STUDY OF THE ROAD PERFORMANCE OF WATERPROOF MATERIALS FOR CONCRETE BRIDGE DECKS

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ABSTRACT

Through the analysis of the performance requirements of waterproof materials for asphalt concrete pavements on concrete bridge decks, this paper presents two key properties for evaluating waterproof materials, namely bond property and shear property. Based on the results of 'pull-out' testing and LLM testing, it is shown how these properties are influenced by material composition, ambient temperature and the condition of the concrete surface; this provides a scientific basis for the design and construction of waterproof materials.

Keywords: Waterproof material, Concrete bridge deck, Bond properties, Shear properties, laboratory testing

1. INTRODUCTION

Due to a number of factors, including the rusting of steel and the carbonation of concrete, bridges often require reinforcing work or even reconstruction well before the end of their design lives. The rusting of steel is probably the main factor leading to bridge damage, as has been indicated by surveys on bridge durability and statistical data from both China and many other countries (Martinelli, 1996; NCHRP, 1995).

The main reason for the rusting of steel is the infiltration of erosive solutions, especially those containing chloride ions (Cl+). Rain, air pollution, de-icing salt during winter maintenance and an erosive environment (in the case of sea bridges, etc.) all contribute to the risks of rusting of steel, and air voids in concrete and deck paving materials provide the passageway for these erosive solutions into the bridge structure.

The damage caused by the rusting of steel in bridge decks was first recognised in the US in the 1960s. An initial investigation indicated that water and de-icing salt were the main factors responsible for the freeze-thaw damage of concrete and the rusting of steel in bridge decks, which accordingly called for higher quality and thicker layers of concrete bonding materials, or even speciality techniques for protecting bridge decks. As a result, waterproof membranes (flexible, waterproof materials paved on bridge decks) began to be used in bridge deck paving. In July 1972, 14 OECD countries published a research report summarising the situation and the methods adopted by member countries to waterproof bridge decks, and proposed technical specifications for testing the materials in use.

Since the early 1980s, China has gradually acknowledged the rusting of steel and the need to use waterproof materials in bridge decks. Yet no systematic study was performed regarding relevant techniques; activities simply followed the instructions from the material suppliers – even though the material itself was manufactured mainly for house-roofing purposes.

Through investigation, the author (Pei, Jian-zhong, 2001) identified quite a few problems in the currently limited practice of waterproofing bridge decks: (1) lack of specifications and lack of awareness of the need for integration in the design process; (2) selection of materials on the basis of experience and performance claims from commercial suppliers, the credibility and service quality of which vary significantly; (3) only a few physical properties having been tested in laboratory work, with minimal specification of road performance and resistance to construction damage; (4) simple or even no steps being taken during construction for deck surface treatment, although according to the author's investigation, roughness, water content and dust impurity can all have an effect on the waterproof properties.

For these reasons, a systematic study on the properties of flexible waterproof materials, especially the bond and shear properties between the concrete bridge deck and the asphalt paving layer, was sorely needed.

2. REQUIREMENTS FOR WATERPROOF PAVING MATERIALS ON BRIDGE DECKS

- Ability to maintain impermeability throughout service life
- Strong bond with surfacing layer and bridge deck
- Resistance to damage induced by concrete cracks when paved on bridge decks
- Good durability
- Resistance to sheer stress imposed by (braking, accelerating, cornering) vehicle wheels
- Resistance of aggregates to breakdown under heavy traffic
- Resistance to water or solution erosion
- Adaptability to changes in temperature.

3. ASSESSMENT CRITERIA AND METHODS

The experiments discussed in this paper were concerned with the working environment that waterproof materials may be subjected to when used on bridge decks, including horizontal and vertical stress, dynamic loading, impact and vibration due to surface irregularity, and temperature changes with time and season. The physical and chemical reactions between waterproof materials and other paving structures (e.g. surface course, base course) were also investigated. The tests were therefore aimed at evaluating the long-term properties of waterproof materials. Among those properties, bond property and shear property are the most important, and were studied in detail.

4. TESTS FOR BONDING PROPERTIES

To test the adhesion of waterproof materials to concrete decks and asphalt surfacing, and the mechanism of damage where the bond strength is insufficient, bonding properties are evaluated by means of the 'pull-out' test instrument (see Figure 1).

Test results are measured in bond strength: $g = F / S$

Where:

g = bond strength (N/m^2)
F = tensile force (N)
S = transverse area (m^2).

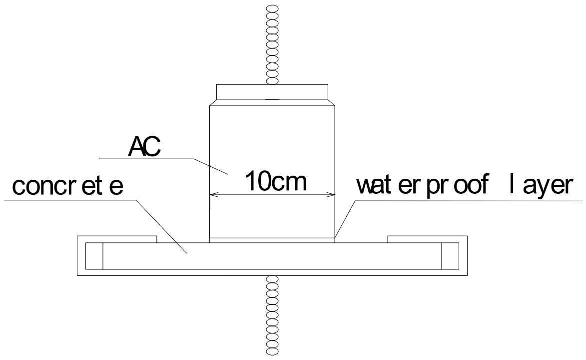

Figure 1. 'Pull-out' test device.

5. TESTS FOR SHEAR PROPERTIES

According to a field survey, the stripping of material particles is the main mechanism for the surface failure of asphalt paving on concrete bridge decks. This is often due to the insufficient shear resistance of paving layers to horizontal stress. Therefore, simulation tests are performed in the laboratory to determine how the shear strength of waterproof materials and the test conditions affect the shear properties of materials. The results could be referred to for material selection and structural design.

The LLM testing system, developed at Chang'an University, is adopted in evaluating the test results. The mechanical parts are responsible for loading onto the test specimen, which has three sensors attached to it. Two sensors are used to measure vertical and horizontal stress, the other to measure shear displacement. These sensors are all connected to a data collector, which controls the whole process by means of a specialised program and is used to store, calculate and analyse the data collected. The purpose of the environmental system is to ensure that the test specimen is kept at a specified temperature (see Figure 2).

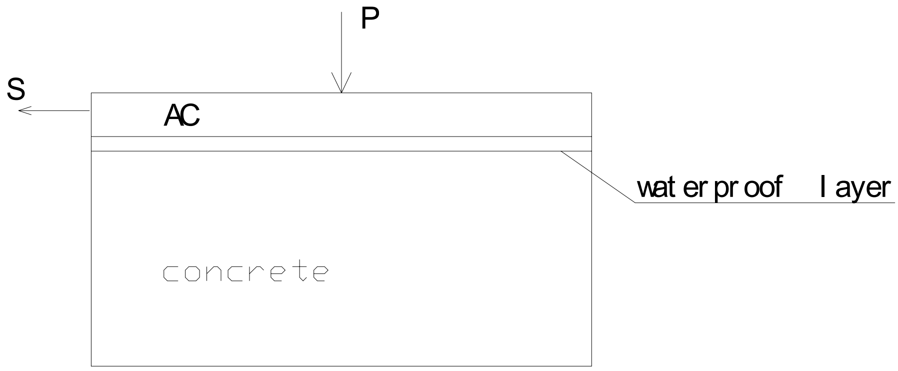

Figure 2. Shear testing model.

There are two methods for analysing the test results:

1. *Ks modulus analysis*

The relation between shear stress and displacement could be indicated by the Goodman hypothesis:

$$\tau = K_s \triangle U$$

Where Ks is the interface shear coefficient and can be determined by the modulus, which in turn can be calculated by tangent through the point-of-origin modulus, the secant modulus and the tangent modulus. The secant modulus, the tangent value of the secant connecting a certain point with a stress of τ_0 (in most cases: $\tau_0 = 0.5\tau max$) and the point of origin, is relatively easier to calculate with precision and objectivity.

$$K_s = \tau_0 / \triangle U_0 = tg\,\varphi$$

2. *Shear strength analysis*

The shear stress can be calculated as below:

$$\tau = \frac{F}{S}$$

Where:

τ= shear stress (Pa)

F = tensile strength (N)

S = shear area (m^2).

6. MATERIALS SELECTION

The details of the test materials are shown in Table 1.

Table 1. Details of the test materials.

Material code	Material description	Type
APP	3 cm, covered with stone chips	APP-modified asphalt sheet, China
Sd/Sp	Covered with 3 mm protection plate	Asphalt base coating film, USA
FYT		Asphalt base coating film, China
B5300		Asphalt base auto-adhesive sheet, USA

7. BOND TEST RESULTS AND ANALYSIS

7.1 Bond Strengths of the Different Materials

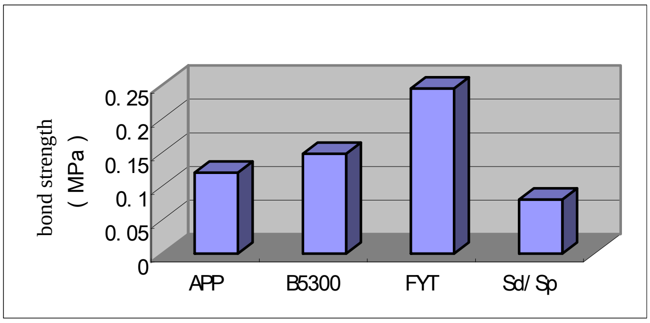

Figure 3. Bond strengths of the different materials.

As indicated in Figure 3, bond strength varies significantly among different materials. FYT, a coating film, has the highest strength, while Sd/Sp, a coating film with a protection plate, has the lowest strength. In FYT, the fracture starts with the tearing open of glass fibres. In the 'pull-out' process with Sd/Sp, the concrete and waterproof material layers are still connected to thin films even when torn apart as much as 5 cm, which indicates the superior ductility of the material.

7.2 Bond Strengths with Changes in the Temperature

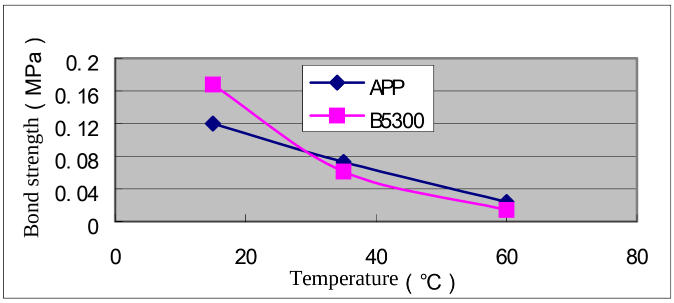

Figure 4. Bond strengths with changes in the temperature.

Asphalt-base waterproof materials are temperature-sensitive. The bond strength of both materials used in the test decreases significantly as the temperature increases; the strength at 15^{o}C is 5 and 10.6 times that at 60^{o}C, respectively. The curve shows a downward slope, which means that the decrease in bond strength with a drop in temperature slows down as the temperature increases. In addition, the temperature sensitivity of modified materials changes as the type and composition of the base bitumen and modifier mixture differ. The test results are shown in Figure 4.

7.3 Bond Strength with Changes in the Concrete Surface

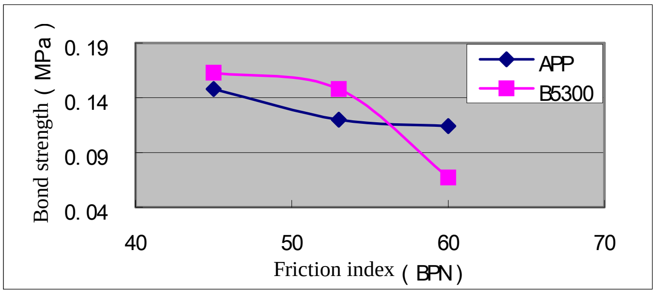

Figure 5. Bond strength with changes in the concrete surface.

Due to the difference in roughness of concrete surfaces, contact areas between the waterproof materials and concrete vary, resulting in different bond strengths. Rougher concrete surfaces are supposed to have less contact area with waterproof materials and thus there should be less bond strength between them. However, the results from direct-shear tests indicate otherwise, a finding that merits further research. The test results are shown in Figure 5.

7.4 Rebonding Ability of the Different Materials

A series of experiments was designed to test the ability to rebond between waterproof materials and the concrete base under normal temperatures. The test results indicate that in most cases, sheet materials have about half the bond strength after rebonding, while coating film materials lose almost all their bond strength once torn apart from the concrete. As indicated in Figure 6, the rebonding ability decreases with the aging of materials; thus quality control is of great importance when paving with these materials, for reasons of durability.

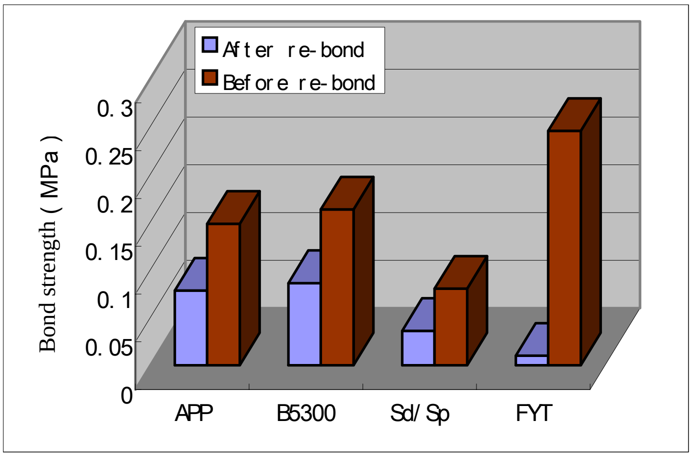

Figure 6. Rebonding ability of the different materials.

8. SHEAR TEST RESULTS AND ANALYSIS

8.1 Shear Strength with Changes in the Condition of the Concrete Surface

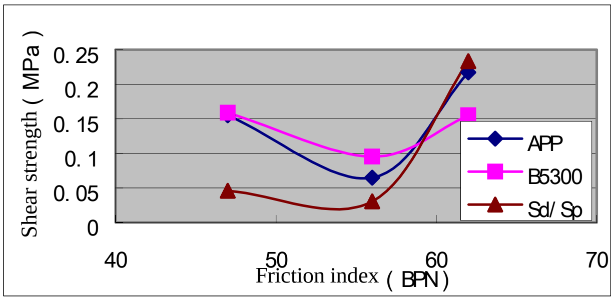

Figure 7. Shear strength with changes in the condition of the concrete surface.

As indicated in Figure 7, for each surface property, there is a minimum value of shear strength and that usually shows on an untreated surface. The reasons for this could be (a) the laitance at the top of the concrete surface has a low bond strength and will be torn apart under horizontal shear stress, or (b) dust on the concrete surface decreases the bond strength. At the same time, different waterproof materials provide varied levels of shear strength and should therefore be applied under different surface conditions, with appropriate surface treatments.

8.2 Shear Strength with Changes in Temperature

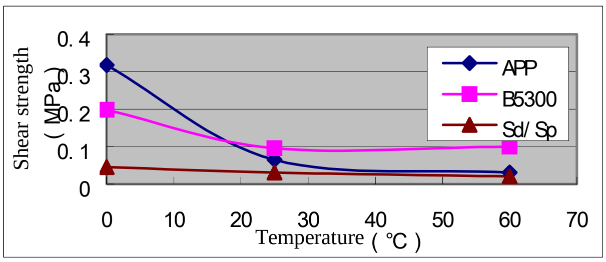

Figure 8. Shear strength with changes in temperature.

As indicated in Figure 8, different materials vary with regard to their temperature sensitivity. APP-modified asphalt sheet materials and Sd/Sp series materials have the highest and lowest sensitivities, respectively. An important assessment criterion for a material is to gauge its shear strength under a certain temperature (especially under the most adverse conditions) and how it changes with the temperature. At 0°C, the APP material has a higher shear strength than Sd/Sp, while under the most adverse conditions (60°C) the value gap becomes marginal. Actual road practice requires the shear strength to be not only minimally susceptible to temperature, but also to have a high value under all temperatures. As a comparison, the B5300 material exhibits the desirable properties.

9. MODULUS ANALYSIS OF SHEAR TEST RESULTS

9.1 Shear Coefficient with Concrete Surface Condition

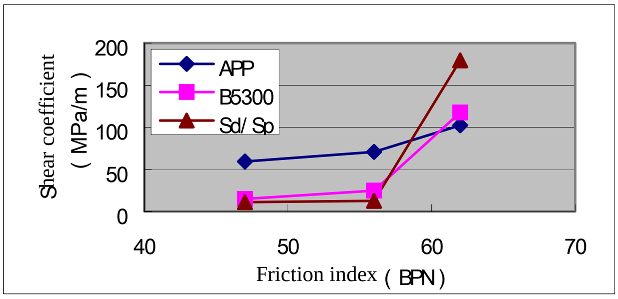

Figure 9. Shear coefficient with concrete surface condition.

As indicated in Figure 9, the shear coefficient of all three materials increases quickly as the concrete surface gets coarser, which indicates that the shear strength between the waterproof materials and the concrete surface increases as the roughness coefficient rises.

9.2 Shear Coefficient with Changes in Temperature

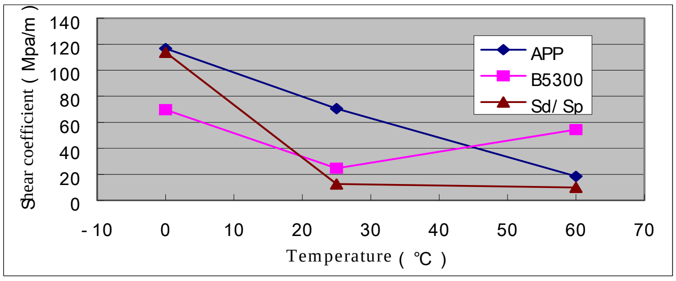

Figure 10. Shear coefficient with changes in temperature.

As indicated in Figure 10, the shear strength between the waterproof materials and the concrete surface decreases as the temperature drops. This explains how heat could damage asphalt paving on bridge decks and how these paving materials behave under high temperatures. At 25°C, the test results of B5300 differ from those of the other two materials, which is attributed to irregular factors during the test.

10. CONCLUSIONS

- According to the test results, material type and composition both have significant effects on a material's bond properties and shear properties, thus determining its relevant application in practice.
- Bond properties and shear properties differ greatly when the temperature changes, which should be acknowledged in material selection for different climatic conditions.
- The pre-paving condition of the bridge surface has a huge effect on the test results, which calls for proper treatment prior to construction.

11. REFERENCES

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