
Standard Practice for

**Determining Aggregate Source
Shape Values from Digital Image
Analysis Shape Properties**

AASHTO Designation: R 91-18 (2022)¹

Adopted: 2018

Reviewed but Not Updated: 2022

Technical Subcommittee: 1c, Aggregates



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1. SCOPE

- 1.1. This standard covers the determination of aggregate source and source blend shape characteristics using gradation analysis and shape properties determined by means of digital image analysis.
- 1.2. *This standard may involve hazardous materials, operations, and equipment. This standard does not purport to address all of the safety problems 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.*

2. REFERENCED DOCUMENTS

- 2.1. *AASHTO Standards:*
- [T 11](#), Materials Finer Than 75-μm (No. 200) Sieve in Mineral Aggregates by Washing
 - [T 27](#), Sieve Analysis of Fine and Coarse Aggregates
 - [T 84](#), Specific Gravity and Absorption of Fine Aggregate
 - [T 85](#), Specific Gravity and Absorption of Coarse Aggregate
 - [T 381](#), Determining Aggregate Shape Properties by Means of Digital Image Analysis
- 2.2. *Other Document:*
- National Cooperative Highway Research Program Report 555, *Test Methods for Characterizing Aggregate Shape, Texture, and Angularity*, 2007

3. TERMINOLOGY

- 3.1. *aggregate size*—material retained on a given sieve size after passing the next larger sieve.
- 3.1.1. *fine aggregate*—aggregate material passing 4.75-mm (No. 4) sieve. Sieve sizes are 2.36 mm (No. 8), 1.18 mm (No. 16), 0.60 mm (No. 30), 0.30 mm (No. 50), 0.15 mm (No. 100), and 0.075 mm (No. 200).
- 3.1.2. *coarse aggregate*—aggregate material retained on 4.75-mm (No. 4) sieve. Sieve sizes are 25.0 mm (1 in.), 19.0 mm (³/₄ in.), 12.5 mm (¹/₂ in.), 9.5 mm (³/₈ in.), and 4.75 mm (No. 4).

3.2. *Shape Properties for Each Retained Sieve (x):*

- 3.2.1. *gradient angularity (GA)*—applies to both fine and coarse aggregate sizes and is related to the sharpness of the corners of two-dimensional images of aggregate particles. The gradient angularity quantifies changes along a particle boundary with higher gradient values indicating a more angular shape. Gradient angularity has a relative range of zero to 10,000, with a perfect circle having a value of zero.

Gradient angularity:

$$GA = \frac{1}{\frac{n}{3} - 1} \sum_{i=1}^{n-3} |\theta_i - \theta_{i+3}| \quad (1)$$

where:

- θ = angle of orientation of the edge points,
 n = the total number of points, and
 i = denoting the i th point on the edge of the particle.

- 3.2.2. *texture (or microtexture) (TX)*—applies to coarse aggregate sizes only and describes the relative smoothness or roughness of surface features less than approximately 0.5 mm in size that are too small to affect the overall shape. Texture has a relative scale of zero to 1000 with a smooth polished surface approaching a value of zero.

$$TX_n = \frac{1}{3N} \sum_{i=1}^3 \sum_{j=1}^N \left(D_{i,j}(x, y) \right)^2 \quad (2)$$

where:

- D = decomposition function,
 n = decomposition level,
 N = total number of coefficients in an image,
 i = 1, 2, or 3 for detailed images,
 j = wavelet index, and
 x, y = location of the coefficients in transformed domain.

- 3.2.3. *sphericity (SP)*—applies to coarse aggregate sizes only and describes the overall three-dimensional shape of a particle. Sphericity has a relative scale of zero to one. A sphericity value of one indicates a particle has equal dimensions (cubical).

$$SP = \sqrt[3]{\frac{d_s \times d_l}{d_L^2}} \quad (3)$$

where:

- d_s = particle shortest dimension,
 d_l = particle intermediate dimension, and
 d_L = particle longest dimension.

Note 1—The term “sphericity” has been used for many years in research to describe this measurement. In principle, a cube does not have a sphericity of one because the diagonal is considered to be the longest dimension. A digital image acquisition and analysis system would measure a value of one for a cube because it would be sitting in front of the camera on one of its faces and the longest dimension will be measured as the width.

- 3.2.4. *Form 2D*—Applies to fine aggregate sizes only and is used to quantify the relative form from 2-dimensional images of aggregate particles. Form 2D has a relative scale of 0 to 20. A perfect circle has a Form 2D value of zero.

$$\text{Form 2D} = \sum_{\theta=0}^{\theta=360-\Delta\theta} \left[\frac{R_{\theta+\Delta\theta} - R_{\theta}}{R_{\theta}} \right] \quad (4)$$

where:

R_{θ} = the radius of the particle at an angle of θ , and

$\Delta\theta$ = the incremental difference in the angle.

3.2.5. *flat and elongated*—those particles having a ratio of longest dimension to shortest dimension greater than a specified value.

Aggregate particle dimensions in an x, y, z coordinate system:

d_s = particle shortest dimension,

d_I = particle intermediate, and

d_L = particle longest dimension.

$$\text{Flatness ratio } (S / L): \text{flatness} = \frac{d_s}{d_I} \quad (5)$$

$$\text{Elongation ratio } (I / L): \text{elongation} = \frac{d_I}{d_L} \quad (6)$$

$$\text{Flat and elongated value } (F \& E): L / S = \frac{d_L}{d_s} \quad (7)$$

3.2.6. *flat or elongated*—those particles having a ratio of intermediate dimension to shortest dimension or longest dimension to intermediate dimension greater than a specified value.

$$\text{Flat or elongated } (F \text{ or } E): \frac{d_I}{d_s} \text{ or } \frac{d_L}{d_I} > \text{ratio} \quad (\text{i.e., } 1, 2, 3 \dots) \quad (8)$$

3.2.7. $\% \text{pass}_x$ = percent passing sieve x .

3.2.8. $\%R_x$ = percent retained on sieve x (passing sieve $x + 1$).

4. SIGNIFICANCE AND USE

4.1. Shape, angularity, and surface texture of aggregates have been shown to directly affect the engineering properties of highway construction materials such as hot mix asphalt concrete, portland cement concrete, and unbound aggregate layers. This standard is used to characterize the combined shape values for an aggregate source from the individual particle shape properties determined by digital image analysis from T 381. The aggregate shape characterization includes gradient angularity, Form 2D, sphericity, texture, and flat and elongated values.

Note 2—The National Cooperative Highway Research Program Report 555 provides background information relevant to characterizing aggregate shape, texture, and angularity.

4.2. This practice may be used to characterize the shape characteristics of single-source aggregate materials and multiple-source aggregate material blends.

5. PROCEDURE

5.1. Determine the aggregate sample grading according to T 27 and the amount finer than 75 μm according to T 11.

5.2. Determine the aggregate sample specific gravities according to T 84 and T 85.

- 5.3. Determine the material sample shape values for Form 2D, gradient angularity, sphericity, form ratios ($F\&E$, F or E), and texture according to T 381.

6. CALCULATIONS—SINGLE SOURCE

- 6.1. The material sample is typically characterized by individual evaluation of material retained on each sieve size, passing the next larger sieve. For the purpose of calculating the combined shape values, consider any sizes that contain inadequate percent retained mass to achieve minimum particle count to have the same shape value as the average of the next larger or the next smaller size, whichever is present.

- 6.2. Calculate the percent retained for the aggregate sample on each sieve using the T 27 results.

Sieve sizes (x):

Coarse: 25.0 mm (1 in.), 19.0 mm ($3/4$ in.), 12.5 mm ($1/2$ in.), 9.5 mm ($3/8$ in.), 4.75 mm (No. 4)

Fine: 2.36 mm (No. 8), 1.18 mm (No. 16), 0.60 mm (No. 30), 0.30 mm (No. 50), 0.15 mm (No. 100), 0.075 mm (No. 200)

Percent passing:

$\%pass_x$ = percent passing sieve x

Percent retained:

$\%R_x$ = percent retained on sieve x

$\%R_x = \%Pass_{x+1} - \%Pass_x$

- 6.3. Calculate average particle size, volume, and surface area for each sieve size x for unit mass.

For the purposes of shape characterization, volume and surface area of an average particle are estimated by using a cubical shape with side dimensions estimated by the average of the retained sieve and next larger sieve dimension.

$$\text{Average particle size : } D_x = \frac{(\text{sieve}_x + \text{sieve}_{x+1})}{2} \quad (\text{mm}) \quad (9)$$

$$\text{Average particle surface area (cubical) : } PSA_x = 6 \times D_x^2 \quad (\text{mm}^2) \quad (10)$$

$$\text{Average particle volume (cubical) : } V_x = D_x^3 \quad (\text{mm}^3) \quad (11)$$

- 6.4. Calculate number of particles per sample unit mass for each sieve size from the size distribution of T 27 and the respective bulk specific gravities (G_{sb}) from T 84 and T 85.

$$\text{Number of particles per sieve size : } \#P_x = \frac{\%R_x \times 1000}{G_{sb} \times V_x} \quad (12)$$

Note 3—A mass of one is assumed in Equation 12. This calculation determines the weighting factor applied to each sieve size for a material sample; therefore, actual mass is not required.

- 6.5. Calculate total particle surface area for each sieve size per sample unit mass:

$$\text{Particle surface area (each sieve } x) \text{ (mm}^2\text{): } SSA_x = PSA_x \times \#P_x \quad (13)$$

- 6.6. Calculate sample surface area (per unit mass).