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Deformation characteristic and mechanism of blisters in cement concrete bridge deck pavement

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HIGHLIGHTS

- The environmental simulation blister test was proposed originally.
- The deformation field of the blister was measured by MTI-3D.
- The stages of the blister deformation were determined.
- The failure time was shortened sharply with the test temperature rising.
- The debonding length had a negative correlation with the test temperature.

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ABSTRACT

The waterproofing membrane applied on cement concrete bridge deck usually experiences small uplift blisters, which leads to serious corrosive problems when water infiltrates into the bridge deck through the blister area. It is very important to reveal the formation and propagation of the blister for decreasing the damage of bridge deck pavement. In this paper, the environmental simulation blister test is proposed originally, and MatchID-3D (MTI-3D) structural deformation analysis system is adopted to measure the blister deformations. The deformation characteristic and mechanism of the blister are investigated. The test results show that the stages of blister deformation can be determined according to the deflection rate. The deflection deformation of the blister is a rapid process happening mainly in the third stage, while the debonding deformation is a relatively stable and long-term process. The test temperature, initial debonding aperture, and water have great influences on the failure time, meanwhile the former two factors also affect the total debonding length seriously. An improved blister test method is developed in this paper to accurately study the blister deformation under different environmental conditions, which helps to determine effective measures to eliminate the blister in bridge deck pavement.

1. Introduction

Waterproofing membrane makes a significant contribution to the safety and durability of the bridge, preventing water from infiltrating into the bridge deck [1]. It is found that the waterproofing membrane usually experiences blisters occurring between the waterproofing membrane and the bridge deck [2–4]. Blisters can seriously destroy the integrity of the waterproofing membrane and lead to severe corrosive problems. It is generally recognized that the primary cause of the blister is the internal pressure produced by gas-forming materials trapped underneath the waterproofing membrane, such as moisture, water and other volatile liquid [5–7]. The gas-forming material vaporizes and expands at elevated temperature, and if the expanded gas cannot escape in a short period, it will lead to the formation and propagation of the blister [8].

Blister test is a suitable method to simulate the blister formation and propagation of the waterproofing membrane. Blister test was first developed by J. W. Beams to measure the mechanical properties of thin films [9]. In the test, the blister deflection was controlled by changing the pressures on both sides of the membrane fixed on the substrate with a circular hole in the center. Inspired by Beams, H. Dannenberg developed a uniform pressurized blister test device for examining the bonding properties between the film and the substrate, as shown in Fig. 1(a) [10]. In the pressurized blister test, the upward pressure was applied through a hole in the concrete substrate up to the waterproofing membrane bonded to it [11,12]. The stress-strain behavior was quite similar to that of the blister, so the device could be intro-

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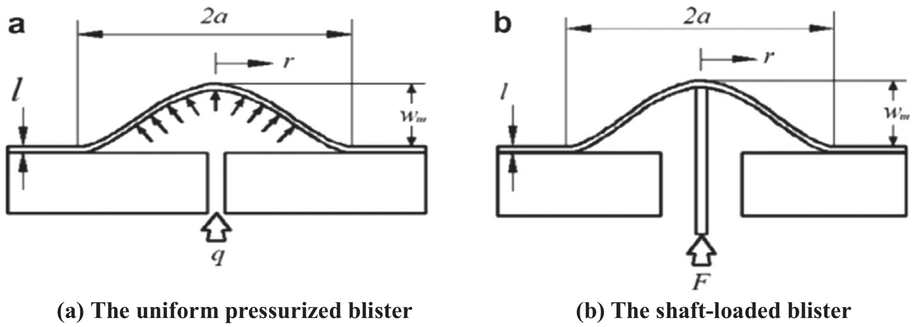

Fig. 1. Schematics of blisters with different loading modes.

duced to simulate the blister of the waterproofing membrane on bridge decks. B. M. Malyshev and R. L. Salganik proposed the shaft loading method for the pressurized blister test [13], as shown in Fig. 1(b). But the asphalt membrane might be damaged easily by the shaft, and the stress singularity was inevitable. K. Liao, X. J. Xu et al. changed the shape of the shaft head to a sphere or spherical crown to solve the problem [14,15]. G. M. H. Beijers developed a simulation test for the blister propagation of asphalt mortar on concrete bridge deck [16]. Asphalt mortar was spread over a concrete substrate with a circular hole; then the sample was heated by infrared to cause the occurrence of the blister. E. H. Fini and I. L. Al-Qadi developed a new type of blister test device for investigating the bonding properties of the crack sealing material [17]. The displacement sensors used in the test could accurately record the deflections during the blister propagation. Nevertheless, the deformation of blister surface could only be measured at each single point, which made it difficult to determine the maximum deflection of the blister. Moreover, the debonding length between the blister and substrate could not be obtained in the test. To measure the deformation of the blister accurately, Digital Speckle Correlation Method (DSCM) has been introduced. DSCM is a non-contact and full-field deformation measurement method with high precision, wide measurement range and low condition requirements [18], which is very suitable for measuring the deformation of the waterproofing membrane. Z. Wang et al. obtained the three-dimensional deformation of the nickel film based on DSCM, indicating that DSCM is a reliable and convenient tool for characterizing the properties of thin films [19].

In recent years, a few researches have been performed for studying the blisters in bridge deck pavement. B. W. Hailesilassie et al. performed blister tests on concrete plates to study adhesive blister propagation by applying controlled pressure between the polymer modified bitumen membrane and the concrete plates [1]. B. W. Hailesilassie conducted experiments on the blister deformation of asphalt mastic, and test results showed that the vertical deflection at the center of the blister was more sensitive to temperature [20]. B. W. Hailesilassie et al. also performed the blister test on three different types of asphalt mastic under different test conditions, and found that test temperature had a great influence on the formation of the blister [21].

In conclusion, the blister test has been improved for different research purposes by many researchers. The blister deformation measurement method has been upgraded with DSCM to get the large-area and full-field deformation. However, most of the previous researches focus on the mechanical properties of thin film, or the bonding properties between the film and the substrate. The blister distress of waterproofing membrane on bridge deck is rarely studied in details.

In this paper, the deformation characteristic and mechanism of blisters of the waterproofing membrane on concrete bridge deck are investigated quantitatively. The waterproofing membrane is produced with styrene-butadiene styrene (SBS) modified asphalt which is frequently applied on the bridge decks. The environmental simulation blister test method is put forward to simulate the formation and propagation of the blister in a test environment where the temperature and humidity can be adjusted. The blister of the asphalt membrane is produced under the uniform internal pressure caused by the expanded air at elevated temperature. Meanwhile, the full-field deformation of the blister is measured and analyzed accurately by the MTI-3D structural deformation analysis system using DSCM. Moreover, the influence degrees of initial debonding aperture, environmental temperature and water on the deformation of the blister are revealed respectively through orthogonal experiments and variance analysis. This study contributes to the in-depth understanding of the formation and propagation of the blister of waterproofing membrane, which is essential to the prevention and treatment for the blister.

2. Materials and experimental procedures

2.1. Materials

The waterproofing membrane was produced with SBS modified asphalt (properties see Table 1) whose usage was determined 1.8 kg/m^2 according to the shear resistance and pullout resistance of the SBS modified asphalt film. The gravel gradation of the cement concrete substrate is shown in Table 2.

2.2. Experimental procedures

2.2.1. Development of environmental simulation blister test chamber

An environmental simulation blister test chamber (dimensions of 80 cm × 80 cm×80 cm) was developed autonomously in this study to quantitatively adjust the test temperature and humidity, as shown in Fig. 2. It consisted of the heating system, the humidi-

Table 1
Properties of SBS modified asphalt.

Properties		Technical requirement	Measured value
Penetration (25 °C, 5 s, 100 g)/0.1 mm		60–80	65.5
Softening point (ball and ring method)/°C		≥55	73.0
Ductility (5cm/min, 5 °C)/cm		≥30	43.5
Density 25 °C/g·cm^{-3}		Measured value	1.038
Thin Film Oven Test (163 °C, 5 h)	Quality change (%)	≤±1.0	−0.70
	Penetration ratio (%)	≥60	76.64
	Ductility (5°C) /cm	≥20	25.8