Study on the Effect of Porous Additives on the Hydrophilicity and Mechanical Properties of Epoxy-Based Absorbent Surface Layers

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Abstract. This study involves the preparation of epoxy-based pervious surface materials by mixing snow-white sand with epoxy resin in the range of 10~20 mesh. During the research process, it was observed that the self-made permeability agent T20 significantly reduced the contact angle of the adhesive material. Moreover, at a dosage as low as 1.67%, T20 notably improved hydrophilicity while hardly affecting the strength. However, as the dosage increased, the enhancement in hydrophilicity became less significant and substantially decreased the strength. Furthermore, water-thermal aging tests revealed that the reduction in strength due to water-thermal environmental aging was much greater than the impact of the permeability agent T20 on strength. This finding provides preliminary insights into the mechanical property changes of epoxy-based pervious surfaces under water-thermal conditions, offering a new perspective for enhancing the strength of epoxy-based pervious surfaces under such conditions.

Keywords: water-friendly modification; microporous permeability; sand-based surfaces; adhesives; epoxy resins

1 Introduction

In response to the developmental needs of urban environments and to promote the construction of "sponge cities," various permeable pavement materials, such as permeable concrete and permeable bricks, have been successively introduced to the market. Meanwhile, traditional permeable pavement materials composed of cement and aggregates have been criticized for problems such as surface cracking, alkali efflorescence, and short effective service life, resulting in poor aesthetics and durability[1][2][3]. To improve the artistic effect and enhance the durability of permeable pavement, Wang Haifeng[4] utilized natural colored sand as aggregates and a two-component epoxy resin as the adhesive material to develop a new type of environmentally friendly permeable

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pavement material, addressing the issues of aesthetic appearance and durability in permeable pavement. However, the inherent hydrophobicity of epoxy-based materials tends to diminish the permeability of pervious pavement surfaces[5]. Moreover, research on hydrophilic modification of epoxy-based pervious surfaces remains scarce. This paper aims to address this gap by investigating the hydrophilic modification of adhesive materials using permeability agents. The study focuses on the mechanical properties of pervious surface materials under water-thermal aging conditions. The goal is to enhance permeability while ensuring excellent mechanical properties of the pervious surface materials. This research seeks to fill the void in the field of hydrophilic modification and wet-thermal aging studies of epoxy-based pervious pavement materials.

2 Raw Materials and Tests

2.1 Raw Materials

(1) Adhesives

Adhesive A component: epoxy resin E51: viscosity 11500~15000mPa·s, epoxy value (eq/100g) 51~54; gcidyl ether active diluent: viscosity 40~80mPa·s, epoxy value (eq/100g) 0.35~0.40.

Adhesive B component: Self-made amine curing agent, the main components are modified polyether amines, with a viscosity of 30±10 mPa·s (25°C), an amine value of 400~500 (mgKOH/g), and a colorless to pale yellow transparent liquid.

The adhesive material ratio: adhesive component A: adhesive component B = 11: 3.

(2) Filler

The use of inorganic fillers can improve the bonding properties of epoxy adhesives by reducing intermolecular cohesion and increasing adhesion. Considering the special requirements for pavement preparation involving the mixture of adhesives and aggregates, there is a high demand for the abrasion resistance of the adhesive. Glass powder, primarily composed of SiO2, enhances the abrasion resistance of aggregates. Additionally, when mixed with adhesive materials, glass powder presents a transparent appearance, allowing the original color of colored sand to be visible. Therefore, this study selects glass powder as the filler. The main technical specifications of the filler are shown in Table 1.

Table 1. Main technical specifications of filler

packing material	base	Bulk density (g/cm^3)	specific surface area	average diameter	exterior condition	quantity contained
glass powder	SiO2	2.7g/cm³	5.1m²/g	7um	White powder	≥99%

(3) Permeability aids

The permeable agent T20 is a self-made non-ionic surfactant, it is both hydrophilic and oil-friendly.

(4) Aggregate

The main component of 10~20 mu snowflake sand is SiO2, Mohs hardness is 3.5~4.0 so it is suitable for pavement material; particle size is 850~1700 μm, can achieve the pore only dozens of microns, play anti-blocking effect; the color is white and clean, easier to compare the color change after hydrothermal aging. The main technical specifications of aggregates are shown in Table 2.

Table 2. Main technical specifications of aggregates

Aggregate type	Apparent density/(g/cm³)	Bulk density/(g/cm³)	Stacking porosity/%	Crushing value/%	Water absorption/%
snow white sand	2.75	1.710	35.12	13	0.04~1.4

2.2 Test Conditions

This paper uses a hydrothermal aging test to simulate the actual road environment[6][7][8]. The rationale behind this method stems from the comparative study conducted by Wang[9] on different evaluation methods for the wet heat durability of epoxy resin. The results revealed that the test results after 7 days of accelerated boiling aging were comparable to those of the conventional wet heat aging for 900 days. Therefore, to effectively shorten the testing period, the accelerated boiling aging method can be utilized for screening the wet heat durability performance of epoxy resin adhesives.

Hydrothermal aging is divided into wet-heat conditions and wet-dry cycle conditions.

(1) Moist heat condition: 70°C water bath immersion for 7d.

(2) Dry and wet cycle conditions: 50 °C dry (6h) + 70 °C water bath immersion (18h) for a dry and wet cycle, for seven cycles.

(3) After hydrothermal aging for 7d, the specimens were tested for flexural and compressive strength after being placed in an oven at 50°C for 24h. The reference group specimens were tested at the same age as the hydrothermal aging specimens.

2.3 Sample Preparation and Determination of Contact Angle and Mechanical Properties

2.3.1 Sample Preparation

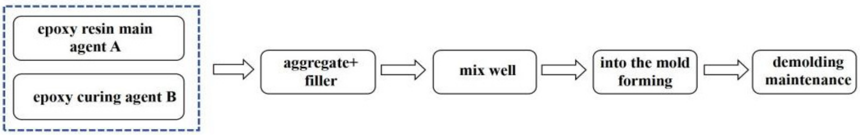

Fig. 1. Flow chart of specimen preparation

Table 3. Group allocation ratio of the water surface layer

Material name	10~20mesh aggregates / g	Adhesive (aggregate mass fraction)/%	Filler (adhesive quality fraction)/%
dosage	1000	5	40

According to the proportion of weighing and mixing the adhesive added the mixer and filler, aggregate mixing about 5min; after the mixture was loaded into the mold (Figure 1, Table 3), the specimen was shaped by layering and intermixed with manual compaction to ensure the compactness of the aggregate[10]. The quality error of each mold filled with the mixture was not more than 5%; the specimen was taken out of the mold at room temperature at 20±2°C for 24h and then placed in an oven at 70°C for 24h and then cooled down to carry out hydrothermal test.

2.3.2 Determination of the Contact Angle and the Mechanical Properties

Contact Angle Test: In this paper, the contact angle is referred to as GB/T 30693-2014 'plastic film and water contact angle', and the image processing software Image J is utilized for the measurement of the contact angle.

Mechanical properties test: refer to GB/T 17671-2021 'Cementitious Sand Strength Test Method (ISO Method)', the microporous permeable surface layer material is prepared into 40mm×40mm×160mm size for mechanical properties test.

3 Results and Discussion

3.1 Effect of the Amount of Water-Permeable Additives on the Contact Angle of Adhesive Materials

The epoxy resin reacts with the homemade non-ionic surfactant T20, wherein the epoxy resin retains one end of the epoxy group, and the hydroxyl group of the non-ionic surfactant reacts with one end of the epoxy resin molecule through grafting reaction forming an ether bond with the C-O-C group as the backbone[11]. This process fixes the hydrophilic groups as side chains on the resin, ensuring good hydrophilicity of the adhesive even after resin curing.

The size of the contact angle can be used as one of the indicators for evaluating the size of the surface polarity; the smaller the contact angle of the material, the stronger the wettability and the better the hydrophilicity of the surface of the material (Figure 2).

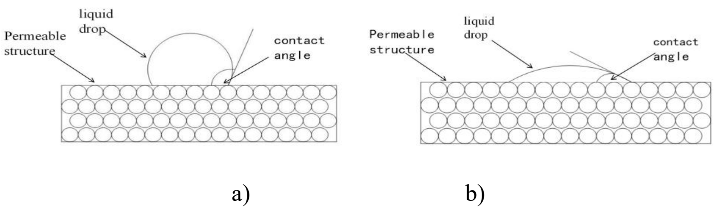

Fig. 2. Schematic diagram of contact angle

Table 4. The dosage of T20 and the contact angle of the adhesive material

T20 share/%	Contact angle/°	Drop infiltration time/s
0.00	65.0	8
0.42	56.5	1
0.83	45.4	0.5
1.67	41.5	0
3.33	31.2	0
6.67	33.6	0
13.33	30.3	0

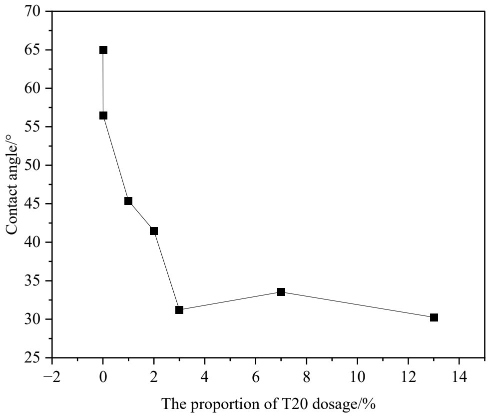

Fig. 3. Effect of T20 dosage on the contact angle of adhesive materials

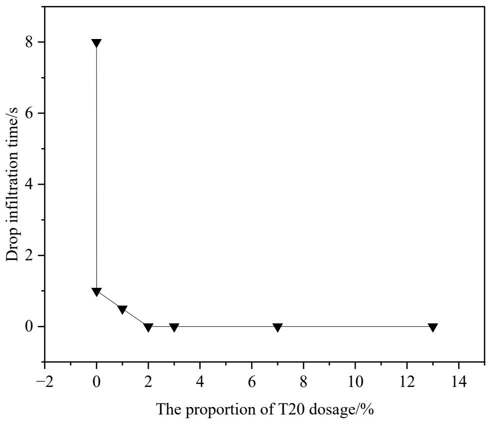

Fig. 4. Effect of T20 dosage on the time of droplet infiltration

Based on the results from Table 4 and Figure 3, it is evident that the hydrophilicity improvement effect of the permeability additive T20 is significant as its mass fraction increases from 0.42% to 13.33%. Particularly, within the range of addition from 0.42% to 3.33%, the contact angle decreases significantly, reaching a minimum of 31°. When the mass fraction is approximately 3.33%, the contact angle remains at around 30°. By preparing samples by mixing hydrophilically modified adhesive materials with colored sand aggregates and conducting water droplet tests, it was found that the infiltration time decreased from 8 seconds to 1 second when the addition was 0.42%, further reducing to 0 seconds with an increase in dosage to 1.67%. This phenomenon aligns with the trend of contact angle variation of the adhesive material (Figure 4). Therefore, it can be concluded that at lower addition levels, T20 exhibits a prominent effect in enhancing permeability.

3.2 Effect of Permeable Aid Dosage on the Mechanical Properties of Permeable Surface Layer Materials

Table 5. Effect of the T20 dosage on the mechanical properties

Condition T20 usage/%	G[a]		W[b]				D+W[c]			
	B[d]/MPa	C[d]/ MPa	B/M Pa	B-R[e]/%	C/M Pa	C-R/%	B/M Pa	B-R/%	C/M Pa	C-R/%
0	7.8	21.5	6.0	76.5	17.8	82.9	5.5	70.4	16.8	78.0
0.42	7.6	22.7	5.9	77.2	18.7	82.5	5.3	70.2	16.6	73.1
0.83	7.7	22.5	5.7	73.0	17.5	77.7	5.3	68.5	16.6	74.0
1.67	7.5	22.1	5.6	73.7	16.7	75.3	5.2	69.1	16.4	74.0
3.33	7.3	20.5	5.2	71.2	15.6	76.1	4.9	66.4	14.1	68.7
6.67	6.8	18.6	4.7	69.1	14.1	75.5	4.4	64.7	12.2	65.6
13.33	4.6	16.6	3.3	70.7	12.1	73.1	3.2	69.8	10.2	61.7

a. Reference group, average conservation, denoted by G.
b. Moisture-heat aging, denoted by W.
c. Dry and wet cycle aging, denoted by D+W.
d. Letter B is bend strength; letter C is compressive strength.
e. The letter R is the strength retention rate.

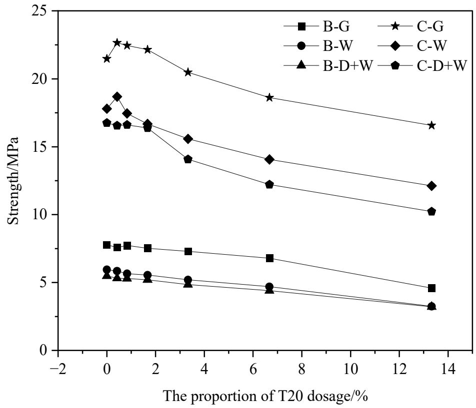

Fig. 5. Effect of T20 dosage on strength

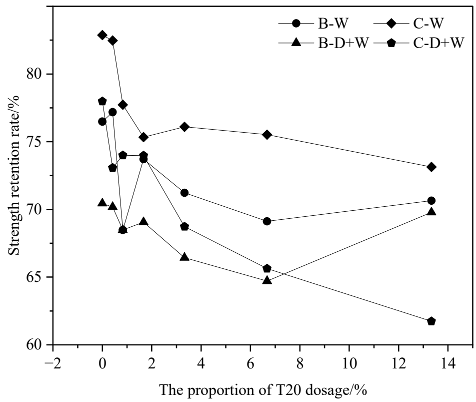

Fig. 6. Effect of T20 dosage on strength retention

The results from Table 5 and Figure 5 indicate that in the reference group, the strength of the specimens shows a trend of initially stabilizing and then gradually decreasing as the dosage of the permeability additive T20 increases. Within the range of T20 addition from 0% to 1.67%, the influence of T20 addition on the strength of the specimens is minimal, with a slight decrease in strength ranging from 7.53 MPa to 7.80 MPa for flexural strength and from 21.48 MPa to 22.65 MPa for compressive strength. However, within the range of T20 addition from 3.33% to 13.33%, the increase in T20 significantly affects the strength with a greater reduction in magnitude. The flexural strength decreases from 7.53 MPa to 4.60 MPa, and the compressive strength decreases from 16.68 MPa to 12.12 MPa. This may be attributed to the relatively small initial dosage of T20, which does not impact the curing graft reaction of epoxy resin. However, with the increase in dosage, a large number of active agent molecules solidify on the side chains of the resin cross-linking network, negatively affecting the three-dimensional adhesive network and thereby leading to a decrease in strength of the specimens. As the dosage of T20 gradually increases, the strength of the specimens under the three curing conditions exhibits a pattern of initial slight stabilization followed by rapid decline. The three curves demonstrate a parallel trend, with the overall strength reduction during dry-wet cycles being greater than that during wet-heat conditions. This indicates that the alternating temperature and humidity have a more significant impact on material performance degradation, which is consistent with the results obtained by KO[12] as well as the studies conducted by Wang[13] and Jedidi[14] using temperature and humidity alternating accelerated cycling methods.

According to the results from fig 6, within the range of T20 dosage from 0% to 13.33% under wet-heat and dry-wet cycle conditions, an increase in T20 dosage leads to a decrease in strength retention rate. Under wet-heat conditions, the retention rates of flexural and compressive strengths decrease from 76.5% to 70.7% and from 82.8% to 73.1%, respectively. Under dry-wet cycle conditions, the retention rates of flexural and compressive strengths decrease from 70.4% to 69.8% and from 78.0% to 61.7%, respectively. This phenomenon can be attributed to the sensitivity of polymers to moisture absorption. Resin molecules can interact with water molecules, thereby disrupting the hydrogen bonds between the molecular chains, increasing chain mobility, and reducing fracture stress[15]. With the addition of permeability additives, this process becomes more pronounced within the three-dimensional adhesive structure of epoxy resin.

4 Conclusion

The optimal dosage of the self-made permeability agent T20 for hydrophilic modification of adhesive materials is found to be 1.67%, which has minimal impact on the strength of the pervious surface layer. As the dosage of T20 increases, both the strength and strength retention rate of the microporous pervious surface layer decrease. This decline becomes more pronounced, especially when the dosage exceeds 3.33%. Through orthogonal comparison experiments on changes in contact angle and strength, it is demonstrated that there is an optimal dosage of T20, namely 1.67%. Water-thermal conditions negatively impact the mechanical properties of the pervious surface layer, resulting in a certain degree of strength loss when the pervious surface layer is used under water-thermal conditions. This can serve as an indicator for comparing and analyzing the strength loss rates of different types of adhesives prepared for pervious surface layers under more realistic service conditions of water-thermal aging. Consequently, more resilient adhesives or curing agents resistant to water-thermal aging can be selected, significantly expanding the range of epoxy-based materials for use in pervious pavements, from sidewalks and park roads to driveways. In the future, by analyzing the microstructure of T20 additives, further investigation into the mechanism underlying their hydrophilic effects will be conducted. This research aims to develop new additives that enhance hydrophilic effects more prominently and are more economically viable.

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