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Evaluation of Bonding Adhesion Strength and Failure Modes of Different Types of Cutback Asphalts

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Abstract

A tack coat is a minimal coating of asphalt cement, cut-back asphalt, or asphalt emulsion to an existing pavement surface between layers to guarantee proper bonding between the two layers and longitudinal and transverse joints. Numerous researchers have assessed interlayer adhesion employing failure-mode behavior tests, such as pull-off, direct shear, and torsion testing. This study aims to quantify the best tensile resistance obtained using three types of cutback asphalt (RC70, RC800 modified with polymer 4.5% & MC70). All are applied on concrete surfaces at a rate of 0.5 L/m². The Proceq DYNA Z16 pull–off tester is used to measure the tensile strength at a rate of 0.25 kN/s. It is found that the average tensile strength of the tack coat materials is (0.319, 0.138, 0.028) MPa, respectively. It is concluded that RC70 has the maximum tensile strength. Also, the different types of solvent affect adhesion strengths; RC70 was Prepared using gasoline, while MC70 used petroleum. Gasoline has greater volatility and thus increased adhesion. Failure strength modes of interior bonding varied between cohesive failure adhesive and adhesive failure.

Keywords: Pull-off Test, Tack Coat, Bonding Strength, Tensile Strength, Proceq DYNA Z16

تقييم قوة التصاق الترابط وطرق الفشل لأنواع مختلفة من الأسفلت المقطوع

طيبة فالح ، علاء حسين عبد

الخلاصة

مادة التاك كوت عبارة عن غطاء خفيف من مواد اسفلتية (سمنتية ، كات باك ، مستحلبة) توضع على سطح التبليط بين الطبقات للحصول على ترابط كافي بين الطبقات وعند المفاصل الطولية والعرضية. العديد من الدراسات قيمت التلاصق الداخلي باجراء الفحوصات التي توضح سلوك هذه الطبقات عند الفشل. هذه الفحوصات متمثلة بفحص السحب , فحص الفص المباشر وفحص الالتواء. هذه الدراسة تهدف الى تقييم افضل مقاومة للشد يمكن الحصول عليها باستخدام ثلاثة انواع من الكات باك السائل (السريع التصلب ٧٠ ، السريع التصلب ٨٠٠ المعدل بالبوليمر بنسبة ٤,٥٪ والمتوسط التصلب ٧٠). جميع هذه المواد وضعت على سطح الكونكريت بمعدل ٠,٥ كغم / م٢. تم اجراء فحص الشد باستخدام جهاز البروسيك ز.١٦ وبمعدل حمل ٠,٢٥ كن / ث. وجد انه معدل قوة مقاومة الشد للمواد المستخدمة تتابعا هي (٠,٣١٩ ، ٠,١٣٨ ، ٠,٠٢٨) ميكاباسكال. ما تم استنتاجه من هذه الدراسة هو ان الاسفلت السريع التصلب ٧٠ يمتلك اعلى مقاومة شد وان اختلاف نوع المذاب يؤثر على قوة التلاصق . الاسفلت سريع التصلب تم تحضيره باستخدام البانزين بينما الاسفلت المتوسط التصلب تم تحضيره بواسطة النفط . وبما ان البنزين يمتلك خاصية التطاير بنسبة اعلى من النفط لذا فان مقدار التلاصق سيكون اعلى . حالات الفشل للترابط الداخلي تنوعت بين فشل تلاصق وفشل تماسك وتلاصق.

1. Introduction

A tack coat is a thin coarse of an adhesive and cohesive material that creates a firm contact between the new pavement and the prevailing surface [1]. Because the broken connection affects the system's rigidity, it is possible that loads won't be supported and disbursed as planned. Pavement distresses, such as slippage cracks, debonding, early fatigue cracking, and compaction difficulties may occur [2,3]. Reducing the bonding condition from 100% (no slippage) to 90% (partial slippage) dramatically raised the stress and strain values in the pavement and shortened its ultimate service life by about 50% [4]. The affective factors are major factors affecting internal bonding [5]. One of them is the application rate which plays a main role. An excessive amount of tack coat can cause slippage, whereas too little may result in debonding problems, and that is happen because the bonding strength between pavement layers is a function of both cohesion between layers and the available friction between them [6]. Researchers have done several studies to identify the tensile strength of the tack coat, such as the Wedge Splitting Test (Tensile Notch Bond Test). The principle of the test is to split double–layered specimens at the interface between two adjacent layers. As long as the bilayer specimen's layers are distinct, a thin wedge is pressed into the interface due to the horizontal component of applied force [7]. Interface bond test (IBT) evaluates the interface properties in asphalt concrete. The IBT makes use of the standard fracture mechanics approach with a notched sample and test control, according to the crack mouth opening displacement. The fundamental tensile fracture data generated through the IBT could directly be employed in computational models for the facilitation of system optimizing and linking material features and field performances [8]. These methods based on composite samples have some negative characteristics, such as fast travel rates creating fracture breaks at the fixture attachment point, and fractures through the weakest plane (not necessarily the interface) [9]. Therefore, this study utilized this approach to examine the adhesion strength of several types of tack coat material in direct contact with concrete cubes surfaces.

2- Materials and Mix Design

Asphalt cement, cutbacks, and emulsions are all used as tack coats worldwide [10]. Asphalt is given strong adhesiveness when combined with a solvent to make the proper viscous degree of the tack coat solvent. [11]. According to the specifications of (AASHTO M 140, 2016), the tack coat may be constructed from a cutback asphalt or a rapid-setting asphalt emulsion which satisfies the standards of (AASHTO M 20, 1970) [10,11]. Tack coat materials commonly employed include polymer-modified emulsions and crumb rubber-modified emulsions [12]. Rapid-setting emulsion grades, including polymer-modified emulsions, have higher break time and viscosity in cooler weather. They have tracking problems similar to asphalt binders because of the required residual rate [13]. Asphalt binder should be considered for working in cooler weather; it is advantageous for paving asphalt as it eliminates the need for any break time before overlaying [14]. Cutbacks can be used in colder climates than emulsions [15].

2.1-Materials:

This research included evaluating the effect of three types of cutback asphalt (RC70, RC800 modified with polymer 4.5% & MC70).All the tack coats selected met the test requirements specified in the Specifications. Each tack coat material type is liquid at 25 C.

2.1.1-Materials Tests:

-Cutbacks are characterized by measuring Specific Gravity, Density, Flashpoint, and Kinematic Viscosity, as shown in Table 1.
-Cement, aggregates, and water include a wide range of properties summarized in Tables (2-4)

Table (1): Physical Properties of Cut Back Asphalt RC 70, RC 800 modified with Polymer 4.5%. &MC70

Test Type	Test Condition	ASTM Designation	Test Result & Specification Limits ASTM D2028/D2028M-15 / D2027/D2027M − 13					
			RC70		RC800		MC70	
Specific Gravity	25	D-70	0.939	---	0.999	---	0.946	---
Density (kg/m^3)			936	---	996	---	944	---
Flashpoint (C)	---	D-92	70	---	66	≥80	95	38
Kinematic Viscosity (C.P)	60	D-2170	101	(70 – 140)	820	(800 – 1600)	97	(70 – 140)

Table (2): Gradation of Aggregate in PCC Mix and HMA Mix

Sieve size	Selected gradation Passing%	(S.C.R.B) Limits Passing%
11/2	100	90-100
1/2"	69	35-70
3/4"	19	10-30
3/8"	2	0-5
No.4	95	95-100
No.8	---	45-80
No.16	78	---
No.30	---	90-100
No.50	20	12-30

Table (3): Characterizations of Coarse & Fine Aggregate

Property	Coarse aggregate	(SCRB) Specification Limits	Fine aggregate	(SCRB) Specification Limits
SSD Specific Gravity (ASTM C-127)	2.684	-----	2.6539	-----
Water Absorption% (ASTM C-127)	0.3	≤ 40	1.4	-----
Loss Angeles Abrasion% (ASTM C-131)	15	-----	-----	-----

Moisture Content% (ASTM C566)	0.1	-----	-----	-----
Density (kg / m^3) (ASTM C-127)	1631	-----	-----	-----
Clay Lumps & Friable Particles % (AASHTO T 112)	0.04	**≤ 3**	2.4	**≤ 3**
SO3% Content (I.Q 45/1984)	0.046	**≤ 0.1**	0.34	**≤ 0.5**
O.D Specific Gravity (ASTM C-128)	2.6135	-----	-----	-----
Apparent Specific Gravity (ASTM C-128)	2.7234	-----	-----	-----

Table(4): Chemical Properties of Water

Property	PH	TDS	EC	Clorides	SO_3
Test Result (Mg/L)	250	0.29	850	420	7.1
Iraqi spesification 1703 / 1992 (Mg/L)	≤1000	≤500	—	≤1000	—

2.1.2. Environmental Effect of Cutback Tack Coat:

Cutback asphalts (liquid asphalts) are dissolved in petroleum (cutter). Typical solvents include naphtha (gasoline) and kerosene. Their use significantly declined when it was rejected because the solution had a detrimental impact on the environment [16].

2.2.Mix Design of Concrete*:*

Concrete mixture prepared according to the specification (SCRB), which is interested in maintaining the rigidity, durability, and strength of concrete pavement against traffic load. One of the main characteristics of concrete mix is the compressive strength which must be greater than 30 MPa. to prevent failure during the test due to concrete weakness. The preparation stage, test, and mixture properties are shown in Table (5).

Table (5): Characteristics of Concrete Mixture

Material Type	Quantity (kg/m^3)	(SCRB)Specification Limits
Cement	370	≥360
Coarse Aggregate	1050	-----
Fine Aggregate	780	-----
Water	130	-----
HM P21	3	-----
W/C	0.41	≤0.45

Test Type	Test Results	(SCRB)Specification Limits
Compressive Strength (E.N 12390-3-09) (MPa)	44.29	≥30 MPa
Density (E.N 12390-7-09) (kg/m^3)	2321	-----

3. Methodology

The tension between two pavement layers is one of the things that might irritate people. This test was designed to simulate the anxiety brought on by tension mode. This test involves applying a tensile force perpendicular to the application surface until two layers separate. Bond strength is the maximal force necessary to break the link between two layers [17]. The test is carried out by placing the tack coat material on a clean, concretizing surface virtually free of prominent pores. At a rate of 0.5 Litter per square meter (as specified in SCRB specification). The area covered by the material above the surface of the concrete is 0.00196 m^2 and is equal to the area of the test disc placed above it for adhesion. It is left for seven days as a maximum curing time and then tested with Proceq DYNA Z16 pull–off, the tester, as shown in Figure (1). This device is a machine that checks the quality of adhesion and adhesive strength of different materials [18]. Figure (2) shows the device parts we need to explain the test process. Firstly, the crank is turned back to its initial position in a counterclockwise direction until slight resistance is encountered. The crank is turned once in a clockwise direction (to relieve the hydraulic system). Secondly, the coupling of the draw spindle is connected to the draw bolt of the test disc, and the wheel is turned clockwise until slight resistance is encountered. After that, the position of the pull-off tester is such that the tensile force is applied perpendicular to the test surface. So to achieve this, the legs of the pull-off tester are adjusted until no "pulling at a slant" can occur. At the end of the alignment, the draw spindle is slightly released with the wheel, and the digital manometer is switched on, which displays the current value. The test stops by detaching the metal disk from the tack coat material or the concrete surface. Finally, pressing the "PEAK" key in the digital manometer displays the peak value (18). Since asphalt is a viscoelastic material, the loading rate is crucial in determining bond strength. Multiple Trial experiments were undertaken to establish the ideal loading rate. The lessening of the loading rate is more consistently determined by the bond strength values and the percentage of interface failure. Therefore, the lowest achievable loading rate was used for this investigation. As with Proceq, the lowest permissible loading rate for DYNA Z16 is two lbf/s. The procedure of the test is according to ASTM D 4525

Figure (1): The Pull-off test

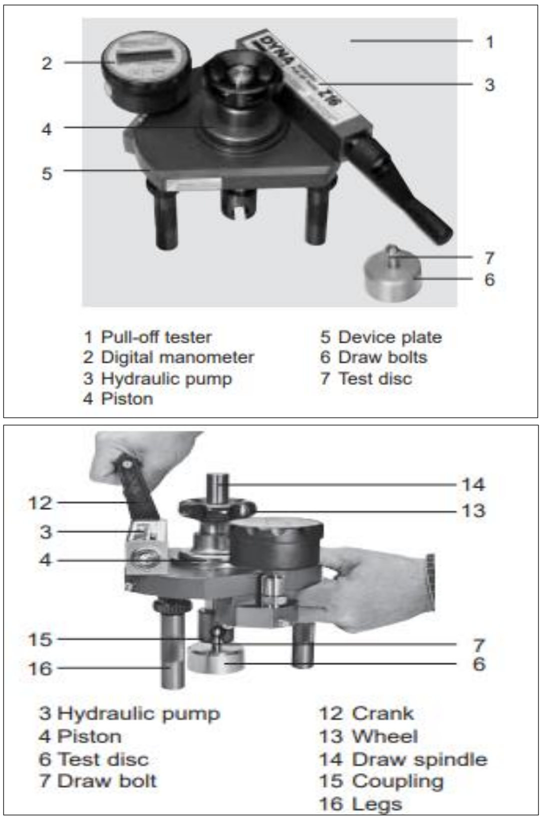
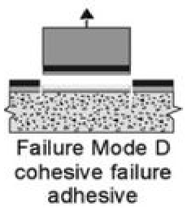


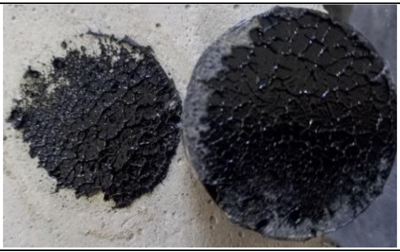
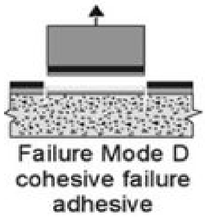
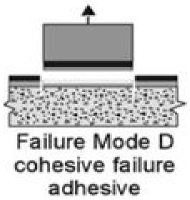
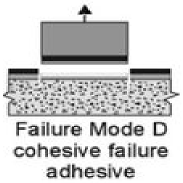
Figure (2): Proceq DYNA Z16 (Device Manual)

4. Results of the Pull-Off Test

Bond strength is the highest force necessary to break the adhesion between two layers. There are several types of failure related to this sort of test. In addition, During the test, a combination of the failure modes might happen, such as cohesive failure adhesive. In this state, the ratio of interface failure inability will also be noted. [19&20]. Table (6) presents the pull-off test results.

Table (6): Pull-off test results on tack coat materials

Bonding material type	Specimen No.	Pull-off adhesion strength (MPa)	Failure surface	Failure modes according to ASTM D7522
RC 70	1	0.229		
	2	0.408		

RC 800 modified with polymer	1	0.132		
	2	0.143		
MC 70	1	0.025		
	2	0.031		

5. Discussion of the Results

Asphalt is a material that is absorbable by surface pores and is licensed according to thermal distribution. These properties manifest an apparent effect in some inspection samples due to the small size of the sample, even though the ratio of pores does not exceed the permissible limit. Absorbing the conduit pores of asphalt makes the highest failure ratio cohesive, which appeared in RC70. The first sample gives cohesive failure adhesive with an adhesion strength of 0.229 MPa. While the second specimen provides 0.408 MPa with adhesive failure.

- MC70 has a lower adhesion strength (Av. = 0.0028 MPa) when compared with RC70
- Despite the convergence of viscosity values for each RC70 & MC70, the different types of solvent give different adhesion strengths; RC70 is Prepared using gasoline while MC70 by using petroleum. Gasoline has greater volatility and, thus, increased adhesion strength. The specimens show homogeneity in results and failure modes (cohesive adhesive failure mode).
- The cutback asphalt RC800 modified with polymer 4.5% has lower adhesion strength than RC70 with cohesive failure adhesive mode.

6. Conclusion

Pull-of test for tack coat materials shows various adhesion strengths and failure modes:

- The adhesion strength of RC70 with cohesive failure and cohesive failure adhesive is (0.229-0.408) MPa, respectively.
- With cohesive failure adhesive, the adhesion strength of RC800 modified with polymer varies between (0.132- 0.143) MPa.
- With cohesive failure adhesive, the adhesion strength of MC70 varies between (0.025-0.031) MPa. the average pull-off strength is 0.028 MPa and thus reduces by 91.2% with cohesive failure adhesive mode.
- The highest adhesion strength found in RC 70
-All tack coat materials used in this research are available and able to use in the field depending on the required tensile strength

7. References:

[1] Mohammad, L. N., Elseifi, M. A., Bae, A., Patel, N., Button, J., & Scherocman, J. A. (2012). Optimization of Tack Coat for HMA Placement, National Cooperative Highway Research Program (NCHRP) Report 712. Transportation Research Board, National Research Council, National Academies, Washington, DC.

[2] Huang, Yang Hsien. Pavement analysis and design. Vol. 2. Upper Saddle River, NJ: Pearson Prentice Hall, 2004.

[3] Shahin, M. Y., Blackmon, E. W., Van Dam, T., Kirchner, K. (1987). "Consequence of Layer Separation on Pavement Performance." Report No. DOT/FAA/PM-86/48. Federal Aviation Administration, Washington, D.C.

[4] King, G. and R. May. (2003). New Approaches to Tack Application, Presented at the 83rd Annual

Meeting of the Transportation Research Board, Washington, D.C.
[5] Wang, J., F. Xiao, Z. Chen, X. Li and S. Amirkhanian. (2017). Application of tack coat in pavement engineering. Construction and Building Materials, Vol. 152, pp. 856-871.
[6] Biglari, M., Asgharzadeh, S. M., & Sharif Tehrani, S. (2019). Evaluation of factors affecting tack coat bond strength. Canadian Journal of Civil Engineering, 46(6), 270–277.
[7] Stanzl, S. E., Tschegg, E. K., & Mayer, H. (1986). Lifetime measurements for random loading in the very high cycle fatigue range. International Journal of Fatigue, 8(4), 195–200.
[8] Hakimzadeh, S., Kebede, N. A., Buttlar, W. G., Ahmed, S., & Exline, M. (2012). Development of fracture-energy based interface bond test for asphalt concrete. Road Materials and Pavement Design, 13(sup1), 76–87.
[9] Tack Coat Materials and methods for optimaizing for thin HMA applications. (2011, May). Road Science, LCC..
[10] Roffe, J.-C., & Chaignon, F. (2002). Characterization tests on bond coats: worldwide study, impact, tests, recommendations. proceedings of the 3rd international conference on bituminous mixtures and pavements, held thessaloniki, greece, november 2002., 1 (11) Tampanatu P.F. Sompie. Syanne Pangemanan (May 2018). Shear Strength of Tack Coat on Flexible Pavement and Composite Pavement. Journal of the Civil Engineering Forum Vol. 4 No. 2.
[11] Hachiya, Y., Umeno, S., & Sato, K. (1997). Effect of tack coat on bonding characteristics at interface between asphalt concrete layers. Doboku Gakkai Ronbunshu, 1997(571), 199–209.
[12] Wood, T. J., Janisch, D. W., & Gaillard, F. S. (2006). Minnesota seal coat handbook 2006.
[13] Chen, D.-H. (2010). Slippage failure of a new hot-mix asphalt overlay. Journal of Performance of Constructed Facilities, 24(3), 258,264.
[14] Cross, S. A., & Shrestha, P. P. (2005). Guidelines for using prime and tack coats. United States. Federal Highway Administration Central Federal Lands Highway
[15] West, R. C., Zhang, J., & Moore, J. (2005). Evaluation of bond strength between pavement layers. Auburn University. National Center for Asphalt Technology
[16] Raab, C., & Partl, M. N. (2009). Evaluation of interlayer shear bond devices for asphalt pavements. The Baltic Journal of Road and Bridge Engineering, 4(4), 186–195
[17] Haftprüfgerät, Pull-off Tester, proceq DYNA Z16 manual.
[18] Raab, C., & Partl, M. N. (2004). Effect of tack coats on interlayer shear bond of pavements. Proceedings of the 8th Conference on Asphalt Pavements for Southern Africa (CAPSA'04), 12, 16.
[19] Talha, S.K., Abu, M.S., August 2019, Civil Engineering. Laboratory and Field Characterization of Micro-surfacing Mix Bond Strength.

Specifications

ASSHTO American Association of State Highway and Transportation Officials
ASTM American Society for Testing and Materials
SCRB Standard Specifications for Roads and Brides