasi Suhu Tinggi Asfalt)

MINGXING GAO\*, YANHUA XUE, PENG GUAN & FEILONG YUAN

### ABSTRACT

To deeply show the internal reasons for the effects of epoxy resin and curing agent on the high-temperature performance of asphalt, nine kinds of asphalt with different content of epoxy resin and curing agent were prepared. On the premise of ensuring that the softening point, penetration and ductility of epoxy asphalt no attenuation, the dynamic shear rheology test and Saybolt viscosity test were used to examine the rutting factor ( $G^*/\sin \delta$ ), complex shear modulus ( $G^*$ ), phase angle ( $\delta$ ), and viscosity of asphalt with different epoxy resin and curing agent contents. With the help of fluorescence microscopy, microscopic morphology was analyzed, and the micro-image was further analyzed quantitatively by using 3D surface and particle statistics. The results show that adding epoxy resin and curing agent into asphalt can significantly improve the rutting factor and complex shear modulus of asphalt and reduce the phase angle and the viscosity growth rate of asphalt changed from fast to slow. Fluorescence and 3D surface imaging results indicate when the epoxy resin and the curing agent are uniformly distributed and forms microfloculent structures, the epoxy resin can fully swell in asphalt, and the fluorescence intensity is uniform. The statistical analysis of particles shows that the improvement in high-temperature performance of asphalt by epoxy resin and curing agent results from the distribution of particle area above  $26.7346 \mu\text{m}^2$ . The high-temperature performance of epoxy asphalt is optimal when the content of epoxy resin and curing agent is 6 %.

*Keywords:* 3D surface; fluorescence; micromorphology; particles of statistical

### ABSTRAK

Dalam usaha secara mendalam untuk menunjukkan sebab dalaman kesan resin epoksi dan agen pengawetan pada prestasi suhu tinggi Asfalt, sembilan jenis daripada asfalt dengan kandungan resin epoksi dan agen pengawetan telah disediakan. Dalam usaha untuk memastikan takat pelembutan, penembusan dan kemuluran epoksi asfalt tiada pengecilan, ujian reologi ricih dinamik dan ujian kelikatan Saybolt digunakan untuk memeriksa faktor rut ( $G^*/\sin \delta$ ), modulus ricih kompleks ( $G^*$ ), sudut fasa ( $\delta$ ) dan kelikatan asfalt resin epoksi berbeza serta kandungan agen pengawetan. Dengan bantuan mikroskopi pendarfluor, morfologi mikroskopi telah dianalisis dan imej mikro dianalisis lebih lanjut secara kuantitatif menggunakan statistik 3D surface dan statistik zarah. Keputusan menunjukkan bahawa penambahan resin epoksi dan agen pengawetan ke dalam asfalt boleh menambah baik secara signifikan faktor rut dan modulus ricih kompleks asfalt serta mengurangkan sudut fasa dan kadar pertumbuhan kelikatan asfalt berubah daripada laju kepada perlahan. Pendarfluor dan keputusan pengimejan 3D surface menunjukkan apabila resin epoksi dan agen pengawetan diagihkan secara seragam dan membentuk struktur mikroberflokulasi, resin epoksi boleh membengkak sepenuhnya dalam asfalt dan keamatan kependarfluoran adalah seragam. Analisis statistik zarah menunjukkan pembaikan dalam prestasi suhu tinggi asfalt oleh resin epoksi dan agen pengawetan hasil daripada taburan kawasan zarah di atas  $26.7346 \mu\text{m}^2$ . Prestasi suhu tinggi asfalt epoksi adalah optimum apabila kandungan resin epoksi dan agen pengawetan adalah 6%.

*Kata kunci:* 3D surface; mikromorfologi; pendarfluor; zarah statistik

### INTRODUCTION

Epoxy asphalt is a homogeneous complex composed of epoxy resin, asphalt, and curing agent (Huang 2003). Compared with other modified asphalts, epoxy asphalt has better pavement performance, thermal stability, rutting resistance, and durability (Cong et al. 2011a). In addition, it is an excellent pavement building material with broad application prospects in many engineering fields (Kang et al. 2010).

With the rapid growth of road traffic demand and the change of design concept, the application of epoxy asphalt on ordinary roads has attracted increasing attention (Lu & Bors 2015). Early scholars found that adding epoxy resin could significantly improve the performance of asphalt (Jun et al. 2007; Motamedi et al. 2017; Zhendong et al. 2007). Chen et al. (2007) shows that epoxy resin can improve the high-temperature stability and road performance of asphalt. Kang et al. (2015) and Peiliang et

al. (2010) studied the effects of epoxy resin content on the rheological properties of epoxy asphalt and proved that epoxy asphalt has excellent high-temperature stability. Yin et al. (2014, 2013) evaluated the thermal, damping, and mechanical properties, morphology, and other properties of epoxy asphalt. Many studies mainly focus on the mixture ratio, mechanical analysis, structural analysis, and macro performance evaluation of epoxy asphalt. The deformation and destruction of materials result from the processes that occur in materials on microscopic and atomic scales; i.e. the properties of materials depend on the atomic and microscopic structures of materials. Among the microstructure analysis techniques of asphalt, fluorescence microscopy is the most commonly used technique to evaluate the dispersion state of polymer in polymer-modified asphalt (Cong et al. 2016). Epoxy resin has a strong fluorescence when excited by blue light (488 nm), and the size and distribution of epoxy components in epoxy asphalt can be showed by fluorescence microscopy (Cabanelas et al. 2005). Yu et al. (2009) studied the influence of the ratio of epoxy asphalt and curing temperature on its performance by means of infrared spectrum and fluorescence microscopy (Cabanelas et al. 2005). The results show that with the increase of epoxy resin content, the microstructure of epoxy asphalt changes from dispersed structure to network structure. Dong and Li (2015) studied the morphology and dynamic mechanical properties of epoxy asphalt with fluorescence microscopy and dynamic mechanical analyzer. The results showed that when the content of epoxy resin was more than 3 %, stable continuous phase could be formed. Cong et al. (2019) studied the microstructure of epoxy asphalt binder with fluorescence microscopy and observed its phase transition. Therefore, the microstructure analysis of epoxy asphalt is a necessary means to study its macro performance changes, but only the qualitative analysis of the morphology of epoxy asphalt (Cong et al. 2011b; Si et al. 2019).

The main purpose of this research was to use fluorescence microscopy to combine qualitative and quantitative analyses and to make a deep analysis of the internal correlation between high-temperature physical

properties and microstructure of epoxy asphalt under different content of epoxy resin and curing agent. Moreover, we attempt to show the micromechanism underlying the changes in high-temperature performance of epoxy asphalt, and put forward the suitable content of epoxy resin and curing agent in road epoxy asphalt.

## MATERIALS AND METHODS

The base asphalt model selected is SK90#; the physical properties of the asphalt are summarized in Table 1. The epoxy resin was E-44 (6101), and the curing agent was a low-molecular polyamide 650. Both were supplied by Shandong Deyuan Epoxy Technology Co. LTD.

The preparation process of epoxy asphalt is as follows. Heat the epoxy resin and curing agent to 60°C and mix them at a ratio of 1:1 (The epoxy resin and curing agent are hereinafter referred to as the epoxy system), producing the epoxy system. Heat the matrix asphalt to 150°C. Mix the epoxy system with the asphalt for 4 min, incubate at 150°C in an oven for 3 h, cure in a 60°C oven for 4 days, and store 1 day at room temperature before testing (Fu et al. 2007). The content of epoxy system in the epoxy asphalt was set as 2, 3, 4, 5, 6, 7, 8, 9, and 10%, respectively. As shown in Table 2.

The softening point, penetration, and ductility of the cured epoxy asphalt were determined according to the test specification of the asphalt and asphalt mixture for highway engineering (JTG E20-2011). The viscosity of epoxy asphalt was measured by a heavy oil viscometer. A dynamic shear rheometer (DSR) was used for temperature scanning of epoxy asphalt. The temperature range was 42-82°C, and a scan was performed every 4°C.

Fluorescence microscopy is the most commonly used technique to evaluate the dispersion state of polymer in polymer-modified asphalt (Cong et al. 2016). Epoxy resin has a strong fluorescence when excited by blue light (488 nm), and the size and distribution of epoxy components in epoxy asphalt can be shown by fluorescence microscopy (Cabanelas et al. 2005). The microscopic samples were prepared by the pressing method. In the pressing method,

TABLE 1. Physical properties of asphalt

Physical property	Measured value
Penetration (25 °C, 5 s, 100 g, 0.1 mm)	81
Softening point (°C)	45.5
Ductility (10°C, cm)	>100
Ductility (15°C, cm)	>100
Viscosity (60°C/Pa·s)	156.8

TABLE 2. Epoxy modified asphalt with different content

Serial number	1	2	3	4	5	6	7	8	9
Epoxy resin and curing agent	2%	3%	4%	5%	6%	7%	8%	9%	10%

a small drop of the asphalt is placed between two heated microscope glass slides and pressed to form a thin film (Sengoz & Isikyakar 2008). The prepared samples were 200 times larger than the blue channel of the fluorescence microscope for image acquisition.

The larger the magnification of the microscope, the smaller the field of view. In order to obtain images with wider field of view under high resolution, the image analysis results are more scientific and universal. Use the image stitching function, with the first image acquired by the microscope as the starting point, a marking point at the lower right corner was selected, and four images were continuously collected with a 25% overlap in a counterclockwise direction. LAMOS Pro software was used to splice the collected images. The splicing effect is shown in Figure 1. The splicing image was processed by gray scale and binarization, and 3D surface renderings and particle statistical analysis were used to study the effects of particle morphology, distribution, size, and number in the microscopic image on the high-temperature performance of epoxy asphalt.

## RESULTS AND DISCUSSION

### PHYSICAL PROPERTIES

#### *The three major indices*

The three major indices of asphalt are softening point, penetration and ductility. Generally, three major indexes are used to characterize the road performance of asphalt. Before further study on epoxy asphalt, it is necessary to ensure that the three major indices of epoxy asphalt meet the road requirements.

The softening point represents the high-temperature stability of asphalt; as the softening point increases, its

high-temperature stability also increases (Rafi et al. 2018). The needle penetration can reflect the consistency of asphalt, and as the needle penetration decreases, the consistencies of asphalt and hardness both increase. The ductility index can indicate the low-temperature performance of asphalt. As the ductility value increases, the low-temperature performance improves (Sun et al. 2017; Yildirim 2007). The measurement results of these three major indices of epoxy asphalt are shown in Table 3. As the epoxy system content increases, the softening point of asphalt increases, indicating that the epoxy system can improve the stability of asphalt at high temperature. The penetration degree of asphalt decreases with increased epoxy system content, indicating that the consistency of asphalt increases and asphalt becomes harder with increasing epoxy system content. The ductility of asphalt decreases with increasing epoxy system content, indicating that the epoxy system reduces the low-temperature performance of asphalt.

According to the Technical Specification for Highway Asphalt Pavement Construction (JTGF40-2004), all three indices of epoxy asphalt meet the required pavement performance of asphalt. According to the presented experimental results, the epoxy system can improve the high-temperature stability of asphalt, but it has a certain weakening effect on the low-temperature performance of asphalt. Therefore, the epoxy system content in epoxy asphalt should not be too high.

### VISCOSITY ANALYSIS

The kinematic viscosity is the ratio of the dynamic viscosity of the fluid to the density  $\rho$  of the fluid at the same temperature. It is a measure of the flow resistance of the asphalt under gravity, and it is used to characterize the

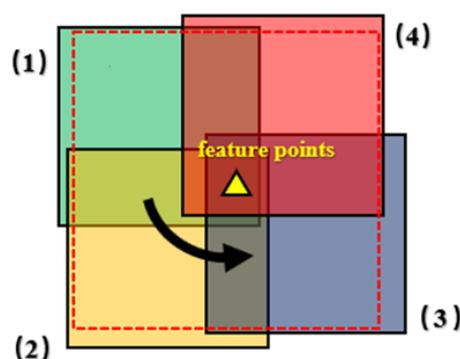


FIGURE 1. Image stitching

TABLE 3. Physical properties of epoxy asphalt with different epoxy system content

Content (%)	2	3	4	5	6	7	8	9	10
Softening point (°C)	54.8	56.6	58.7	62.1	65	65.5	65.2	65.4	68.6
Penetration (25°C, 5 s, 100 g, 0.1 mm)	39.7	36.4	38.5	35.5	34.2	30.2	29.1	28.3	26.8
Ductility (25°C, cm)	551.0	509.7	467.2	405.7	420.3	386.0	319.0	305.0	204.3

high-temperature performance of the bituminous material. A higher viscosity corresponds to a better temperature performance of the asphalt (Chen et al. 2019). The viscosity of the epoxy asphalt was tested by a Saybolt viscometer, and the kinematic viscosity of epoxy asphalt with different epoxy system content was obtained by instrument conversion. The test results are shown in Figure 2.

The figure shows that as the epoxy system content increases, the viscosity value globally increases. When the epoxy system content is less than 6%, the viscosity of epoxy asphalt increases rapidly. When the epoxy system content is 6%, the viscosity of epoxy asphalt increases sharply. However, as the epoxy system content increases further, asphalt viscosity slowly rises, showing that the epoxy system can improve the high-temperature stability of asphalt.

### DSR ANALYSIS

Superpave uses the rutting factor ( $G^* / \sin \delta$ ) to indicate the permanent deformation resistance of asphalt as a measure of the high-temperature performance of asphalt (Zhang et al. 2017). The complex shear modulus( $G^*$ ) represents the total resistance of asphalt under repeated

shear deformation. The phase angle( $\delta$ ) reflects the proportional relationship between the lost elastic modulus and the stored elastic modulus in complex shear modulus( $G^*$ ) and is the lag degree index of strain phase to stress (Cong et al. 2016). The shear deformation resistance of epoxy asphalt is analyzed by measuring  $G^*$  and  $\delta$  and calculating the rutting factor at different temperatures. The rutting factor for epoxy asphalt with different epoxy system content and at different temperatures is shown in Figure 3.

According to the SHRP study, as the rutting factor increases, the rutting resistance performance of the asphalt increases (Yao et al. 2013). As shown in Figure 3(a), as the temperature increases, the rutting factor decreases, indicating a decrease in rutting resistance of the asphalt. When the temperature is constant, the rutting factor of epoxy asphalt is  $6\% > 9\% > 7\% > 10\% > 5\% > 8\% > 4\% > 3\% > 2\%$ , while the rutting factor of the base asphalt is the lowest, showing that the addition of epoxy system increases the deformation resistance and improves the high-temperature stability of asphalt.

The phase angle( $\delta$ ) and the complex shear modulus( $G^*$ ) characterize the viscoelastic properties of the asphalt. The complex shear modulus( $G^*$ ) is composed of two parts, i.e.

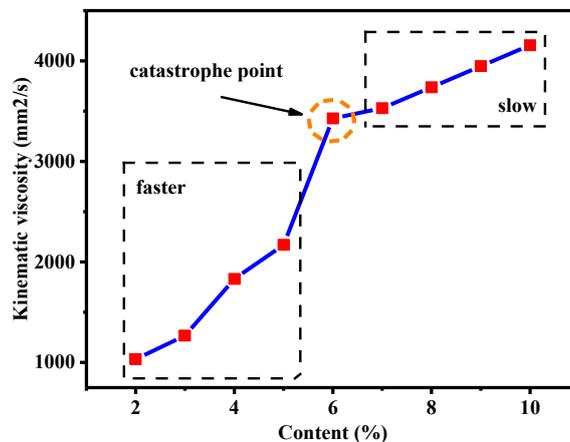


FIGURE 2. Viscosity of epoxy asphalt of different content

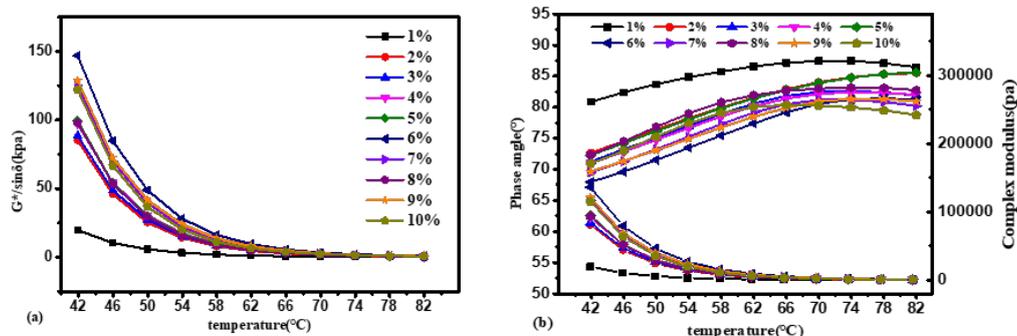


FIGURE 3. (a) Rutting factor-temperature diagram, and (b) Complex shear modulus-temperature and phase angle-temperature diagram

the elastic modulus  $G^* = G^* \cos \delta$  and the viscous modulus  $G'' = G^* \sin \delta$ . As phase angle decreases, asphalt more closely resembles an elastomer, therefore, the high-temperature deformation resistance is higher. Conversely, as phase angle increases, asphalt more closely resembles a viscous body. A higher  $G^*$  and a lower  $\delta$  are desired for rutting resistance (Ahmedzade 2013). As shown in Figure 3(b), as the temperature increases, the complex shear modulus of asphalt decreases. At the same temperature, the complex shear modulus of epoxy asphalt is  $6\% > 9\% > 7\% > 10\% > 5\% > 8\% > 4\% > 3\% > 2\%$ , indicating that an epoxy system content of 6% has the best hardening effect on asphalt. The phase angle gradually increases with temperature, indicating that the elastic component of the asphalt decreases when the viscous component increases and that the epoxy asphalt more closely resembles a viscous body under high-temperature conditions. At the same temperature, the epoxy system can significantly reduce the phase angle of the base asphalt, indicating that the epoxy system can effectively increase the high-temperature performance of the asphalt and that the epoxy asphalt has good elastic recovery ability and high-temperature stability.

The mentioned analyses indicate that with increasing epoxy system content, the softening point of asphalt increases, the penetration degree decreases, and ductility decreases. The viscosity increases as the epoxy system content increases, and the viscosity increases sharply when the content reaches 6%. The DSR results show that the epoxy system can significantly improve the rutting factor and complex shear modulus of asphalt, reduce the phase angle, and improve the high-temperature stability and shear resistance of asphalt. From the perspective of road performance and economics, optimal performance was achieved at an epoxy system content of 6%.

## MICROMORPHOLOGY ANALYSIS

### *Morphology*

The properties of polymer-modified asphalt depend on the fining degree of modifier and the distribution uniformity in the matrix asphalt. The microstructure of modified asphalt can effectively be used to evaluate the effects of the modification (Kui 2013). Fluorescence microscopy is the most valuable method to study the morphology of polymer-modified asphalt (Sengoz & Isikyakar 2008). To characterize the effects of epoxy system on asphalt morphology and high-temperature performance, the microstructure of nine kinds of epoxy asphalt, with different epoxy system content, was determined by fluorescence microscopy. In fluorescent images, the asphalt is yellow, and the epoxy is tinted or bright white. Microscopic images of epoxy asphalt with different epoxy system content are shown in Figure 4.

When low concentrations of epoxy system are added to the asphalt, the epoxy resin is more dispersed in the asphalt, the particle size is small and uniform, the formation of microfloculent structures is decreased, and the effects

on asphalt morphology are weak. At an epoxy system content ( $>6\%$ ), the epoxy resin exhibits a microfloculent structure and granular structure distribution, and as the epoxy system content increases, the granular structures increase and the epoxy system is superimposed and condensed, so that the consistency of the asphalt increases and the asphalt becomes harder, causing a certain weakening effect on the asphalt at low temperatures. When the epoxy system content is 6%, the distribution of granular structures is low, the epoxy system forms microfloculent structures (as shown in Figure 5(e)), and the asphalt is the strongest. In addition, the epoxy resin and asphalt are continuous and interlock, which can be beneficial to the asphalt macrostructure and improve the high-temperature stability.

### *3D Surface*

3D imaging technology is one of the most advanced computer display technologies in the world. It can accurately display the microscopic overall structure of epoxy asphalt with different epoxy system content. The 3D surface measurement parameters were defined by participants of the first European Community Workshop in 1991 to complement traditional 2D metrology parameters. The 3D surface measurement parameters comprise four general categories: amplitude, spatial, hybrid, and functional. The amplitude parameters are based on overall heights and include the root-mean-square of height distribution, skewness (or the degree of asymmetry of a surface height distribution), degree of peakedness of a surface height distribution, and the average of the highest and lowest points.

This paper uses the 3D surface technology of Lycra's LAMOS Pro software to process the stitched microscopic image to obtain 3D surface renderings. In Figure 5, the convex substance in the figure is the distribution state of the epoxy system on the microscopic pattern, and the different protrusion colors represent the intensity of the fluorescence excited by the epoxy resin in the asphalt (Cabanelas et al. 2005). When the epoxy resin swells sufficiently, it is slightly flocculent in the asphalt, and the fluorescence intensity is weak. When the swelling of epoxy resin is not sufficient, it shows a granular distribution in the asphalt.

According to the 3D surface effect diagram of epoxy asphalt with different epoxy system content, as the amount of epoxy resin decreases, the height of the protrusions in the 3D image decreases and tends to be highly uniform, and the shape and size of the raised epoxy resin tend to be uniform. When the amount of epoxy system is small, the polymer distribution in the epoxy asphalt is decreased gradually. When the content is 2%, the polymer distribution is the lowest, the height and number of protrusions are low, and epoxy resin has weak fluorescence. When the content of epoxy system increases, the protrusion distribution tends to be denser, and when it reaches 10%, the protrusion distribution reaches its maximum, and the epoxy resin fluorescence is strong, indicating that the epoxy system in

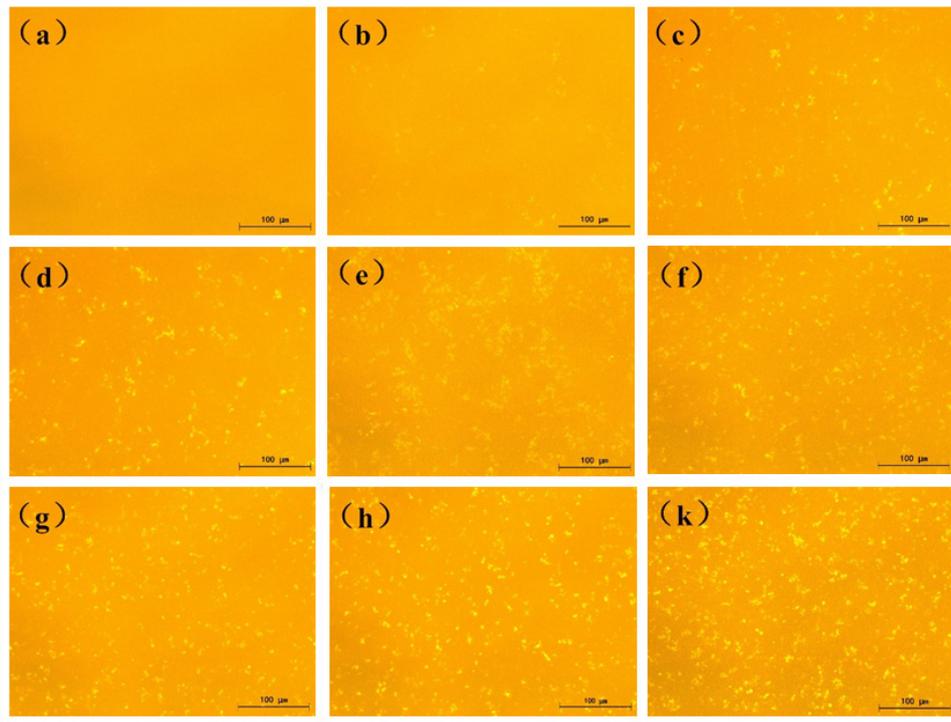


FIGURE 4. Microstructure of epoxy asphalt with different epoxy system content (a) 2 wt. %, (b) 3 wt. %, (c) 4 wt. %, (d) 5 wt. %, (e) 6 wt. %, (f) 7 wt. %, (g) 8 wt. %, (h) 9 wt. % & (i) 10 wt. %

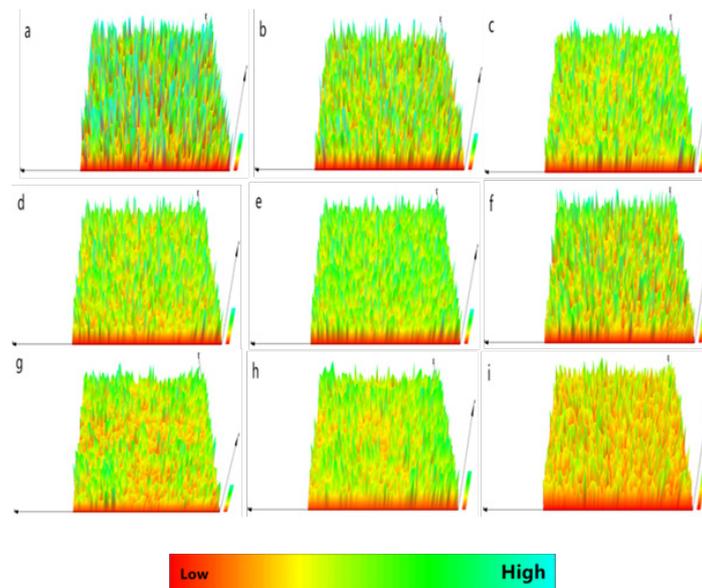


FIGURE 5. 3D surface images of epoxy asphalt with different epoxy system content. (a) 10 wt. %, (b) 9 wt. %, (c) 8 wt. %, (d) 7 wt. %, (e) 6 wt. %, (f) 5 wt. %, (g) 4 wt. %, (h) 3 wt. % & (i) 2 wt. %

asphalt is not fully swollen but is mainly distributed as particle structures. When the epoxy system content is 6 %, the polymer distribution is relatively uniform and the fluorescence intensity is uniform, showing a microfloculent structure distribution, indicating blending at 6 %. At higher epoxy resin amounts, it can fully swell. This shows that the epoxy resin can fully swell when the content is 6 %.

As shown in Figure 6, the distribution of epoxy system at high concentrations is less uniform than at low concentrations. The main reasons are the following: as the content increases, the epoxy system exhibits a granular-microflocculent-granular structure transition. An epoxy system content of 6 % yields good results; When the content reaches 6 %, the epoxy resin can fully react in asphalt and show the appearance of microfloculent

structure, and the macroscopic structure of epoxy asphalt has good elastic resilience and stable high-temperature performance.

#### STATISTICAL ANALYSIS OF PARTICLES

When analyzing the microstructure, the size, morphology, and distribution of particles in the matrix are very important to the properties of materials (Hou 2006). The microscopic images were analyzed for particle size using the area as a parameter. The image was binarized and segmented to extract the epoxy resin particles in the image, and the total number of particles, area content, minimum particle area, maximum particle area, and average particle area of the image were determined. The particle area is the number of pixels occupied by the particles, namely, the pixels

contained in the region and the boundary. The statistical results are shown in Table 4.

As shown in Table 3, as the content of epoxy system increases, the number of particles increases. When the content reaches 6%, the growth rate of the number of total particles in epoxy asphalt samples increases. The area content of epoxy system particles in asphalt increases as the number of particles increases. The minimum particle area of epoxy asphalt with different epoxy system content is the same, and the average particle area increases with increasing epoxy asphalt content, but the maximum particle area is different from the content of epoxy asphalt. When the content of epoxy system is 6%, the maximum particle area increases sharply.

According to the microscopic morphology, 3D surface images, and mechanical properties, the viscosity of epoxy

TABLE 4. Descriptive statistics of particle parameters of epoxy asphalt with different epoxy system content (units/picture element)

Content (%)	Number of particles	Area of content(%)	Minimum particle area	Maximum particle area	Average particle area
2	1266	1.71	0.1736	5.3820	0.4696
3	1979	3.03	0.1736	16.2500	1.1497
4	2056	4.74	0.1736	27.3958	1.4141
5	2265	6.31	0.1736	32.3562	1.8263
6	2468	7.86	0.1736	38.3564	2.4562
7	3126	7.10	0.1736	32.1352	2.5265
8	3358	8.45	0.1736	32.8215	2.6432
9	3066	10.53	0.1736	36.7361	3.2942
10	3392	12.02	0.1736	35.5902	3.3983

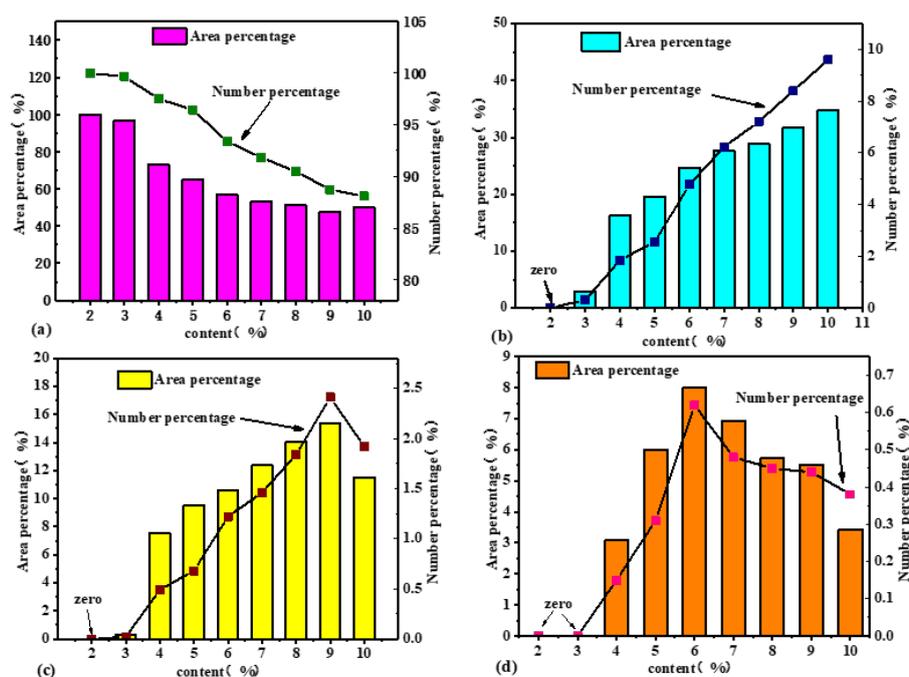


FIGURE 6. The particle size distribution of epoxy resin in different areas (a) 0.1736-9.0249, (b) 9.0249-17.8798, (c) 17.8798-26.7346 & (d) >26.7346

asphalt increases sharply when the content is 6 %. When the content is more than 6 %, the viscosity tends to rise gently, which is reflected in the microscopic morphology. When the epoxy system content reaches 6 %, the growth rate of the total particle number in the epoxy asphalt sample is accelerated, indicating that the large increase in the number of particles in the asphalt sample inhibits the increase of the viscosity of the epoxy asphalt; the epoxy system reaches 6 % in the 3D surface effect diagram. The morphology of the microflocule-like structures in the asphalt is a result of the fact that the ratio of the maximum particle area and the particle area to the total area increases significantly when the content is 6 %, indicating that the microfloculent structure is determined by the large particle area.

Through segmenting the threshold interval, the obtained threshold range is divided into sections, and the distribution of the number of epoxy resin particles in different particle area sections is obtained, as shown in Figure 6.

The distributions of epoxy resin particles in nine kinds of epoxy asphalt are presented in Figure 6(a)-6(d). When the content of epoxy system is low, the particle area is mainly distributed in the interval of  $0.1736-9.0249 \mu\text{m}^2$ , and the area of the particles distributed in the range of  $0.1736-9.0249 \mu\text{m}^2$  is more than 99 % when the content is 2 % and 3 %. When the content is increased to 6 %, the particle area is mostly distributed above  $26.7346 \mu\text{m}^2$ . When the content is more than 6 %, the particle area is mainly distributed in the ranges of  $9.022-17.8798 \mu\text{m}^2$  and  $17.8798-26.7346 \mu\text{m}^2$ , and there are a large number of particles.

According to our analysis of the microstructure, 3D surface images, and mechanical properties, when the content of epoxy system is low, the particle area is mainly distributed in the interval of  $0.1736-9.0249 \mu\text{m}^2$ , and when the particles cannot form a continuous phase, this distribution structure has a weak effect on the high-temperature stability of epoxy asphalt. When the content is high, the particles forming a large area are fewer, and the particles are mainly concentrated in the range of  $9.024-26.7346 \mu\text{m}^2$ ; when the number of particles is high, this distribution structure has an inhibitory effect on the high-temperature stability of epoxy asphalt. When the content is 6%, the particle area is mainly distributed above  $26.7346 \mu\text{m}^2$ . This distribution structure plays a decisive role in the mechanical properties of epoxy asphalt.

#### CONCLUSION

The physical properties and microstructure of epoxy asphalt with 2 % - 10 % epoxy resin and curing agent were tested, the following conclusion can be drawn:

According to the softening point, penetration, ductility, viscosity, and DSR test results, the epoxy resin and curing agent can improve the high-temperature stability of asphalt. Based on road performance and economic benefits, epoxy

asphalt with 6 % epoxy resin and curing agent has more advantages in high-temperature performance than other contents. The change of microstructure shows that the high-temperature stability of asphalt can be improved when the epoxy resin is distributed in microflocule structure. As the content of epoxy resin and curing agent increases, the microstructure of epoxy asphalt exhibits a granular-microfloculent-granular structure transition. The change of 3D surface image shows that when the epoxy resin and the curing agent are uniformly distributed and forms microfloculent structures, the fluorescence intensity is uniform, which indicates that the epoxy resin is fully swelling in asphalt. According to the particle statistical analysis, the particles with an area of  $0.1736-9.0249 \mu\text{m}^2$ , this distribution structure has a weak effect on the high-temperature stability of epoxy asphalt. The particle area is mainly concentrated in the range of  $9.024-26.7346 \mu\text{m}^2$ , more particles and less particles in large area, this distribution structure has an inhibitory effect on the high-temperature stability of epoxy asphalt; the particle area is mainly distributed above  $26.7346 \mu\text{m}^2$ . This distribution structure plays a decisive role in the mechanical properties of epoxy asphalt. When the content reaches 6 %, the epoxy resin can fully react in asphalt and form microfloculent structure, the particle area is mainly distributed above  $26.7346 \mu\text{m}^2$ . This distribution structure gives the asphalt better performance at high temperatures. It shows that the mechanical properties of epoxy asphalt at high temperature depend on its high-temperature structure.

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- Mingxing Gao\*, Yanhua Xue & Feilong Yuan  
College of Energy and Transportation Engineering  
Inner Mongolia Agricultural University  
Hohhot, Inner Mongolia, 010018  
China
- Peng Guan  
President of Hongrui Road and Bridge Engineering Science and Technology Research Institute  
Hinggan League, Inner Mongolia, 137400  
China

\*Corresponding author; email: gaomingxing\_2000@imau.edu.cn

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