Designation: D8541 – 23

Standard Test Method for Determination of Relative Rotation to Evaluate the Workability of Asphalt Mixture Using Wireless Particle-Size Sensors[1]

This standard is issued under the fixed designation D8541; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This test method covers the determination of relative rotation to evaluate the workability of asphalt mixture during compaction using a wireless particle-size sensor. It is applicable to asphalt mixture being compacted using the Superpave Gyratory Compactor (SGC).

1.2 This test method is appropriate for use to determine the relative rotation of laboratory-produced and plant-produced asphalt mixtures, regardless of the type or gradation of the aggregates, and whether reclaimed asphalt pavement (RAP), warm mix asphalt (WMA) additives, or any type of modifiers are used in the asphalt mixture.

1.3 *Units*—The values stated in SI units are to be regarded as the standard. No other units of measurement are included in this standard.

1.4 The text of this standard references notes and footnotes which provide explanatory material. These notes and footnotes (excluding those in tables and figures) shall not be considered requirements of the standard.

1.5 Since a complete precision and bias statement for this standard has not been developed, the test method is to be used for research and informational purposes only. Therefore, this standard should not be used for acceptance or rejection of a material for purchasing purposes.

1.6 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety, health, and environmental practices and determine the applicability of regulatory limitations prior to use.*

1.7 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

D979/D979M Practice for Sampling Asphalt Mixtures

D3549/D3549M Test Method for Thickness or Height of Compacted Asphalt Mixture Specimens

D3665 Practice for Random Sampling of Construction Materials

D3666 Specification for Minimum Requirements for Agencies Testing and Inspecting Road and Paving Materials

D6925 Test Method for Preparation and Determination of the Relative Density of Asphalt Mix Specimens by Means of the Superpave Gyratory Compactor

2.2 *AASHTO Standards:*[3]

R 30 Standard Practice for Mixture Conditioning of Hot Mix Asphalt (HMA)

R 83 Standard Practice for Preparation of Cylindrical Performance Test Specimens Using the Superpave Gyratory Compactor (SGC)

3. Terminology

3.1 *Definitions of Terms Specific to This Standard:*

3.1.1 *average residual rotation, ARR, n*—the average value of the residual rotation between two asphalt mixtures from the initial number of gyrations (N_{inital}) to the design number of gyrations (N_{design}).

3.1.2 *global coordinate, n*—the Cartesian coordinate system that is fixed in space and unaffected by the position and orientation of the object.

3.1.3 *local coordinate, n*—the coordinate system that is attached to the sensor and changes with the movement and rotation of the wireless sensor.

[1] This test method is under the jurisdiction of ASTM Committee D04 on Road and Paving Materials and is the direct responsibility of Subcommittee D04.26 on Fundamental/Mechanistic Tests.

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[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

[3] Available from American Association of State Highway and Transportation Officials (AASHTO), 555 12th St., NW, Suite 1000, Washington, DC 20004, http://www.transportation.org.

3.1.4 *quaternion, n*—an expression to describe the orientation or rotation of an object in 3D space using an ordered set of four numbers.

3.1.4.1 *Discussion*—If an object's orientation is expressed as $a + bi + cj + dk$, where a, b, c, d are real numbers and i, j, k are symbols of three spatial axes with unit vectors, the set of the four ordered numbers, a, b, c, and d is a quaternion.

3.1.5 *relative rotation, RR, n*—the difference between the maximum and minimum value of the Euler angle in a single compaction cycle, recorded by a wireless particle-size sensor.

3.1.6 *relative rotation capacity, RRC, n*—the area under the relative rotation curve from the N_{inital} to the N_{design}.

3.1.7 *residual rotation, n*—the difference in the relative rotation between the test mix and the control mix at the same gyration compaction.

3.1.8 *rotation matrix, n*—the matrix derived from the quaternion that can be used to transform the data between the local and the global coordinate systems.

3.1.9 *workability, n*—a term used to describe the relative ease of compaction of an asphalt mixture using the Superpave Gyratory Compactor (SGC).

3.1.9.1 *Discussion*—The workability describes the specific free rotation capability of the asphalt mixture particle under compaction loading in the SGC.

4. Summary of Test Method

4.1 This test procedure is used to determine the relative rotation to evaluate the workability of asphalt mixture during Superpave gyratory compaction (SGC) using a wireless particle-size sensor.

5. Significance and Use

5.1 Workability is one of the main factors that influence the compaction quality and ultimately the performance of asphalt pavement. This method uses the relative rotation measured by the wireless particle-size sensor to evaluate the workability of the asphalt mixture.

5.2 This test method is used to generate information concerning the workability of an asphalt mixture. Workability characteristics, in turn, can give users insight as to how the mixture will handle and compact in the field.

5.3 This method is used to evaluate workability of the mix in a situation where it is being used for research or mix design. It is not intended to be a quality control (QC) evaluation.

5.4 This test method can be used to evaluate conventional and modified asphalt mixtures to achieve the best workability at an appropriate compaction temperature. The test method can be used to determine the compaction temperature and optimal dosage rate of additives or modifiers to achieve the best workability for the modified asphalt mixtures, such as polymer modified, crumb rubber modified, waste plastic modified, etc.

5.5 This test method is appropriate for laboratory-produced mixtures and plant-produced mixtures, regardless of the type or grade of the binder, the type or gradation of the aggregates, and whether RAP, WMA additives, or other modifiers are used in the asphalt mixture.

NOTE 1—The quality of the results produced by this standard is dependent on the competence of the personnel performing the procedure and the capability, calibration, and maintenance of the equipment used. Agencies that meet the criteria of Specification D3666 are generally considered capable of competent and objective testing, sampling, inspection, etc. Users of this standard are cautioned that compliance with Specification D3666 alone does not completely ensure reliable results. Reliable results depend on many factors; following the suggestions of Specification D3666 or some similar acceptable guideline provides a means of evaluating and controlling some of those factors.

6. Apparatus

6.1 *Superpave Gyratory Compactor and Specimen Mold*—An electromechanical, electro-hydraulic, or electro-pneumatic compactor comprised of the required system components as determined by Test Method D6925 shall be utilized. The relevant parameter of the gyratory compactor and specimen mold should refer to Test Method D6925.

6.2 *Oven*—A forced-draft oven, thermostatically controlled, capable of maintaining any desired temperature setting. The oven shall be available for heating aggregates, asphalt, and equipment.

6.3 *Wireless Particle-Size Sensor*—The wireless particle-size sensor shall survive in a high-temperature environment for at least 10 min. The sensor shall collect the Euler angle or quaternion of the particulate material during the entire compaction process. The wireless particle-size sensor shall be able to connect to digital devices, such as computers, for data transmission. The size of the sensor should not be larger than one fifth of the diameter of the specimen mold. The sampling frequency of the quaternion shall be greater than 5 Hz (10 Hz and higher is recommended).

7. Test Specimens

7.1 *Preparation of Lab Mix Lab Compacted (LMLC) Test Specimens*—Samples of lab-mixed asphalt mix shall be obtained according to Test Method D6925 or other specified sampling method.

7.2 *Preparation of Plant Mix Lab Compacted (PMLC) Test Specimens*—Samples of plant-mixed asphalt mix shall be obtained according to Practices D3665 and D979/D979M or other specified sampling method.

7.3 *Conditioning of the Mixture*—Weigh the mixture to the required mass. Place the mixture in a pan and spread it to an even thickness ranging between 25 mm and 50 mm. Place the mixture and pan in the oven at the required temperature for 2 h ± 5 min short-term aging before compaction in accordance with AASHTO R 30.

7.3.1 *Specimen Size*—The specimens shall be compacted to 150 mm in diameter in accordance with Test Method D6925.

NOTE 2—Sample heights of 80 mm up to 180 mm can be used; however, this will impact the resulting kinematic parameters for relative rotation analysis.

NOTE 3—The specimen mass should follow the mix design after subtracting the mass of the sensor when the height of 115 mm is used.

7.4 *Preparation of Wireless Particle-Size Sensor*—The wireless particle-size sensor shall be able to operationally connect to digital devices before compaction.

7.4.1 *Collection of Initial Quaternion*—Initial data burst shall be collected with the sensor stationary and on a horizontal platform before compaction. A 30 s duration is recommended for coordinate transformation.

8. Procedure

8.1 Subject the loose mix to the appropriate conditioning in accordance with AASHTO R 30 or other asphalt mix conditioning practices. Stir the mix every 60 ± 5 min to maintain uniform conditioning.

8.2 Place a compaction mold assembly in an oven at the required compaction temperature for a minimum of 45 min prior to the compaction of the first mixture specimen.

8.3 At the end of the conditioning period, remove the loose mix sample and the compaction mold assembly from the oven. Place a paper disk inside the gyratory mold to aid the separation of the specimen from the base plate after compaction.

8.4 Quickly place approximately half of the mixture into the mold using a transfer bowl or other suitable device. Place the wireless sensor on the flattened surface of the loose mix and then place all the remaining loose mix in the mold. After the mixture has been completely loaded into the mold, place a paper disk on the mixture to avoid material adhering to the ram head or top mold plate.

8.5 Load the compaction mold into the SGC and initiate the compaction process. Collect the compaction data using the wireless sensor during the entire compaction process. The collected data from the wireless sensor shall include but not be limited to the quaternion or Euler angle data of the sensor during compaction.

NOTE 4—Specimens with the sensor should be compacted to the number of gyrations equal to or larger than N_{design}; the maximum number of gyrations (N_{max}) is recommended.

8.6 At the end of the compaction process, remove the mold assembly from the SGC. Extrude the compacted specimen from the mold and remove the paper disks. Remove the sensor from the mix and let the sensor cool to room temperature.

NOTE 5—Experience has shown this step is critical to maintaining an operational sensor. Residual heat buildup during the compaction process can render the sensor inoperative. The wireless sensors should be cooled down below 30 °C before the next compaction data collection.

8.7 Clean the mold and end plates, then place the compaction mold and end plates back in the oven for a minimum of 20 min before reusing. Save the specimen height measurement results in an SGC data file.

NOTE 6—Printouts of gyratory data can be manually entered into the computer prior to data analysis.

NOTE 7—The height differences between the replicate test specimens should be within ±2.5 mm in accordance with AASHTO R 83. Measure the height of the asphalt specimen in accordance with Test Method D3549/D3549M.

9. Calculation or Interpretation of Results

9.1 *Calculation of Euler Angle*—The calculation of the Euler angle should be conducted based on the quaternion data when the quaternion is initially collected by a wireless sensor during compaction. The calculation between the quaternion and the Euler angle can be referred to in the literature.[4]

9.1.1 The conversion between the quaternion $q = (q_0, q_1, q_2, q_3)$ to the Z-Y-X Euler angle (α, β, γ) is:

$$[\alpha\ \beta\ \gamma] = [a\tan2\ (2(q_0 q_1 + q_2 q_3), 1 - 2(q_1^2 + q_2^2))\ \arcsin(2(q_0 q_2 - q_1 q_3))\ a\tan2\ (2(q_0 q_3 + q_1 q_2), 1 - 2(q_2^2 + q_3^2))]$$

NOTE 8—Euler angle (α, β, γ) means rotate α, β, γ degrees around fixed axes x, y, z in order.

NOTE 9—The software for data analysis may be commercially available.

9.1.2 The detrend (removing the trend) of the quaternion or Euler angle should be performed if an unexpected trend has been observed.

9.2 *Transformation of the Coordinate Systems*—Two coordinate systems exist during the mixture compaction: the local coordinate system and the global coordinate system. All compaction data shall be analyzed in the global coordinate system.

9.2.1 The transformation between the local and global coordinate systems can be achieved using the rotation matrix, which is determined by the initial quaternion data. The configuration of the rotation matrix can be referred to in the literature.[4,5]

9.3 *Determination of Relative Rotation*—The relative rotation can be calculated based on the Euler angle of the particle sensor in the global coordinate system during compaction. The relative rotation at a specific gyration cycle is the difference between the peak and valley value of the Euler angle at the corresponding gyration (shown in Fig. 1).

9.3.1 The average relative rotation at horizontal directions (x- and y-directions) should be used for workability analysis.

9.4 *Determination of Relative Rotation Capacity*—The relative rotation capacity (RRC) is the area under the relative rotation curve from $N_{initial}$ to N_{design} (see Fig. 2).

$$RRC = \sum_{i=N_i}^{N_d} \frac{(RR_{i+1} + RR_i) \times l}{2}$$

where:

RR_i	=	relative rotation of the compacted asphalt mixture at i^{th} gyration,
RR_{i+1}	=	relative rotation of the compacted asphalt mixture at $(i+1)^{th}$ gyration,
N_i	=	initial number of gyrations of the compacted asphalt mixture,
N_d	=	design number of gyration of the compacted asphalt mixture, and
l	=	length of the unit x-axis; typically is one compaction gyration.

[4] Wang, X., et al., "Characterization of Particle Movement in Superpave Gyratory Compactor at Meso-Scale Using SmartRock Sensors," *Construction and Building Materials*, Vol 175, 2018, pp. 206–214. https://doi.org/10.1016/j.conbuildmat.2018.04.146.

[5] Yu, S., et al., "Effect of Warm Mix Asphalt Additive on the Workability of Asphalt Mixture: From Particle Perspective," *Construction and Building Materials*, Vol 360, 2022, 129548. https://doi.org/10.1016/j.conbuildmat.2022.129548.

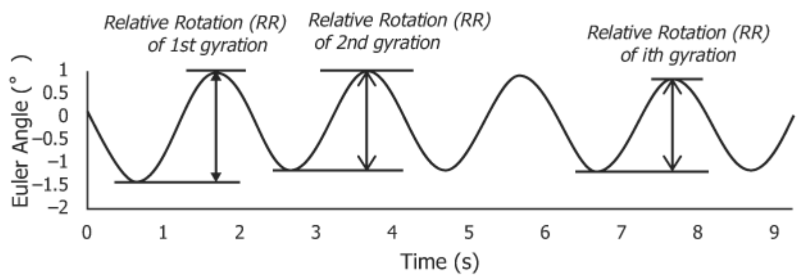

FIG. 1 Illustration of the Relative Rotation

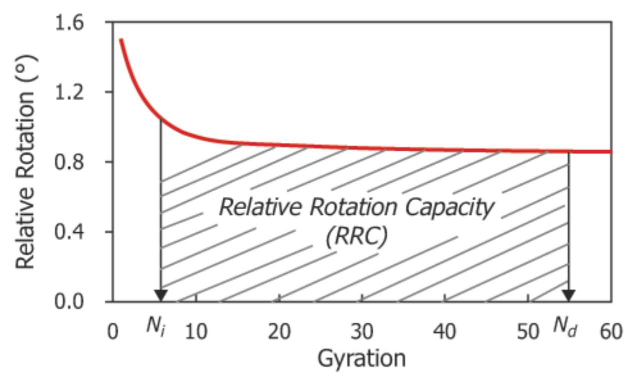

FIG. 2 Determination of the Relative Rotation Capacity (RRC)

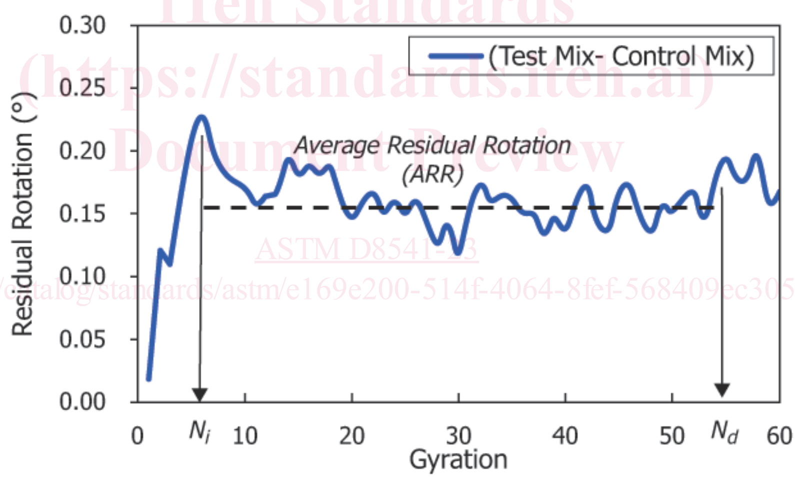

FIG. 3 Determination of the Average Residual Rotation (ARR)

9.5 *Determination of the Average Residual Rotation*—The residual rotation can be calculated by comparing the relative rotations of two asphalt mixtures. The residual rotation at a specific gyration cycle is the difference of the relative rotation between two asphalt mixtures at the corresponding gyration (that is, test mix versus control mix in Fig. 3). The average residual rotation (ARR) is the average value of the residual rotation from $N_{initial}$ to N_{design} (shown in Fig. 3).

$$ARR = \sum_{i=N_i}^{N_d} \frac{(RR_{t,i} - RR_{c,i})}{N_d - N_i} \times Q$$

where:

$RR_{c,i}$ = relative rotation of the control mix at i^{th} gyration,
$RR_{t,i}$ = relative rotation of the test mix at i^{th} gyration,
N_i = initial number of gyrations of the compacted asphalt mixture,
N_d = design number of gyrations of the compacted asphalt mixture, and
Q = coefficient for improving the sensitivity of the parameter; a scaling factor of 10 is suggested for conventional asphalt mixtures.

9.5.1 The average relative rotation of replicate test mixes and control mixes, respectively, are recommended to be used for the calculation of the average residual rotation (ARR).

10. Precision and Bias

10.1 Since a complete precision estimate for this standard has not been developed, the test method is to be used for