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Long-Term Performance Analysis of Epoxy Resin Ultra-Thin Wearing Course Overlay on Cement Concrete Pavement

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Abstract: The overall rigidity of the cement concrete pavement is high, but there are defects such as easy cracking and insufficient anti-slip performance. The epoxy resin ultra-thin wearing course overlay can effectively solve these issues. However, there is still a lack of knowledge about the long-term performance of epoxy resin ultra-thin wearing course overlay on cement concrete pavement. Therefore, this article analyzed the interlayer adhesion and durability of epoxy resin ultra-thin wearing course overlay through the Hamburg rutting test and a series of shear tests under damp heat, thermal oxygen aging, and ultraviolet (UV) aging conditions. Shear test results indicated that the shear performance of epoxy resin overlay grew with the increase in epoxy resin content and was severely affected by high temperature, and the optimal content was set as 3.4 kg/m^2. The Hamburg rutting test results showed that the epoxy resin overlay exhibited satisfactory high-temperature performance and water resistance. For the damp heat effect, it was revealed that damp heat led to more significant shear strength loss compared with the overlay specimens without damp heat. The water immersion caused the shear strength decline due to the water damage to the overlay interface. As for the thermal oxygen aging effect, it was reflected that the short-term thermal oxygen aging had a minor impact on the shear performance of the epoxy resin overlay. However, with the increase in thermal oxygen aging duration, the shear strength of the epoxy resin overlay significantly decreased due to the aging of epoxy resin binders. Regarding the UV aging impact, it was also found that the shear performance of the epoxy resin overlay rapidly decreased as the UV aging duration grew whether at 20 °C or 60 °C. Moreover, UV aging led to a more significant impact on the shear performance of the epoxy resin overlay than thermal oxygen aging.

Keywords: road engineering; ultra-thin wearing course overlay; epoxy resin; long-term performance; aging; shear performance

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1. Introduction

The resin ultra-thin wearing course overlay is a critical coating technology that can effectively solve early pavement damage such as cracks, peeling, and potholes in cement concrete pavement; meanwhile, it can also improve driving comfort and anti-slip performance [1–5]. Sprinkel [6] conducted a long-term tracking investigation on a road surface paved with the resin wearing course and found that it had excellent anti-slip performance and long service life. Hong [7] proposed a new type of tunnel pavement, i.e., polyurethane ultra-thin wearing course, which exhibited satisfactory mechanical properties and wear resistance, and had nearly no harmful emissions due to its room-temperature construction. Compared with traditional asphalt mixtures, the resin ultra-thin wearing course was proved to have excellent mechanical properties, slip resistance, sound absorption, flame retardancy, and other functional properties, as well as good environmental performance.

The resin ultra-thin wearing course is mainly composed of aggregates and resin-based binders. Aggregates are used to enhance the friction coefficient of road surfaces and play a role in anti-slip. Wear-resistant and anti-slip materials such as ceramic particles and quartz sand can be selected. Deng et al. studied the performance and nano adhesion behavior of the overlay using experimental and molecular dynamics simulation methods [8,9] and found that using diamond sand with a particle size of 2–3 mm as the ultra-thin overlay aggregate exhibited more favorable wear and skid resistance than ceramic particles. The resin binders play a bonding role and are often selected from resin materials such as polyurethane or epoxy resin, which have good bonding performance, stability, and wear resistance. Compared with an asphalt binder, most of these resins exhibit thermosetting behavior as the temperature rises, and the molecular networks created during hardening are refined to form other networks. In contrast, asphalt binders tend to soften at high temperatures. As a result, these binders perform better, especially in high temperatures where the use of an asphalt binder can cause the binder to bleed out. Wu et al. confirmed that using an epoxy resin ultra-thin wearing course overlay can significantly improve the poor anti-slip performance of steel bridge decks, and the ultra-thin wearing course has good high-temperature resistance and mechanical properties [10]. After 7 months of use, the overall condition of the road surface was good, with a structural depth of over 1.4 mm, and the bond strength was still stable at 3.71 MPa. The experimental results from Stenko et al. [11] showed that the compressive strength of the epoxy resin ultra-thin wearing course material was about 40 MPa and the bending strength was about 13 MPa. Horn et al. [12] compared different types of resin concrete and established that the performance of epoxy resin concrete was superior to that of methyl acrylic acid resin concrete in all aspects. Attanayake et al. [13] found that regardless of the concrete age at the time of overlay application, the bond strength of an epoxy overlay under elevated temperatures was less than 1.7 MPa. The primary failure type was a bond failure at the concrete/overlay interface. Freeseman et al. [14] proposed that the accelerated freezing and thawing exposure greatly affects the bond strength of epoxy overlays.

The epoxy resin has certain chemical activity and can be ring-opened, cured, and cross-linked by compounds containing active hydrogen to form a network structure [15], Therefore, the epoxy resin ultra-thin wearing course overlay can play a role in anti-slip and extending the service life of the road surface [16,17]. However, the long-term performance of epoxy resin ultra-thin wearing course overlay is affected by rain, high temperatures, and strong ultraviolet radiation during service, and its durability varies with different environmental influences. Therefore, the long-term durability of the epoxy resin ultra-thin overlay layer is closely related to the impact of aging. Epoxy resin is prone to aging during use, manifested in surface yellowing, loss of gloss, cracking, and overall mechanical properties degradation [18]. Epoxy resin aging is mainly divided into three types: thermal oxygen aging, humid heat aging, and ultraviolet aging. Among them, when the epoxy resin is thermally excited in an oxygen-containing environment, the molecular chain will absorb the oxygen in the environment and generate hydroperoxide, which will lead to instability of hydroperoxide, rearrangement reaction of polymer main chain, and chain breaking or cross-linking, which will degrade the performance of polymer materials and lead to thermal–oxidative aging [19]. Yu conducted a 30-day thermal aging of an epoxy resin matrix at 130~160 °C to study the effect of thermal oxygen aging on epoxy resin [20]. The FTIR results indicated that during the thermal aging process, the epoxy resin sample undergoes oxidation and molecular rearrangement. The bending test results indicated that the thermal aging significantly reduced the fracture strain, while the bending strength was only slightly affected and the modulus increased. When epoxy resin materials underwent high humidity or rainwater environments during service, they will experience significant damp heat [21,22], resulting in a performance degradation and an inability to meet usage requirements. Wang et al. conducted an in-depth study on the effects of humidity and time on the structure and mechanical properties of phenolic epoxy resin during the wet heat aging process [23]. The results indicated that the moisture absorption rate increased linearly with the square root of aging time and follows Fick's second law. There were two main types of reactions during wet heat aging: the first type was the post-curing process, which led to a higher crosslinking density and reduced internal stress; another was the plasticization and degradation of epoxy resin caused by the entry of moisture. The unsaturated bonds or polar groups such as benzene rings and ether bonds contained in epoxy resin, as well as impurities introduced during the polymerization stage and processing, were prone to absorbing ultraviolet radiation and causing photooxidation reactions in epoxy resin [24]. Affected by aging, the bonding and shear properties of epoxy resin decrease. Therefore, the firmness of the bonding between the epoxy resin ultra-thin overlay layer and cement concrete pavement is one of the key issues that needs to be solved when adding the epoxy resin ultra-thin overlay layer to cement concrete pavement.

Overall, it was noted that there is still a lack of knowledge about the long-term performance of epoxy resin ultra-thin wearing courses. Firstly, the optimum dosage and high temperature resistance of epoxy resin ultra-thin wear layer covering were evaluated by oblique shear test and Hamburg rutting test. Secondly, the effects of different aging conditions, including damp heat, thermal oxygen aging, and ultraviolet aging, on the shear resistance of epoxy resin ultra-thin wearing course overlay were investigated by means of oblique shear tests. This study was expected to provide an experimental theoretical basis for the engineering feasibility of the epoxy resin ultra-thin wearing course overlay on cement concrete pavement.

2. Materials and Experiment Methods

2.1. Materials

The performance of the epoxy resin was the key to ensuring the quality and longevity of the epoxy resin ultra-thin wearing course. The epoxy resin materials were divided into two components, A and B, and were blended in proportion to the application. Two kinds of commercial epoxy resin materials were shown in Figure 1, i.e., RS epoxy resin and RA epoxy resin, were selected. The main performance indicators after the blending reaction are shown in Table 1.

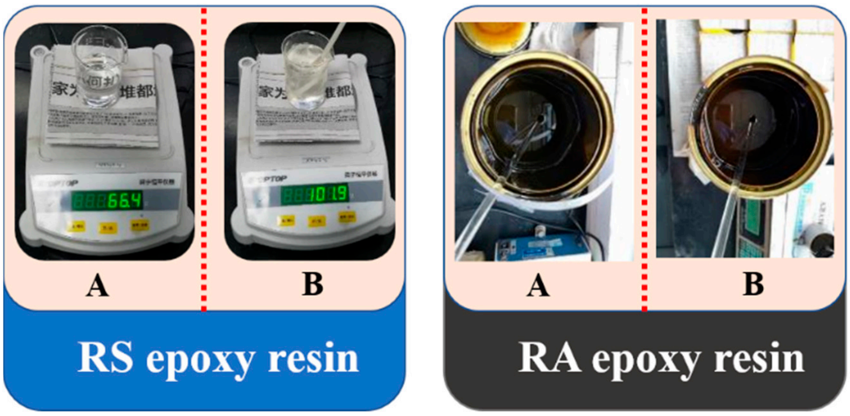

Figure 1. Two kinds of commercial epoxy resin materials.

Table 1. Performance indicators of epoxy resins used in this study.

Index	Unit	RS Epoxy Resin	RA Epoxy Resin
Solids content	%	99.7	99.7
Tensile strength (25 °C)	MPa	20.3	10.6
Elongation at break (25 °C)	%	45.0	30.5
Tensile strength (25 °C)	Mpa	7.6	18.0
Tensile strength (60 °C)	Mpa	4.8	4.8

2.2. Preparation

The cement concrete panel was made of C40 strength grade concrete. In order to simulate the actual situation of cement concrete pavement with epoxy resin ultra-thin overlay, composite rutting specimens were formed by using special rutting plate test molds. Firstly, according to the requirements of the "Test Procedure for Cement and Cement Concrete in Highway Engineering" [25], $30 \times 30 \times 7$ cm^3 cement concrete specimens were prepared by vibratory compact forming method using asphalt mixture rutting plate. The cement concrete panel was then cleaned and dried naturally, placed under standard curing conditions, and cured for 28 d to reach the design strength; the cured cement concrete panel was put into a $30 \times 30 \times 7$ cm^3 mold, the epoxy resin components A and B were mixed and stirred nicely, and the designed amount of resin was evenly applied using a brush. After the resin was applied, the gravel was spread in time according to the design requirements after the first layer of resin was cured and stabilized, the unadhered aggregate was swept away and the second layer of resin material was applied, the gravel was spread in time after the resin was cured and stabilized, the unadhered aggregate was swept away, and the specimen was cured for 3 days at room temperature. The automatic rock cutting machine was used to cut the cured composite rutting slab into composite specimens of $8 \times 8 \times 7$ cm^3, which were subjected to the 45° oblique shear test and pull-out test, with three parallel specimens in each group. The forming process is shown in Figure 2.

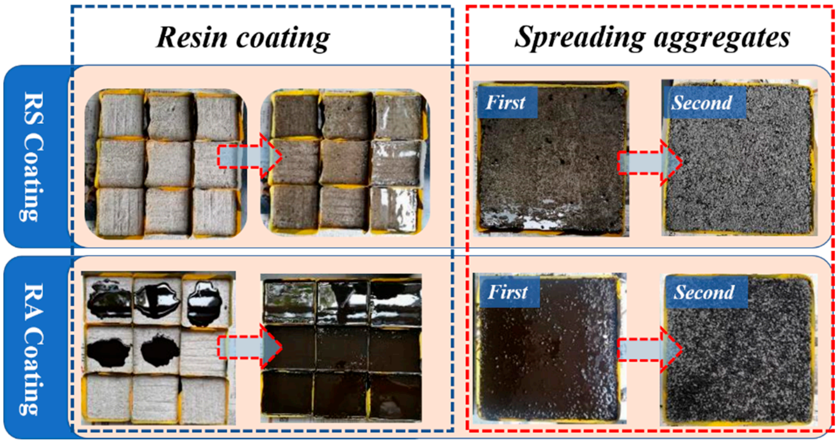

Figure 2. Preparation process of test samples.

2.3. Test Methods

2.3.1. Shear Test

The sample group was fixed to conduct the shear test using the 45° oblique shear fixture and oblique shear instrument [26,27]. Evaluation of shear resistance was carried out in an electro-hydraulic servo mechanical test system with a measurement accuracy of 1 N for the pressure measuring unit, 0.1 mm for the displacement sensor, and 0.1 °C for the ambient room temperature sensor. The shear stress and shear strain were calculated according to Equation (1). The tests started with the preparation of thin layers on cement concrete panels at room temperature with different resin dosages selected and tested for shear resistance, the main test procedure is shown in Figure 3 below. The load was then applied at a rate of 1.0 N/s until shear damage occurred to the specimen. The value of the applied load at the time of damage was recorded and the shear strength of the shear surface was calculated.

$$\tau = \frac{P \times \sin \alpha}{S} \tag{1}$$

P—load (N); S—shear area of the specimen (mm^2); τ—shear strength (MPa); α—angle between shear surface and horizontal surface, which, in this test, was 45 degrees.

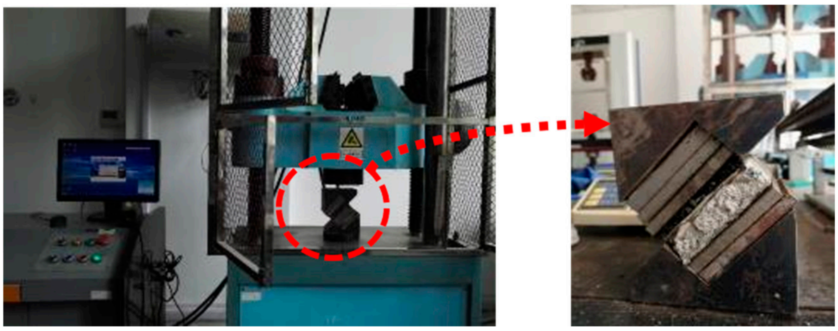

Figure 3. Shear test.

2.3.2. Hamburg Rutting Test

The high-temperature performance and water resistance of epoxy resin ultra-thin overlay under the combined action of water and heat was evaluated by conducting Hamburg rutting test according to the AASHTO T324 specification [28]. The test piece was placed in a water bath of the Hamburg rut testing machine, maintained in a 60 °C water bath for 30 min, and the test was then conducted under a pressure of 0.7 MPa. When the steel wheel passed 20,000 cycles or reached the maximum allowable rut depth, the instrument automatically stopped the test.

2.3.3. Durability Tests

(1) Damp heat impact test

Summer high temperatures and rainfall were vital factors affecting road paving. To evaluate the impact of high temperature and rainfall on epoxy resin ultra-thin wearing course overlay, the test was carried out by submerging thin resin pavement specimens in a water bath at 60 °C for 48 h and examining the shear resistance of the pavement under damp heat conditions by means of a shear test.

(2) Thermal oxygen aging impact test

High-temperature thermal oxygen aging was one of the important factors affecting the performance of resin materials. Resin materials exposed to long-term, high-temperature air were prone to oxidation, degradation, cross-linking, or creep damage, resulting in a decrease in bonding strength. The epoxy resin ultra-thin wearing course specimens were aged for 7, 14, and 28 days in a 60 °C oven, and their shear resistance after aging was tested.

(3) Ultraviolet (UV) aging impact test

China has a vast territory, and most areas are affected by strong solar radiation. The problem of UV aging of the road pavement cannot be ignored. Therefore, the epoxy resin ultra-thin wearing course specimens were aged for 7, 14, and 28 days, respectively, at 60 °C, 70%, and 1000 W/m^2 of radiant intensity. The daily working time of the equipment was 20 h. The conversion between indoor ultraviolet radiation time and outdoor strong sunlight radiation time is shown in Table 2.

Table 2. Conversion between UV aging time and outdoor aging time.

Aging Mode	Aging Time		
Indoor simulation	7 days	14 days	28 days
Outdoor aging	6 months	12 months	24 months

3. Results and Discussion

3.1. Determination of the Optimal Dosage of Epoxy Resin Overlay

The failure load and shear strength of the RS epoxy resin ultra-thin wearing course overlay with different content is shown in Figure 4. Shear test was used to test the ability of epoxy resin ultra-thin wearing course overlay to resist shear stress generated by vertical and horizontal forces under driving loads. In order to determine the optimal dosage of the RS ultra-thin wearing course overlay, shear tests were used to evaluate the shear resistance performance of the RS ultra-thin wearing course overlay with different ratios. In this experiment, the ratio of A and B in RS was 1:2. The used RS was applied in the first layer and second layer. For example, the RS content of 1.8 (0.6 + 1.2) kg/m^2 meant that the first layer used 0.6 kg/m^2 RS and the second layer used 1.2 kg/m^2 RS. Correspondingly, the aggregate dosage was set as 13.0 (5.4 + 7.6) kg/m^2. It can be found that with the increase in RS content, its failure load and shear strength increase significantly. It indicated that with the increase in RS dosage, the shear resistance of the epoxy resin ultra-thin wearing course was greatly improved. However, with the increase in RS content, the increase percent of shear strength and failure load gradually decreased. Compared with the addition of 1.8 kg/m^2, the shear strength increased by 129% with the addition of 3.4 kg/m^2. During the test, the surface of the epoxy resin overlay specimen with 3.4 kg/m^2 resin did not deform, and only a minor amount of aggregate fell off. It was because the epoxy resin greatly improved the bonding among aggregates as its dosage increased. This indicated that the epoxy resin overlay structure had good deformation resistance and certain wear resistance; therefore, only aggregates with poor surface adhesion fell off. Thus, based on the comprehensive shear strength and the shedding during the test, the optimal dosage of the RS resin overlay was determined as 3.4 kg/m^2. To compare with the RS ultra-thin wearing course overlay, the dosage of the RA resin pavement was also determined to be 3.4 kg/m^2.

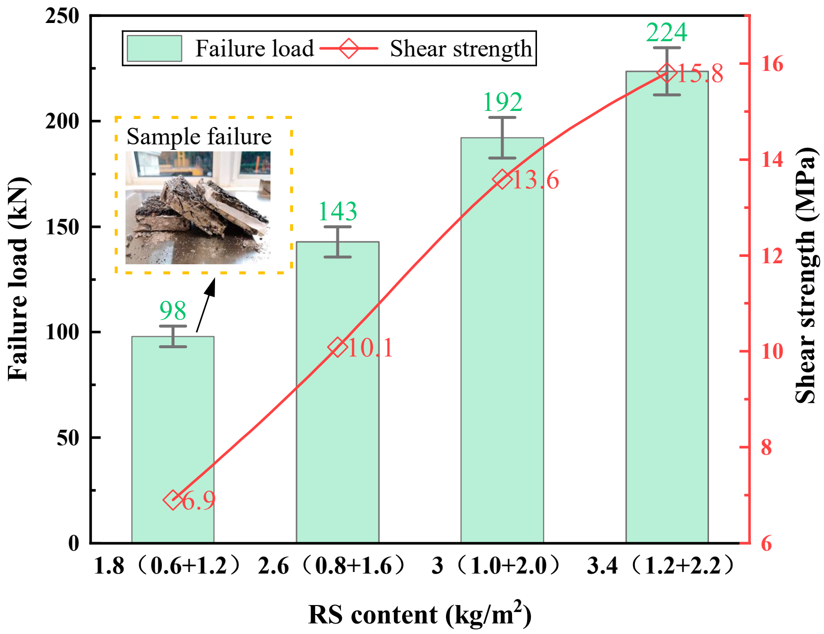

Figure 4. Failure load and shear strength of RS epoxy resin overlay with different content.

3.2. High-Temperature Shear Performance of Epoxy Resin Overlay

(1) High-temperature shear test results

To investigate the effect of high temperature on the shear resistance of epoxy resin overlay bonding, the epoxy resin overlay specimens were placed in an oven at 60 °C and 70 °C for 6 h before conducting shear tests. The results are shown in Figure 5. Obviously, the shear strength of the RS epoxy resin overlay was highest at room temperature (20 °C), indicating that the shear resistance of the RS epoxy resin overlay at room temperature was excellent. With the increase in temperature, the shear strength of the RS and RA epoxy resin overlays both decreased significantly, indicating that the shear performance of epoxy resin overlay was severely affected by high temperature. When the temperature reached 60 °C, the shear strength of RS was reduced by 53.2%; when the temperature reached

70 °C, the shear strength dropped by 98.0%. Compared with the shear strength at 20 °C of the RA epoxy resin overlay, its shear strength at 60 °C was reduced by 46.5%; when the temperature reached 70 °C, its shear strength decreased by 93.3%. Nonetheless, the shear strength of the RS epoxy resin overlay was obviously higher than that of the RA epoxy resin overlay at 20 °C and 60 °C, while it was lower at 70 °C. In fact, the RA epoxy resin overlay showed slightly higher high-temperature resistance than the RS epoxy resin overlay due to the smaller decrease percent with test temperature. Overall, the results indicated that the high-temperature performance of epoxy resin overlay was poor. Although the shear resistance of epoxy resin overlay decayed quickly with temperature, it was still higher than the performance of traditional asphalt bonding materials (0–0.2 MPa). The shear failure was generally between the resin and cement board surface, indicating that, at this time, a strong bonding force had not yet formed between the thin layer of this type of resin and the cement board. The reason for this phenomenon was that the high temperature reduced the bond between the epoxy resin overlay and the cement concrete interface, resulting in the epoxy resin overlay spalling from the cement concrete surface more easily at high temperatures [13].

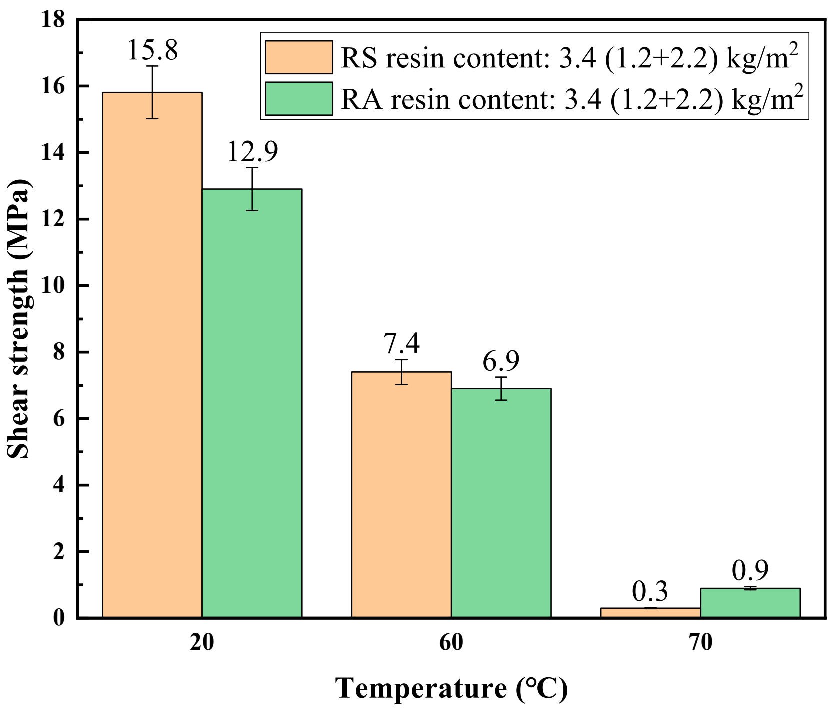

Figure 5. Effect of high temperature on shear resistance of epoxy resin overlay.

(2) Hamburg rutting test results

The Hamburg rut test results are shown in Figures 6 and 7, and Table 3. The Hamburg rut test was conducted under high temperature and water bath conditions by applying repeated steel wheel loads to the specimen [29]. The test termination condition was controlled by two indicators: rolling frequency and rut depth, with a maximum rolling frequency of 20,000 cycles and a maximum rut depth of 20 mm [30]. When the rolling depth reached 20 mm, the test was terminated; if the number of rolling passes reaches 20,000 cycles and the rut depth still does not reach 20 mm, the test will also be terminated. The test piece terminated due to the maximum number of rolling cycles had better high-temperature performance and water damage resistance than the test piece terminated due to the maximum rut depth. If the number of rolling tests reached 20,000 cycles, the smaller the rut depth, the better its high-temperature and water resistance performance; if the number of passes did not reach 20,000 cycles, the higher the number of passes, the better its high-temperature and water resistance performance. Through the results of the

Hamburg rut test, it was found that after 20,000 cycles of the Hamburg rut test, the RS ultra-thin wearing course had a maximum rut depth of 1.73 mm at 60 °C and 0.7 MPa. At the same time, when the number of rolling cycles was 15,000–20,000 cycles, the rolling depth fluctuated significantly, indicating that the RS ultra-thin wearing course had better deformation resistance; the maximum rut depth of RA ultra-thin wearing course at 60 °C and 0.7 MPa was 2.14 mm. Throughout the entire test process, the rolling depth fluctuated greatly with the increase in rolling times, indicating the deformation resistance of the RA epoxy resin overlay. After the experiment, it was found that both types of epoxy resin paving specimens exhibited obvious peeling and particle shedding on the surface, indicating that the coupling of high temperature and water can lead to a decrease in the adhesion ability of the surface, resulting in peeling. The two types of epoxy resin ultra-thin wearing course had a rolling frequency of 20,000 cycles and a lower rolling depth, indicating that epoxy resin overlay had excellent high-temperature performance and water damage resistance; however, further research is needed on its anti-peeling performance. At the same time, the RS epoxy resin overlay had better high-temperature performance and water resistance than the RA epoxy resin overlay.

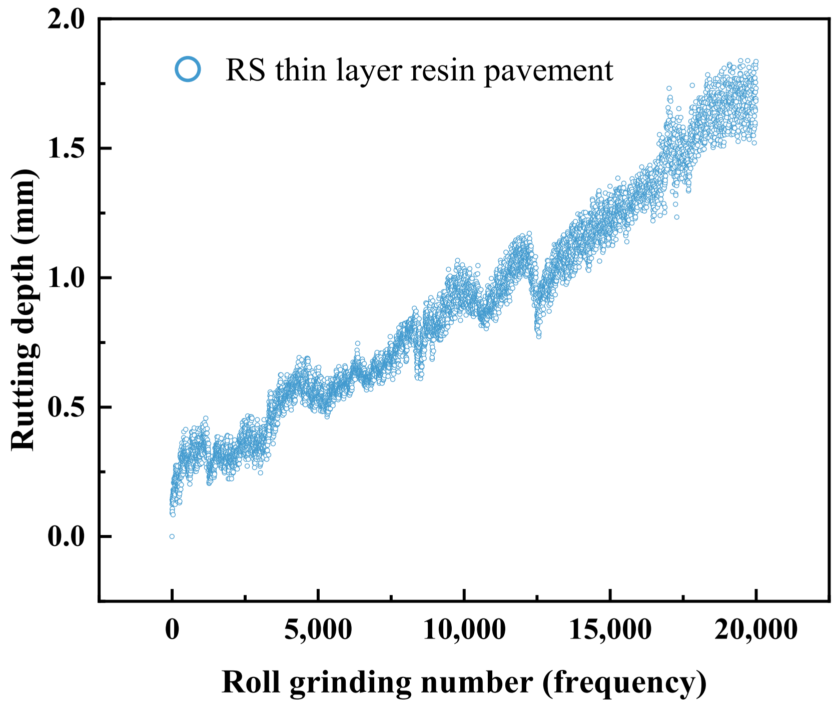

Figure 6. Results of Hamburg rutting test for RS epoxy resin overlay.

Table 3. Hamburg rutting test results.

Materials	Temperature (°C)	Stress (MPa)	Rolling Times (Freq)	Rutting Depth (mm)
RA RS	60	0.7	20,000	1.731 2.142

3.3. Durability Performance Evaluation of Epoxy Resin Overlay

3.3.1. Effect of Damp Heat on Shear Resistance of Epoxy Resin Overlay

The effect of damp heat on the shear strength of epoxy resin overlay is shown in Figure 8. To simulate the effect of summer rainwater on the ultra-thin wear layer, the resin overlay was immersed in a water bath at 60 °C for 48 h; then, we conducted shear performance tests at temperatures of 20 °C and 60 °C. Compared with the shear strength results in the air bath (see Figure 5), it was found that the shear strength of both epoxy resin overlays after water immersion was reduced, especially at 60 °C, indicating that the water immersion caused the shear strength decline due to the water damage to the overlay interface. As for the couple impacts of damp heat, the shear strength at 60 °C of the RS epoxy resin overlay dropped by 73.4% compared with the shear strength at 20 °C, and the shear strength at 60 °C of the RA epoxy resin overlay decreased by 74.6%. Obviously, the damp heat led to more significant shear strength loss than the overlay specimens without damp heat. Moreover, the RS epoxy resin overlay showed similar damp heat resistance to the RS epoxy resin overlay according to the close decrease percent.

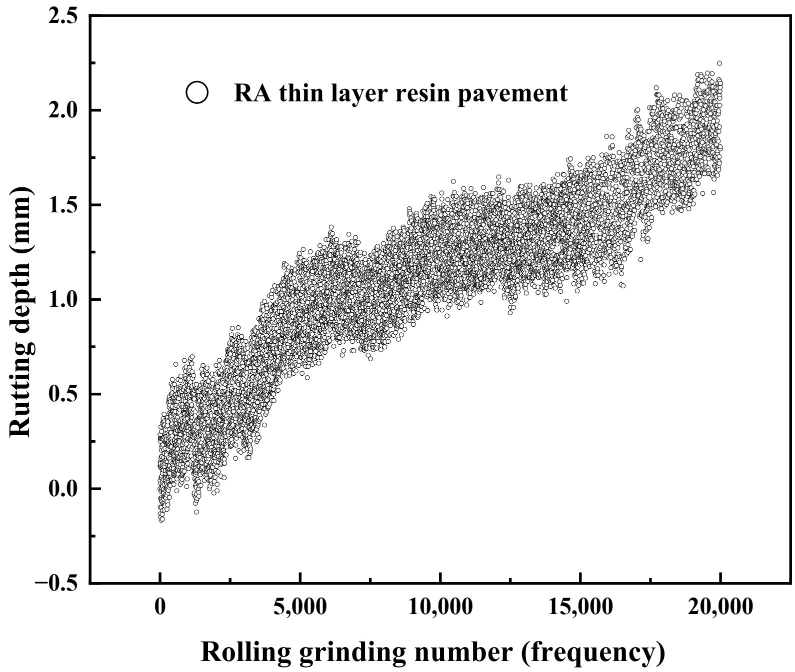

Figure 7. Results of Hamburg rutting test for RA epoxy resin overlay.

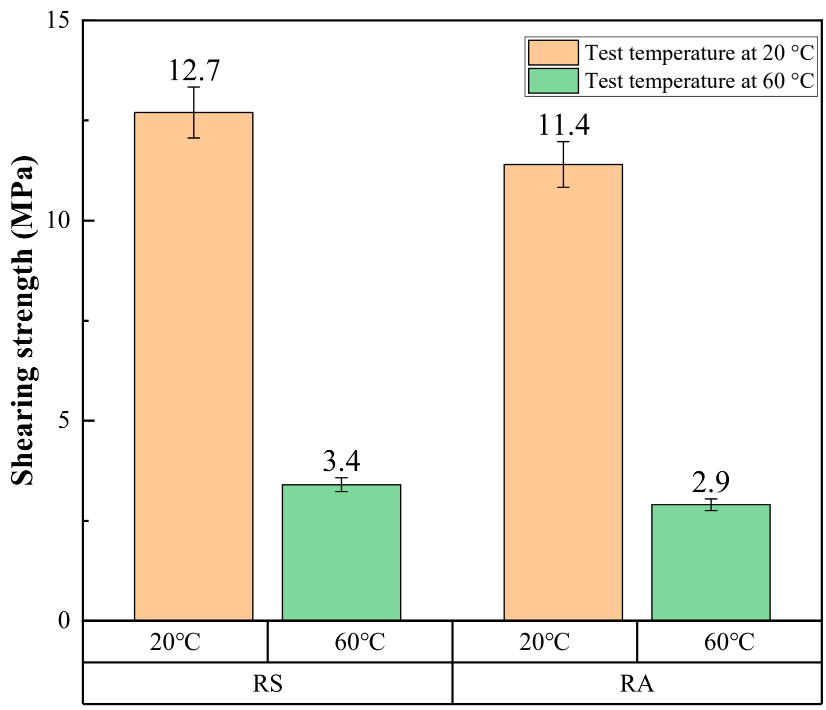

Figure 8. Effect of damp heat on shear strength of epoxy resin overlay.

3.3.2. Effect of Thermal Oxygen Aging on Shear Resistance of Epoxy Resin Overlay

The effect of thermal oxygen aging on the RS epoxy resin overlay is shown in Figure 9. High-temperature thermal and oxygen aging was one of the most important factors in the aging of resin material properties. Resin materials exposed to long periods of high-temperature air were susceptible to oxidation, degradation, cross-linking, or creep damage, resulting in a reduction in bond strength. The test was carried out on resin thin-layer specimens aged at 60 °C in an oven for 7, 14, and 28 days and tested for shear resistance after aging. The results showed that the shear strength of the RS resin laminate decreased significantly as the aging time increased, with an 8.3%, 25.7%, and 62% reduction in the shear strength of the specimens after 7, 14, and 28 days of aging, respectively, compared to the unaged test. This indicates that aging over a short period of time does not have a significant impact on shear resistance. However, aging over a long period of time had a serious impact on the shear resistance based on the significant reduction in the bonding properties of the epoxy resin, which can be attributed to the long-term aging induced structural damage of the resin material. The effect of thermo-oxidative aging on the epoxy resin overlay mainly occurred on the surface. With the increase of aging time, the effect of thermo-oxidative aging was gradually strengthened, and the macroscopic manifestation was the reduction in bonding performance and aggregate spalling. After aging, the different shear resistance test temperatures also had a significant effect on the shear strength of the RS resin paving. The aging shear resistance was tested at 20 °C and 60 °C to evaluate the shear strength decay at room temperature and high summer temperatures, respectively. At 60 °C, the shear strength decreased by 16.2%, 34.1%, and 71.4%, respectively, with increasing aging time. It can be found that aging has a more significant effect on high-temperature shear performance. Results indicated that the resin material a had further reaction at the initial stage of high temperature, so short-term aging has a lesser effect on the shear performance; however, the time aging and high temperature have more effect on the shear performance of this epoxy resin ultra-thin wearing course overlay. With the continuous increase in aging duration and aging temperature conditions, the adhesion will decompose due to oxidation and its shear strength will gradually decrease, with the decreasing trend gradually increasing, which seriously reduces the bonding performance of the epoxy resin overlay.

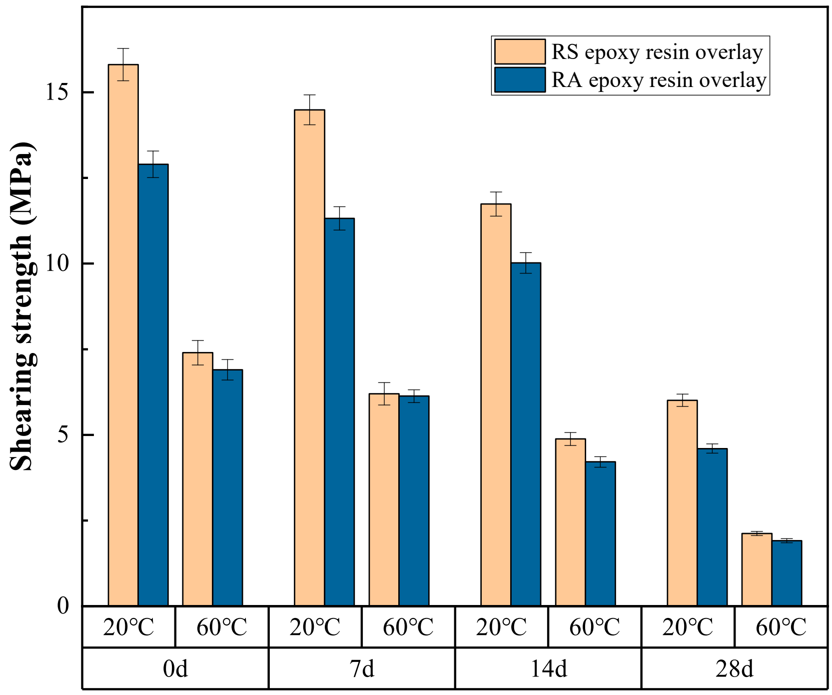

Figure 9. Effect of thermal oxygen aging on the shear strength of epoxy resin overlay.

The shear strength of the RA epoxy resin overlay decreased substantially as the aging time increased, with the shear strength of the specimens decreasing by 12.2%, 22.3%, and 64.3% after 7, 14, and 28 days of aging, respectively, relative to the unaged test. This indicates that aging had a greater effect on shear resistance in a shorter period of time; however, the severity of the effect on shear resistance increased over a longer period of time, mainly due to the significant reduction in bonding properties of the epoxy resin as a result of aging. After aging, the shear strength of RA resin paving was significantly affected by thermal oxygen aging at high temperatures. The shear strength decreased by 11.1%, 39.0%, and 72.3%, respectively, as the aging time increased in the test environment of 60 °C. The effect of aging on the high-temperature shear performance of the RA thin-layer resin overlay was even more significant, severely reducing the bonding performance of the overlay. Additionally, the RS epoxy resin overlay had superior thermal oxygen aging resistance to the RA epoxy resin overlay.

3.3.3. Effect of UV Aging on the Shear Resistance of Epoxy Resin Overlay

The effect of UV aging on the shear resistance of RS resin overlay is shown in Figure 10. Ultraviolet light is one of the main natural factors that causes the aging of resinous thin-layered paving. UV light degrades epoxy resins because the aromatic structure of epoxy resins is susceptible to UV light absorption and oxidation. As a polymeric material, the bond between the resin and the aggregate is easily weakened by UV light, which causes the aggregate to fall off and affect the durability of the resin paving. The shear strength of the RS resin overlay decreased by 25.1%, 36.1%, and 81.9% at 20 °C after 7, 14, and 28 days, respectively. The interlayer shear resistance of the RS resin overlay showed a significant decrease with the increase in UV aging time, and the bonding performance decayed significantly. UV aging had a significant effect on the bonding shear resistance of the epoxy resin ultra-thin wearing course overlay. In order to simulate the simultaneous effect of high temperature and UV aging in summer, the shear resistance of the RS thin-layer resin overlay samples treated with different UV aging times was tested at 60 °C. After 7, 14, and 28 days of UV aging, their shear strength at 60 °C was reduced by 13.8%, 37.3%, and 86.8%, respectively. The results show that the combination of extreme temperature and UV aging leads to a significant reduction in the shear strength of the RS epoxy resin overlay, especially at 28 days. Compared with thermal-oxidative aging, the shear resistance decreased more significantly after UV aging, and the effect of UV aging on the shear resistance of the RS resin overlay was also significant. As the UV aging time increases, the surface of the epoxy resin continues to become rough and is accompanied by the emergence of wrinkles, surface layer peeling, hole generation, and other phenomena. This resulted in a decrease in the bonding ability between the epoxy resin and the aggregate, and between the epoxy resin and the cement concrete interface.

The shear strength of RA resin overlay decreased by 6.12%, 30.1%, and 69.6% at 20 °C after 7, 14, and 28 days, respectively. The shear resistance of the RA resin overlay showed a significant decrease with the increase in UV aging time, and the bonding performance decayed significantly. In order to simulate the effects of high temperatures and UV aging in summer, the shear resistance of the RA thin-layer resin overlay samples treated with different UV aging times was tested at 60 °C. After 7, 14, and 28 days of UV aging, their shear strength at 60 °C was reduced by 8.7%, 54.5%, and 90.9%, respectively. The results show that the coupled effects of high temperature and UV aging caused a significant reduction in the interlayer shear resistance of the RA epoxy resin overlay. Moreover, the results from the decrease percent further confirmed that the RS epoxy resin overlay had superior UV aging resistance to the RA epoxy resin overlay.

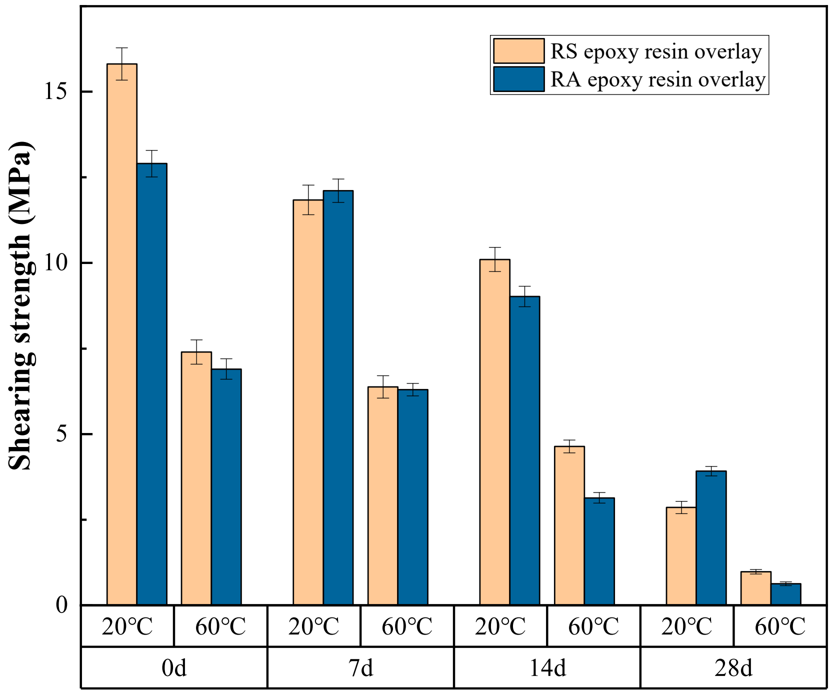

Figure 10. Effect of UV aging on shear strength of epoxy resin overlay.

4. Conclusions

(1) Through shear tests, it was found that the shear strength of epoxy resin overlay grew with the increase in epoxy resin content, and the optimal content was set as 3.4 kg/m^2. The Hamburg rutting test results showed that the epoxy resin overlay exhibited satisfactory high-temperature performance and water resistance, and the RS epoxy resin overlay had better high-temperature performance and water resistance than the RA epoxy resin overlay. Moreover, the shear performance of the epoxy resin overlay was severely affected by high temperature.

(2) Compared with the overlay specimens without damp heat, the damp heat led to more significant shear strength loss. The shear strength of both epoxy resin overlays after water immersion was reduced, especially at 60 °C, indicating that the water immersion caused the shear strength decline due to the water damage to the overlay interface. Moreover, the RS epoxy resin overlay showed similar damp heat resistance to the RS epoxy resin overlay.

(3) As for the thermal oxygen aging effect, it was reflected that the short-term thermal oxygen aging had a minor impact on the shear performance of the epoxy resin overlay. However, with the increase in thermal oxygen aging duration, the shear strength of epoxy resin overlay significantly decreased, especially at 60 °C, due to the aging of epoxy resin binders. The shear strength at 60 °C of the RS and RA epoxy resin overlays decreased by 71.4% and 72.2%, respectively, after 28 days of aging. Additionally, the RS epoxy resin overlay had superior thermal oxygen aging resistance to the RA epoxy resin overlay.

(4) Regarding the UV aging impact, it was also found that the shear performance of epoxy resin overlay rapidly decreased as the UV aging duration grew, whether at 20 °C or 60 °C. After 28 days of UV aging, the shear strength of the RS and RA epoxy resin overlays decreased by 86.8% and 90.1%, respectively. Moreover, the UV aging led to a more significant impact on the shear performance of the epoxy resin overlay than thermal oxygen aging, and the RS epoxy resin overlay had superior UV aging resistance to RA epoxy resin overlay.

Overall, the epoxy resin ultra-thin wearing course overlay has excellent high-temperature performance and durability and can be used as a long-term, high-performance pavement structure. In the future, in-depth research can be conducted on the anti-peeling performance of the epoxy resin ultra-thin wearing course overlay under different aging and temperature conditions in order to provide the design and construction of the epoxy resin ultra-thin wearing course overlay and compose a reference for cement concrete pavement engineering.

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