Standard Method of Test for

**Determining Asphalt Binder Bond Strength by Means of the Binder Bond Strength (BBS) Test**

AASHTO Designation: TP-XX-11

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1. **SCOPE**

1.1 This test method quantifies the tensile force needed to remove a pullout stub adhered to a solid substrate with asphalt binder. Samples are prepared at controlled environmental (i.e., temperature and humidity) and moisture conditions. After conditioning, a pneumatic load is applied to a pullout stub using an ASTM D 4541 Type IV adhesion tester until failure. The pullout tensile strength and mode of failure are used to describe the bonding properties of the asphalt binder and compatibility between aggregates and asphalt binders.

1.2 The values stated in SI units are to be regarded as the standard.

1.3 *This standard may involve hazardous materials, operations, and equipment. This standard does not purport to address all of the safety concerns associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

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2. **REFERENCED DOCUMENTS**

2.1 **AASHTO Standards:**

- M 140, Emulsified Asphalt
- M 208, Cationic Emulsified Asphalt
- M 316, Polymer Modified Cationic Emulsion
- T 40, Standard Method of Test for Sampling Bituminous Materials
- T 315, Determining the Rheological Properties of Asphalt Binder Using a Dynamic Shear Rheometer.

2.2 **ASTM Standards:**

- D 4541, Pull-Off Strength of Coatings Using Portable Adhesion Testers
- E 77, Inspection and Verification of Thermometers
- E 145, Gravity-Convection and Forced-Ventilation Ovens
3. TERMINOLOGY

3.1 Definitions

3.1.1 saturated surface dry (SSD) condition — in this condition, the void structure of the aggregate is filled with moisture, while the main surface area of the aggregate particles remains dry.

3.1.2 pullout tensile strength - pressure required to remove a pullout stub attached to a prefabricated surface by asphalt binder with force applied in the normal direction. Used in this procedure as a parameter to evaluate the quality of the bond.

3.1.3 failure mode: Indicator of the weakest component of the asphalt/surface system. In applications to this test procedure failure can occur at three locations: within the asphalt binder, at the asphalt binder/substrate interface, or in a mixed mode.

4. SUMMARY OF METHOD

4.1 The adhesion tester applies a pneumatic load via a pressure ring to a pullout stub fixed to a rigid substrate with asphalt binder, as shown in Figure 1. The binder is adhered to the substrate and subjected to differing curing conditions. For curing emulsified binders, fixed levels of temperature and humidity are used. Moisture conditioning is used for both hot-applied binders and emulsion residues to evaluate the effects of moisture damage. During the test pressure vs. time is monitored and the load is applied until failure. The output of the test is pressure at failure. The surface is also inspected visually to determine the nature of failure.

Figure 1 - Schematic Representation of the Testing Assembly for the Binder Bond Strength Test.
5. **SIGNIFICANCE AND USE**

5.1 Pullout tensile strength values measured over a range of environmental conditions and curing times provide information related to the bond strength at the interface between a substrate and hot-applied or emulsified asphalt binder.

5.2 Evaluation of pullout tensile strength on different aggregate substrates provides a measure of asphalt-aggregate compatibility.

5.2.1 Applications to emulsified binders include assessment of curing rate and ultimate tensile strength.

5.2.2 Applications to hot-applied binders and recovered emulsion residues include evaluation of the effects of application temperature and moisture conditioning on pullout tensile strength.

6. **APPARATUS**

6.1 **Molds**

6.1.1 *Emulsified Binders:* For emulsified binders use a silicone mold measuring approximately 20 mm (0.79 in) in diameter, 5 mm (0.20 in) in width, and 5 mm (0.20 in) in thickness. The mold has no backing and is used to contain the emulsion on aggregate surface. A diagram of the mold is presented in Figure 2a.

6.1.2 *Hot-Applied Binders and Emulsion Residues:* Use a silicone mold measuring approximately 40 mm by 40 mm (1.6 in. by 1.6 in.) with a 8-mm (0.32-in.) diameter cavity with a 2.0-mm (0.08-in.) depth. This mold is similar to the molds used to prepare Dynamic Shear Rheometer (DSR) test samples provided in 6.2 of AASHTO T315. A diagram of the mold is provided in Figure 2b.

![Mold Diagrams](image)

**Figure 2** - Mold Dimensions (mm) for Emulsified Binders (left) and Hot Binders (right) – *Drawings not to Scale*
6.2 **Substrate** — Composed of solid aggregate or aggregate composite with dimensions as defined in Section 9.

6.3 **Testing Machine**—Use a Type IV adhesion tester as defined in ASTM D 4541 for all tests. At a minimum the device must consist of the components detailed in 6.3.1-6.3.3. An example of the testing machine is provided in Figure 3.

6.3.1 **Control Module** – Capable of air pressure load range from 1 – 5000 psi equipped with a digital or analog display, loading rate control, and data acquisition software capable of monitoring air pressure with time.

6.3.2 **Load Assembly** – Consists of a piston, reaction plate, gasket, and air hose.

6.3.2.1 **Piston and Reaction Plate** – Select a piston and reaction plate assembly with sufficient diameter to allow for loading of the sample until failure. Air pressure at failure is a function of test temperature, loading rate, and asphalt binder stiffness. Application of the device to asphalt binders and mastics indicates that a minimum piston/reaction plate diameter of 57.2 mm (2.25 in) is required.

6.3.2.2 **Gasket** – Composed of polymer or other material with properties and dimensions capable of providing an air tight seal between the piston and reaction plate. The gasket must be inspected regularly to ensure the air tight seal is maintained and replaced when the gasket is no longer functional.

6.3.2.3 **Air Hose** – Rated for a maximum psi value that exceeds the air supply specified in 6.3.3.
**Figure 3- General Representation of Binder Bond Strength Test Apparatus.**

**Note 1:** The testing apparatus depicted in Figure 3 is a commercially available device produced by GARDCO Inc. The F-4 piston depicted in the figure has a diameter of 73.0 mm (2.88 in). Other devices meeting the requirements of this procedure can be used.

6.4 *Air Supply*—Capable of producing a consistent air pressure of at least 0.7 MPa (100 psi) as read on the supply gauge. Self-contained air cylinders, shop (bottled) air, or air from an automatic pump can be used.

6.5 *Pullout Stubs*—Stainless steel or any other suitable material with dimensions shown in Figure 4. Stub edges are beveled to reduce the amount of binder trapped between the stub edge and substrate to ensure a uniform film thickness. Inspect pull-off stub edges frequently to verify that the edge is consistent along the diameter of the stub with no visible chips or dents. Discard damaged stubs. The stub surface is roughened to increase the surface area in contact with the asphalt binder.

![Roughened Stub Surface](image)

**Figure 4 – Pull-off Stub Dimensions (mm) for Asphalt Bond Strength Test**

<table>
<thead>
<tr>
<th>Dimensional Equivalents</th>
<th>mm</th>
<th>in</th>
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<tbody>
<tr>
<td>mm</td>
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<td>5</td>
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<td>20</td>
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<tr>
<td>22</td>
<td>22</td>
<td>0.9</td>
</tr>
<tr>
<td>40</td>
<td>40</td>
<td>1.6</td>
</tr>
</tbody>
</table>

**Note 2:** Dimensions presented in Figure 4b are specific to the device used in development of this test procedure, if another device is used adjust dimensions to match the pull-off stub with the load assembly of the device. Pull-off stub diameter (20 mm in Figure 4b) is an input to the calculation of pull-off tensile strength (POTS). Maintain a tolerance of ±0.025 mm in stub diameter to ensure consistent results. Procedure was developed based on pull-off stub diameter of 20 mm, it is recommended the user maintains this dimension for testing.

6.6 *Ring Support*—Provides support to the piston and reaction plate support also provides space between the substrate and load assembly to minimize the risk of eccentric loading. The ring support (e.g. shaft collar) has minimum dimensions of 12.5 mm (0.5 in) in
height and a 25.4 mm (1.0 in) diameter. An example is provided in

![Image](image1.png)

6.7 Figure 5.

**Figure 5 – Pull-off Stub Metal Ring Support.**

6.8 *Forced Draft Oven*—Capable of maintaining temperatures of at least 150 ± 3°C (302 ± 6°F) for preparing all aggregate and binder samples. Use as many temperature-controlled ovens of Type IIA or IIB as defined in ASTM E 145 as necessary to accommodate the different heating conditions required in the sample preparation process detailed in Section 10.

6.9 *Environmental Chamber*—Capable of maintaining temperatures between 15°C and 75°C ± 1°C (60 and 167 ± 2°F), and relative humidity between 20 percent and 80 percent ± 1 percent, for curing all emulsion samples.

6.10 *Thermometer*—For tests performed at 25°C (77°F), use ASTM Thermometer No. 17C (17F) to measure the temperature of the aggregate surface prior to testing. For tests performed at other temperatures, use ASTM thermometers of an appropriate range and accuracy equal to that of the No. 17 thermometer. Since the accuracy of test results depends upon closely controlled temperature conditions, calibrate thermometers in accordance with ASTM E 77. Thermometric devices with the same accuracy as ASTM thermometers may also be used.

6.11 *Container*—Any suitable container may be used to hold the hot-applied asphalt binder material while it is being melted. For emulsified asphalt binders, the containers may be plastic, non-metal, or if metal, epoxy lined.

6.12 *Ultrasonic Cleaner*—Needed to remove residual particles from substrate prior to testing. Capable of maintaining bath temperatures of 60°C ± 1°C (140 ± 2°F) and with a sufficiently large chamber large to allow for complete submersion of the substrate.
6.13 280 Grit Silicon Carbide Material – On a standard lapidary wheel to ensure uniform surface roughness on substrate.

6.14 Bench Scale - Capable of meeting GP2 requirements as specified in ASTM D4753.

6.15 Water Bath - Capable of maintaining temperature a minimum temperature of 40 ± 3°C with sufficient dimensions to allow for complete submersion of asphalt-aggregate systems in water during moisture conditioning.

7. SAFETY PRECAUTIONS

7.1 Observe standard laboratory safety precautions when preparing and testing hot-applied binders and emulsified binders.

8. CALIBRATION OF TESTING EQUIPMENT

8.1 Verify the operating condition of all physical components in the testing system (i.e., air supply, pressure ring, software, and connections) prior to testing.

8.2 Calibration of Loading Rate

8.2.1 Turn on adhesion testing equipment, computer, and data acquisition system per manufacturer instructions.

8.2.2 Insert gasket into piston and place reaction plate over piston, as indicated in Figure 3. Clamp top (reaction plate) and bottom (piston) of loading assembly using an appropriately sized C-Clamp.

8.2.3 Set loading rate to predetermined setting, note position of loading rate setting relative to the position that corresponds to the minimum or zero loading rate.

8.2.4 Apply air pressure for a maximum of 3 seconds. Monitor air pressure vs. time through data acquisition system or manual readings. For electronic sampling devices, this step also verifies that the data acquisition system is functioning.

8.2.5 Calculate the loading rate based on the slope of the air pressure vs. time curve between 20% and 80% of maximum pressure. Verify that the actual loading rate is within 10% of the pre-selected target value. If the measured value falls outside the target range, adjust the pressure setting and repeat steps 8.2.2 – 8.2.4.

8.3 Conduct the verification of testing equipment and calibration of loading rate procedures specified in 8.1 and 8.2 prior to each day of bond strength testing.

9. AGGREGATE TEST SPECIMENS

9.1 Solid Aggregate Substrates—Cut aggregate substrates from either quarried rocks or cored rock samples using standard rock saws such that plate faces are parallel. Lap all substrates using a 280-grit silicon carbide material on a standard lapidary wheel to remove saw marks and ensure a consistent surface roughness. Once cut and lapped, clean
samples for 60 minutes in an ultrasonic cleaner containing distilled water at a temperature of 60°C ± 1°C (140 ± 2°F) to remove residual particles on the plate surface. Limit the re-use of the same solid aggregate substrate to five times per cut surface.

9.2 Composite Substrates—Composite substrates contain aggregate chips and a rapid-setting cement compound. Prepare composite substrates by casting samples in portland cement concrete cylinder molds measuring 152 mm (5.98 in) diameter and 354 mm (13.94 in) in height. Cure samples per cement compound manufacturer instructions. After curing cut, lap, and clean the composite substrates according to the procedures provided in Section 9.1. Limit the re-use of the same composite substrate to five times per cut surface.

9.3 Substrate Dimensions –Cut solid aggregate or aggregate composite substrates to a minimum thickness of 20 mm (0.8 in) and dimensions that provide sufficient surface area for placement of four pull-off stubs on one substrate. A minimum center to center spacing between two pull-off stub shafts of 73.0 mm (2.87 in) is required for clearance of the load assembly.

Note 3- Asphalt Mixture Substrates-Asphalt mixture core samples obtained from field sites are not used as a substrate due to deviations in surface roughness, which does not allow for uniform binder film thickness. For laboratory asphalt mixture specimens prepared using a Superpave gyratory compactor, lapping surfaces will damage lapidary equipment and is not recommended.

10. SAMPLE PREPARATION

10.1 Hot Applied Asphalt Binders and Emulsion Residues

10.1.1 Obtain a representative sample of the material for testing using procedures specified in T 40. Handle materials and instruments with clean laboratory gloves throughout the test procedure to prevent contamination of testing surfaces.

10.1.2 Place substrates and pullout stubs in a forced draft oven at 150 ± 2°C (302 ± 4°F) for a minimum of 30 minutes to remove residual moisture from the substrate surface and to pre-heat pullout stubs for application.

10.1.3 Remove substrates from the first forced-draft oven and place them in a second forced-draft oven at the user defined application temperature for a minimum of 1 hour.

Note 4: Bond strength measurements are significantly influenced by application temperature. It is recommended that the user select an application temperature similar to those for HMA or WMA mixture production. For emulsion residues a minimum pull-off stub application temperature of 80°C is recommended to ensure adhesion between the stub and residue.

10.1.4 While the substrates reach the application temperature, heat the hot-applied asphalt binder in an appropriate container to the asphalt binder melting temperature in a forced draft oven. Minimize or avoid heating of emulsion residues.
10.1.5 Upon reaching the melting temperature, pour the liquid binder into mold cavities according to guidance provided in AASHTO T315. For emulsion residues, use glove protected fingers to roll residue into a ball and place in mold to ensure the sample is the correct size. For both asphalt binders and emulsion residues cool and de-mold the samples following the procedures specified in 10.3.3 of AASHTO T315. If cooling below ambient temperature is required, follow guidelines provided in Note 22 of AASHTO T315 for use of a refrigerator to cool samples.

10.1.6 Remove the pullout stubs from the first forced draft oven, and place the de-molded asphalt binder onto the stub surface for approximately 10 seconds. An example is provided in Figure 6.

![Figure 6](image)

**Figure 6** – The Asphalt Binder Sample is placed into the Stub Surface for Approximately 10 Seconds.

10.1.7 Firmly press each pullout stub to the substrate surface to bond the stub to the substrate with hot-applied asphalt binder. Continue to apply a downward normal force to the stub until it reaches the substrate surface. Expect excess binder to flow out of the pullout stub channels.

**Note 5:** Pullout stubs must be placed on the substrate normal to the surface to avoid eccentricity during loading and with minimal twisting to prevent the formation of entrapped air bubbles within the sample. An example of a properly applied stub is provided in Figure 7a.

10.1.8 Position a minimum of four pullout stubs on the substrate with the minimum center on center spacing specified in 9.3 An example of the stub configuration on an aggregate substrate is provided in Figure 7b.
10.1.9 Conditioning to Assess Potential for Moisture Damage

10.1.9.1 Allow dry samples to acclimate to lab conditions for 24 hours before testing.

10.1.9.2 To assess moisture damage of wet-conditioned samples, allow samples to acclimate to lab conditions for 1 hour before wet conditioning. Place samples in a submerged environment of 40 ± 2°C for a predetermined conditioning interval. Conditioning intervals ranging from 24 hours – 96 hours have been used. Water or a combination of water and de-icing agents may be used for wet conditioning. After conditioning allow wet conditioned samples to acclimate to lab conditions for 1h before testing.

10.2 Emulsions

10.2.1 Obtain a representative sample of the material for testing using procedures specified in M 140 for emulsified binders in general and M 208 for cationic emulsified binders or M316 for polymer-modified cationic asphalt emulsions.

10.2.2 Heat the emulsified asphalt binder in a container deemed suitable for use with emulsions as defined in 6.10 to 60 ± 2°C (140 ± 4°F) or the supplier recommended storage temperature in a forced-draft oven. Heat the sample no longer than 1 h to avoid premature breaking of the material.

10.2.3 Simultaneously heat the substrates to the user determined application temperature in a forced draft oven or environmental chamber. The test is intended to simulate emulsion curing, requiring use of temperatures within the range of those expected at placement.
10.2.4 If pre-conditioning aggregates to have entrapped moisture trapped in surface voids, submerge the substrates in a bath of heated distilled water to achieve the SSD condition while preheating to the application temperature.

10.2.5 Place molds described in 6.1.1 and shown in Figure 2a on the substrate surface and weigh the substrate with the molds in place on a bench scale. Position the molds on the substrate to allow for placement of at least four molds, spaced according to guidance provided in 9.3. Refrain from applying emulsion on previous areas of application.

10.2.6 Fill each mold with the emulsion quantity as defined by Equation 1 using a graduated eyedropper to ensure a consistent sample size. The mold will be slightly over-filled. An example of the emulsion/mold assembly on the substrate is provided in Figure 8.

\[
EA = \frac{0.45}{AC}
\]

(Eq 1)

Where:

\(EA\) = Emulsion Amount (g)

\(AC\) = Asphalt Content of the Emulsion

10.2.7 Cure the substrate and filled molds under controlled conditions for a pre-determined curing time. Recommended curing times range from 1 hr to 24 hrs. Select curing conditions to represent the expected field conditions. Samples can be cured in a forced draft oven, environmental chamber, or under laboratory conditions. Regardless of device used for curing control temperature and humidity at minimum tolerances of ±3°C and ±10%.

10.2.8 While the emulsified asphalt binder assembly cures, heat the pullout stubs to 60 ± 2°C (140 ± 4°F) in a forced draft oven for a minimum of 1 hr.

10.2.9 After curing, remove the emulsified asphalt binder- substrate assembly from the curing chamber, if not cured under laboratory conditions. Remove the silicone molds encircling the cured binder and immediately bond the heated pullout stubs to the substrate according to guidance in 10.1.8 and Note 5.
If curing under laboratory conditions, let the sample rest for 1 hr prior to testing. If curing at other conditions return the testing assembly to the curing chamber set at the conditions used in 10.2.7 for 1 h to allow samples to acclimate to testing conditions. It is recommended to conduct curing and testing at the same temperatures.

11. **BOND STRENGTH TESTING**

11.1 *Description:* The bond strength testing applies to hot binders, emulsion residues, and emulsions that are not fully cured.

11.2 Set the rate of loading to 690 kPa/sec (100 psi/sec). Verify the loading rate setting using the calibration procedure detailed in 8.2.

11.3 Record the temperature of the substrate surface before testing the first pullout stub.

11.4 Place the ring support concentrically around the stub, which is bonded to the substrate by the asphalt binder. Place the metal ring support concentrically around the pull-off stub.

11.5 Secure the gasket inside the piston and place the piston over the pullout stub. Move the piston down until it is in contact with the ring support. Do not disturb the pullout stub while placing the piston to prevent inducing premature strains in the sample.

11.6 Screw the reaction plate onto the pullout stub taking care not to rotate the stub, until the reaction plate is in contact with the piston. Do not cause rotation of the stub by securing the reaction plate too tightly. An example of the full testing assembly is provided in Figure 9.

![Figure 9 – Asphalt-Aggregate System Prepared to be Tested Using the BBS Testing Apparatus.](image)

11.7 Test the pullout stub bond to the substrate using the adhesion testing device in accordance with the manufacturer’s instructions. Record the environmental conditions (i.e. temperature and humidity) for all tests.
11.8 Record the air pressure at failure and determine the pull-off tensile strength (POTS) using Equation 2. 

\[ POTS = \frac{(BP - A_G) - C}{A_{PS}} \]  

(Eq 2)

Where:

- POTS = Pull off tensile strength (kPa)
- BP = Burst pressure (kPa)
- \( A_G \) = Contact Area of Gasket with Reaction Plate (mm²)
- \( C \) = Piston Constant (Provided by manufacturer)
- \( A_{PS} \) = Area of pull-off stub (mm²)

11.9 Repeat steps 11.2 – 11.9 for remaining pull-off stubs on the aggregate substrate. Re-condition the sample under the appropriate conditions or discard the test result if the substrate temperature for a replicate deviates by ±2°C from the initial substrate temperature measured in 11.3 prior to the first test.

11.10 Evaluate failure mode of each test result using visual observation or digital image analysis and document. Failure can occur at two locations: within the asphalt or at the asphalt binder/aggregate interface, examples are provided in Figure 9. Discard any results that demonstrate failures at the pull-off stub/binder interface, as this is a result of incorrect sample preparation. An example of a pull-off stub that demonstrates adequate coverage and thus is deemed an acceptable test is provided in Figure 11.

**Figure 10** – Examples of Bond Strength Testing Failure Modes for Asphalt-Aggregate Systems: a) Failure Within the Binder , b) Failure at the Interface

**Figure 11** – Example of Acceptable Test Result - Pull-off Stub without Failure at Surface.
12. **REPORT**

12.1 *Sample Preparation and Test Conditions*

12.1.1 *Hot Applied Binders and Emulsion Residues*: Test temperature to the nearest °C and moisture condition (dry or wet).

12.1.2 *Emulsified Binders*: Curing conditions including time (hrs.), temperature (°C), and humidity (%). It is recommended that the same temperatures are used for curing and testing. Document if a different temperature is used for testing.

12.2 *Test Results*

12.2.1 Obtained directly from adhesion testing device or calculated based on Equation 2. Report the following:

12.2.1.1 Results of individual measurements of pull-out tensile strength to the nearest 0.1 kPa.

12.2.1.2 Arithmetic mean and standard deviation of at least four individual measurements to the nearest 0.1 kPa.

12.2.2 *Failure mode*: Identify mode of failure based on definition provided in 3.1.3 and examples provided in Figure 9.

13. **PRECISION AND BIAS**

13.1 Precision and bias has yet to be established for this test method.