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A BOND STRENGTH ANALYSIS OF CARBONCOR ASPHALT LAYER ON ROAD SURFACES

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Abstract. Transport infrastructure is a critical component of socio-economic development, particularly in rapidly urbanizing Vietnam, where increasing traffic congestion poses significant challenges. Road surface quality and durability are essential factors in ensuring the efficiency and longevity of the transportation system. Carboncor Asphalt (CA) material, with its superior resistance to cracking, water damage, and harsh weather conditions, is a promising solution for road surface construction in Vietnam. However, there is a limitation of research on the mechanical behavior of carboncor asphalt in the specific climatic and environmental conditions of the country. To address this knowledge gap, this study investigates the shear behavior of a carboncor asphalt layer interfaced with both asphalt concrete and cement concrete surface layers. A comprehensive range of laboratory tests is conducted to assess the bond strength between the carboncor asphalt layer and the overlying road surfaces. Results indicate a negative correlation between temperature and bond strength for the overlay carboncor asphalt layer on both asphalt and cement concrete substrates. Notably, bond strength demonstrated a significant increase over time. The findings in this study are expected to have significant implications for road construction and maintenance using CA overlay in Vietnam. By providing a scientific foundation for material selection, design, and construction of road surfaces tailored to local conditions, this study aims to enhance investment efficiency and reduce maintenance costs.

Keywords: Carboncor asphalt, bond strength, road surface, pull-off test, direct shear test.

1. INTRODUCTION

In the 21st century, the quality of transportation infrastructure is an important factor in a nation's economic and social progress. Road surfaces, in particular, hold significant importance [1,2,3], especially in developing countries like Vietnam, where the transportation network is undergoing rapid expansion. In recent years, Carboncor Asphalt (CA) material has garnered considerable attention from researchers and practitioners due to its exceptional properties in enhancing the performance and durability of road surfaces [4].

Carboncor asphalt is composed of three primary components: crushed stone, screened coal slag, and a carbon-permeable emulsion. The adhesive and structural integrity of carboncor asphalt are derived from a chemical reaction involving water, air, the carbon-permeable emulsion, and the carbon atoms present in the coal slag. This reaction results in the formation of a solid, monolithic bond between the carboncor asphalt material and the underlying road surface. Consequently, carboncor asphalt exhibits superior durability, water resistance, anti-slip properties, and improved pedestrian comfort. The synergistic interaction between water and the carbon-absorbent emulsion enables the material to penetrate the existing road foundation to a depth of 5-7 mm, enhancing its adhesion. The material's strength is further augmented by the combined effects of temperature-induced water evaporation, vehicular traffic, and bitumen, which facilitate tighter bonding between particles.

Given its exceptional crack resistance, water resistance, and adaptability to harsh climatic conditions, carboncor asphalt emerges as a promising candidate for road construction projects in Vietnam. However, a comprehensive understanding of carboncor asphalt 's mechanical behavior under specific Vietnamese climatic and environmental conditions remains limited. This study aims to address this knowledge gap by investigating the mechanical properties of carboncor asphalt when employed as a road surface material in Vietnam. Through a rigorous combination of theoretical analysis and experimental testing, this research seeks to advance our understanding of carboncor asphalt and inform strategies for optimizing road construction and maintenance practices in Vietnam. The application of a novel material that offers standard strength while simplifying production and construction processes is a critical requirement for effective road maintenance in the country.

Carboncor Asphalt (CA) material is categorized into five types based on the maximum nominal particle size of the aggregate mixture: CA 4.0, CA 6.7, CA 9.5, CA 12.5, and CA 19 (porous) (see Fig. 1).

Figure 1. Classification of carboncor asphalt materials (figures provided by Carboncor Vietnam).

To analyze the shear strength behavior of carboncor asphalt on various substrates (bituminous and concrete pavements), this study employs two types of shear tests: the Pull-off test and the Direct shear test [5,6]. These tests are conducted on carboncor asphalt CA 9.5 material under varying temperature conditions to evaluate the bond strength of the interface layer.

2. EXPERIMENTAL DETEMINATION OF BOND STRENGTH BETWEEN CARBONCOR ASPHALT LAYER AND CEMENT CONCRETE LAYER AND ASPHALT CONCRETE LAYER

2.1. Experimental methods

To assess the shear bond strength at the interface between carboncor asphalt and various pavement surfaces, two primary shear tests are utilized: the Pull-off test and the Direct shear test. The equipment and procedures for these tests are detailed in the subsequent sections.

2.1.1. Pull-off test

The Pull-off test (see Fig. 2) is a widely used method for assessing the interfacial bond strength between pavement layers [7,8,9,10,11]. The test configuration adheres to the standards outlined in ASTM C1583/C1583-13 [12] and TCVN 9491:2012 [13].

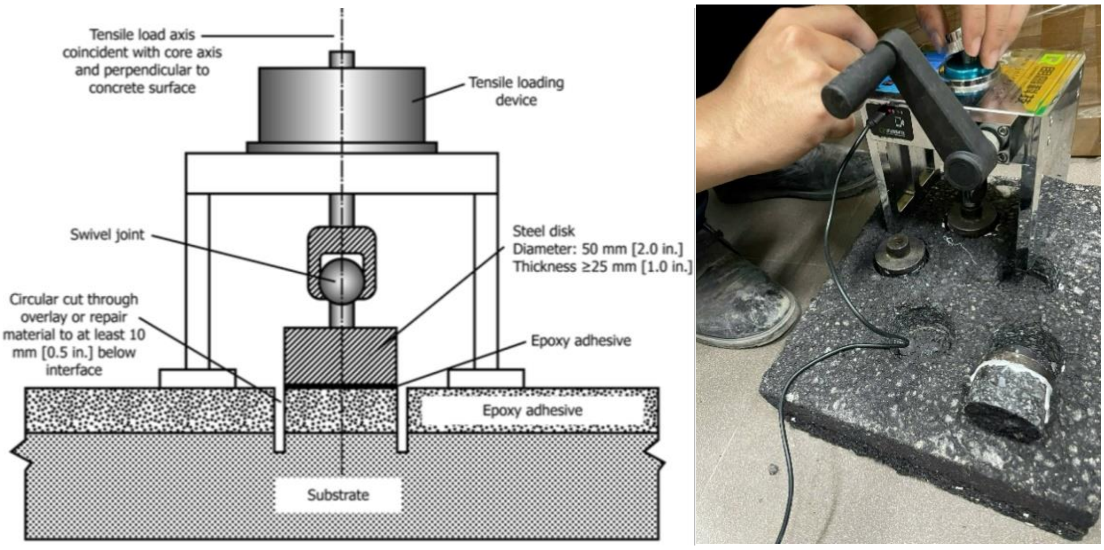

Figure 2. Schematic of the Pull-off test (adapted from [12]) and the test setup used in this study.

The pull-off test procedure involves the following steps:

- Specimen preparation: Test specimens are cut perpendicular to the interface to a depth of approximately 10 mm. The surfaces are cleaned and dried before attaching a steel disk to the top surface using epoxy adhesive.
- Tensile load application: A tensile load is applied to the specimens at a constant rate to achieve a constant tensile stress increase rate of 35 ± 15 kPa/s.
- Failure load and mode recording: The failure load and mode of failure are recorded, which may occur within the substrate, at the interface, within the overlay, or at the epoxy-overlay interface, as illustrated in Fig. 3.

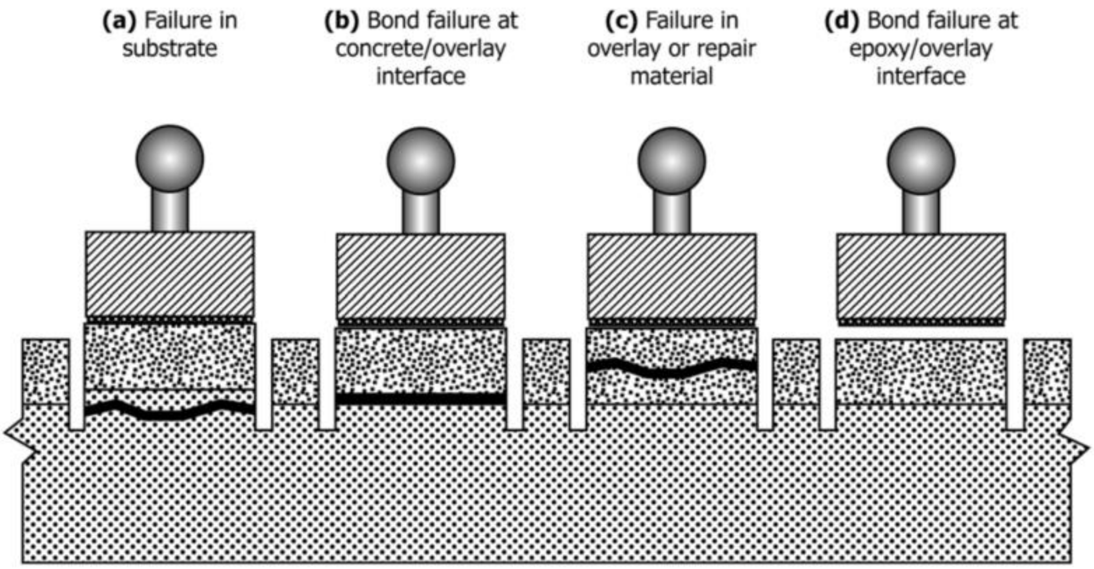

Figure 3. Different failure modes in the pull-off test (adapted from [12]).

2.1.2. Direct shear test

The direct shear tests conducted in this study adhere to the principles outlined in the AASHTO TP 114-15 standard [14] for determining the interlayer shear strength of asphalt pavement layers. The test procedure involves the following steps:

- Specimen preparation: Core specimens with a diameter of 100 mm.
- Conditioning: Condition the specimens at the designated test temperature for a minimum of 2 hours.
- Specimen assembly: Place the specimen between two shear rings (see Fig. 4) to position the interlayer within the gap between the rings.
- Shear load application: Apply a continuous load at a constant displacement rate of 1 mm/min until failure occurs. Record the load and displacement throughout the test.
- Interlayer shear strength calculation (see Fig. 5): Calculate the Interlayer Shear Strength (ISS) using the following equation:

$$ISS = \frac{P_{max}}{\frac{\pi D^2}{4}} \tag{1}$$

where:

ISS: Interlayer Shear Strength, N/mm^2;

P_{max}: Maximum load applied to specimen, N;

D: Diameter of the specimen (mm).

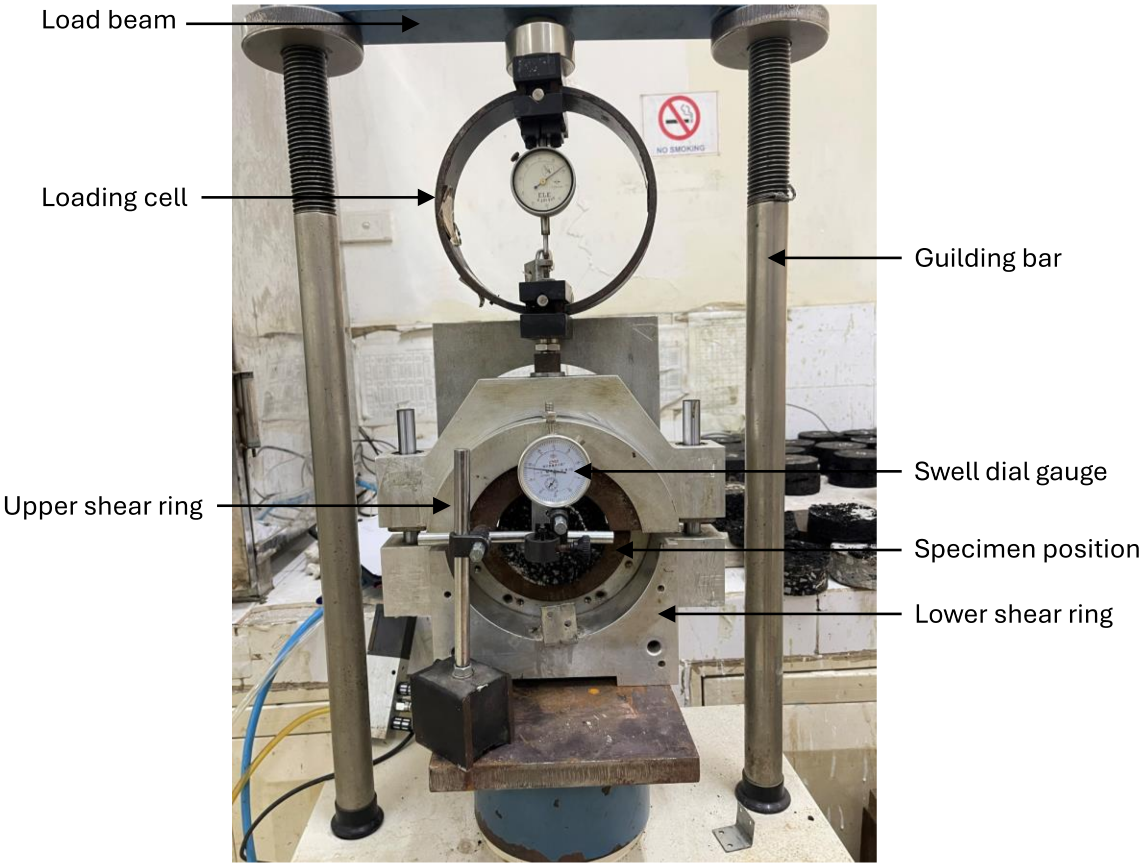

Figure 4. Direct shear test configuration in this study.

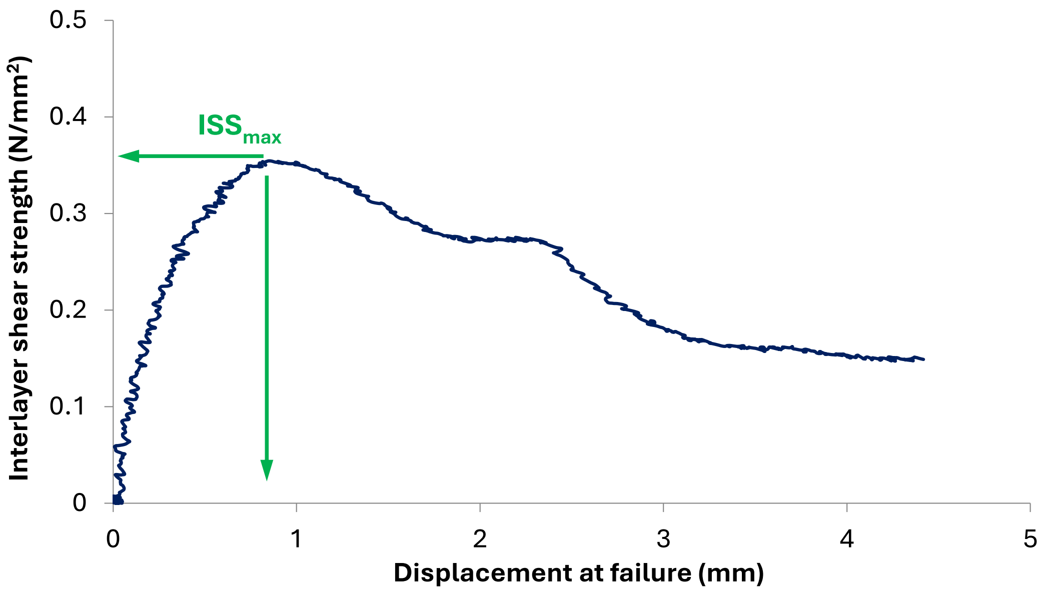

Figure 5. Direct shear test result in this study.

2.2. Sample preparation

The shear bond tests in this study are conducted on samples prepared using carboncor asphalt CA 9.5 material with an aggregate gradation as shown in Fig. 6. The carboncor asphalt material is taken from 25 kg bags manufactured at a factory in Ha Nam Province, Vietnam. Properties of CA 9.5 material is presented in Table 1.

Table 1. Properties of CA 9.5 material used in the study.

Material	Marshall stability at 60°C (kN)	Marshall ductility at 60°C (mm)	Unit Weight (kg/m^3)	Indirect tensile strength at 25°C (kPa)	Air voids (%)
CA 9.5	12.9	3.4	2.3	1306.8	3.29

To fabricate the experimental samples, three types of specimens are prepared:

- Cement concrete slabs: 300 mm x 250 mm x 50 mm;
- Asphalt concrete slabs: 300 mm x 250 mm x 50 mm;
- Carboncor asphalt CA 9.5 layers: Paved and compacted on both cement concrete and asphalt concrete slabs.

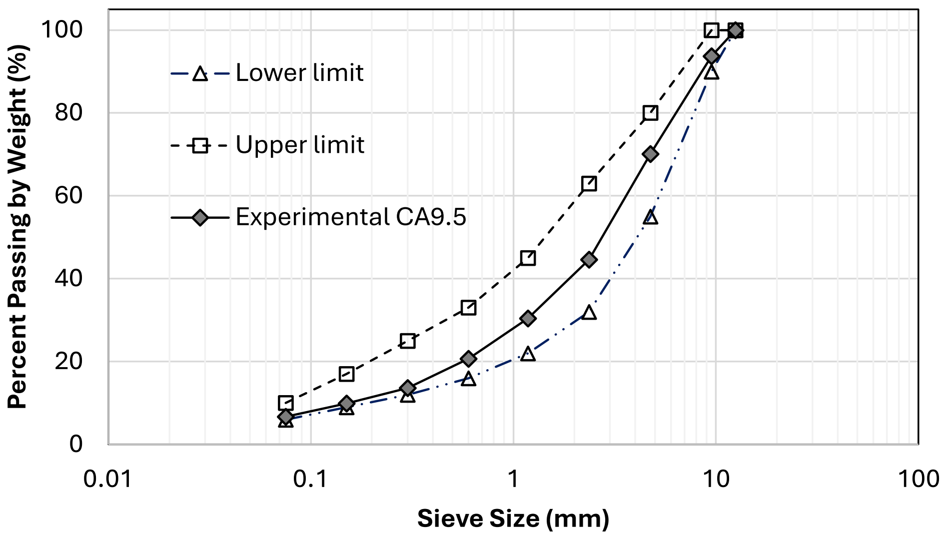

Figure 6. Aggregate grading curve for experimental material carboncor asphalt CA 9.5.

The process of preparing experimental samples involves the following steps (see Fig. 7):

- **Initial material preparation**: Carboncor asphalt material is poured into a tray and spread evenly to a thickness of no more than 25 mm. The material is then left in a well-ventilated area at a temperature of 25 ± 1°C for 2 hours.
- **Water addition**: The carboncor asphalt material is mixed with the optimum water content, which corresponds to 5% of the volume of the air-dried material. Water at room temperature (25 ± 1°C) is slowly added over 1.5 minutes and thoroughly mixed.
- **Preparation of the slabs surface**: Prior to CA material compaction, both cement concrete and asphalt concrete slab surfaces are cleaned to remove all dust and debris. The asphalt concrete slab surface was then lightly moistened with water, while the cement concrete surface received a preparatory treatment: it is evenly coated with an alkaline CA emulsion at a rate of 0.5 l/m^2.
- **Sample preparation**: The carboncor asphalt mixture is evenly spread onto the slabs

(placed in molds) and compacted using a roller compaction method (as specified in wheel track test procedures).

- **Curing**: The samples are left in the molds for one day at room temperature in a well-ventilated area.
- **Drying**: The samples are removed from the molds and placed in a drying oven at 38°C for one day.
- **Final curing**: The samples are removed from the oven and allowed to cure for two weeks at room temperature.
- **Specimen preparation for testing**: The samples are cored to obtain specimens with diameters of 100 mm and 50 mm for direct shear tests and pull-off tests, respectively (see Fig. 8).

Figure 7. Steps for preparation of testing samples.

Figure 8. Coring the slabs to obtain the samples.

2.3. Experimental plan

To investigate the shear bond strength at the interface between the carboncor asphalt layer and underlying cement concrete or asphalt concrete layers, a series of laboratory tests are conducted. The experimental design involved testing at three temperatures (15°C, 30°C, and 60°C), with three samples per temperature condition (as shown in Table 2). Each sample type is subjected to both pull-off and direct shear tests.

Additionally, in-situ samples are collected after seven months of construction (see Fig. 9) in cylindrical form and tested using the direct shear test at a temperature of 30°C. The results from these in-situ tests were compared to the laboratory test results to assess the time-dependent evolution of shear strength.

Figure 9. In-situ samples to perform direct shear test.

Table 2. Design of experimental plan.

Test type	Sample type	Temperature	Samples/temperature
Pull-off test	Carboncor Asphalt/ Asphalt concrete	30°C	3x1
	Carboncor Asphalt/ Cement concrete	30°C	3x1
Direct shear test	Carboncor Asphalt/ Asphalt concrete	15°C+30°C+60°C	3x3
	Carboncor Asphalt/ Cement concrete	30°C	3x3
Direct shear test on in-situ samples	Carboncor Asphalt/ Cement concrete	30°C	3x1

3. RESULTS AND DISCUSSION

The results of the pull-off and direct shear tests conducted on 14-day laboratory-manufactured samples and in-situ samples are presented in Table 3 and Table 4, respectively.

Table 3. Pull-off test results.

Test type	Sample type	Temperature (°C)	Bond strength (MPa)		Failure mode
			Individual sample	Average	
Pull-off test	Carboncor asphalt/ Asphalt concrete	30	0.008	0.009 (±0.002)	At the interface
			0.009		
			0.011		
	Carboncor asphalt/ Cement concrete	30	0.092	0.080 (±0.012)	In carboncor asphalt layer
			0.069		
			0.079		

Based on the test results, the following observations can be made:

- **Substrate influence:** The average bond strength between carboncor asphalt and cement concrete is higher than that between carboncor asphalt and asphalt concrete in both pull-off and direct shear tests.
- **Temperature effect:** The bond strength between carboncor asphalt and asphalt concrete decreases with increasing test temperature, as evident in the direct shear test results.
- **Time-dependent behavior:** In-situ samples, which are aged for seven months after construction, exhibit higher bond strength compared to 14-day laboratory-cured samples at the same test temperature. This can be attributed to the gradual formation of carbon chemical bonds within the carboncor asphalt emulsion over time. This process creates a strong interlock, often referred to as a "rooting effect" between the carboncor asphalt layer and the underlying surface.
- **Failure mode:** The primary failure mode in the laboratory tests is interfacial failure between the carboncor asphalt and the underlying layer (asphalt concrete or cement

concrete), except for the carboncor asphalt-cement concrete pull-off test at 30°C, where failure occurred within the carboncor asphalt layer. In contrast, the in-situ samples (Carboncor asphalt-cement concrete, direct shear test at 30°C) exhibited failure within the carboncor asphalt layer.

Table 4. Direct shear test results.

Test type	Sample type	Temperature (°C)	Bond strength (MPa)		Failure mode
			Individual sample	Average	
Direct shear test	Carboncor asphalt/ Asphalt concrete	15	0.172	0.173 (±0.009)	At the interface
			0.182		
			0.164		
		30	0.043	0.043 (±0.002)	At the interface
			0.042		
			0.045		
		60	0.010	0.009 (±0.001)	At the interface
			0.009		
			0.008		
	Carboncor Asphalt/ Cement concrete	30	0.061	0.060 (±0.001)	At the interface
			0.058		
			0.060		
	In-situ Carboncor asphalt/ Cement concrete	30	0.199	0.216 (±0.013)	In carboncor asphalt layer
			0.254		
			0.194		

4. CONCLUSION

The primary objective of this study is to investigate the bond strength properties of carboncor asphalt material on various pavement types (asphalt concrete and cement concrete). To achieve this, two principal tests, the pull-off test and the direct shear test, are conducted on 14-day laboratory-manufactured samples and in-situ samples (collected after seven months of construction). Based on the results, the following conclusions can be drawn:

- The bond strength at the interface between carboncor asphalt and asphalt concrete/cement concrete increases significantly over time. A similar trend is observed in the failure modes. To further elucidate this time-dependent behavior, continued research with samples of varying ages is necessary.
- The bond strength between carboncor asphalt and cement concrete is generally higher than that between carboncor asphalt and asphalt concrete, under identical curing conditions and test temperatures.
- Bond strength is significantly influenced by temperature, with increasing temperature leading to decreased bond strength.

The experimental results presented in this study represent an initial step in the research program. Future research will involve conducting experiments on samples of different ages and under a wider range of temperature conditions. The findings of this research would provide valuable insights into the bond and shear strengths behavior of the carboncor asphalt overlay and contribute to the design and construction of durable and long-life pavement structures.

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REFERENCES

[1]. L. S. Nkomo, S. A. Desai, K. E. Seutloali, K. Y. Peerbhay, T. Dube, Assessing the surface material quality of unpaved rural roads to understand susceptibility to surface deterioration. A case study of four rural areas in KwaZulu-Natal, South Africa, Physics and Chemistry of the Earth, Parts A/B/C 112 (2019) 3–11. https://doi.org/10.1016/j.pce.2019.04.005
[2]. B. Wang, H. Guan, P. Lu, A. Zhang, Road surface condition identification approach based on road characteristic value, Journal of Terramechanics, 56 (2014) 103–117. https://doi.org/10.1016/j.jterra.2014.09.001
[3]. A. Liu, D. Li, L. Liu, Y. Guan, Understanding the Role of Urban Road Surface Characteristics in influencing Stormwater Quality, Water Resour Manage, 28 (2014) 5217–5229. https://doi.org/10.1007/s11269-014-0788-7
[4]. N. Quang Phuc, T. Thi Cam Ha, N. Van Tuong, Researching parameters of carboncor asphalt layer in designing plexible pavement structures in Vietnam, 75 (2024) 1750–1762. (In Vietnamese). https://doi.org/10.47869/tcsj.75.5.4
[5]. A. Destrée, J. De Visscher, A. Vanelstraete, Field study to evaluate different pre-normative interlayer adhesion tests, in: Proceedings of 6th Eurasphalt & Eurobitume Congress, Czech Technical University in Prague, 2016. https://doi.org/10.14311/EE.2016.095
[6]. A. D'Andrea, C. Tozzo, Interface stress state in the most common shear tests, Construction and Building Materials, 107 (2016) 341–355. https://doi.org/10.1016/j.conbuildmat.2016.01.016
[7]. Y. Bai, P. A. M. Basheer, D. J. Cleland, A. E. Long, State-of-the-art applications of the pull-off test in civil engineering, IJSTRUCTE, 1 (2009) 93. https://doi.org/10.1504/IJSTRUCTE.2009.030028
[8]. H. Fazli, A. Y. M. Yassin, N. Shafiq, W. Teo, Pull-off testing as an interfacial bond strength assessment of CFRP-concrete interface exposed to a marine environment, International Journal of Adhesion and Adhesives, 84 (2018) 335–342. https://doi.org/10.1016/j.ijadhadh.2018.04.015
[9]. E. Bonaldo, J. A. O. Barros, P. B. Lourenço, Bond characterization between concrete substrate and repairing SFRC using pull-off testing, International Journal of Adhesion and Adhesives, 25 (2005) 463–474. https://doi.org/10.1016/j.ijadhadh.2005.01.002
[10]. M. Lee, C. H. Wang, E. Yeo, Effects of adherend thickness and taper on adhesive bond strength measured by portable pull-off tests, International Journal of Adhesion and Adhesives, 44 (2013) 259–268. https://doi.org/10.1016/j.ijadhadh.2013.03.014
[11]. N. M. M. Ramos, M. L. Simões, J. M. P. Q. Delgado, V. P. De Freitas, Reliability of the pull-off test for in situ evaluation of adhesion strength, Construction and Building Materials, 31 (2012) 86–93. https://doi.org/10.1016/j.conbuildmat.2011.12.097
[12]. ASTM C1583/C1583M − 13, Standard Test Method for Tensile Strength of Concrete Surfaces and the Bond Strength or Tensile Strength of Concrete Repair and Overlay Materials by Direct Tension (Pull-off Method), ASTM International, (2013). https://doi.org/10.1520/C1583_C1583M-13
[13]. TCVN 9491:2012, Standard test method for tensile strength of concrete surfaces and the bond strength or tensile strength of concrete repair and overlay materials by direct tension (pull-off method), V.N. specification, 2012. (In Vietnamese).
[14]. AASHTO TP 114-15, Standard Method of Test for Determining the Interlayer Shear Strength (ISS) of Asphalt Pavement Layers, AASHTO, 2015.