Enhancing Shear Strength of Bonding Materials Used for Asphalt Concrete and Composite Pavement Layers

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Abstract. A tack coat is a thin cut-back cement or asphalt emulsion coating applied on an existing non-absorbent pavement. A good bonding between the asphalt and concrete is necessary to provide sufficient structural strength. Poor adhesion will result in shear failure. The shear test is one of the basic tests to determine bond strength. This study aims to quantify the best shear resistance obtained using three types of cut-back asphalts (RC70, RC800 modified with polymer 4.5% and MC70), PG (76-10) modified asphalt cement with polymer 4.5%, Sikadur®-31 CF usage at elevated temperatures between +25°C and +45°C and Nitomortar TC2000 epoxy from Fosrok company. All are applied on concrete surfaces with an application rate of 0.5kg/m^2 except for Nitomortar, which depends on layer thickness ranges between (1-2.5) mm instead of the application rate. A special attachment and loading mechanism were designed to facilitate the measurement of the asphalt-to-concrete contact shear strength in Al-Ahmad Lab-Baghdad. Vertical shear force is applied to a multiple-layer sample with a 0.25 kN/sec rate until the failure occurs at the interface. The final result of this test is stated in terms of the maximal force or power needed to break the bond. The average shear strength of tack coat materials is (0.049, 0.0455, 0.0085, 0.677, 1.088, 1.361) MPa Respectively. It concluded that Fosrok epoxy has the maximum shear strength. Also, adding polymer to asphalt increased the viscosity. All materials used enhanced the shear strength of bonding materials used for asphalt concrete and composite pavement layers

Keywords: Direct shear test; tack coat; bonding strength; shear strength.

1. INTRODUCTION

A tack coat is a skinny layer of asphalt cement., cut-back asphalt, or asphalt emulsions to an existing pavement surface between layers to ensure good bonding between the two layers and longitudinal and transverse Joints. [1-2]. There are two forms of failure at the intersection of two pavement layers: tension and shear [3]. When the bonding between road pavements is weak, the pavement does not function as a rigid structure but rather as numerous designs sliding past one another as they flex. [4]. According to layered elastic analysis, this reduces the structure's stiffness [5]. The higher layers might delaminate in pavement regions where turning, deceleration, or acceleration occurs, triggering slippage failures [6]. A poor interlayer connection causes slippage between the layers. A part of the asphalt surface moves laterally away from the rest of the surface due to lateral and shear stresses caused by traffic [7]. Insufficient adhesion between pavement layers may reduce the pavement's expected lifespan from 20 to 7 years [8]. Therefore, scientists have undertaken various studies to assess the quality of tack coatings with varying loading kinds and degrees. Many of these tests fall under a shear or pull-off test; each test has other test parameters and can measure various characteristics of the tack coat. For example, the Louisiana Transportation Research Center Direct Shear Test and the Texas Transportation Institute Torsional Shear Test are both shear tests. Still, they measure something different about the tack coat and pavement specimen. The LTRC Direct Shear Test determines the shear stress at the sample's failure point.

At the same time, the TTI Torsional Shear Test measures the shear strength of the specimen but also calculates the cohesion of the sample and the tangent of the internal friction angle [9]. Leutner Shear Testing Method assesses the effectiveness of the bonding within layers and, subsequently, the tack coat components; the maximum load related to its displacement is measured. The samples are continuously loaded in a strain-controlled manner [10]. Ancona Shear Testing Research and Analysis (ASTRA) test is another direct shear test method whereby a continuous vertical force is supplied to establish confinement. At the same time, a constant horizontal displacement is delivered to the sample's top layer [11]. The direct shear test fixture determines the direct shear load values and displacement. The shear fixture is placed within a temperature-controllable environmental chamber. Two layers comprise the testing mechanism, with one layer kept stationary while the other is loaded at a certain shear displacement rate [12]. Virginia Shear Fatigue Test determines the ideal application rate of asphalt binder tack at the interface between two layers by counting the shear loading cycles till failure [13]. The Superpave Shear Test assessed how different tack coat kinds, application rates, and test temperatures affected the interface shear strength. Shear equipment was positioned within the SST and had two pieces that held specimens during testing. Until failure, a steady shear stress of (222.5 N/min) was applied to the specimen [14]. Most of the shear tests the effects of interface sliding but can't separate friction from the bond [15]. From all previous experiments and due to the importance of realistic simulation of composite models, a device has been adapted for shear inspection.

2. MATERIALS AND MIX DESIGN

Emulsions, paving-grade asphalt cement, and cut-back asphalts are used for tack coats. Since emulsions are much easier to use, they have become the most prevalent asphalt for tack coatings. Slow-setting grades are set more slowly than quick-setting or rapid-setting emulsions. Due to this, they are not recommended as a tack coat during calm weather or even at nighttime. Instead, quick settings are used for these conditions. The last have higher viscosity because they include polymer-modified emulsions. [2,16,17]. As a tack coat material, any asphalt paving grade is appropriate. Utilizing the equivalent grade of paving asphalt used in the asphalt concrete mixture would be optimal [2]. Asphalt cut-back (liquid asphalt) is dissolved in petroleum (cutter). Naphtha (gasoline) and kerosene are examples of standard solvents. The choice of the solvent determines the cut-back's curing period and, therefore, when it reaches its maximum strength. Naphtha (gasoline) is used for quick-curing cut-backs, whereas kerosene is used for medium-curing cut-backs. The quantity of cutter impacts the viscosity of the asphalt that has been cut back—the more significant the proportion of cutter, the lower the viscosity and the greater the fluidity [18].

2.1 Materials

This research included evaluating the effect of:

- Three types of cut-back asphalts (RC70, RC800 modified with polymer 4.5% and MC70).
- PG (76-10) modified asphalt cement with polymer 4.5%.
- Sikadur®-31 CF usage at elevated temperatures between +25°C and +45°C, an epoxy-resin-based adhesive, and repair mortar with specific fillers.
- Nitomortar TC2000 epoxy resin-based sealing compound from Fosrok company.
- All the tack coats selected met the test requirements specified in the Specifications. Each tack coat material type is liquid at 25°C except PG (76-16) modified asphalt cement with polymer 4.5%, which needs to heat up to about 48°C to become fluid enough to pour on a concrete surface.

2.1.1 Materials Tests

PG (76-16) have significant tests in addition to those in cut-backs and are determined by dynamic shear, bending beam rheometer, and mass loss (%), as shown in Table 1. Epoxy material's essential tests are compressive, tensile, and flexural strength in Table 2. Cement, aggregates, asphalt, and water include various properties summarized in Tables 3-6. Cut-backs are characterized by measuring specific gravity, density, flashpoint, and kinematic viscosity, as shown in Table 7.

Table 1: Physical Properties of PG (76-10) Modified Asphalt Cement with polymer 4.5%.

Aging	ASTM	Original Binder	(RTFO)	(PAV-110°C)
Rotational Viscosity (Pa.sec)	D4402	@135°C = 1.34	—	—
Specific Gravity	D70	1.063	—	—
Dynamic Shear Rheometer (kPa)	D70	@76°C = 1.81	@76°C = 2.41	@37°C = 3950
Flashpoint (°C)	D92	270	—	—
Softening point (°C)	D36	48	—	—
Mass loss (%)	D2872	—	0.65	—

Table 2: Properties of Sikadur®-31 CF Slow and Nitomortar TC2000 (Products data sheets).

Mix density (kg/L)	Tensile strength (ASTM D412:1980) (N/mm²)	Flexural strength (BS-6319 Part 3:1999) (N/mm²)	Compressive strength (BS-6319 Part 2) (N/mm²)	Pot life @ 25°C (hr, min)	Test and Epoxy Type
	All were cured in 7 days				
1.68	18	20	65	3,15	Nitomortar TC2000
1.93 ± 0.1	13	27	52	2	Sikadur®-31 CF Slow

Table 3: Gradation of aggregate in PCC Mix and Wearing HMA.

Percent passing by weight of total aggregate						Aggregate Type	Sieve size
HMA Mix				PCC Mix			
(S.C.R.B) Limits	Selected Filler	(S.C.R.B) Limits	Selected gradation	(S.C.R.B) Limits	Selected gradation		
—	—	—	—	90-100	100	Coarse Aggregate	11/2
—	—	100	100	35-70	69		1/2"
—	—	—	—	10-30	19		3/4"
—	—	90-100	94	0-5	2		3/8"
—	—	44-74	48	95-100	95	Fine Aggregate	No.4
—	—	28-55	33		—		No.8
—	—	—	—	45-80	78		No.16
100	100	—	—	—	—		No.30
95-100	95	5-21	13	12-30	20		No.50
—	—	—	—	2-10	4		No.100
70-100	72	4-10	5	0-3	2.4		No.200

Table 4**:** Chemical Properties of Water

Property	**pH**	**TDS**	**EC**	**Chlorides**	**SO_3**
Test result (mg/L)	250	0.29	850	420	7.1
Iraqi spesification 1703 / 1992 (mg/L)	≤1000	≤500	——	≤1000	——

Table 5: Characterizations of Course and Fine Aggregate.

Property	**Coarse aggregate**	**(SCRB)Specification Limits**	**Fine aggregate**	**(SCRB)Specification Limits**
SSD Specific Gravity (ASTM C127)	2.684	-----	2.6539	-----
Water Absorption % (ASTM C127)	0.3	-----	1.4	-----
Loss Angeles Abrasion % (ASTM C131)	15	≤ 40	-----	-----
Moisture Content % (ASTM C566)	0.1	-----	-----	-----
Density (kg/m^3) (ASTM C127)	1631	-----	-----	-----
Clay lumps and friable Particles % (AASHTO T112)	0.04	**≤ 3**	2.4	**≤ 3**
SO_3% Content (I.Q 45 /1984)	0.046	**≤ 0.1**	0.34	**≤ 0.5**
O.D Specific Gravity (ASTM C128)	2.6135	-----	2.613	-----
Apparent Specific Gravity (ASTM C128)	2.7234	-----	2.723	-----

Table 6: Physical properties of asphalt cement (40-50).

Test Type	**ASTM Designation**	**Test Results for original asphalt**	**(SCRB) Specification Limits**	**Test Results after residue of thin film oven test**	**(SCRB) Specification Limits**
Penetration (1/10mm)	D-5M	44	40 - 50	53.5	40-50
Ductility (cm)	D-113M	>100	>100	125	>55
Specific Gravity	D-70	1.052	-	-	-
Flashpoint (C)	D-92	240	>232	-	-
Softening point (C)	D-36	44	-	-	-
Viscosity @60 C (centipoise)	D-4402	1220	4000 ±800	-	-
Loss in weight %	D 1754	-	-	0.15	<0.75

Table 7: Physical Properties of Cut Back Asphalt RC 70, RC 800 modified with Polymer 4.5%. andMC70.

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

2.2 Mix Design of Concrete and Asphalt Mixture

Concrete mixture prepared according to the specification (SORB), 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 8. Hot mix asphalt surface layer prepared to complete the composite model within the tack coat between layers. The asphalt tests are flash point, penetration, viscosity, Ductility, and softening point. The Marshall test is essential to ascertain their cohesiveness and tolerability during their heat caps above the concrete- coated with a tack coat. The characteristics are shown in Table 9.

Table 8**:** Concrete mix design properties.

Material Type	**Quantity (kg/m^3)**	**(SORB) Limits**
Cement	370	≥360
Coarse aggregate	1050	-----
Fine aggregate	780	-----
Water	130	-----
HM P21 chemical additive	3	-----
W/C	0.41	≤0.45
Compressive strength (E.N 12390-3-09) (MPa)	44.29	≥30
Density (E.N 12390-7-09) (Kg/m^3)	2321	-----

Table 9: Hot mix asphalt mixture Properties

Marshall Criteria	**Test Result**	**Property**
Marshall Stability (kN)	≥8	8.6
Marshall Flow (mm)	2-4	3
Voids in Marshall specimen (%)	3-5	4.1
Density (gm/cm^3)	-----	2.354

3. METHODOLOGY

The tack coat served as an adhesive coating necessary for adhesion between the existing pavement layer and the new pavement layer or with concrete pavement in order to provide a considerable uniformity that could sustain the shear strength of the weight of the vehicle on top of it. Strong adhesion of the tack coat would increase shear strength between pavement course surfaces [19].

3.1 Preparation of Laboratory Specimen

Concrete Specimens: Consisting of 12 cylindrical concrete samples with dimensions (200×100) mm. and smooth surface finishing. Asphalt Specimens: Consisting of 12 cylindrical hot mix asphalt samples with dimensions (100×100) mm. with aggregates grading and mixing properties conforming to the characteristics of the surface asphalt course. As shown in Figure 1, the composite specimen places the tack coat material on a clean, concretizing surface virtually free of prominent pores. The tack coat was poured on the concrete surface with a rate of 0.5 Kg/m^2 for asphalt materials and distributed 3mm thick for epoxy materials (The rate is controlled by using a syringe in cubic centimeters), the cylindrical concrete specimen layer and then pressing the asphalt layer directly over the tack coat to simulate the surface layer application process in the field. Composite Samples were left for seven days and then tested in the direct shear device.

Figure 1: Composite Specimens used in a direct shear test.

3.2 Direct Shear Device

A special attachment and loading mechanism was designed to facilitate the measurement of the shear strength of the asphalt-to-concrete interfaces when a shear force is acting simultaneously, and it is proportional. The device in the original is the concrete flexural strength machine with a central loading point. The main parts represented by the testing machine bed, rigid support structure, steel rods, balls, and loading block connected to an electronic device to display the value of the applied force during the test in kN. Units. Changes made on the device to fit the shear test are summarized in the following points and shown in Figure 2.

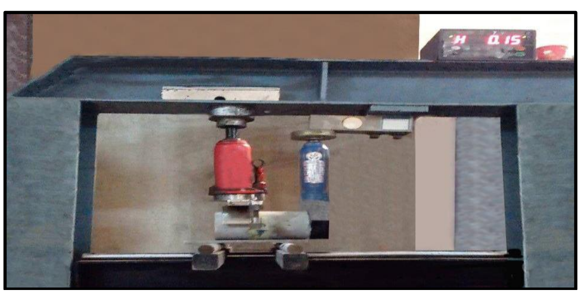

Figure 2: Direct shear device.

- A metal plate was placed on the steel rods so the cylindrical concrete part of the specimen could be placed on it.
- Two-ring dynamometer spring steel to install the asphalt and concrete parts of the sample.
- Two Asphalt sample ejectors with a hand operator are installed on the rings. The red one prevented the concrete part from moving during the test process. The blue one was used to apply normal force on the asphalt specimen.

3.3 Test Procedure

- The sample is placed horizontally on the metal plate and then pressed by the rings of dynamometer spring steel and the ejectors.
- Normal force was applied on the side of the asphalt specimen using the rod in the blue hand-operated asphalt sample ejectors with a rate of 0.25 kN/sec.
- The force will continue until the asphalt layer part of the composite sample descends.
- The test is carried out at 25ºC.

4. RESULTS AND DISCUSSION

A double-layered sample is subjected to a vertical shear force until it fails along the contact. The outcome of this testing is the maximal force or energy required to break the bond. [20]. The use of polymer-modified asphalt cement in pavement construction is essential in increasing the life and durability of asphalt roads [21]. This test was carried out for twelve samples. When normal pressure is applied, there is an increase in bond strength. The shear strength is obtained by dividing the highest force on the face of the composite specimen by its surface area. The weight of the ring dynamometer spring steel is added as a force. Table 10 presents the shear test results. All of them indicate a cohesive failure. Adding polymer to asphalt increased viscosity, making its shear strength higher than the other asphalt materials. Direct shear strength is approximately homogeneous between specimens for the same tack coat type. One exception happened in Sikadur®-31 CF Slow; the result difference between the samples occurred because of the absence of adherence between the tack coat and asphalt surface layer at the edge, which was apparent in the failure shape.

Table 10: Direct shear test results on tack coat materials.

Failure surface	Av. Strength (MPa)	Direct shear strength (MPa)	Specimen No.	Bonding material type
	0.049	0.050	1	RC 70
		0.048	2	
	0.0455	0.045	1	RC 800 modified with polymer 4.5%
		0.046	2	
	0.0085	0.009	1	MC 70
		0.008	2	
	0.677	0.674	1	PG (76 -10) modified with polymer (4.5%)
		1.199	2	
	1.088	1.014	1	Sikadur®-31 CF Slow
		1.164	2	
	1.361	1.199	1	Nitomortar TC2000
		1.523	2	

5. CONCLUSIONS

Direct shear tests for tack coat materials show various shear strengths:

- The average shear strength for RC70 equals (0.049) MPa.
- Average shear strength for RC 800 modified with polymer 4.5% equal (0.0455) MPa.
- The average shear strength for MC 70 equals (0.0085) MPa.
- Average shear strength for PG (76 -10) modified with polymer (4.5%) equal (0.677) MPa.
- Average shear strength for Sikadur®-31 CF Slow equal (1.088) MPa.
- Average shear strength for Nitomortar TC2000 equals (1.361) MPa
- The highest adhesion strength was found in the epoxy Nitomortar TC2000 from the Fosrok company.

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