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Study on Modification Mechanism and Performance of Waterborne Epoxy Resin Micro-Surfacing

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Abstract: This study examines the mechanical performance, deformability properties and rheological properties of a newly developed waterborne epoxy resin (WER)-modified emulsified asphalt (WE/A) binder for micro-surfacing. Two types of WER, semi-flexible and rigid, were used to modify the binder. Furthermore, the modification mechanism was investigated using the fluorescent microscope test and the scanning electron microscope (SEM). In addition, the pavement performance at micro-surfacing was studied using the wet wheel wear resistance test, the pendulum friction test and the slurry rutting test. The results indicated that with a small content (<15%) of WER in WE/A, WER existed as a continuous structure (cellular membrane wrapped around asphalt bubbles), thereby enhancing its high temperature properties and mechanical properties. Meanwhile, it also improved the cohesion properties of the transition interface between the aggregate and asphalt (enhanced by at least 30.0%) and the rutting resistance (improved by about 55.3–63.8%). In addition, WER could also improve the peeling resistance and water damage resistance of the micro-surfacing.

Keywords: waterborne epoxy resin; micro-surfacing; modification; mechanical properties; shear strength

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Citation: Huang, S.; Jin, F.; Chen, D.; Xiao, Q.; Ding, Q. Study on Modification Mechanism and Performance of Waterborne Epoxy Resin Micro-Surfacing. *Coatings* **2023**, *13*, 504. https://doi.org/10.3390/coatings13030504

Academic Editor: Andrea Simone

Received: 29 January 2023
Revised: 16 February 2023
Accepted: 21 February 2023
Published: 24 February 2023

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1. Introduction

Micro-surfacing is a kind of thin overlay paved on a pavement using a mixture, which is composed of coarse and fine aggregates, powder fillers, emulsified asphalt and water. It is one of the main preventive maintenance methods for high-grade asphalt pavements in China. It is mainly used to treat early diseases of asphalt pavements, such as slight cracks, slight rutting, pitted surfaces and skid resistance degradation. This method has the advantages of high construction speed, low energy consumption and enabling cost savings, though it has insufficient durability and high temperature performance [1]. For instance, under normal circumstances, the micro-surface coating with normal emulsified asphalt is always rutting and peeling from a pavement under a high temperature and humid environment after two years of service, because of the lack of cohesion and durability of the asphalt binder.

The main cohesion of the micro-surface slurry is achieved by the emulsified asphalt binder, and the embedding force between the aggregates is very small [2]. Therefore, the high temperature deformation resistance, low temperature crack resistance, water eroding resistance and anti-stripping performance of micro-surfacing are directly related to the performance of the emulsified asphalt binder [3]. In order to improve the performance of asphalt, styrene-butadiene rubber, styrene-butadiene-styrene, polyethylene terephthalate and waterborne epoxy resin (WER) have been used to modify emulsified asphalt [4–6], and have achieved better results. However, with the development of the transportation industry, it is difficult to meet the needs of today's important road maintenance materials. Corresponding to hot asphalt, SBR, SBS and PU are used to modify emulsified asphalt. Y. M. Hou et al. used SBS to modify emulsified asphalt in high, cold regions [7]. X. H. Shen et al. modified emulsified asphalt with polyurethane (PU). When PU content is 6%,

the penetration and ductility of PU emulsified asphalt are better than they are for SBS, but the softening point is relatively insufficient [8]. Using SBR, PU emulsified asphalt is easy to prepare, but its high temperature performance is insufficient. SBS emulsified asphalt has a better (i.e., higher) softening point, but the production process is difficult and the stability is poor. In addition, many research works have also been carried out on waterborne epoxy resin (WER)-modified emulsified asphalt, especially in the aspects of fog seal layer and pavement interlayer. The WER can form a porous continuous structure in WE/A with a low content of 3–4% [9–16], which can benefit the high temperature resistance to deformation performance. It has also been shown that WER can effectively improve properties such as thermal stability and adhesion of emulsified asphalt [17–19]. However, Y. Gu et al. [20] have shown that WER and emulsified asphalt are chemically incompatible, due to epoxy resin being cross-linked with the hydroxyl group in the asphalt during the curing process. Z. Zhang and Q. J. Ding et al. tried to increase the compatibility between WER and asphalt by adding a third phase of organic and inorganic components [21–23], such as polyurethane and cement. However, the cement hydration products greatly reduce the flexibility of modified emulsified asphalt while improving the strength of the three-phase composite. Moreover, the WER can modify emulsified asphalt with lower content in lotion. This is different from the modification effect of epoxy resin in hot asphalt. The modification mechanism of WER on emulsified asphalt has not yet been fully explored. This limits the application of WE/A in engineering applications, especially in micro-surfacing.

The main way to improve the spalling resistance, crack resistance and rutting resistance of micro-surfacing is to improve the properties of the asphalt binding material. In this study, WER-modified emulsified asphalt was used as the binder of the micro-surfacing, which gave the micro-surfacing a better road performance. The road performance and the modification mechanism of modified micro-surfacing is discussed. Tensile strength and elongation at break were tested using the tensile test to evaluate the mechanical and deformability properties. Under different temperatures, complex modulus and phase angle were tested using the DSR test to study the high temperatures rheological properties. By using the fluorescent microscope, distribution of WER in WE/A before and after the reaction could be observed. A scanning electron microscope (SEM) was used to observe the micro-morphology of WER coating on the surface of the aggregate in modified micro-surfacing. The wet wheel wear resistance test, the pendulum friction test and the slurry rutting test were used to research the peeling resistance, water damage resistance, skid resistance and rutting resistance performance.

2. Materials and Methods

2.1. Materials

The self-made WE/A was composed of modified emulsified asphalt and waterborne epoxy resin. The emulsified asphalt was made by heating high viscosity modified asphalt and composite emulsifier. In order to improve the emulsifying ability and stability of the emulsifiers, two kinds of emulsifier were used together, polyvinyl alcohol and calcium chloride were used as stabilizers, and hydrochloric acid was used to regulate pH. Curing B1 was achieved by using ethylene amine adduct, which could react with curing A to form a semi-flexible reaction product with strong adhesion. Curing B2 was composed of alicyclic amine and aliphatic amine, which could react with curing A to form a rigid reaction product with strong hardness. The properties of WE/A and WER are shown in Tables 1 and 2. The index of Table 1 is according to the Standard Test Methods of Bitumen and Bituminous Mixtures for Highway Engineering (JTG E20—2011 [24], Industry Standard in China). Samples were prepared in accordance with the T0602 asphalt sampling method, and dynamic viscosity at 60 °C was according to the T0620 asphalt dynamic viscosity test. Density values were measured as per the T0603 asphalt density and relative density test at 25 °C.

Table 1. Parameters of emulsified asphalt.

Item	Property	Results
Type of particle charge	-	Cationic (+)
Evaporation residue	Evaporation residue content (%)	62.8
	Penetration (25 °C, 0.1 mm)	62.3
	Softening point (°C)	89.5
	Ductility (5 °C, 5 cm/mi, cm)	39.3
	dynamic viscosity (Pa·s)	90,352
Residue on 1.18 mm sieve (%)	-	0.02
Angler viscosity	-	13.0
Storage stability (%)	1 day	0.2
	5 day	2.1

Table 2. Parameters of WER.

Item	Property	Results
Curing A	Appearance	Transparent liquid
	Evaporation residue content (%)	55.1
	Density (g/cm^3)	1.05
	pH	7.2
	Epoxy value (mol/100g)	0.221
Curing B1	Appearance	Light yellow liquid
	Evaporation residue content (%)	56.2
	Density (g/cm^3)	1.08
	pH	7.0
	Active hydrogen equivalent (g/mol)	242
	Amine value (mg KOH/g)	208
Curing B2	Appearance	Light yellow liquid
	Evaporation residue content (%)	55.6
	Density (g/cm^3)	1.12
	pH	7.0
	Active hydrogen equivalent (g/mol)	239
	Amine value (mg KOH/g)	207

2.2. Test Methods

2.2.1. Tensile Test

The tensile test (shown in Figure 1) was carried out according to the test methods for properties of resin casting boby (GB/T 2567-2021) [25]. The semi-flexible WE/A specimen was made by reacting emulsified asphalt and WER produced from curing A with curing B1, and the rigid WE/A specimen was made by reacting emulsified asphalt and WER produced from curing A with curing B2. Test specimens of WE/A with WER content of 4.8%, 9.1%, 13.0%, 16.7%, 20.0%, 23.1%, 25.9%, 28.6%, 31.0% and 33.3% were made to undergo the test.

2.2.2. Dynamic Shear Rheometer (DSR) Test

The test was conducted according to the Standard Test Methods of Bitumen and Bituminous Mixtures for Highway Engineering (JTG E20-2011) (Dynamic Front Shear Rheometer Method) [24]. The complex modulus is given by G* and the phase angle by δ. G*/sinδ of WE/A with WER content of 0, 10%, 20% and 30% were tested using the Dynamic Shear Rheometer (DSR, Kinnexus DSR, Malvern, UK) test. The G*/sinδ was calculated according to the complex modulus (G*) and the phase angle (δ). The scanning temperatures of 58 °C, 64 °C, 70 °C, 76 °C, 82 °C and 88 °C were used, respectively. The 10% maximum strain and angular 10 rad/s speed were set up during the test.

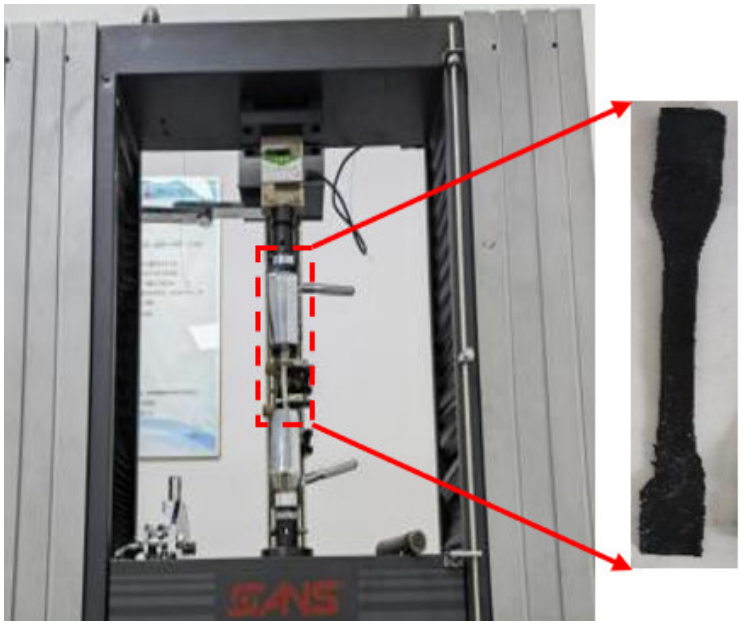


Figure 1. Tensile test.

2.2.3. Fluorescent Microscope Test

As shown in Figure 2, an inverted fluorescence microscope was used to observe the reaction products of WER in the WE/A. The WER amounts in the WE/A were 5%, 10%, 15%, 20%, 25%, 30%, 35% and 40%. Every WE/A with a different amount of WER was observed once at 1 h and 48 h, respectively.

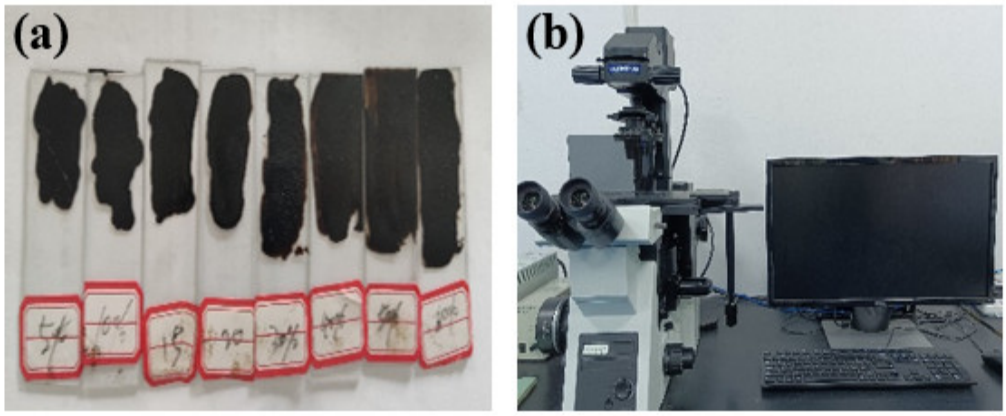


Figure 2. Fluorescent microscope test: (**a**) testing sample; (**b**) test instrument.

2.2.4. Mix Proportion of Micro-Surfacing

The micro-surfacing mix design was determined using the test specified in the Technical Specifications for Construction of Highway Asphalt Pavements (JTG F40-2004). The thickness of the micro-surfacing is about 1 cm, and the maximum nominal diameter of the aggregate is 9.5 mm. The micro-surface mainly has two common gradings, MS-2 and MS-3. The mesh size and mesh mass passing rate of the two gradations are shown in Table 3. According to the construction experience of most road maintenance projects in China, MS-3 graded micro-surfacing has better construction workability and road performance, and lower driving noise. In this study, MS-3 grading was used to prepare the micro-surfacing.

Table 3. Parameters of emulsified asphalt.

Item		Value							
MS-2	mesh size (mm)	9.50	4.75	2.36	1.18	0.60	0.30	0.15	0.075
	Mass passing rate (%)	100	90–100	65–90	45–70	30–50	18–30	10–21	5–15
MS-3	mesh size (mm)	9.50	4.75	2.36	1.18	0.60	0.30	0.15	0.075
	Mass passing rate (%)	100	70–90	45–70	28–50	19–34	12–25	7–18	5–15

2.2.5. Scanning Electron Microscope (SEM) Test

In order to observe the distribution of WER on the aggregate surface of the micro-surfacing slurry, a scanning electron microscope (SEM) test was performed (shown in Figure 3). Micro-surfacing slurries using WE/A binder with a WER content of 0%, 5%, 10%, 15% and 20% were mixed. Each micro-surface slurry was mixed and maintained for 48 h at a temperature of 25 °C. Aggregates coated by WE/A separated from the slurry were immersed and washed in trichloroethylene repeatedly, until all the asphalt was dissolved and washed. Then the micro-structure of the specimen was observed using FE-SEM (QUANTA FEG 450, FEI, Hillsboro, OR, USA).

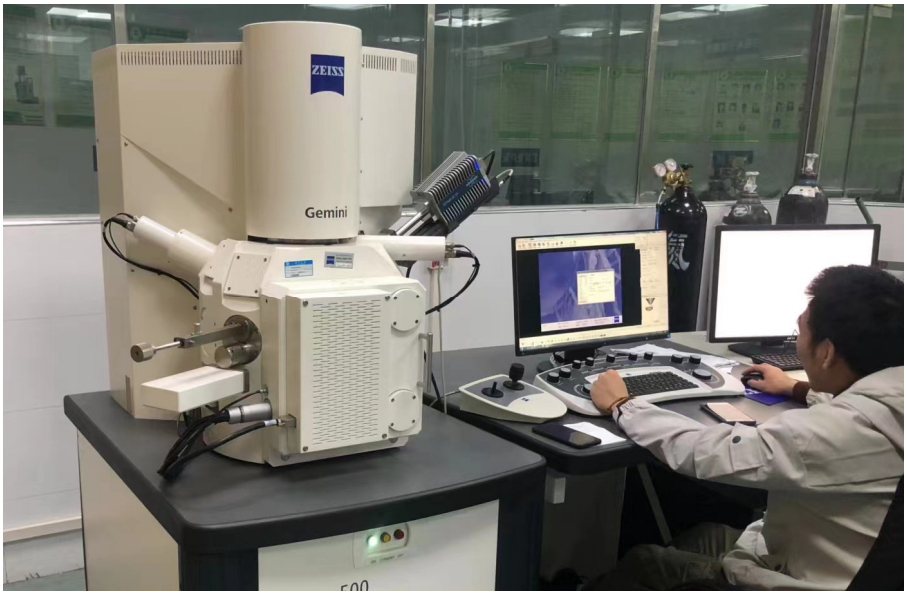


Figure 3. SEM test instrument.

2.2.6. Wet Wheel Wear Resistance Test

As shown in Figure 4, the wet wheel wear resistance test was conducted according to the Standard Test Methods of Bitumen and Bituminous Mixtures for Highway Engineering (JTG E20-2011) [24]. Micro-surfacing slurries using WE/A binder with a WER content of 0%, 5%, 10% and 15% were mixed. Before the test, specimens were immersed in water at 25 °C for 1 h and for 6 days, respectively. During the tests, the abrasion of the mixture lasted for 300 s in the water at the temperature of 25 °C.

2.2.7. Pendulum Friction Test

The micro-surfacing slurry was put on the horizontal and firm ground for 48 h at 25 °C. The test was undertaken according to the Field Test Methods of Highway Subgrade and Pavement (JTG 3450-2019) [26]. Micro-surfacing slurries using WE/A binder with a WER content of 0%, 5%, 10% and 15% were mixed.



Figure 4. Wet wheel wear resistance test.

2.2.8. Slurry Rutting Test

The micro-surfacing slurry was made and maintained for 48 h at 25 °C. Then, the test (shown in Figure 5) was conducted according to the Standard Test Methods of Bitumen and Bituminous Mixtures for Highway Engineering (JTG E20-2011) [24], which, referring to ISSA, is the TB147 load wheel tracking test in the Recommended Performance Guidelines for Micro Surfacing (ISSA A143) [27]. The Lateral Displacement Specific Gravity, LVD, of mixtures was fabricated and rolled 1000 times at 25 °C under a weight of 125 lb (56.71 kg). Micro-surfacing slurries using WE/A binder with a WER content of 0%, 5%, 10% and 15% were mixed and tested.



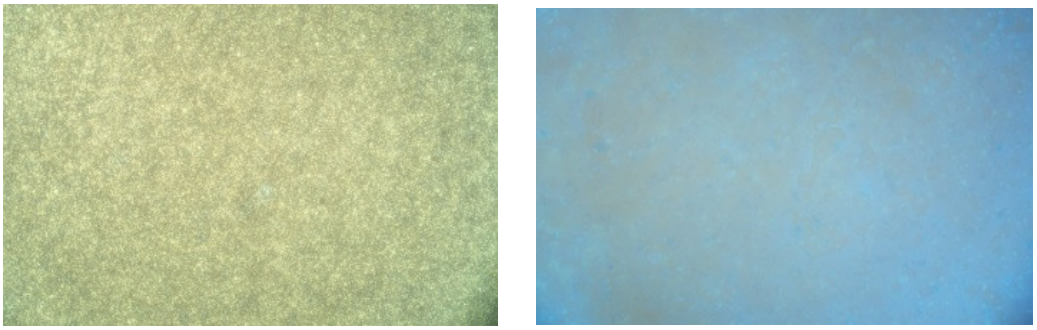
Figure 5. Slurry rutting test.

3. Results and Discussion

3.1. Fluorescent Microscope Test Results

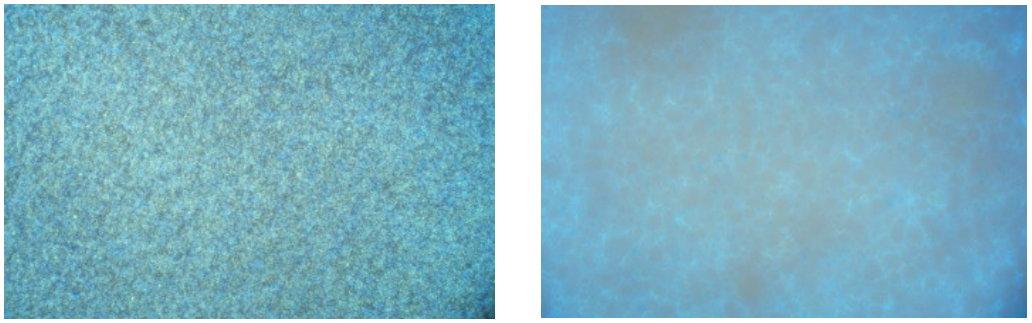
Fluorescent micro-structures of WE/A with WER content of 5–40% are shown from Figures 6–13, respectively. The light blue phase represents the epoxy resin curing product, and the dark phase represents the asphalt.

As is shown in Figure 6, when the WER content was less than 5%, the WER particles were uniformly dispersed in the emulsified asphalt before the curing reaction. Moreover, the cured WER formed dispersed spatial crosslinking products after the curing reaction, which may not provide mechanical properties for emulsified asphalt binders for micro-surfacing.



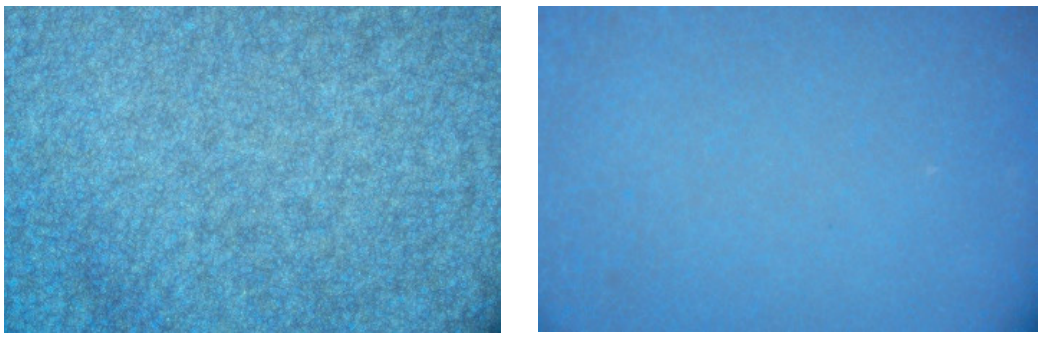
(**a**) (**b**)

Figure 6. Fluorescent micro-structure of WE/A with 5% WER (**a**) 1 h; (**b**) 48 h.



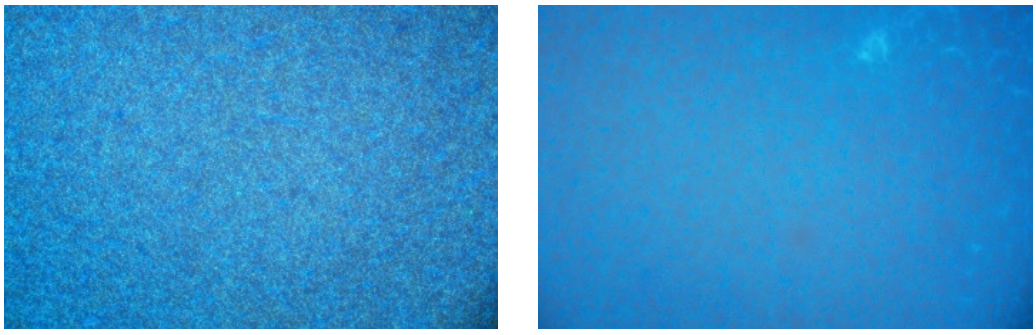
(**a**) (**b**)

Figure 7. Fluorescent micro-structure of WE/A with 10% WER (**a**) 1 h; (**b**) 48 h.



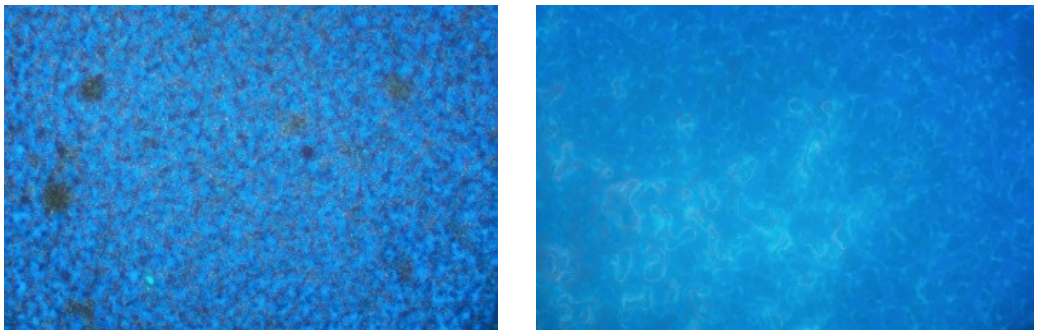
(**a**) (**b**)

Figure 8. Fluorescent micro-structure of WE/A with 15% WER (**a**) 1 h; (**b**) 48 h.



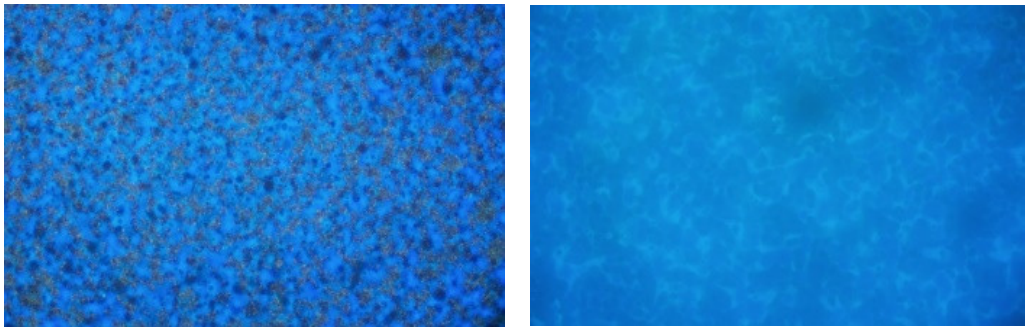
(**a**) (**b**)

Figure 9. Fluorescent micro-structure of WE/A with 20% WER (**a**) 1 h; (**b**) 48 h.



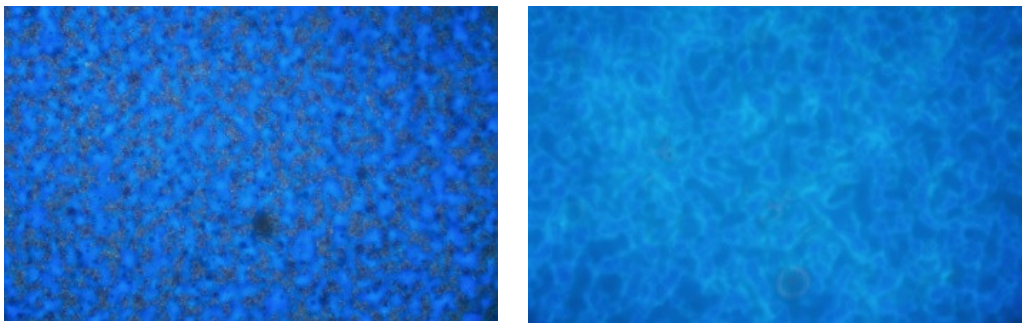
(**a**) (**b**)

Figure 10. Fluorescent micro-structure of WE/A with 25% WER (**a**) 1 h; (**b**) 48 h.



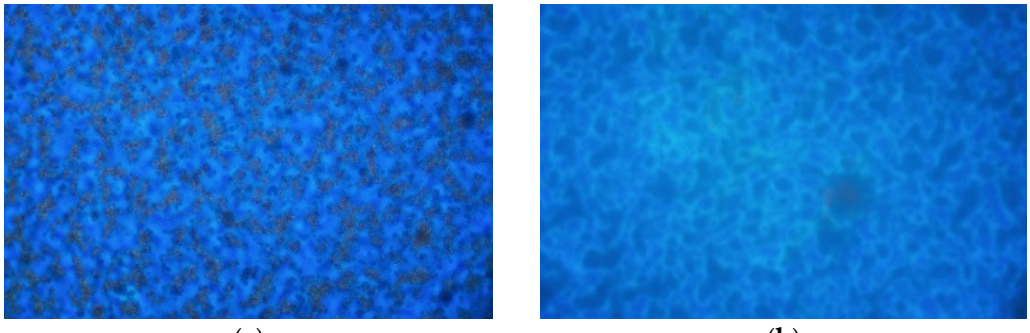
(**a**) (**b**)

Figure 11. Fluorescent micro-structure of WE/A with 30% WER (**a**) 1 h; (**b**) 48 h.



(**a**) (**b**)

Figure 12. Fluorescent micro-structure of WE/A with 35% WER (**a**) 1 h; (**b**) 48 h.



(**a**) (**b**)

Figure 13. Fluorescent micro-structure of WE/A with 40% WER (**a**) 1 h; (**b**) 48 h.

As is shown in Figures 7–9, when WER content was from 10% to 20%, WER particles can be observed clearly in the WE/A in 1 h. Moreover, after 48 h, the emulsified asphalt

bubble coated by the WER membrane can be observed. When the content of WER was insufficient to form a nanometer size microspatial network structure, the WER existed in WE/A as a three-dimensional form of micron level foam film. Water, asphalt and epoxy resin could be stable in a weak three-phase equilibrium until WER had been completely solidified and emulsified asphalt had been completely demulsified. This indicates and explains why the evaporation residue of WE/A could hardly be melted by being heated, but could be sheard under shear stress.

As is shown in Figures 10–13, when WER content was over 25%, epoxy resin particles and asphalt droplets are fused into larger continuous phases, respectively, before curing. Moreover, after the reaction, the WER membrane of the emulsified asphalt bubble becomes thicker, continuous and interlocked with the asphalt. They formed a stable network structure together which could provide WE/A strength and flexibility at a high temperature.

3.2. Tensile Test Result

In this study, the elongation at break and the tensile strength at 25 °C of WE/A with the WER content ranging from 0% to 33.3% were tested. The test results are shown in Figure 14. The overall trend is that the tensile strength increases with the increase in WER content, while the elongation decreases with it. When the content of the WER was 0, the tensile strength of the test specimen was too low to be measured. When the content of the WER was from 5% to 30%, for WE/A with a semi-flexible and rigid WER, the tensile strength was positively correlated with the amount of WER. When the content of WER was over 30%, the tensile strength of WE/A increased rapidly as the content of WER increased.

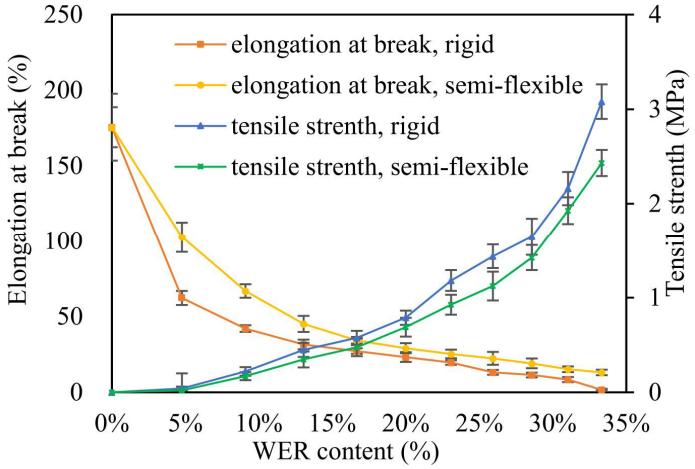


Figure 14. Tensile test result.

In contrast to the appearance of adding epoxy resin in heated asphalt, adding less than 5% WER would reduce the elongation at break of WE/A rapidly. The elongation at break of WE/A with rigid WER decreased by about 115%, and WE/A with semi-flexible WER decreased by about 75%, respectively. When the content of WER was from 5% to 30%, for WE/A with a semi-flexible and rigid WER, the elongation at break was negatively correlated with the amount of WER. When the content of WER was over 30%, the WE/A was nearly at loss flexible deformation capacity. With the same content of WER, the tensile strength of the rigid specimen is higher than of the semi-flexible specimen, whereas the elongation at break of the rigid specimen is lower than of the semi-flexible specimen.

3.3. Dynamic Shear Rheometer (DSR) Test Results

DSR is usually used to evaluate the rheological properties of asphalt materials at high temperatures. In the test for the WE/A samples, it was found that the values of G* and δ at the beginning of the test were different from the values after shearing for a period of time. This difference is significantly greater than for specimens of hot asphalt and modified

asphalt. With the shear test lasting for a period of time, the values of G* and δ tended to be stable.

Complex modulus (G*) can be used to evaluate the deformation resistance of viscoelastic material under shear stress. The larger the G* present, the stronger the deformation resistance and the better the toughness of the asphalt binder material. Figure 15a reveals that WE/A with different WER contents all show a trend that their G* values decrease with increasing temperature. Therefore, WE/A was a thermoplastic material when the WER content was below 30%. WE/A with a higher content of WER had a higher complex modulus (G*) than WE/A with less WER. At 60 °C, the common maximum average temperature of asphalt pavement in hot summer areas, the complex modulus of WE/A with 10%, 20% and 30% WER content is 332.3%, 216.1% and 83.9% higher than WE/A without WER, respectively.

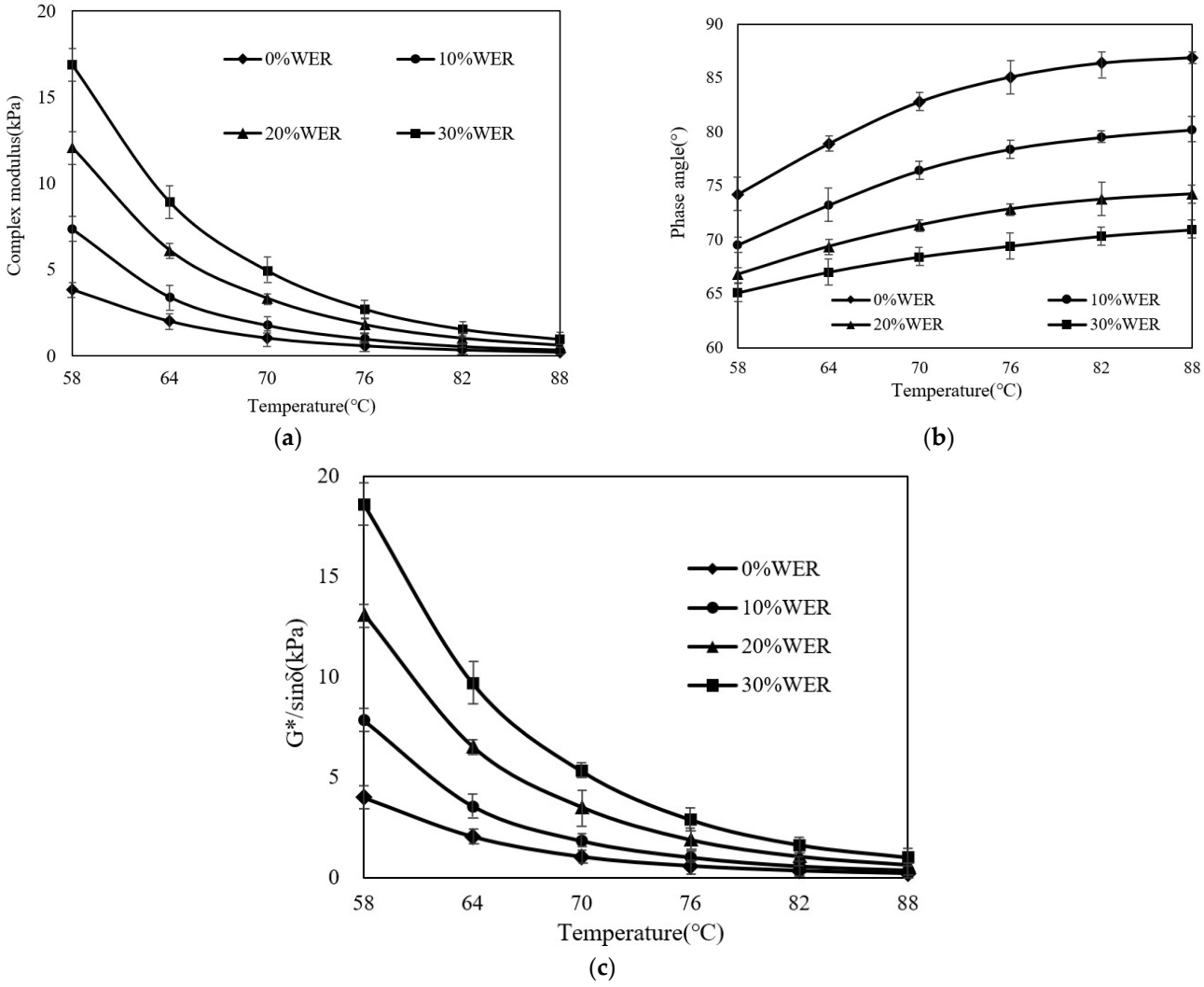


Figure 15. Results of DSR test: (**a**) complex modulus (G*); (**b**) phase angle (δ); and (**c**) G*/sinδ.

The phase angle (δ) can reflect the viscoelastic proportion of the material. When the phase angle is 90°, the specimen is the ideal viscous material, and a smaller phase angle indicates that the specimen is approaching an elastomer. Figure 15b shows that adding more WER will reduce the phase angle at the same temperature. For example, at 88 °C, when the WER content increases from 0 to 30%, the corresponding phase angle decreases by 18°. Moreover, the changing amplitude of the phase angle in different temperatures decreases with the increase in WER content. For WE/A with a WER content of 10%, the phase angle decreased by 10.7% when the temperature increased from 88 °C to 58 °C.

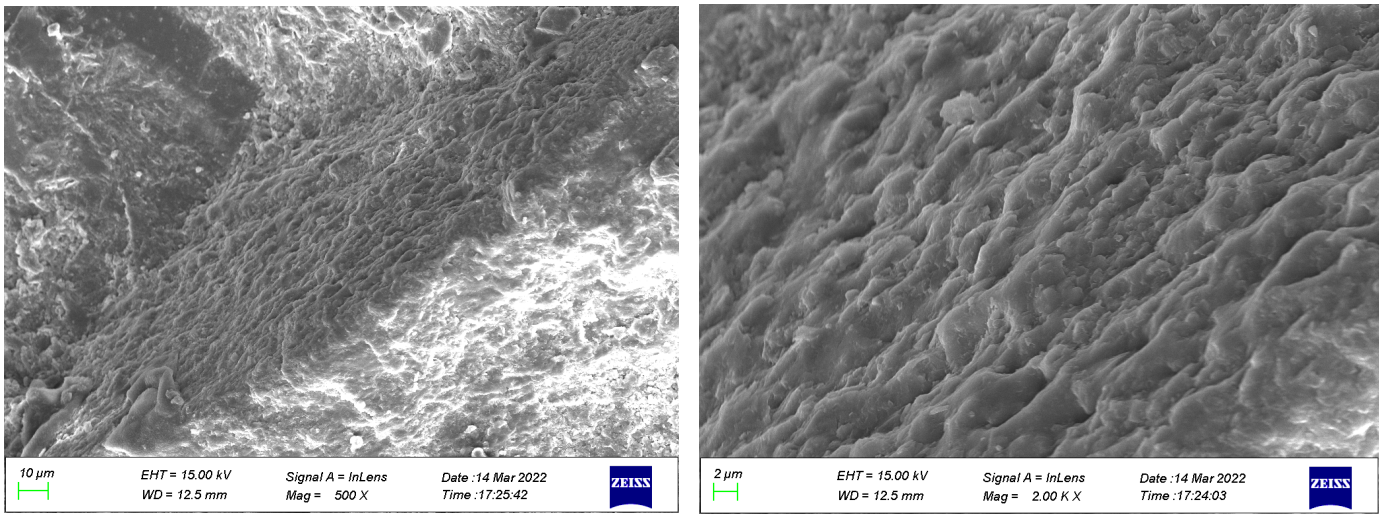
Meanwhile, for WE/A with a WER content of 30%, the phase angle increased by 2.6% when the temperature decreased from 88 °C to 58 °C. In addition, at the temperature of 88 °C, when the WER content was over 20%, the WE/A was transformed from a viscous material to a viscoelastic material. When the temperature rose, the organic asphalt gradually softened and became a viscous fluid, but the thermoplastic epoxy resin can also maintain a solid state at high temperature. The micron level reaction product of the epoxy resin structure in WE/A changed the rheological state of asphalt.

G*/sin δ always regards the rut factor and evaluates the high temperature performance of asphalt. As shown in Figure 15c, the rutting factor became larger with increasing WER content at the same temperature. Moreover, the rutting factor showed a decrease with increasing temperature, regardless of the amount of the WER dosing. This is mainly due to the cured WER, which continuously exists in the WE/A as a spatial network, and the WER frame can provide most strength when bearing shear stress. As a result, WE/A had better high temperature performance due to the addition of WER.

3.4. SEM Test Result

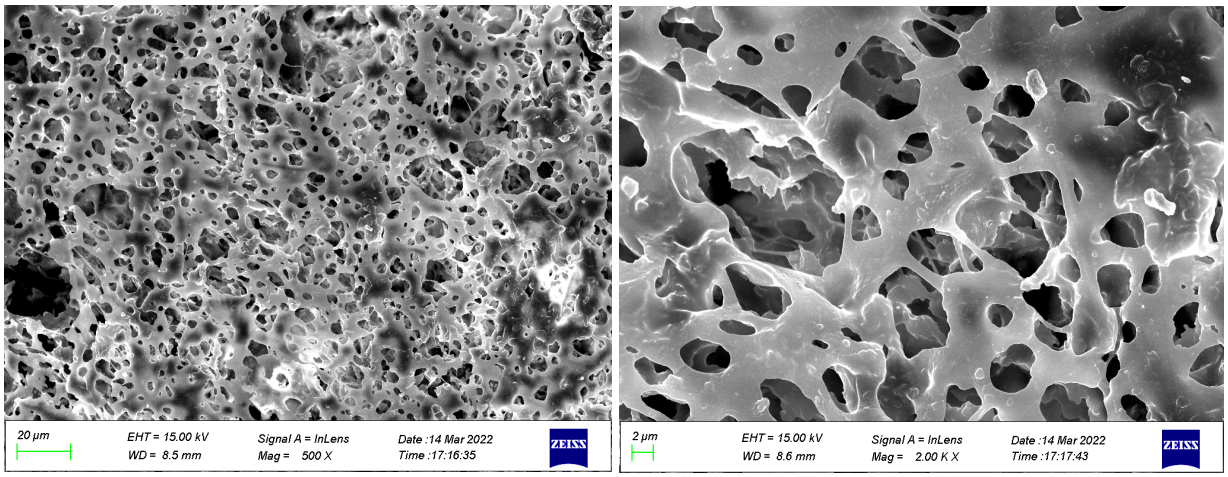
Figure 16 shows that the texture of the surface of the aggregate of micro-surfacing slurry without WER could be clearly observed when the asphalt was cleaned using trichloroethylene. Figure 17 reveals that, when the WER content was 5%, the residual WER membrane presented a faveolate network structure on the aggregate's surface when asphalt inside of the bubble was extracted. This meant that, at the content of 5%, the WER solidification product was enriched on the surface of the aggregate. It improved the interface performance between the aggregate and the asphalt. As a result, the adhesion of the surface between the asphalt and aggregate in micro-surfacing slurry would be effectively improved, even if the tensile strength of the binder was not significantly improved, when the content of WER was as low as 5%.

Figure 18 shows that, when the content of WER was 10%, aggregates in micro-surfacing could be completely wrapped by WER. Figures 19 and 20 reveal that the micro-morphology of WER wrapped on the aggregate surface had no obvious change when the content of WER increased. According to the fluorescent microscope test results, WER presents as a form of membrane of a bubble. Meanwhile, due to the asphalt foam being in an unstable state, the polarity of the aggregate surface affected the charge balance of the WE/A, the mixture of WER and emulsified asphalt. Thus, the curing products of the WER would preferentially enrich on the aggregate surface. After the surfaces of the aggregates were wrapped, WER in the asphalt could form a spatial network structure.



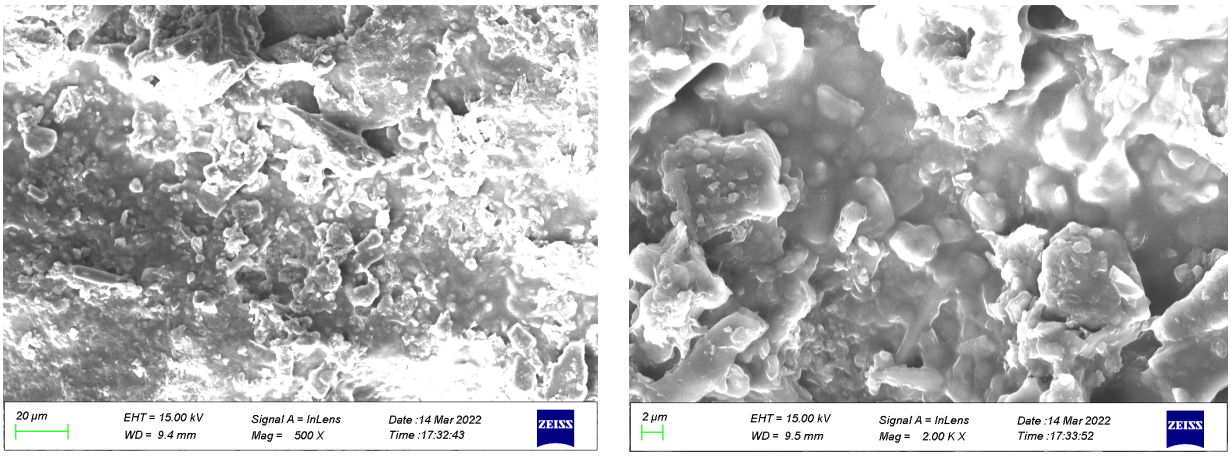
(**a**) (**b**)

Figure 16. Micro-structure of aggregate, WER content 0%: (**a**) 500×; (**b**) 2000×.



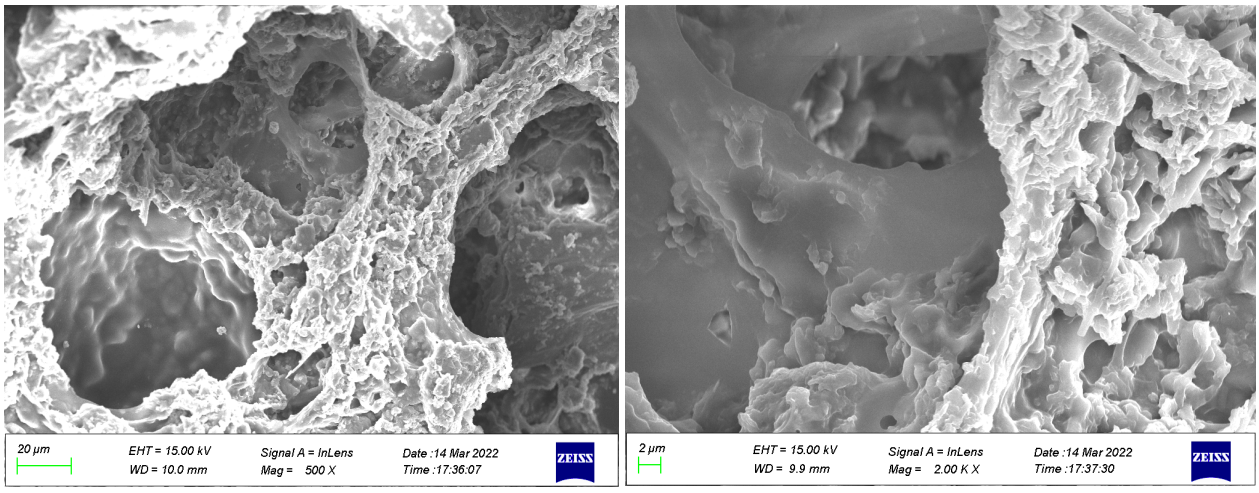
(**a**) (**b**)

Figure 17. Micro-structure of aggregate, WER content 5%: (**a**) 500×; (**b**) 2000×.



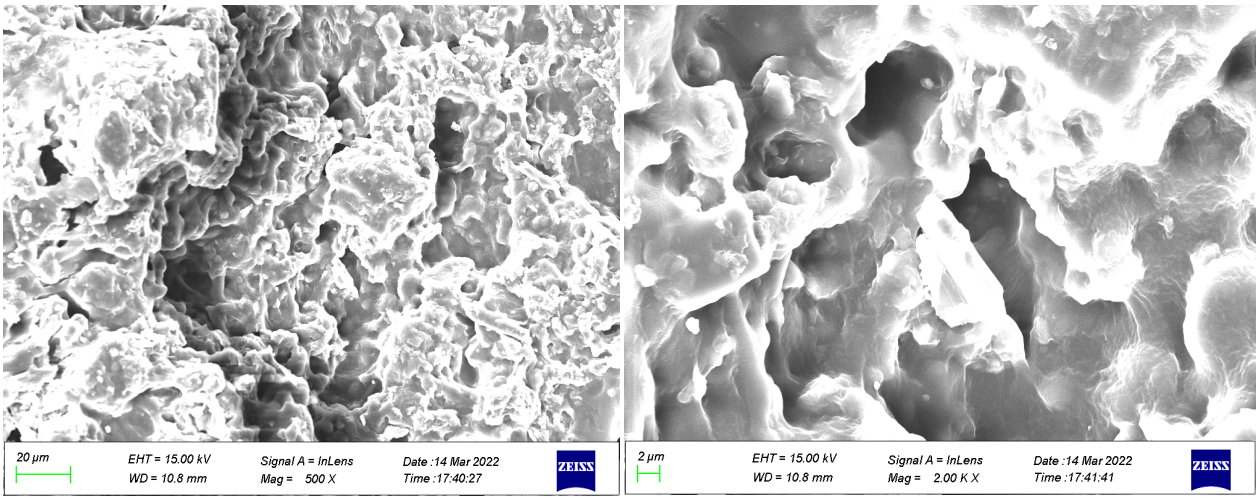
(**a**) (**b**)

Figure 18. Micro-structure of aggregate, WER content 10%: (**a**) 500×; (**b**) 2000×.



(**a**) (**b**)

Figure 19. Micro-structure of aggregate, WER content 15%: (**a**) 500×; (**b**) 2000×.



(**a**) (**b**)

Figure 20. Micro-structure of aggregate, WER content 20%: (**a**) 500×; (**b**) 2000×.

Fewer WER curing products concentrated on the aggregate surface increases the roughness of the aggregate surface, bridges the gap between the aggregate and asphalt, enhances the cohesion between the aggregates and binder, and improves the transition interface between the aggregate and asphalt. The transition interface between the aggregate and asphalt could thus be effectively improved. When the content was more than 10%, the free epoxy resin curing products outside the interface between the aggregates and asphalt react to form a continuous spatial structure. WER could enhance the strength of the modified emulsified asphalt binder in the micro-surfacing mixture.

3.5. Wet Wheel Wear Resistance Test Result

During the test, the abrasion value of the specimen immersed for 1 h was used to reflect its peeling resistance, and the abrasion value of the specimen immersed for 6 days was used to reflect its water damage resistance [28]. As shown in Figure 21, when WER content was 5%, 1 h abrasion resistance values of rigid and semi-flexible samples reduced by 7.3% and 20.6%, respectively, whereas 6 days abrasion resistance values of rigid and semi-flexible samples reduced by 5.8% and 12.2%, respectively. When WER content was 10%, 1 h abrasion resistance values of rigid and semi-flexible samples reduced by 30% and 48.7%, respectively, and 6 d abrasion resistance values of rigid and semi-flexible samples reduced by 18% and 28%, respectively. This proves that less WER could effectively improve the bonding performance of the interface between aggregate and asphalt in micro-surfacing.

When WER content was 15%, 1 h abrasion resistance values of rigid and semi-flexible samples reduced by 48.7% and 60.6%, respectively, and 6 days abrasion resistance values of rigid and semi-flexible samples reduced by 31.4% and 40.7%, respectively. The 1 h and 6 days abrasion resistance values of both rigid and semi-flexible samples showed a decreasing trend with the increase in WER content. Moreover, the 1 h and 6 days abrasion resistance values of semi-flexible samples was always lower than the rigid samples. This may be because the curing B1 used by semi-flexible WER has longer carbon chains and can better blend with asphalt organic compounds. Semi-flexible specimens cured by the curing B1 present better peeling resistance and water damage resistance than the rigid specimens.

3.6. Pendulum Friction Test Result

The improvement in anti-sliding performance of pavements is mainly caused by fine aggregate texture on the surface of the micro-surfacing mixture. However, the anti-slip performance of different binders is different. Figure 22 reveals that the reduction in BNP values for rigid specimens was greater than for the semi-rigid specimens. Therefore, the micro-surfacing with more content of WER had worse skid resistance. Semi-flexible WER

micro-surfacing had better skid resistance than rigid WER micro-surfacing. According to engineering statistical work, the Sideway Force Coefficient of asphalt pavement was usually higher than 50 when the BPN was higher than 60, and rapidly reduced to under 35 when the BPN decreased below 60.

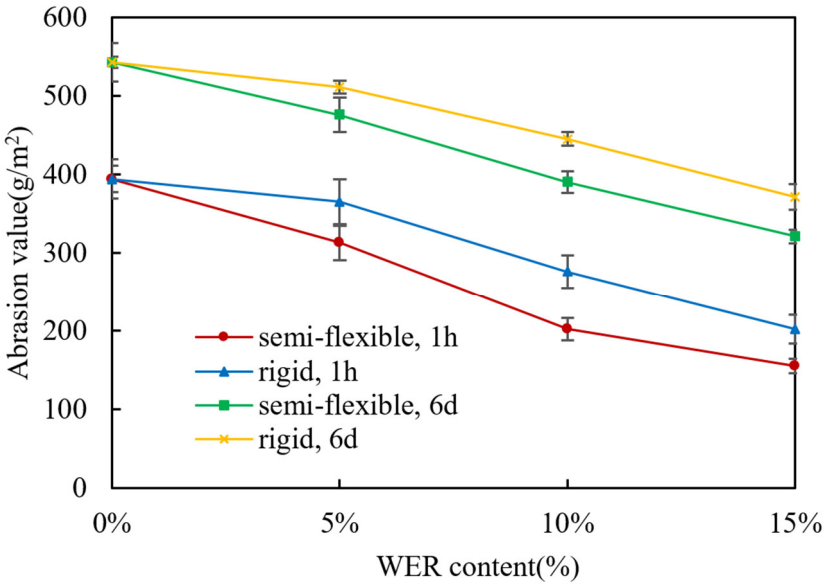


Figure 21. Wet wheel wear resistance test result.

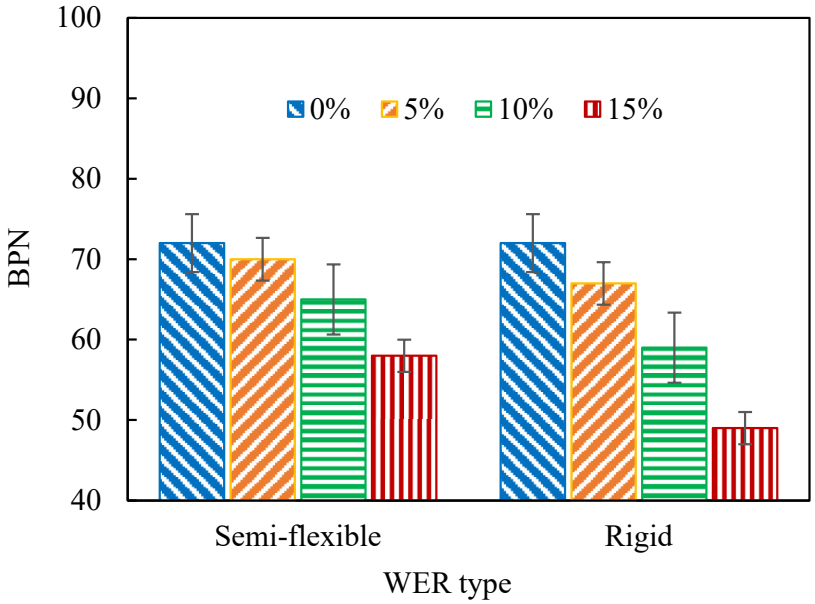


Figure 22. Pendulum friction test result.

This was because the cured product of epoxy resin was smoother than asphalt and had a lower friction coefficient than asphalt at a normal temperature. When WER content was higher than 10%, the epoxy resin curing products with better wear resistance in the WE/A binder formed a space skeleton, and the asphalt with lower wear resistance was filled inside the space of the skeleton. Under the wear of vehicle tyres, the epoxy resin skeleton was gradually exposed, reducing the friction of the micro-surface. To ensure driving safety, the content of the semi-flexible WER should be below 15% and the content of rigid WER should be below 10%.

3.7. Slurry Rutting Test

The thickness of micro-surfacing slurry usually does not exceed 1.5 cm on the pavement, so the rutting resistance of micro-surfacing is usually evaluated by the percentage of width deformation (PLD) instead of dynamic stability of the asphalt mixture thicker than 4 cm. Figure 23 shows that the PLD values for both the semi-rigid and rigid specimens decreased with increasing WER doping, and the decrease range was essentially the same. Moreover, less than 5% WER could barely reduce the PLD of specimens compared with specimens without WER. A total of 10% WER could enhance the rutting resistance of micro-surfacing substantially. When the content of WER was more than 10%, the modification effect did not increase with the adding of more WER, and the cured reaction formed into a continuous phase.

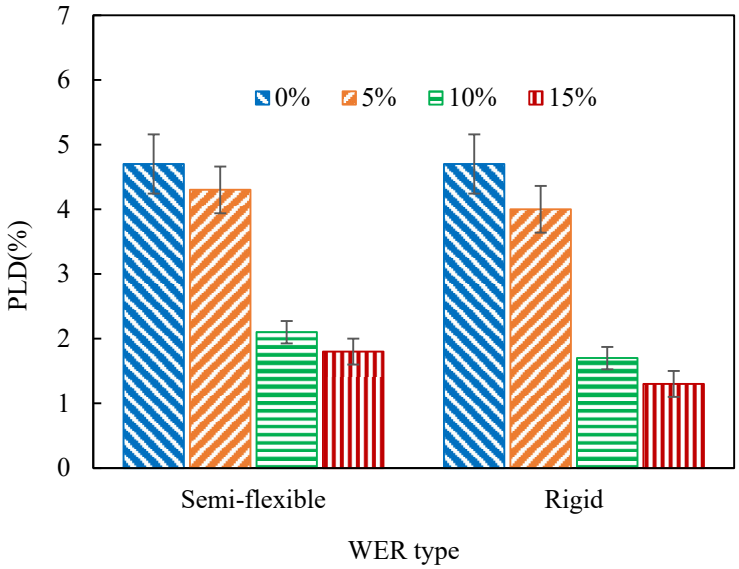


Figure 23. Slurry rutting test result.

On one hand, this is because the WER solidification product was enriched on the surface of the aggregate, improving the interface performance between the aggregate and the asphalt; it required about 5% WER. On the other hand, WER particles adsorbed on asphalt droplets to form an asphalt bubble film.

4. Conclusions

This paper introduced a new waterborne epoxy resin-modified micro-surfacing material. The modification mechanism and road performance of micro-surfacing were discussed. The following conclusions can be drawn:

(1) This paper suggests that the content of WER in WE/A should range from 5% to 10%. Moreover, it explored and proved the modification mechanism of WER modified asphalt or micro-surfing, that is, the reinforcement of the interface and binder.

(2) With little content, WER could concentrate on the aggregate surface in the micro-surfacing slurry, improving the cohesion of the aggregate asphalt transition interface. It also could improve the binding capacity of asphalt to aggregate. In addition to improving the performance of the interface, when more WER was added into WE/A, WER existed as continuous structures rather than island structures. The structure present was a cellular membrane wrapped around asphalt bubbles. Therefore, WER could significantly modify WE/A, and enhance its high temperature properties and mechanical properties.

(3) At a content of 10%, WER could effectively improve the peeling resistance of micro-surfacing by 30.0–48.7%, water damage resistance by 18.0–28.0%, rutting resistance by 55.3–63.8%, and reduce the skid resistance by 9.7–18.1%.

Author Contributions: Conceptualization, S.H.; Methodology, F.J.; Formal analysis, Q.D.; Investigation, D.C.; Data curation, Q.X.; Writing—original draft, F.J.; Writing—review and editing, D.C. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by the National Natural Science Foundation of China (grant number U21A20149).

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Data sharing is not applicable for this article.

Conflicts of Interest: The authors declare no conflict of interest.

Abbreviations

WER	waterborne epoxy resin
WE/A	waterborne epoxy resin-modified emulsified asphalt
DSR	dynamic shear rheometer
SEM	scanning electron microscope
G*	complex modulus
δ	phase angle
PLD	percentage of width deformation

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