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Evaluation of Bonding Interior Layer Failure Strength Modes in the Composite Pavement

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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 PG (76-10) modified asphalt cement with polymer 4.5%, Sikadur®-31 CF (S.E) usage at elevated temperatures between +25 °C and +45 °C, an epoxy-resin-based adhesive, and repair mortar with specific fillers. And Nitomortar TC2000 epoxy (F.E) resin-based sealing compound from Fosrok Company. All are applied on concrete surfaces at a rate of 0.5 kg/m^2 except for Nitomortar, which depends on layer thickness ranges between (1-2.5) mm instead of the application rate. The Proceq DYNA Z16 pull–off tester is used to measure the tensile strength at a rate of 2lb/s. It is found that the average tensile strength of the tack coat materials is (0.607, 1.481, 2.622) MPa, respectively. It concluded that (F.E) epoxy has the maximum tensile strength. Also, adding polymer to asphalt increased adhesiveness. Failure strength modes of interior bonding varied between cohesive failure adhesive, adhesive failure, and cohesive failure in the concrete substrate.

Keywords: Pull-off test; tack coat; Bonding strength; Tensile Strength; Proceq DYNA Z16.

1. INTRODUCTION

A tack coat is a light application of asphalt on an existing, generally non-absorbent pavement surface [1]. Many researchers have assessed interlayer bonding via failure-mode behavior tests, including tensile strength testing. Due to a poor interlayer bond and lateral and shear forces resulting from traffic loads, the upper layer slips, and the paving system deteriorates [2,3]. One of the most challenging issues that shorten the lifespan of composite pavement is permanent deformation [4]. Low bonding between pavement layers might result in a 7–20-year reduction in service life [5]. Many factors affect the tack coat behavior, including the milled surface. It was found that the non-milled segment had a greater pull-off strength value than that of the milled portion, as determined by the pull-off test [6-9]. Researchers have done several studies to identify the tensile strength of the tack coat, like the direct tensile bond energy test, in which Composite specimens -lab-produced or field cores are placed in commercially available tensile/compression equipment. Energy tells a different story than just peak load or stress. This test record loses bond after very little movement and can maintain the microstrain movement of pavement [6]. Switzerland pull-off test comprises tensile stress supplied to asphalt concrete specimens made of two strata at a constant rate. The specimens are cylindrical composites with a diameter of 3.94 in. and glued surfaces. The test conforms to the German testing regulation ZTV-SIB 90 [10]. Depending on composite layers, these methods have negative characteristics, such as needing a fixture to minimize eccentricity [6]. The direct tensile test could be conducted by an adhesion test applied in this research for tack coat material in direct contact with the surface of concrete cubes.

2. MATERIALS AND MIXED DESIGN

Asphalt cement, cut-back, and emulsions are used worldwide as tack coats [11]. The tack coat's tensile strength improved as the tack coat emulsion viscosity increased. A correlation between the maximum tensile strength and a rise in the binder's softening point was also discovered [12]. The upgrading tack coat material using modified asphalt, epoxy resin, and rubber asphalt mastics can improve bonding strength with the overlay [13].

This research included evaluating the effect of:

a) PG (76-10) modified asphalt cement with polymer 4.5%.
b) Sikadur®-31 CF (S.E) usage at elevated temperatures between +25°C and +45°C, an epoxy-resin-based adhesive and repair mortar with specific fillers.
c) Nitomortar TC2000 epoxy (F.E) resin-based sealing compound from Fosrok Company.

All the tack coats selected met the test requirements in the Specifications. Each tack coat material type is liquid at 25 C except PG (76-16) modified asphalt cement with polymer 4.5% needs to heat up to about 48 degrees to become fluid enough to pour on a concrete surface.

- PG (76-16) have significant tests determined by dynamic shear, mass loss%, Rotational Viscosity, Specific Gravity, Flashpoint, and Softening point, as shown in Table 1. Epoxy material's essential tests are compressive, tensile, and flexural strength, as shown in Table 2.
- Cement, aggregates, and water include a wide range of properties summarized in Tables 3 to 5.

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)	D -4402	@135 C = 1.34	—	—
Specific Gravity	D 70	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)	D-36	48	—	—
Mass Loss (%)	D -2872	—	0.65	—

Table 2: Properties of (S.E) and (F.E) (Products data sheets).

Test and Epoxy Type	Pot life @ 25 C (hr, min)	Compressive Strength (BS-6319 Part 2) (N/mm²)	Flexural strength (BS-6319 Part 3:1999) (N/mm²)	Tensile strength (ASTM D-412:1980) (N/mm²)	ix density (kg/L)
		All cured in 7 days			
F.E	3,15	65	20	18	1.68
S.E	2	52	27	13	1.93 ± 0.1

Table 3: Gradation of aggregate in PCC mix and HMA mix.

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

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 coarse 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	≤ 40	1.4	-----
Loss Angeles Abrasion% (ASTM C131)	15	-----	-----	-----
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
SO3% Content (I.Q 45/1984)	0.046	≤ 0.1	0.34	≤ 0.5
O.D Specific Gravity (ASTM C128)	2.6135	-----	-----	-----
Apparent Specific Gravity (ASTM C128)	2.7234	-----	-----	-----

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 6.

Table 6: Concrete mix design properties.

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 [14]. 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 kg per square meter, the tack coat was applied to the concrete's surface for asphalt materials and distributed 3 mm thick for epoxy materials. 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 and then tested with Proceq DYNA Z16 pull–off, the tester, as shown in Figure 1. This machine checks the quality of adhesion and adhesive strength of different materials [15].

Figure 2 shows the device parts we need to explain the test process. Firstly, the crank is turned back to its initial position counterclockwise 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 [16]. 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 bond strength values and the percentage of interface failure more consistently determine the lessening of the loading rate. 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.

Figure1: Pull-off test.

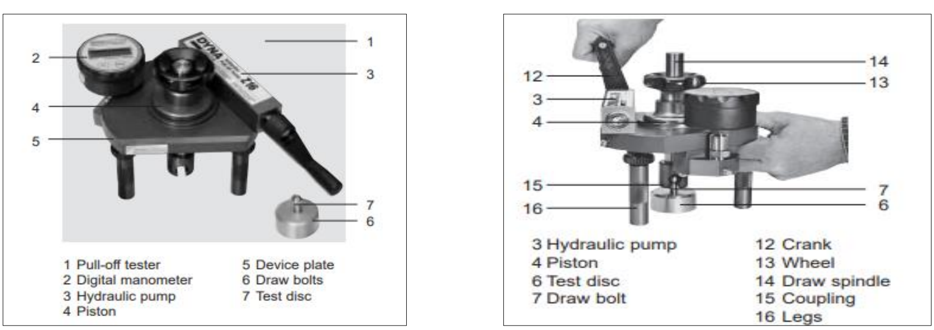
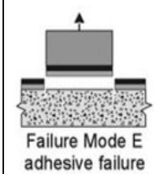
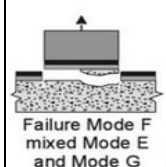
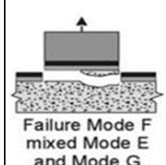
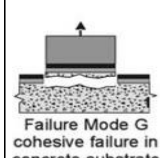


Figure 2: Proceq DYNA Z16 (Device Manual).

4. RESULTS AND DISCUSSION OF THE PULL-OFF TEST

The Pull-off strength has resulted from applying a tensile force perpendicular to the application's surface until two layers are separated. During the test, a combination of failure modes might happen, leading to adhesive failure with a piece of the micro-surfacing layer adhering to the surface. In this state, the ratio of interface failure Inability will also be noted [14,17]. Table 7 presents the pull-off test results.

Table 7: 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
PG (76 -10) modified with polymer (4.5%)	1	0.194		
	2	1.019		
S.E	1	1.432		
	2	1.529		
F.E	1	2.130		
	2	3.113		

- Pull-off strength has adhesive failure mode for a thick layer of 1 mm and cohesive failure in the concrete substrate for a 3 mm thick layer of F.E. A thick layer of 3 mm gives more adhesive strength than a 1 mm thick.

- For S.E., the maximum layer thickness, according to the product data sheet, is 30 mm, and the dependent thickness in this research is 5 mm. Pull-off tests give homogenous results and failure modes in which a combination of adhesive failure and cohesive failure in the concrete substrate has appeared.
- For PG (76-10), the tack coat was applied at two different temperatures, 48 C (soften point) and 60 C, to investigate its effect on adhesion strength. Because of that, the results between the specimens are non-homogenous, and the failure modes in the pull-off test.
- If we consider that PG (76-10) is the reference tack coat material because it has a lower cost, then the other epoxy materials could compare with it and expressed as a percentage increase in cost. Figure 3 explains that clearly.

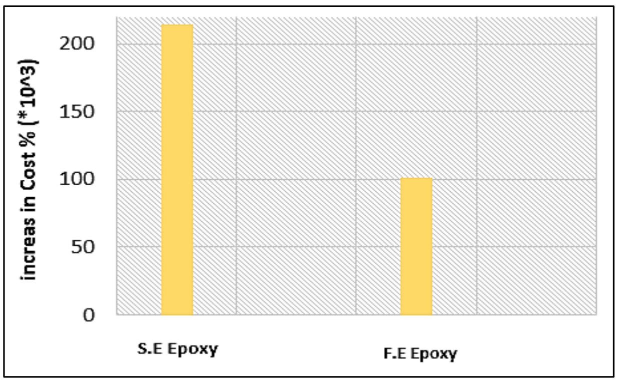


Figure 3: Percentage increase in cost for epoxy materials compared with PG (76-10).

5. CONCLUSIONS

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

- The adhesion strength of PG (76 -10) modified with polymer (4.5%) varies between (0.194-0.1019 Mpa) for adhesive failure and cohesive failure adhesive, respectively. Increasing temperature led to increasing adhesive between layers. Adding polymer to asphalt increased viscosity, making its adhesiveness higher.
- The adhesive force of S.E ranges between (1.432-1.529) MPa for adhesive and cohesive material failure in concrete.
- The adhesive force of Nitomortar TC2000 ranges between (2.130-3.113) MPa for adhesive failure and cohesive failure in the concrete substrate.
- The highest adhesion strength was found in the (F.E) from Fosrok Company.

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