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16. Abstract This report summarizes the design, basic operations, and analysis methods used in the Aggregate Imaging System (AIMS). The system is designed to analyze the form, angularity, and texture of coarse aggregates and the angularity and form of fine aggregates. Aggregates sizes from 37.5 mm to 150 mm can be analyzed using this system. In addition, the report summarizes the statistical-based methodology used in AIMS for the analysis and classification of aggregate shape. This methodology offers several advantages over current methods used in the practice. It is based on the distribution of shape characteristics in an aggregate sample rather than average indices of these characteristics. The coarse aggregate form is determined based on three-dimensional analysis of particles, which allows distinguishing between flat, elongated, or flat and elongated particles. The fundamental gradient and wavelet methods are used to quantify angularity and surface texture, respectively. The classification methodology can be used for the evaluation of the effects of different processes such as crushing techniques and blending on aggregate shape distribution. It also lends itself for the development of aggregate specifications based on the distribution of shape characteristics.					
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**AGGREGATE IMAGING SYSTEM (AIMS):
BASICS AND APPLICATIONS**

by

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PILOT IMPLEMENTATION OF THE AGGREGATE IMAGING SYSTEM (AIMS)

SUMMARY

This report summarizes the design, basic operations, and analysis methods used in the Aggregate Imaging System (AIMS). The system is designed to analyze the form, angularity, and texture of coarse aggregates and the angularity and form of fine aggregates. Aggregates sizes from 37.5 mm to 150 mm can be analyzed using this system. In addition, the report summarizes the statistical-based methodology used in AIMS for the analysis and classification of aggregate shape. This methodology offers several advantages over current methods used in the practice. It is based on the distribution of shape characteristics in an aggregate sample rather than average indices of these characteristics. The coarse aggregate form is determined based on three-dimensional (3-D) analysis of particles, which allows distinguishing between flat, elongated, or flat and elongated particles. The fundamental gradient and wavelet methods are used to quantify angularity and surface texture, respectively. The classification methodology can be used for the evaluation of the effects of different processes such as crushing techniques and blending on aggregate shape distribution. It also lends itself for the development of aggregate specifications based on the distribution of shape characteristics. The detailed procedure for operating AIMS is given in the [Appendix](#) of this report.

DEFINITION OF AGGREGATE SHAPE

Researchers have distinguished between different aspects that constitute particle geometry. Particle geometry can be fully expressed in terms of three independent properties: form, angularity (or roundness), and surface texture. [Figure 1](#) shows a schematic diagram that illustrates the differences between these properties. Form, the first order property, reflects variations in the proportions of a particle. Angularity, the second order property, reflects variations at the corners, that is, variations superimposed on shape. Surface texture is used to describe the surface irregularity at a scale that is too small to affect the overall shape. These three properties can be distinguished because of their different scales with respect to particle

size, and this feature can also be used to order them. Any of these properties can vary widely without necessarily affecting the other two properties.

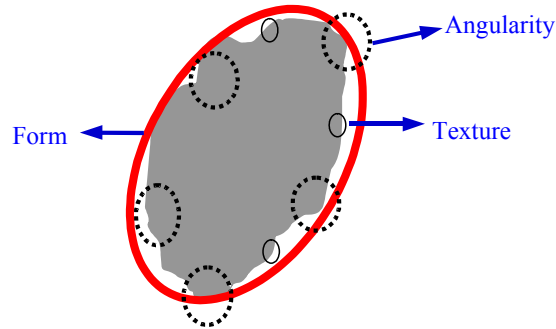


Figure 1. Components of an Aggregate Shape: Form, Angularity, and Texture.

AIMS OPERATIONS

Details of the main components and design of the prototype aggregate imaging system have been reported by Masad (2003). Researchers developed AIMS to capture images and analyze the shape of a wide range of aggregate types and sizes, which cover those used in asphalt mixes, hydraulic cement concrete, and unbound aggregate layers of pavements. AIMS uses a simple setup that consists of one camera and two different types of lighting schemes to capture images of aggregates at different resolutions, from which aggregate shape properties are measured using image analysis techniques.

The system operates based on two modules. The first module is for the analysis of fine aggregates (smaller than 4.75 mm (#4)), where black and white images are captured. The second module is devoted to the analysis of coarse aggregates (larger than 4.75 mm (#4)). In the coarse module, gray images as well as black and white images are captured. Combining both the coarse and fine aggregate analysis into one system is considered an advantage in order to reduce the cost of developing the system. It also allows using the same analysis methods to quantify aggregate shapes irrespective of their size to facilitate relating aggregate shape to pavement performance.

Fine aggregates are analyzed for form and angularity using black and white images captured using backlighting under the aggregate sample tray. This type of lighting creates a

sharp contrast between the particle and the tray, thus giving a distinct outline of the particle. A study by Masad et al. (2001) clearly shows that a high correlation exists between the angularity (measured on black and white images) and texture (measured on gray scale images) of fine aggregates. Therefore, only black and white images are used to analyze fine aggregates.

AIMS is designed to capture images for measuring fine aggregate angularity and form at a resolution such that a pixel size is less than 1 percent of the average aggregate diameter, and the field of view covers 6-10 aggregate particles (Masad et al. 2000). In other words, the resolution of an image is a function of aggregate size. The image acquisition setup is configured to capture a typical image of 640 by 480 pixels at these resolutions in order to analyze various sizes of fine aggregates.

For the case of coarse aggregates, researchers found that there is a distinct difference between angularity and texture, and these properties have different effects on performance (Fletcher et al. 2003). Supported by this finding, AIMS analyzes coarse aggregates for shape and angularity using black and white images, and analyzes texture using gray images. A backlighting table is used to capture the black and white images, while a top lighting table captures gray images of particles surfaces. As for fine aggregates, the image acquisition setup captures images of 640 by 480 pixels. In the coarse aggregate module, only one particle is captured per image in order to facilitate the quantification of form, which is based on three-dimensional measurements. As described later in this chapter, use of the video microscope determines the depth of a particle, while the images of two-dimensional projections provide the other two dimensions to quantify form. Texture is determined by analyzing the gray images using the wavelet method as described later.

AIMS utilizes a closed-loop DC servo control unit of the x, y, and z axes for precise positioning and highly repeatable focusing. The x and y travel distance is 37.5 cm (15 inches); and z travel distance is 10 cm (4 inches). The external controller is housed in a small 15 x 10 cm (6 x 4 inches) case.

Optem Zoom 160 video microscope is used in AIMS. The Zoom 160 has a range of X16 which means that an image can be magnified by 16 times. This magnification allows capturing a wide range of particle sizes without changing parts. AIMS is equipped with a Pulnix TM-9701 progressive scan video camera with a 16.9 mm (2/3 inch) CCD imager. It

has an adjustable shutter speed from 1/60 s to 1/16000 s. The progressive scan video camera allows capturing images at a higher speed than line scan cameras, and they are less affected by noise.

AIMS is equipped with bottom lighting and top lighting, which is a ring mounted on the video microscope (Figure 2). The ring light provides uniform illumination of the region directly in the view of the microscope.

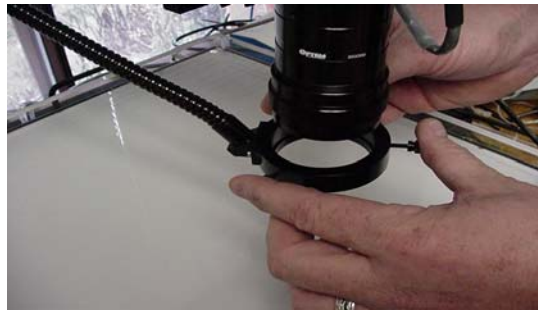


Figure 2. Top Lighting Used in AIMS.

Fine Aggregate Module Operation Procedure

The analysis of fine aggregate starts by randomly placing an aggregate sample (ranges from few grams for small fine aggregate sizes, up to a couple of hundred grams for the larger fine aggregate size) on the aggregate tray with the backlighting turned on. A camera lens of 0.5X objective is used to capture the images. The 0.5X objective lens will provide a field of view of 26.4 x 35.2 mm with a 1X Dovetail tube and a 2/3 inch camera format at a working distance of 181 mm. The camera and video microscope assembly moves incrementally in the x direction at a specified interval capturing images at every increment. Once the x-axis range is complete, the aggregate tray moves in the y-direction for a specified distance, and the x-axis motion is repeated. This process continues until the whole area is scanned.

Depending on the size of aggregates to be analyzed, the z-location of the camera is specified in order to meet the resolution criteria in Table 1. These criteria are established such that the results are not influenced by size (Masad et al. 2000). Aggregates that are not

within the size for which the scan is conducted, and consequently, they do not meet the criteria in [Table 1](#), are removed from the image.

Table 1. Resolutions and Field of View Used in Angularity Analysis of Fine Aggregates.

Particle Size (mm)	Magnification	Field of View (mm)	Resolution (Pixel/mm)
4.725 – 2.36	2.00	13.2 x 17.6	36.36
2.36 – 1.18	4.125	6.4 x 8.5	75.29
1.18 – 0.6	8.25	3.2 x 4.3	148.84
0.6 – 0.30	16	1.65 x 2.2	290.91
0.30 – 0.15	16	1.65 x 2.2	290.91

Coarse Aggregate Module Operation Procedure

The analysis starts by placing the aggregates on the sample tray with marked grid points. The camera lens used in capturing the coarse aggregate has 0.25X objective. The maximum field of view achieved in the coarse aggregate module is 52.8 x 70.4 mm with a 1X Dovetail tube and a 2/3 inch camera format at a working distance of 370 mm. The camera and microscope move as it is the case for fine aggregates but with different distances and intervals. In this module only one particle is captured in each image. Researchers used backlighting to capture images for the analysis of angularity, and they used top lighting to capture images for texture analysis. Two scans are conducted for the coarse aggregate.

Backlighting is used in order to capture black and white images. These images are analyzed later to determine angularity, and the major (longest axis) and minor (shortest axis) axes on these two-dimensional images. The analysis of coarse aggregate angularity starts by placing the aggregate particles in a grid pattern with a distance of 50 mm in the x-direction and 40 mm in the y-direction from center to center. The z-location of the camera

is fixed for all aggregate sizes. [Table 2](#) presents image resolutions used in the coarse aggregate angularity analysis.

Table 2. Resolutions and Field of View Used in Angularity Analysis of Coarse Aggregates.

Particle Size (mm)	Magnification	Field of View (mm)	Resolution (pixel/mm)
9.5 – 4.725	1	52.8 X 70.4	9.12
12.7 – 9.5	1	52.8 X 70.4	9.12
19.0 – 12.7	1	52.8 X 70.4	9.12
25.4 – 19.0	1	52.8 X 70.4	9.12
> 25.4	1	52.8 X 70.4	9.12

Capturing images for the analysis of coarse aggregate texture is very similar to the angularity analysis except that top lighting is used instead of backlighting in order to capture gray images. The texture scan starts by focusing the video microscope on a marked point on the lighting table while the backlighting is turned on. The location of the camera on the z-axis at this point is considered as a reference point (set to zero coordinate). Then an aggregate particle is placed over the calibration point. With the top light on, the video microscope moves up automatically on the z-axis in order to focus on the aggregate surface. The z-axis coordinate value on this new position is recorded. Since the video microscope has a fixed focal length, the difference between the z-axis coordinate at the new position and the reference position (zero) is equal to aggregate depth. This procedure is repeated for all particles. The particle depth is used along with the dimensions measured on black and white images to analyze particle shape or form as discussed later.

AIMS ANALYSIS METHODS

Texture Analysis Using Wavelets

Wavelet analysis is a powerful method for the decomposition of the different scales of texture ([Mallat 1989](#)). In order to isolate fine variations in texture, very short-duration

basis functions should be used. At the same time, very long-duration basis functions are suitable for capturing coarse details of texture. This is accomplished in wavelet analysis by using short high-frequency basis functions and long low-frequency ones. The wavelet transform works by mapping an image onto a low-resolution image and a series of detailed images. The low-resolution image is obtained by iteratively blurring the original images, eliminating fine details in the image while retaining the coarse details. The remaining detailed images contain the information lost during this operation. The low-resolution image can further be decomposed into the next level of low resolution and detailed images.

Figure 3 illustrates the wavelet analysis. The texture information lies in the detail coefficients LH, HL, and HH. The LH coefficients pick up the high frequency content in the vertical direction, the HL coefficients pick up the high frequency content in the horizontal direction, and the HH coefficients pick up the high frequency content in the diagonal direction. Thus, depending upon the selected detail coefficient, directionally oriented texture information can be extracted. Since the directional orientation of the texture content is not emphasized in this project, texture contents in all the directions are given the same weight. Thus, a simple sum of the squares of the detail coefficients (the texture content) is computed as the texture index of the aggregate at that particular resolution. More importantly, detail coefficients have information at different scales, depending upon the level of decomposition. Multi-resolution (or scale) analysis is a very powerful tool that is not possible using a regular Fourier transform.

To describe the texture content at a given resolution or decomposition level, a parameter called the wavelet texture index is defined. The texture index at any given decomposition level is the arithmetic mean of the squared values of the detail coefficients at that level:

$$Texture Index_n(\text{Wavelet Method}) = \frac{1}{3N} \sum_{i=1}^3 \sum_{j=1}^N (D_{i,j}(x,y))^2 \quad (1)$$

where n refers to the decomposition level, N denotes the total number of coefficients in a detailed image of texture, i takes values 1, 2, or 3, for the three detailed images of texture, j is the wavelet coefficient index, and (x,y) is the location of the coefficients in the transformed domain. In this project, the texture is decomposed to six levels. However,

only the results from level 6 are used since previous research showed that level 6 was the least affected by color variations and the presence of dust particles on the surface (Masad 2003).

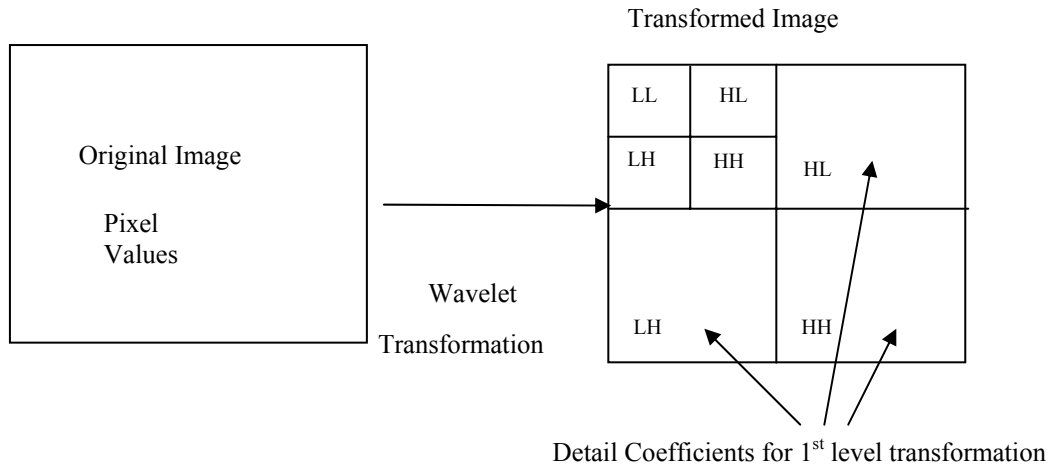


Figure 3. Two-level Wavelet Transformation.

Angularity Analysis Using Gradient Method

In order to measure angularity, a method should be adopted that should assign a finite value of angularity to a highly angular particle that has sharp angular corners, and simultaneously assign near-zero angularity to a well-rounded particle. In addition, the method should be capable of making distinctions between those particle shapes that have intermediate angularities in between these two extremes, and which may appear similar to the naked eye. The gradient method, described below, possesses both of these properties.

The gradient-based method for measuring angularity starts by calculating the gradient vectors at each edge-point using a Sobel mask, which operates at each point on the edge and its eight-nearest neighbors. The gradient of an image $f(x, y)$ at location (x, y) is the vector:

$$\nabla f = \begin{bmatrix} G_x \\ G_y \end{bmatrix} = \begin{bmatrix} \frac{\partial f}{\partial x} \\ \frac{\partial f}{\partial y} \end{bmatrix} \quad (2)$$

It is known from vector analysis that the gradient vector points in the direction of maximum rate of change of f at (x, y) . The magnitude of the vector is given by ∇f , where:

$$\nabla f = \text{mag}(\nabla f) = [G_x^2 + G_y^2]^{\frac{1}{2}} \quad (3)$$

The direction of the gradient vector can be represented by the angle $\theta(x, y)$ of the vector ∇f at (x, y) :

$$\theta(x, y) = \tan^{-1} \left(\frac{G_x}{G_y} \right) \quad (4)$$

where the angle is measured with respect to the x axis. It should be noted that computation of the gradient of an image is based on calculating the partial derivatives $\frac{\partial f}{\partial x}$ and $\frac{\partial f}{\partial y}$ at every pixel location. These derivatives are implemented in the discrete domain using the Sobel operator, which has the advantage of providing both a differentiating and a smoothing effect. The smoothing effect is particularly useful because the derivative operation has the effect of enhancing noise. At sharp corners of the edges of a particle image, the direction of the gradient vector changes rapidly. On the other hand, the direction of the gradient vector for rounded particles changes slowly for adjacent points on the edge.

For the angularity analysis of aggregates, researchers use the angle of orientation values (θ) of the edge-points and the magnitude of the difference in these values ($\Delta\theta$) for adjacent points on the edge, to describe how sharp (large $\Delta\theta$) or how rounded (small $\Delta\theta$) the corner is. Based on the orientation of the gradient-vectors at each edge-point, the angularity index is calculated for the aggregate particle. Angularity values for all the boundary points are calculated and their sum accumulated around the edge to form the

angularity index of the aggregate particle. The angularity index can be represented mathematically as:

$$\text{Angularity Index (Gradient Method)} = \sum_{i=1}^{N-3} |\theta_i - \theta_{i+3}| \quad (5)$$

where the subscript i denotes the i^{th} point on the edge of the particle, and N is the total number of points on the edge of the particle. The step-size used in this project was 3, i.e., the angle of orientation of every third point on the boundary of the aggregate was used to form the angularity index. This value was determined empirically to be optimum, given the resolution of the edge of the images used in the project.

Angularity Using the Radius Method

Masad et al. (2001) developed a method for the analysis of particle form using black and white images. This method, referred to as the radius method, measures the difference between the particle radius in a certain direction and that of an equivalent ellipse:

$$\text{Angularity Index (Radius Method)} = \sum_{\theta=0}^{355} \frac{|R_{\theta} - R_{EE\theta}|}{R_{EE\theta}} \quad (6)$$

where R_{θ} is the radius of the particle at an angle of θ , and $R_{EE\theta}$ is the radius of the equivalent ellipse at an angle of θ (Masad et al. 2001). The equivalent ellipse has the same aspect ratio of the particle but has no angularity (i.e., smooth with no sharp corners). Normalizing with respect to the aspect ratio minimizes the effect of form on the angularity index.

Form Analysis Using Sphericity

Information about the three dimensions of a particle, namely the longest dimension, (d_L), the intermediate dimension (d_I), and the shortest dimension (d_S) is essential for proper 3-D characterization of the aggregate form. Sphericity is defined in terms of these three dimensions as shown in Eq. (7):

$$\text{Sphericity} = \sqrt[3]{\frac{d_s \cdot d_l}{d_L^2}} \quad (7)$$

AIMS uses the auto focus microscope to measure the depth of a particle, while the two-dimensional projections are analyzed using eigenvector analysis to determine the principal axes. In this method, the binary image of the aggregate is treated as a two-dimensional population. Each pixel in the population is treated as a two-dimensional vector $x = (a, b)^T$, where a and b are the coordinate values of that pixel with respect to x and y axes. These vectors are used to compute the mean vector and covariance matrix of the population. The eigenvectors of the covariance matrix are computed, which are orthogonal to each other. The major and minor axes (or the longest and intermediate axes in this case) of the object (aggregate) are aligned along these eigenvectors. Since it is easy to find the centroid of the aggregate, the length of the axes is the same as the distance from the centroid of the aggregate to the edge along the two axes (eigenvectors). This method gives major and minor axes on the projection. These axes with a particle thickness are used to calculate the sphericity in Eq. (7).

Form Analysis Using Form Index

The form index, proposed by Masad et al. (2001), was used here to quantify a particle form in two dimensions. This index uses incremental change in the particle radius. The form index is expressed by the following equation:

$$\text{Form Index} = \sum_{\theta=0}^{\theta=360-\Delta\theta} \frac{|R_{\theta+\Delta\theta} - R_{\theta}|}{R_{\theta}} \quad (8)$$

where R_{θ} is defined as before, and $\Delta\theta$ is the incremental difference in the angle, which is taken to be 4° . By examining Eq. (8), it is apparent that if the particle were a perfect circle the form index would be zero.

AGGREGATE SHAPE CLASSIFICATION

A comprehensive methodology for classification of aggregates based on the distribution of their shape characteristics should exhibit the following features:

- It represents the three characteristics of aggregate shape (three dimensions of coarse aggregates, angularity, and texture).
- It unifies the methods used to measure the shape characteristics of fine and coarse aggregates.
- Similar to what is currently done for aggregate gradation; each of the shape characteristics is represented by a cumulative distribution function rather than an average value. Therefore, the methodology is capable of accommodating variations in shape within an aggregate sample, and better represents the effects of different processes such as blending and crushing on aggregate shape.
- It is developed based on statistical analysis of a wide range of aggregate types and sizes.

The classification methodology is based on measuring the shape characteristics of aggregates from a wide range of sources and varying sizes using AIMS. The analysis generated a total of 195 tests on coarse aggregates and 75 tests on fine aggregates. On average, a coarse aggregate test involved 56 particles; while a fine aggregate test involved about 300 particles. All this amount of data was used in the development of the new classification system.

Researchers used cluster analysis to develop groups (or clusters) of aggregates based on the distribution of shape characteristics. Clustering is a widely used pattern recognition method for grouping data and variables. Grouping is done on the basis of similarities or distances. In many areas of engineering and sciences, it is important to group items into natural clusters. Basic references about clustering methods include most applied multivariate statistical texts (e.g., [Johnson and Wichern 2002](#); and [Morrison 2005](#)). All clustering methods start from a choice of a metric (a distance or closeness among objects) and a choice of a method for grouping objects. The clustering method was applied to the

analysis results of each shape property obtained from AIMS. The research team found that groups or clusters can be developed for each of the shape properties irrespective of aggregate size. [Figure 4](#) shows the developed classification limits. More details on the development of the classification methodology are available in [Al-Rousan et al. \(2005\)](#).

The sphericity value gives a very good indication on the proportions of particle dimensions. However, one cannot determine whether an aggregate has flat, elongated, or flat and elongated particles using the sphericity alone. To this end, the chart shown in [Figure 5](#) is included in the AIMS software to distinguish among flat, elongated, and flat and elongated particles. Superimposed on this chart are the 3:1 and 5:1 limits for the longest to shortest dimension ratio. The use of this chart is illustrated here with the aid of the results from two aggregate samples denoted CA-2 and CA-4. Both aggregates CA-2 and CA-4 pass the 5:1 Superpave requirement (both had less than 10 percent with particles dimensional ratio of 5:1), but they had distinct distributions in terms of flat and elongated particles.

This type of analysis in [Figure 5](#) reveals valuable information about the distribution that would not have been obtained if aggregates were classified based on the ratio of 5:1 only. Such details are needed to understand the influence of shape characteristics on asphalt mix performance. It is believed that some of the discrepancies in the literature in regard to the influence of shape on performance are attributed to the lack of such details, and rely on indirect methods of measuring average indices to describe shape.

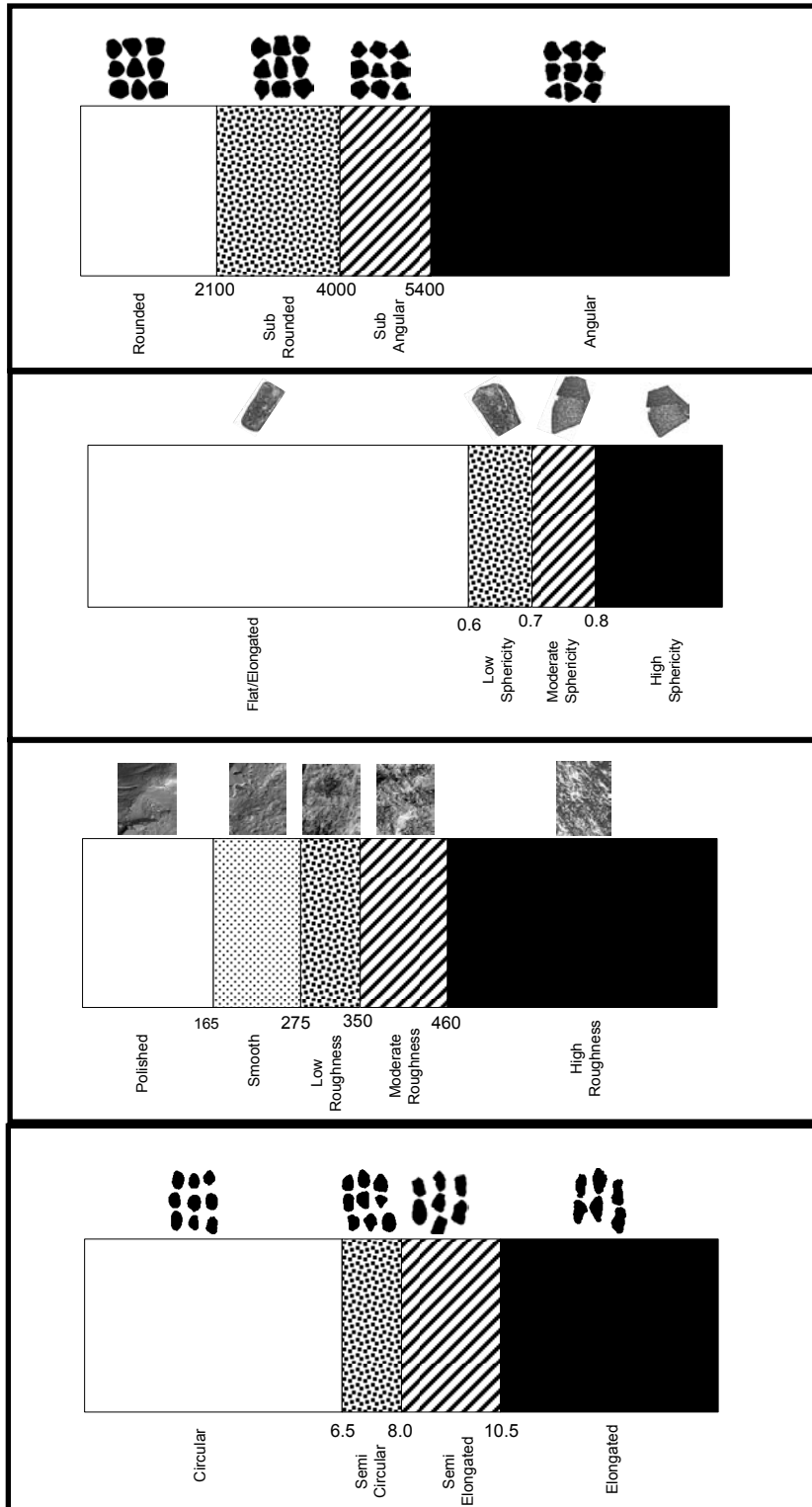


Figure 4. Aggregate Shape Classification Chart.

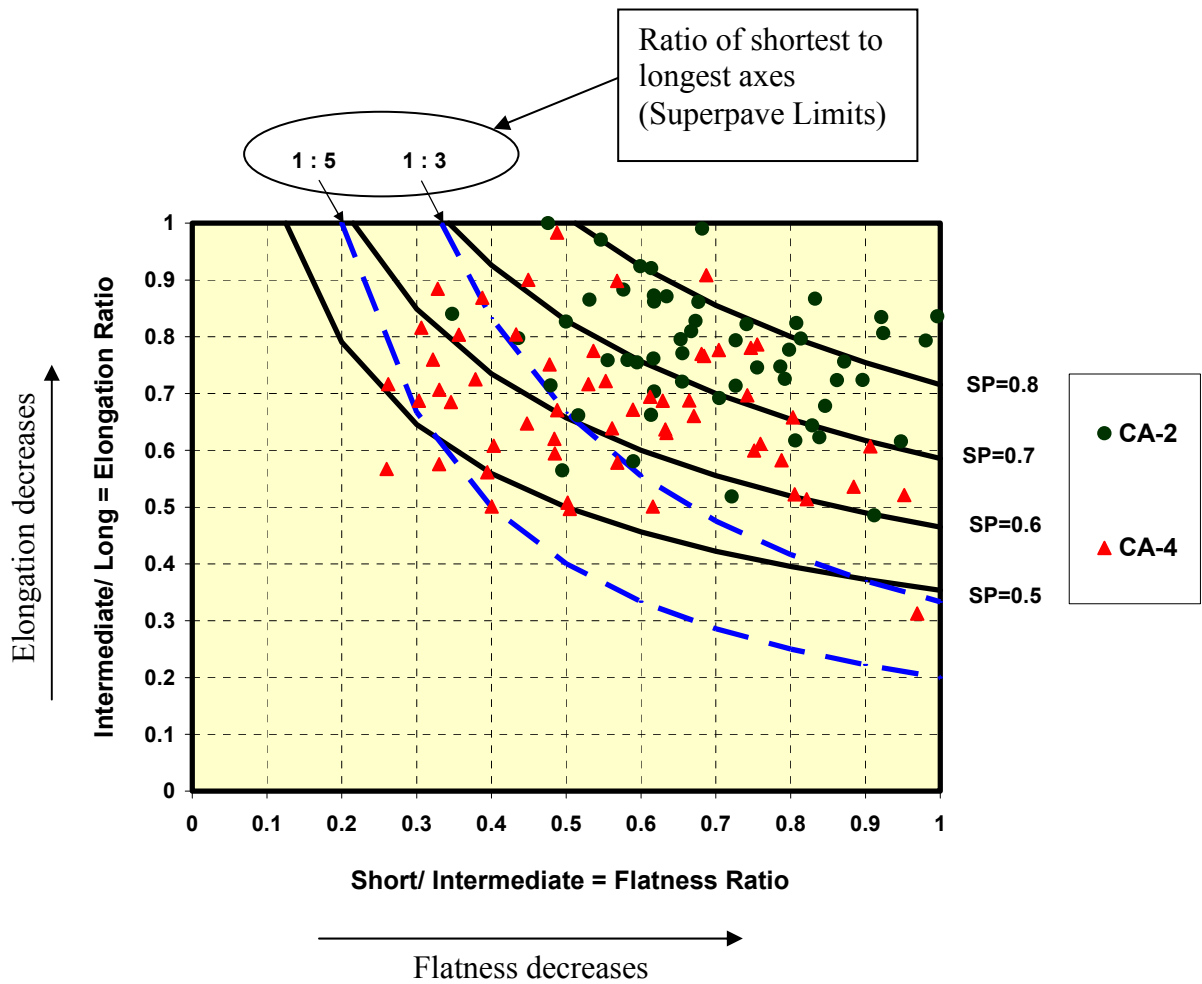


Figure 5. A Chart for Identifying Flat, Elongated, or Flat and Elongated Aggregates.

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Appendix
Standard Method of Test for
SHAPE, ANGULARITY, AND TEXTURE OF AGGREGATE
PARTICLES USING THE AGGREGATE IMAGING SYSTEM
(AIMS)

1. Scope

- 1.1 This method quantifies three-dimensional shape, angularity, and texture of coarse aggregate particles as well as angularity of fine aggregate particles. Testing and analyses are accomplished using the integrated Aggregate Imaging System (AIMS).
- 1.2 Analysis of Coarse Aggregates (Method A) – This method uses aggregates that are retained on a 4.75 mm (No. 4) sieve.
- 1.3 Analysis of Fine Aggregates (Method B) – This method uses aggregates that pass through a 4.75 mm (No. 4) sieve.
- 1.4 Aggregates scanned using this process should be washed to remove clay, dust, and other foreign materials and separated into the appropriate sizes before being analyzed.
- 1.5 *This standard does not purport to address all of the safety problems, if any, 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 *ASTM Standards:*

- D 75 Practice for Sampling Aggregates
- C 136 Test Method for Sieve Analysis of Fine and Coarse Aggregates
- C 702 Practice for Reducing Samples of Aggregate to Testing Size
- E 11 Specification for Wire-Cloth Sieves for Testing Purposes

3. Terminology

3.1 Definitions:

3.1.1 *Shape* – describes the overall three-dimensional shape of aggregate particles, e.g., round, elliptical, flat. The AIMS software sorts the three dimensions based on length and calculates the sphericity index as shown in Eq. (1):

$$\text{Sphericity} = \sqrt[3]{\frac{d_s \cdot d_l}{d_L^2}} \quad (1)$$

where d_L is the longest dimension, d_l is the intermediate dimension, and d_s is the shortest dimension. A sphericity value of one indicates that a particle has equal dimensions.

3.1.2 *Angularity* – is related to the sharpness of the corners of two-dimensional images of aggregate particles. The angularity is analyzed using the gradient method. This method quantifies the change in the gradient on a particle boundary. The gradient method starts by calculating the inclination of gradient vectors on particle boundary points from the x-axis (horizontal axis in an image). The average change in the inclination of the gradient vectors is taken as an indication of angularity as follows:

$$\text{Angularity (Gradient Method)} = \frac{1}{\frac{N}{3} - 1} \sum_{i=1}^{N-3} |\theta_i - \theta_{i+3}| \quad (3)$$

where the subscript i denotes the i^{th} point on the boundary of a particle, and N is the total number of points on the boundary.

3.1.3 *Texture* – describes the relative smoothness or roughness of aggregate particles surfaces. The wavelet method is used to quantify texture. The wavelet analysis gives the texture details in the horizontal, vertical, and diagonal directions in three separate images. The texture index is taken at a given decomposition level as the arithmetic mean

of the squared values of the wavelet coefficients for all three directions. The texture index is expressed mathematically as follows:

$$Texture\ Index_n = \frac{1}{3N} \sum_{i=1}^3 \sum_{j=1}^N (D_{i,j}(x,y))^2 \quad (4)$$

where n denotes the level of decomposition and i takes a value 1, 2, or 3, for the three directions of texture, and j is the wavelet coefficient index.

4. Summary of Methods

4.1 *Method A* – Analysis of coarse aggregates includes three-dimensional shape, angularity, and texture. The analysis starts by placing 56 aggregate particles on the aggregate tray at the specified locations. A 0.25X objective lens and camera acquire images of coarse aggregate particles. The maximum field of view achieved in the coarse aggregate module is 52.8 x 70.4 mm. The camera and video microscope assembly move incrementally in the x direction at a specified interval, acquiring an image of one particle at each increment. Once the x-axis range is complete, the aggregate tray moves in the y-direction for a specified distance, and the x-axis motion and image acquisition process is repeated. This process continues until all 56 aggregates are scanned. Two separate scans are conducted using backlighting and top lighting, respectively. Backlighting is used to acquire two-dimensional images for the analysis of angularity, while top lighting is used for acquiring images for surface texture analysis. These two types of scans are necessary for complete analysis of coarse aggregates (shape, angularity, and texture).

4.2 *Method B* – Analysis of fine aggregate angularity. The 0.5X objective lens is used for acquiring images. The analysis starts by uniformly spreading a few grams of fine aggregate particles on the aggregate tray such that individual particles are not touching each other. Backlighting is used to acquire all images in this analysis. The camera and video microscope assembly move automatically over the aggregate tray until the entire area is scanned. In each x-y scan, the z-

location of the camera is stipulated to meet specified resolution criteria. Aggregates that are not within the size range for which the scan is conducted are removed from the image.

5. Significance and Use

5.1 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. Most methods currently in use for measuring these properties of aggregate particles are indirect measurements of the desired property(s). This test method provides direct measurement of aggregate shape, angularity, and texture and thus provides consistent values that are comparatively more beneficial for use in software designed to predict performance of highway pavements and structures.

6. Apparatus

6.1 The AIMS is an integrated system composed of a camera, video microscope, aggregate tray, backlighting and top lighting systems, and associated software.

7. Sampling

7.1 Obtain aggregate specimens in accordance with Practice D 75, and reduce the specimen to an adequate sample size in accordance with Practice C 702.

8. Preparation of Test Samples

8.1 Wash and oven dry the reduced sample at $110 \pm 5^{\circ}\text{C}$ ($230 \pm 9^{\circ}\text{F}$) to substantially constant mass. The coarse aggregate sample should contain at least 56 particles. The fine aggregate sample should be about 50 gm.

9. Procedure

9.1 *Method A* – Coarse Aggregate Angularity Analysis Procedure

- 9.1.1 The user must ensure that the objective lens used is 0.25X and that the microscope is placed in the coarse position on the dovetail slide. The objective lens can be replaced by removing the fiber-optic ring light by unscrewing the three screws on the ring. Then unscrew the ring light holder from the lower end of the microscope. Then the user will be required to install the required lens type (0.25X in this case), return back the ring holder, and fix the top lighting ring back.
- 9.1.2 Position the microscope on the dovetail slide by releasing the knob of the retaining pin on the left side and sliding the microscope assembly upward/or downward until the “coarse” labels on the left-hand side of the two pieces line up. The user needs to ensure that the retaining pin is engaged to secure the microscope. Then tighten the thumbscrew on the right-hand side of the microscope assembly.
- 9.1.3 On the integrated computer desktop, double click on the “AIMS” icon. The program interface will display a window along with a real-time image (Figure 1). On the program interface window, there are several active buttons with labels that indicate the process they perform.
- 9.1.4 Start the analysis by clicking on the “Project Settings” button. The user must select a name for the project so the analysis results for the aggregate sample will be saved in a file name under the specified directory. This step will allow the user to specify type and size of aggregates to be analyzed. The user is required to click on the “Modify Parameters” button that is available in the “Analysis Parameters” window (Figure 2).
- 9.1.5 At the “Project Parameters” window (Figure 3), enter the drive and directory path desired for the project. Then enter a project name for the aggregates to be analyzed. Then from the “Aggregate Range” drop-list,

the user can select the type of aggregate to be evaluated. For Method A, the user must select “Coarse.” Then click “OK.”

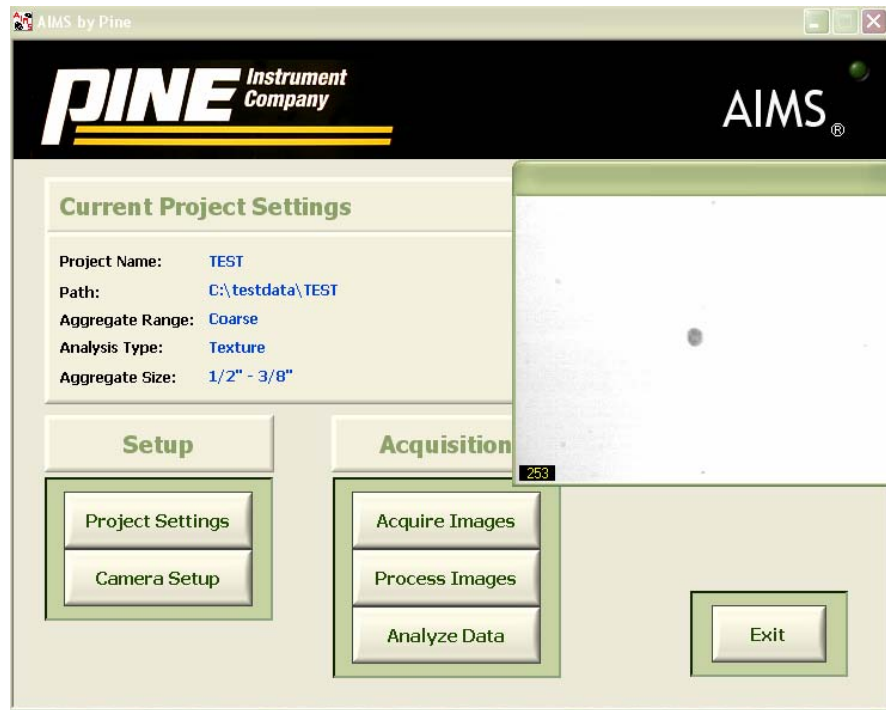


Figure 1. Computer Screen for Setting Up an AIMS Test.

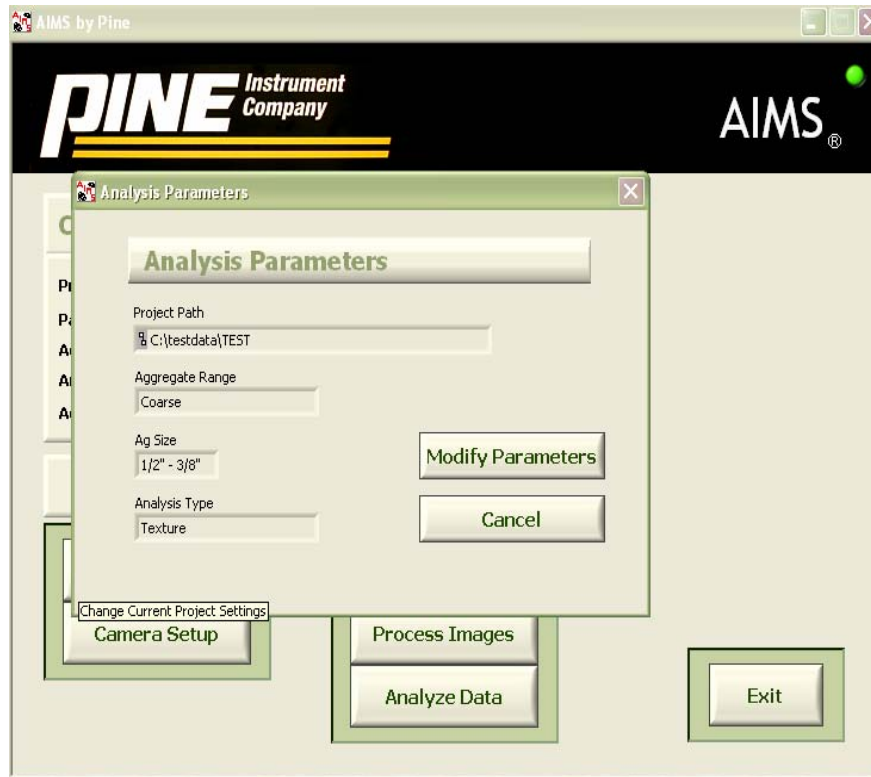


Figure 2. “Analysis Parameters” Window for AIMS Test Setup.

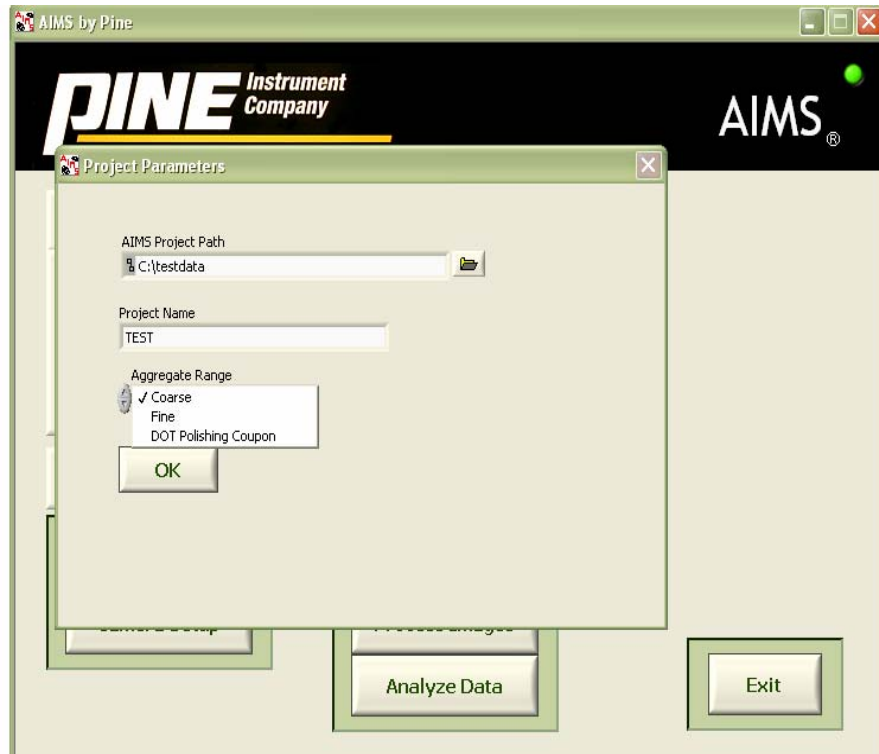


Figure 3. “Project Parameters” Window for AIMS Test Setup.

9.1.6 Clicking the “OK” button on the “Project Parameters” window will display the “Coarse Aggregate Parameters” window (Figure 4). From the “Analysis Type” drop-list, the user must select the type of analysis to be performed (i.e., Angularity, in this case), and click the “OK” button. A “Coarse Aggregate Parameters” window will appear, and the user must select from the drop-list the aggregate size to be analyzed (Figure 5) and click the “OK” button. The first program interface window will appear, showing the information previously entered for current project settings.

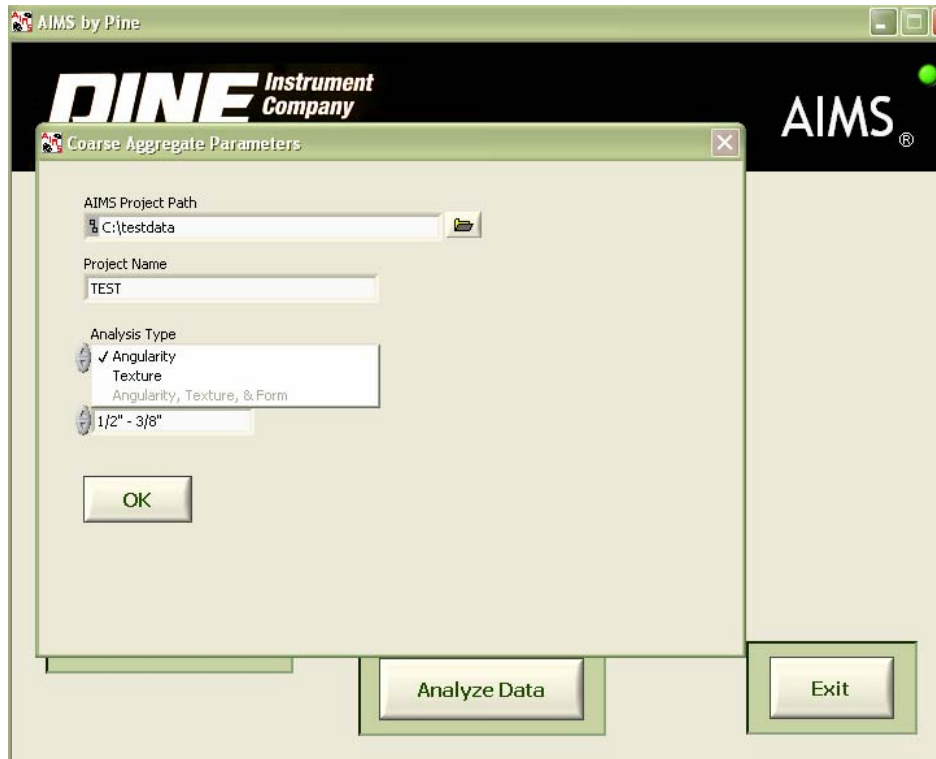


Figure 4. “Coarse Aggregate Parameters” Window for AIMS Test Setup.

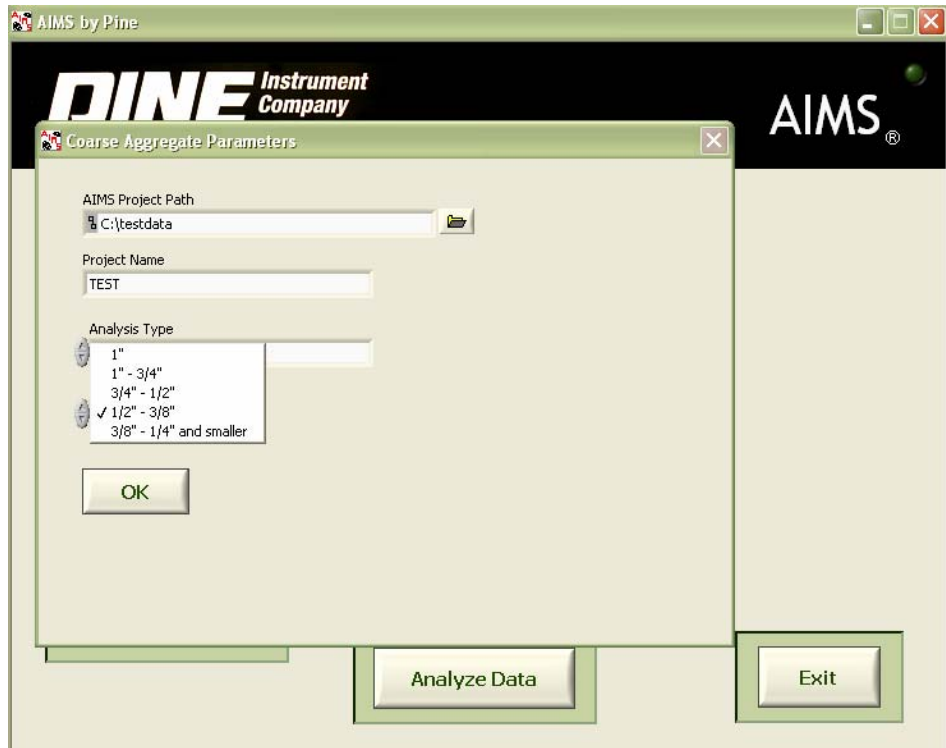


Figure 5. “Coarse Aggregate Parameters” Window for AIMS Test Setup.

- 9.1.7 Turn on the light beneath the aggregate tray, and allow it to warm up for a minimum of two minutes.
- 9.1.8 To calibrate the camera and microscope, click on the “Camera Setup” button. An “AIMS Camera Setup” window will appear, showing a real-time image (Figure 6). Now, the user must focus the camera and microscope on the calibration point marked on the aggregate tray. This point will be used as a reference point for the scan where (x, y, z) coordinates are set to (0, 0, and 0). The user must ensure that the target point is in the center of the image by moving the aggregate tray in x and y direction using the joystick on the controller box. This process is easier if the magnification is set at the lowest level ($M = 1.0$). A magnification of 1.0 is achieved by rotating the dial on top of the controller box while the switch button on the front of the controller is set at zoom position. The

magnification (M-value) appears on the digital screen on the controller box; this value will change when rotating the dial. The minimum value is 1.0 and the maximum value is 16, where maximum magnification is achieved.

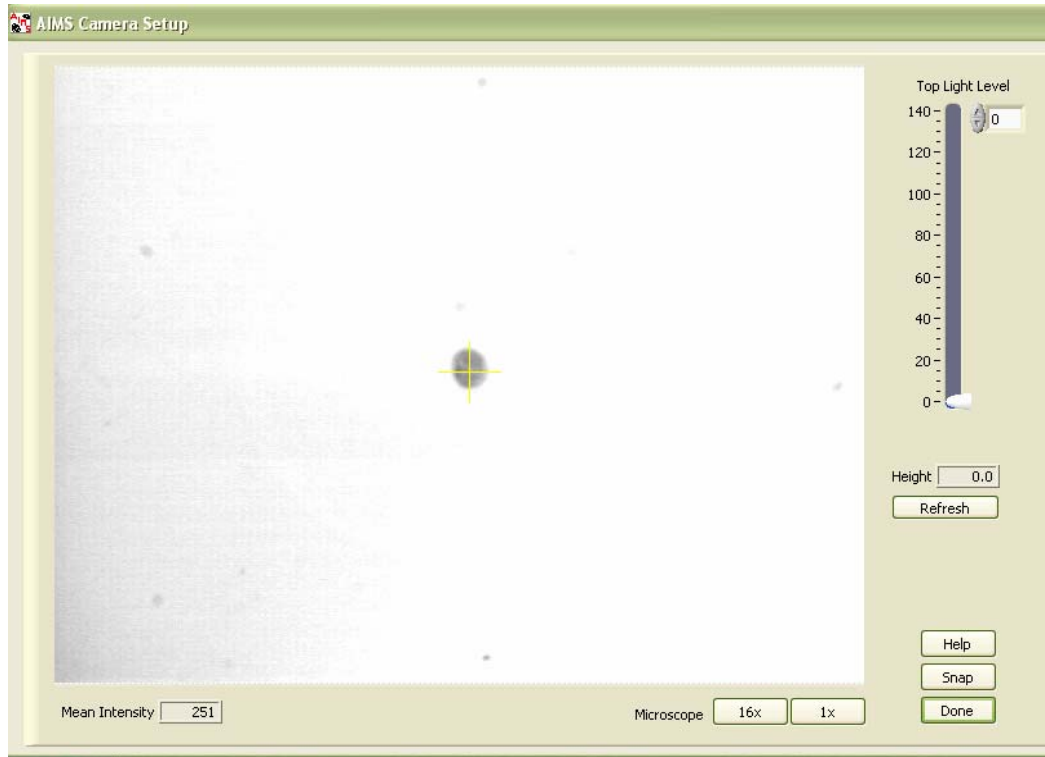


Figure 6. “AIMS Camera Setup” Window.

9.1.9 After centering the calibration point in the image window, the user must click on the “16X” button. Clicking this button will cause the microscope to zoom in and achieve maximum magnification. If the point is not clear or not viewable in the image, move the switch at the front of the controller box to the “Focus” position. Then rotate the dial on top of the controller box to move the microscope up or down until the image

becomes clear. If the calibration point does not appear in the image window, move the joystick in x and/or y direction until the calibration point appears in the center of the image (Figure 8).

Put the switch in the focus position, and use the dial to focus the image at the maximum magnification ($M=16$). This approach is illustrated in Figures 6, 7, and 8.

- 9.1.10 Once the calibration point is centered and well focused in the image, tap the “@” on the controller. This button will cause the microscope to perform auto-focusing and achieve the best image. Then, tap the “Zero” button on the controller box. Then tap “Home.” The “zero” button will set the x, y, and z coordinates to 0, 0, and 0, respectively. The “home” button will cause the camera and microscope to return to the start point after finishing the scan. Then, click the “Done” button on the “AIMS Camera Setup” window; this window will close, and the program interface window will appear again.
- 9.1.11 Image acquisition begins by clicking on the “Acquire Images” button on the computer screen. A new message window will appear giving the option for performing camera setup. If camera setup was not performed in the [previous step](#), it can be done here; otherwise, select “No,” if already performed (Figure 9). When omitting the camera setup option, a new message window appears with instructions (Figure 10).
- 9.1.12 The term “camera origin,” on the screen, signifies camera setup may be performed at this time; however, that is normally performed in the [previous step](#). If so, click cancel, and place aggregate particles on the tray at the indicated locations. Placement of aggregates can be performed at the beginning, but in that case, the user must ensure that the calibration mark is exposed so the camera setup can be performed. If calibration has been performed, one can place aggregates on every marking including the calibration mark. Placement of the aggregates begins by placing a

translucent sheet (Mylar film) between the aggregate tray and the lighting table, which has an alignment grid indicating the position for 56 particles (Figure 11). The Mylar sheet is prepared such that the spacing between the center of the particles is approximately 50 mm in the x-direction and 40 mm in the y-direction. To ensure that the aggregates are properly aligned, the two markings on the right side of the glass aggregate tray should align with the corresponding markings on the Mylar grid sheet (Figure 12). Remove grid sheet after all the particles are positioned. Figure 13 shows the coarse aggregates properly positioned on the glass tray.



Figure 7. Calibration Point Centered at an Intermediate Magnification.

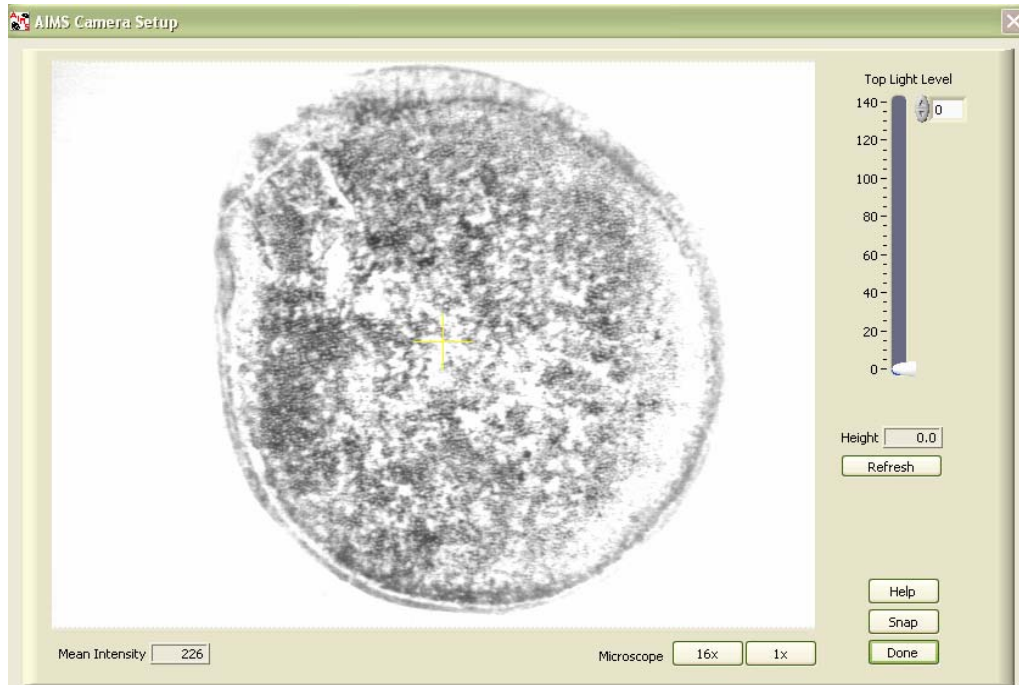


Figure 8. Calibration Point Centered, Focused, and at Maximum Magnification.

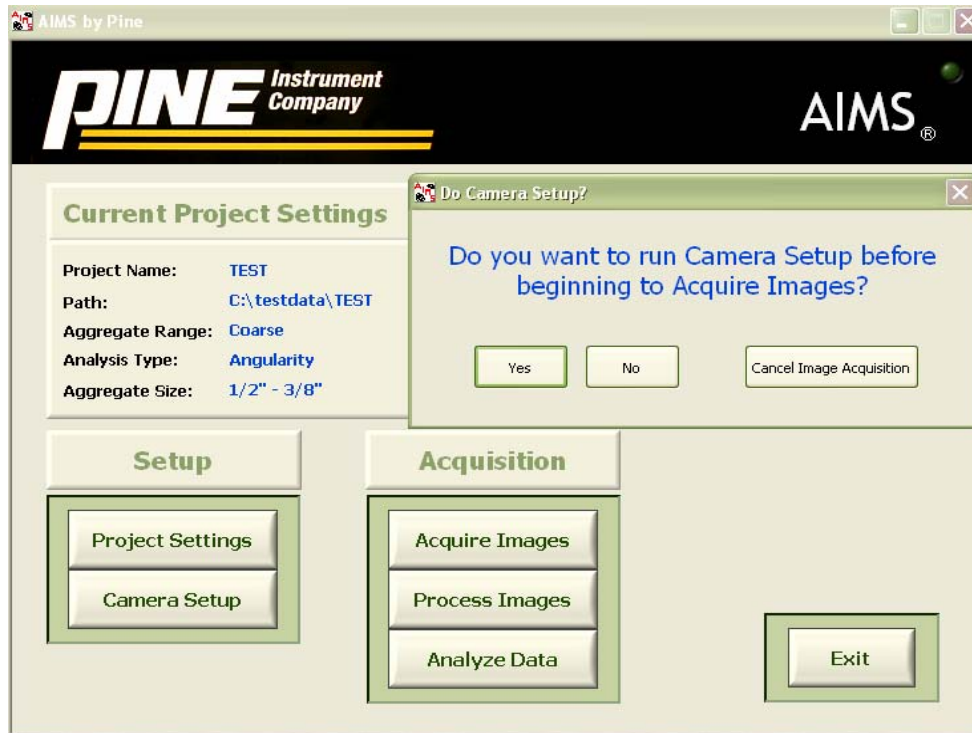


Figure 9. Window Providing Second Opportunity for Camera Setup.

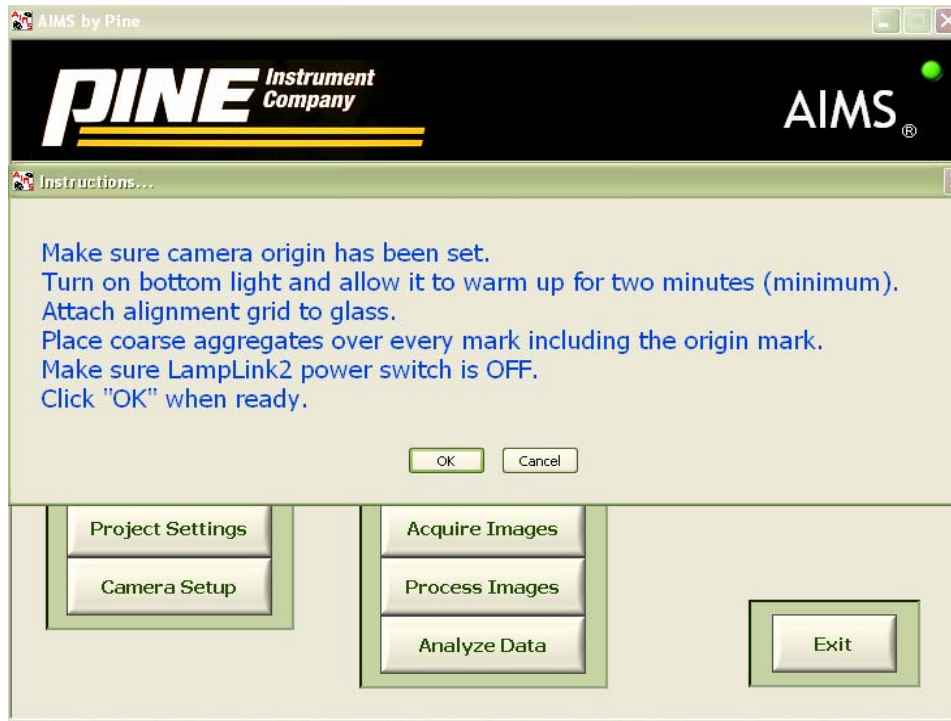


Figure 10. Window Providing Options for AIMS Test Setup.

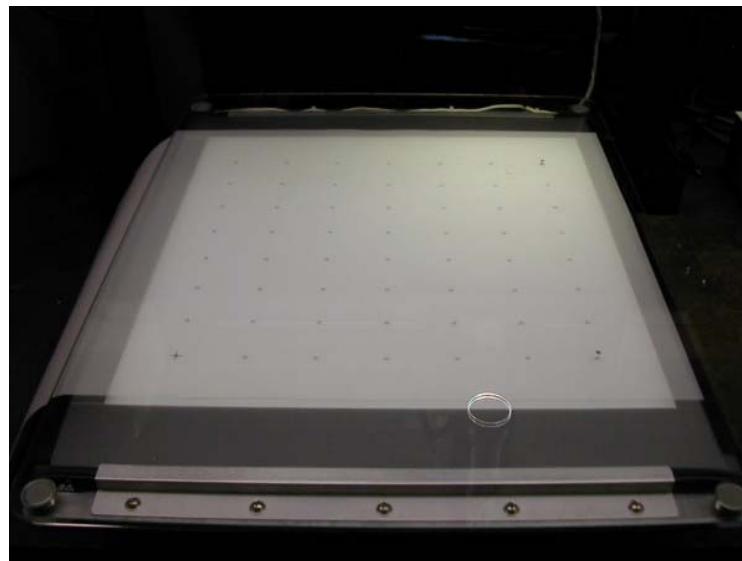


Figure 11. Aggregate Tray with Mylar Grid Sheet Showing Proper Positions of Aggregate Particles.



Figure 12. Close-Up View of Mylar Sheet Over Light Table.
(Note: objects in photo appear misaligned due to parallax error. Look straight down on light table to achieve the optimum alignment.)



Don't place aggregates here until camera is set up.

Figure 13. Coarse Aggregates Properly Positioned on Glass Tray.

9.1.13 After all instructions have been followed, click “OK,” and AIMS will start scanning. Upon scanning all aggregate particles on the aggregate tray, the camera will return to the starting point. [Figure 14](#) shows an example of an image from the scanning process.

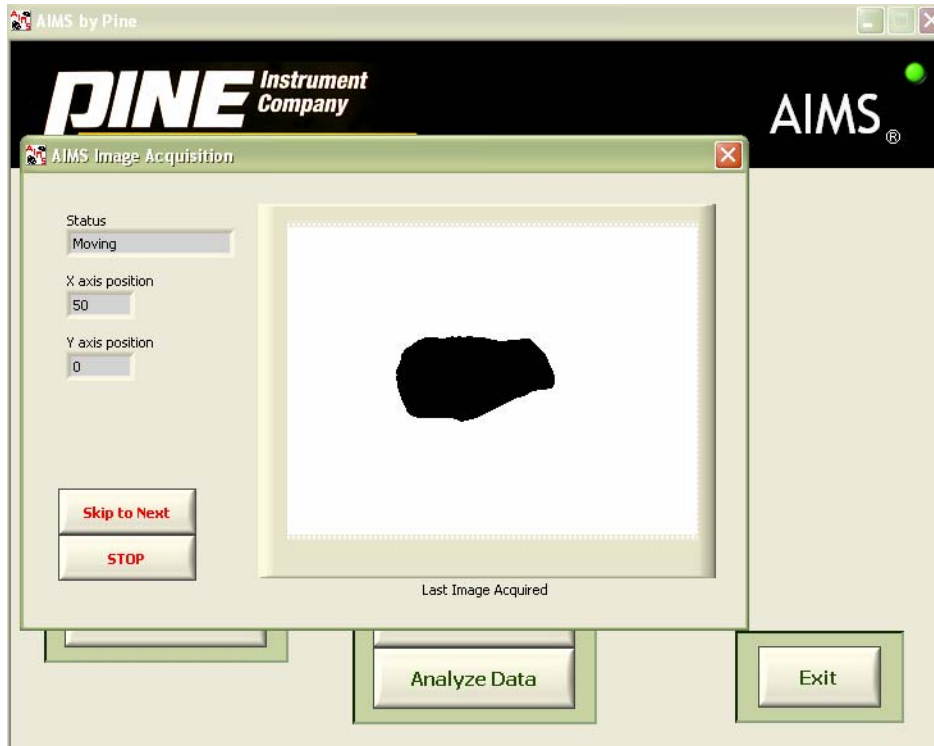


Figure 14. Example of a Two-Dimensional Image of an Aggregate Particle.

9.2 Coarse Aggregate Texture Analysis Procedure

- 9.2.1 For analysis of coarse aggregate texture, the same steps are followed as in the angularity measurement ([Step 9.1](#)), except in [Step 9.1.6](#) for analysis type, select “Texture.”
- 9.2.2 Click on the “Acquire Images” button, and a message window appears, as shown in [Figure 15](#). Follow the instructions and turn off the bottom lighting, and turn on top lighting. If the angularity analysis was not

performed, the aggregates must now be placed on the aggregate tray using the alignment grid sheet, as described in [Subsection 9.1](#).

- 9.2.3 Once the “OK” button is pressed, the system starts scanning the aggregates and acquiring grayscale images for each particle. The system will automatically focus on the top of each aggregate particle and adjust the top lighting. The camera and the microscope will return to the starting point when the scan is completed. [Figure 16](#) shows an example of the scanning process.

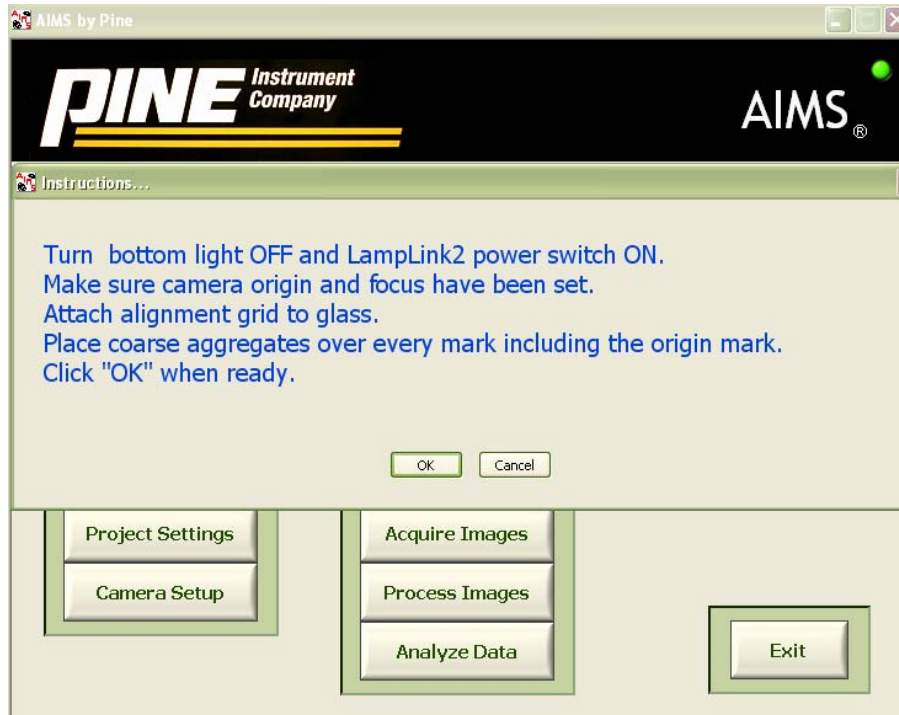


Figure 15. Message Screen When Entering the Texture Measurement Mode.

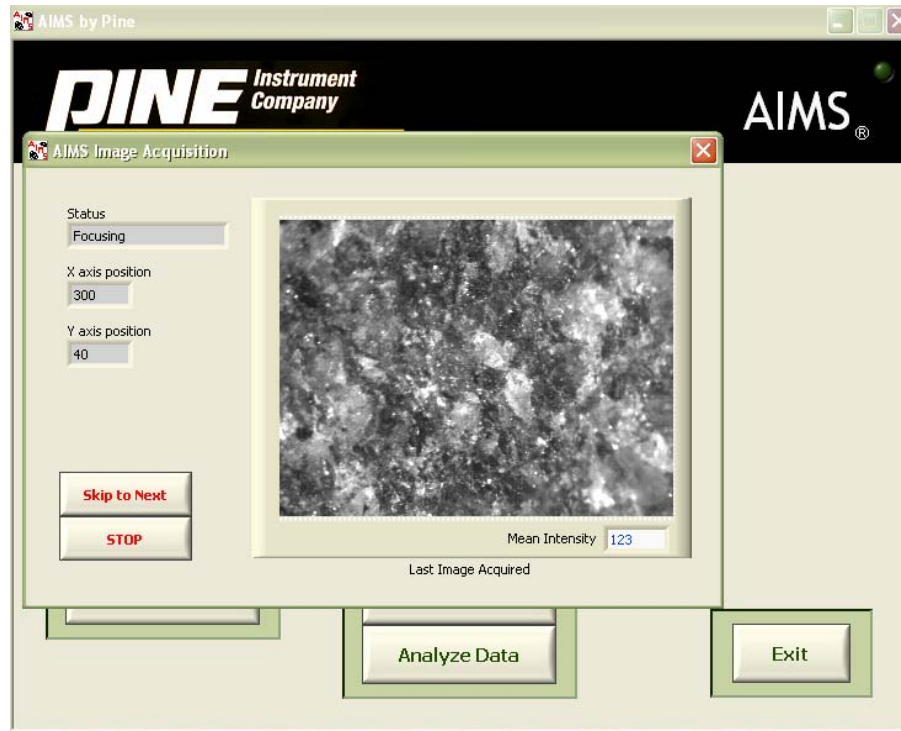


Figure 16. An Example of the Texture Scanning Process.

9.3 Processing of images for angularity and texture analysis: Once the images are collected, they are saved under the directory path specified in [Step 9.1.5](#). Click on the “Process Images” button to process the images using the analysis software. In the new window that appears, specify the project name or the path of the directory in which the images are to be saved. If the analysis was conducted for different aggregate sizes under the same project name, the user has the option to run the analysis for one single size or for all sizes available in that directory ([Figure 17](#)).

9.3.1 Select “OK,” and a new window will appear showing that the analysis process is being performed for the texture images and/or angularity images ([Figure 18](#)). As soon as the analysis is completed, the window will close.

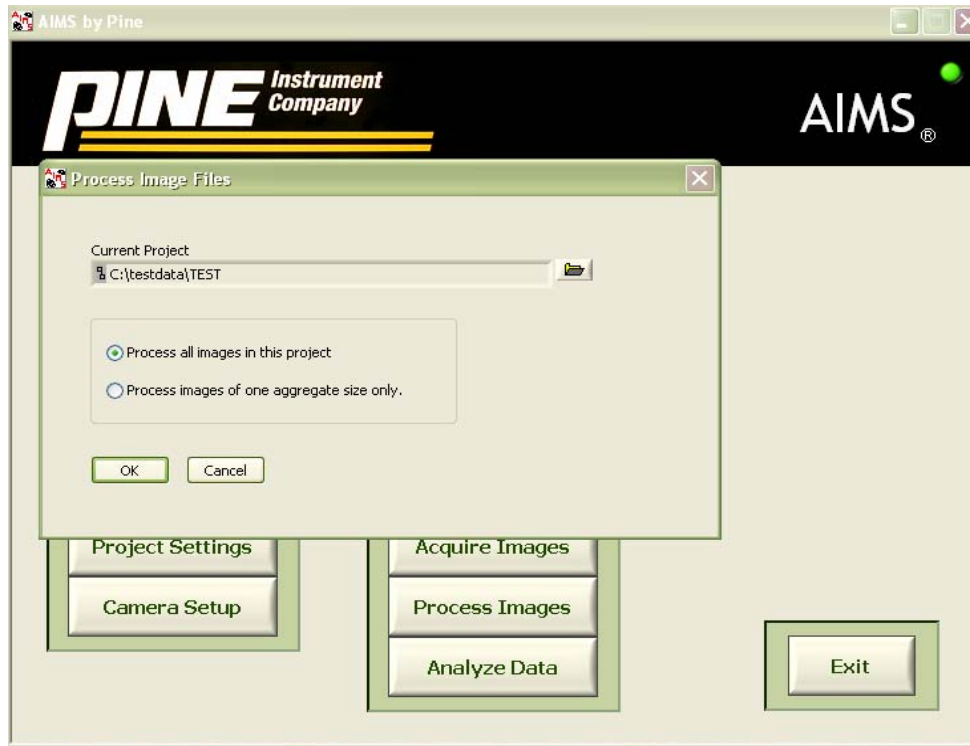


Figure 17. AIMS Permits Processing of All Images or Only Those of a Given Size.

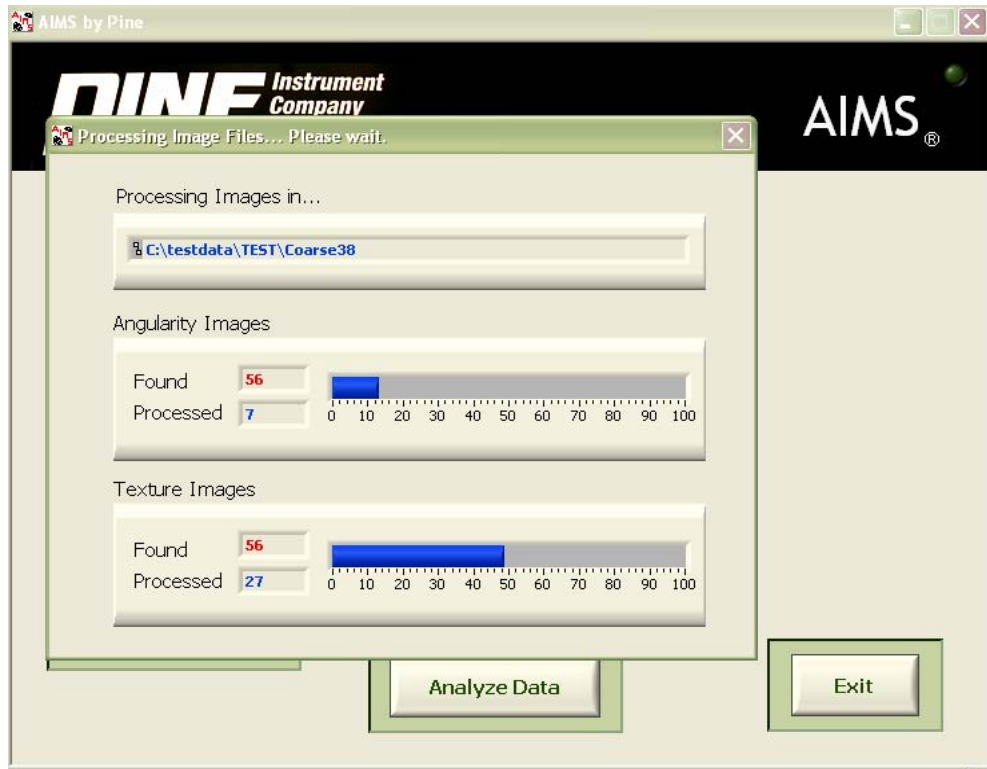


Figure 18. Window Showing That Angularity and Texture Analyses are Being Performed.

9.3.2 Click on the “Analyze Data” button to analyze and obtain the desired data. The new window displayed will allow the user to select the analysis for a single particle size or for all sizes in the directory (Figure 19). Then another window appears (Figure 20), allowing the user to select from a drop-list the directory that contains the processed images and the type of analysis desired (Figure 21). Select the analysis type and the directory, and click on the “Analyze” button. The results will be plotted in cumulative distribution formats (Figures 22 and 23). This process can be repeated sequentially for different analysis types.

9.4 Analyses of shape will be performed only if the user has angularity and texture images of the aggregate stored in that directory.

9.5 Results for each analysis type are saved in an Excel spreadsheet in a folder named “Analysis” that has been created in the directory where the images are saved.

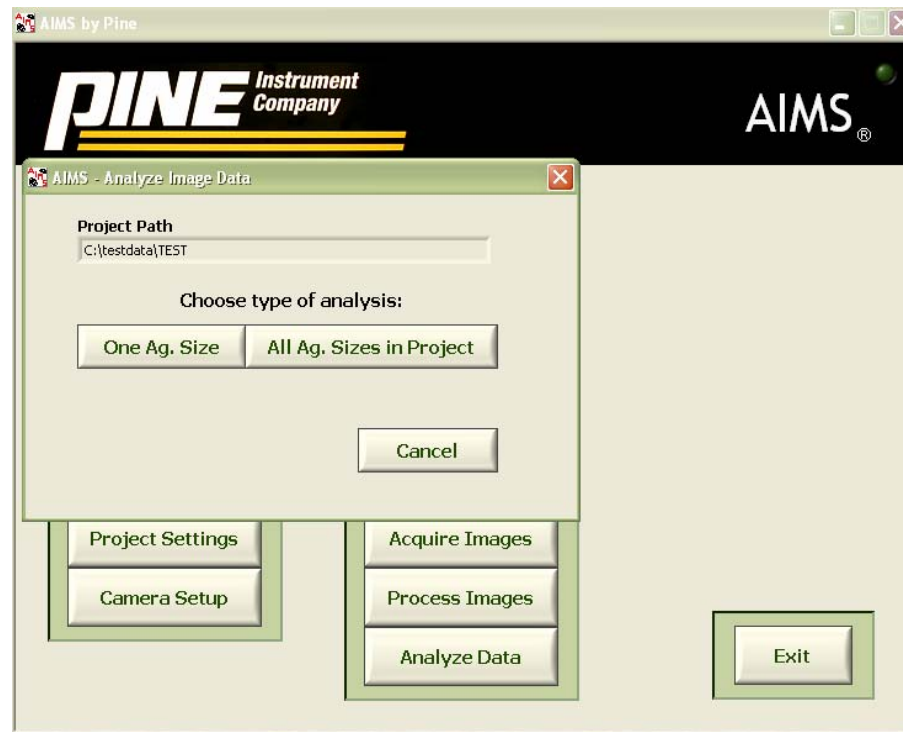


Figure 19. Window for Selecting One or All Aggregate Sizes for Analysis.

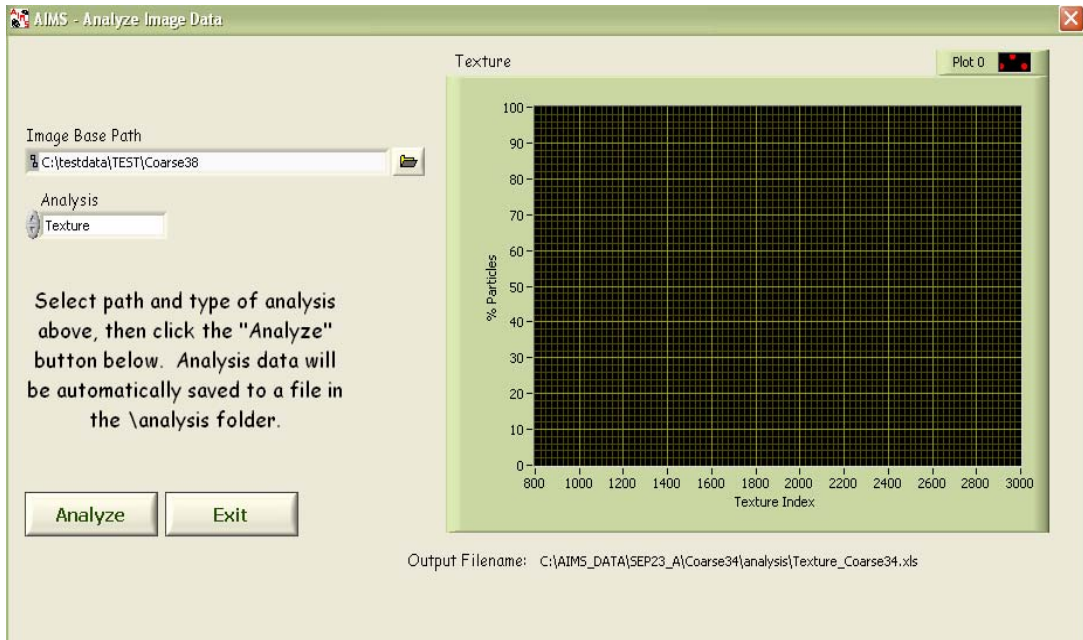


Figure 20. Window for Selecting Directory Type of Analysis Desired.

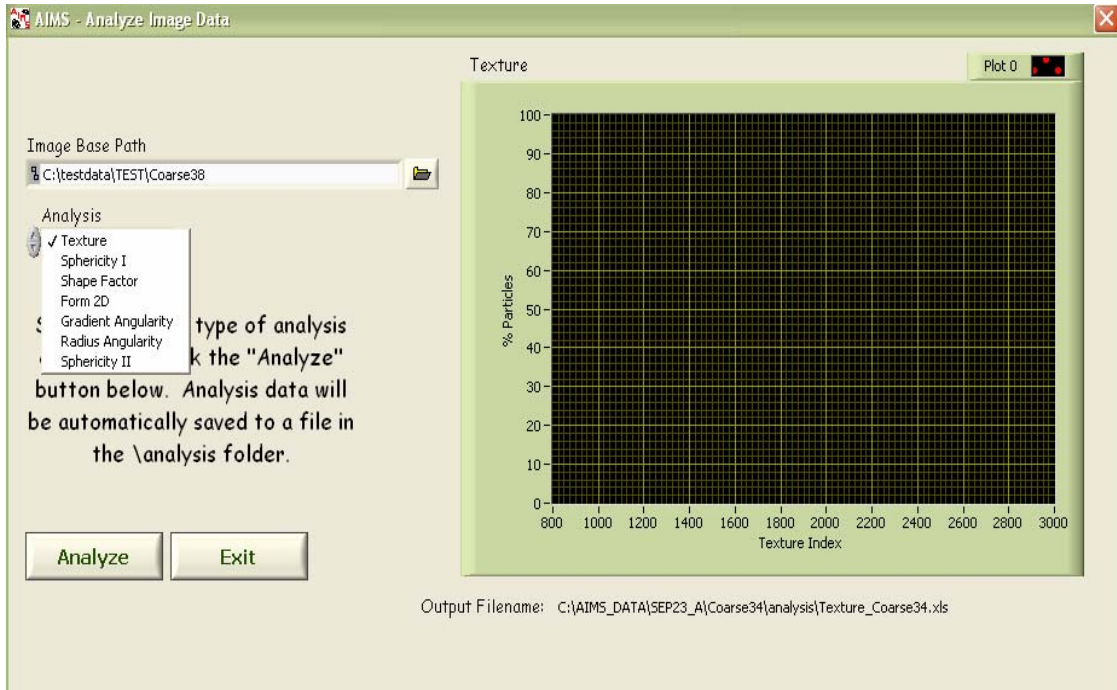


Figure 21. Drop-List for Selecting Type of Analysis.

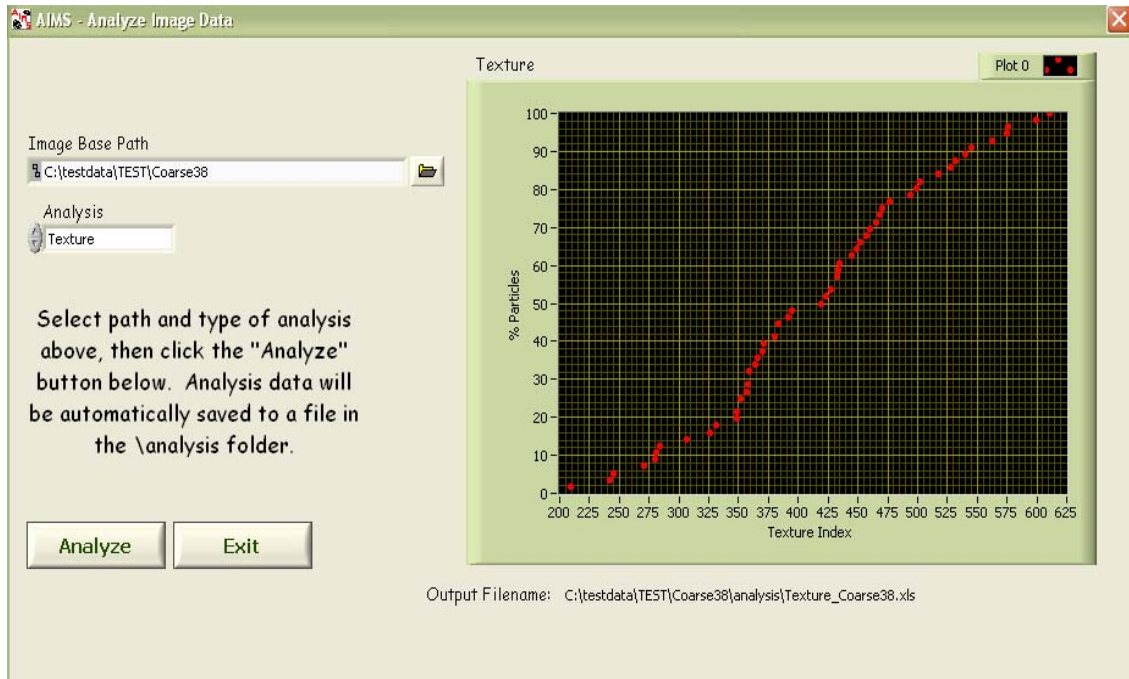


Figure 22. Example of Cumulative Distribution for Surface Texture Index.

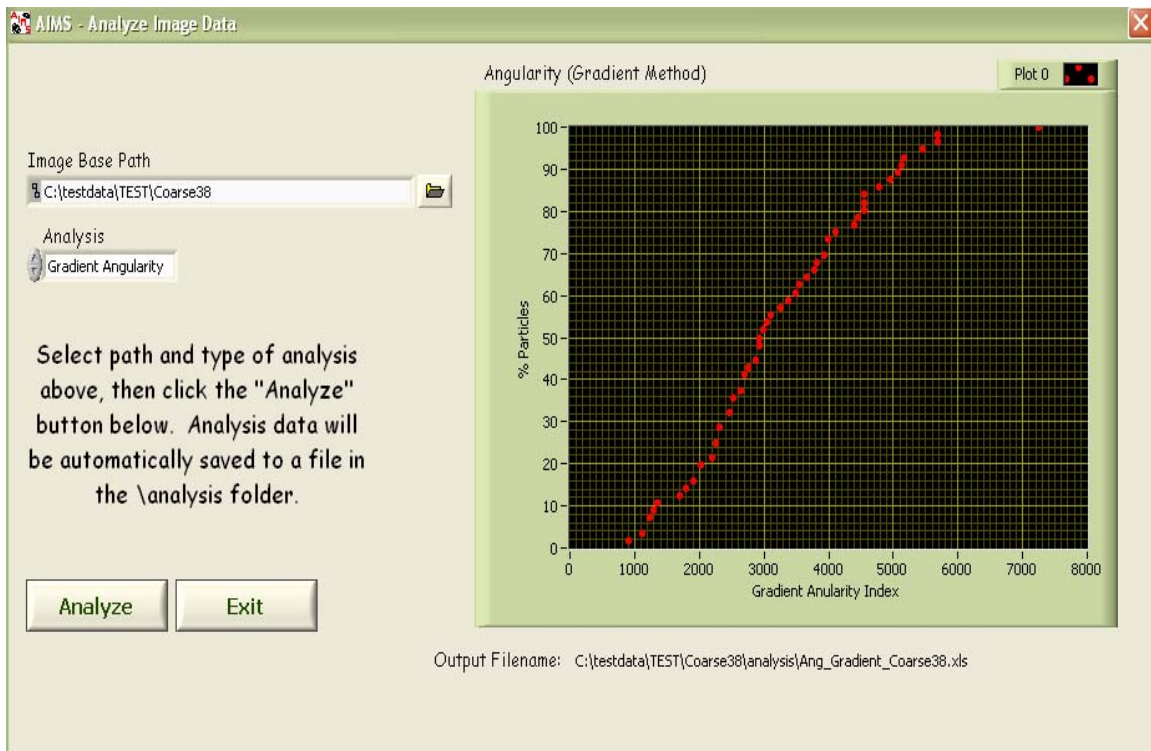


Figure 23. Example of Cumulative Distribution for Gradient Angularity Index.

- 9.6 The “AIMS Analysis Workbook” is another program that can be used to obtain statistics from the data analysis, provide percent of particles in each shape property category, and plot analysis results on Excel charts. The Program is self-guided and very easy to use.
- 9.7 *Method B* – Fine Aggregate Angularity Analysis Procedure: Analysis of fine aggregates is similar to that for coarse aggregate, except the fine aggregates are uniformly spread on the aggregate table, and the texture analysis is not performed.
- 9.7.1 Analysis of fine aggregates starts by uniformly spreading a few grams of fine aggregate particles on the aggregate tray such that individual particles are not touching each other. The 0.5X objective lens is used for acquiring images of fine aggregates. The maximum field of view achieved in the fine aggregate module is 26.4 mm x 35.2 mm. Backlighting is used to acquire all images in this analysis. The camera and video microscope assembly move incrementally in the x-direction at a specified interval and acquire an image at each increment. Once the x-axis range is complete, the aggregate tray moves in the y-direction for a specified distance, and the x-axis motion is repeated. This stepwise process continues until the entire area is scanned. In each x-y scan, the z-location of the camera is stipulated to meet some specified resolution criteria. Aggregates that are not within the size range for which the scan is conducted are consequently removed from the image automatically by the system.
- 9.7.2 Ensure the objective lens is 0.5X and the microscope is placed in the fine position on the dovetail slide. The objective lens is interchanged by removing the fiber-optic ring light and the ring light holder from the lower end of the microscope. Then the required objective lens can be installed on the microscope. The microscope can be easily positioned on the dovetail slide by releasing the knob of the retaining pin on the left

side and sliding the microscope assembly upward/or downward until the “Fine” labels on the left-hand side of the two pieces are aligned. Ensure that the retaining pin is engaged so the microscope cannot fall. Then tighten the thumbscrew on the right-hand side of the microscope assembly.

- 9.7.3 Specify the drive and directory path for the project. Enter a project name for the aggregates to be analyzed. From the “Project Parameters” drop-list, select “Fine,” then select “OK” (Figure 24).
- 9.7.4 Selecting “OK” on “Project Parameters” will display the “Fine Aggregate Parameters” window (Figure 25). From the drop list, select the desired aggregate size, then select “OK,” and the first program interface window will display showing the new entered information for the current project.
- 9.7.5 Turn on the bottom light and allow it to warm up for minimum of two minutes.
- 9.7.6 Adjust the camera settings following the same procedures used for coarse aggregates (Subsection 9.1.8).
- 9.7.7 Initiate image acquisition selecting “Acquire Images.” A new message window will appear giving the option to perform camera setup. If not accomplished in the [previous step](#), camera setup can be performed here; otherwise, select “No.” When omitting the camera setup option, a new message window displays with instructions that must be followed (Figure 26).
- 9.7.8 Spread fine aggregate uniformly on aggregate tray (translucent Mylar alignment grid is not used in this segment), and click the “OK” button. The AIMS system will scan the entire tray and return to the starting point.
- 9.7.9 Fine aggregate image processing is identical to that for coarse aggregates, except no texture images are acquired.
- 9.7.10 Data analysis for fine aggregate is similar to that for coarse aggregate, except the number of analysis parameters (gradient angularity, radius

angularity, and two-dimensional (2-D) form) are fewer (Figures 27 and 28).

9.7.11 Results for each analysis type are automatically saved in an Excel spreadsheet in a folder named “Analysis” that is created in the directory selected in Step 9.7.3.

10. AIMS Analysis Workbook

10.1.1 The AIMS Analysis Workbook contains additional software that can be used to generate statistics from the analysis data, provide percent of particles in each shape category, and plot analysis results on Excel charts. The program is self-guided and very easy to use.

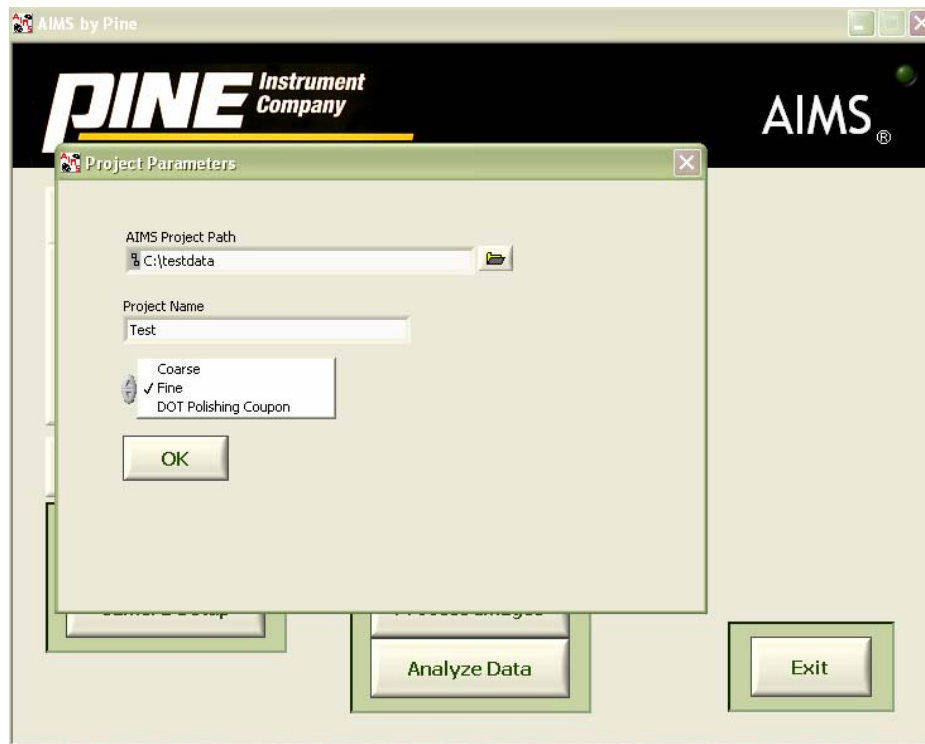


Figure 24. Aggregate Range Drop-List for Fine Aggregate.

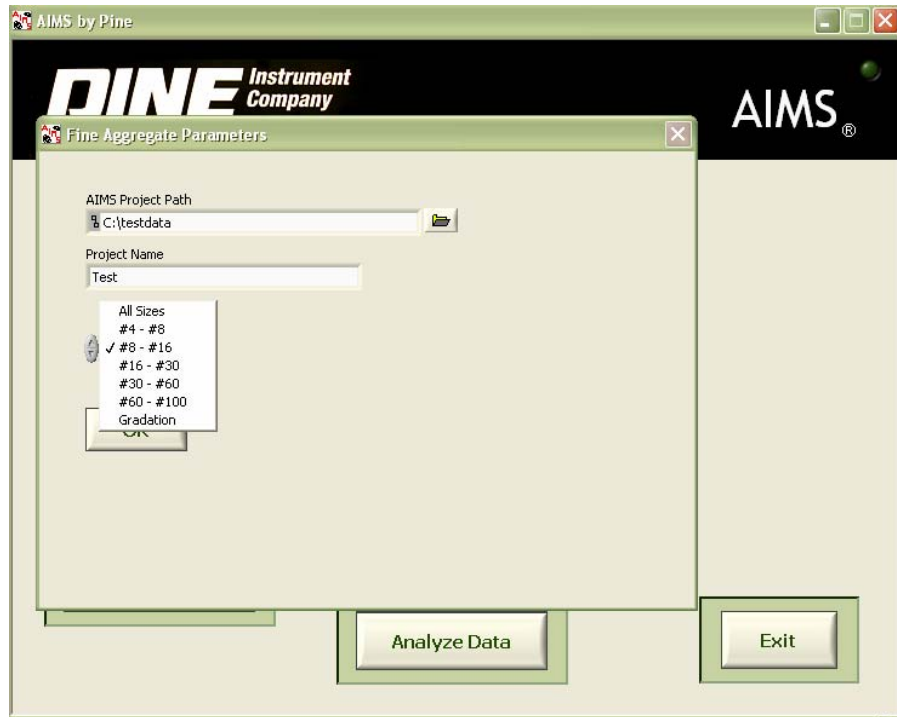


Figure 25. Drop-List for Fine Aggregate Parameters.

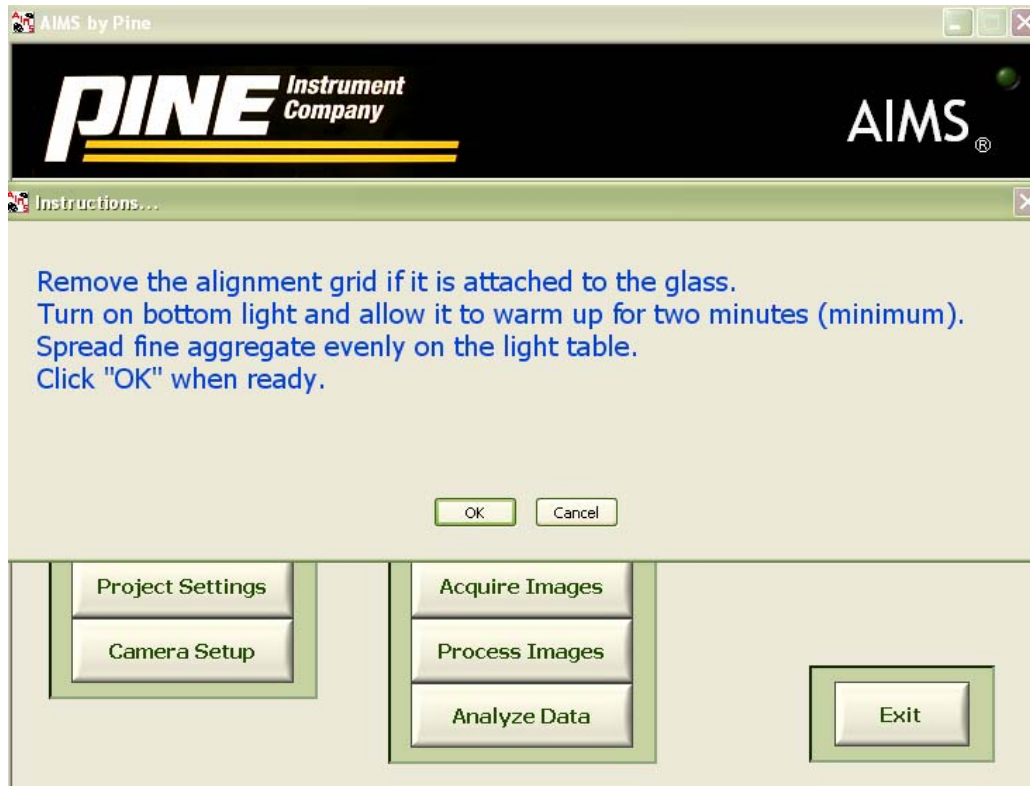


Figure 26. Specific Instructions for Fine Aggregate Analysis.

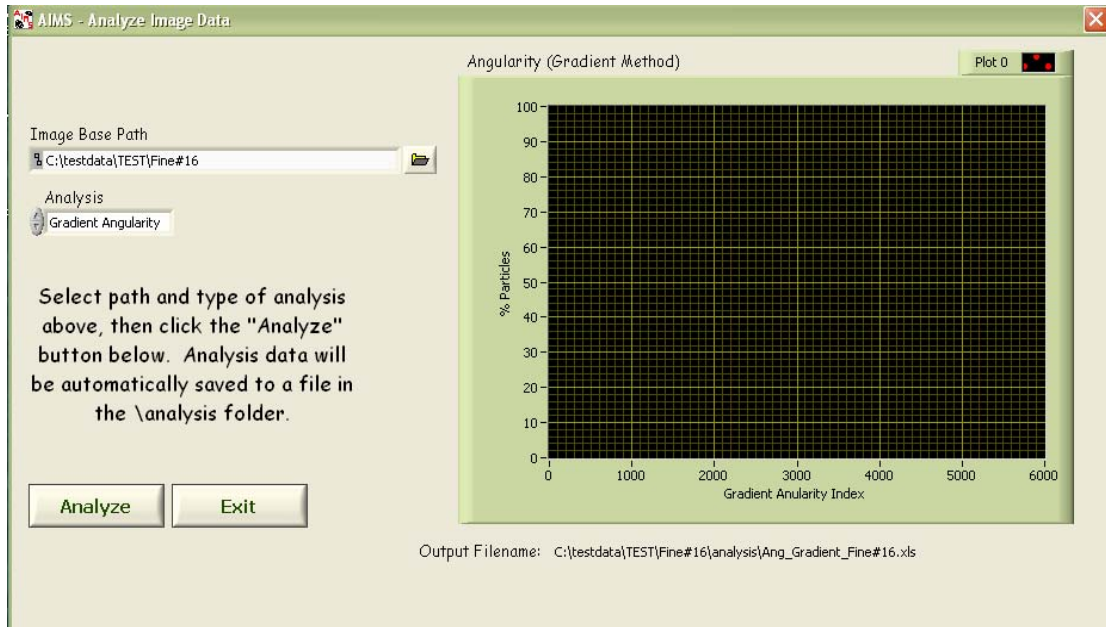


Figure 27. Gradient Angularity Screen for AIMS Fine Aggregate Analysis

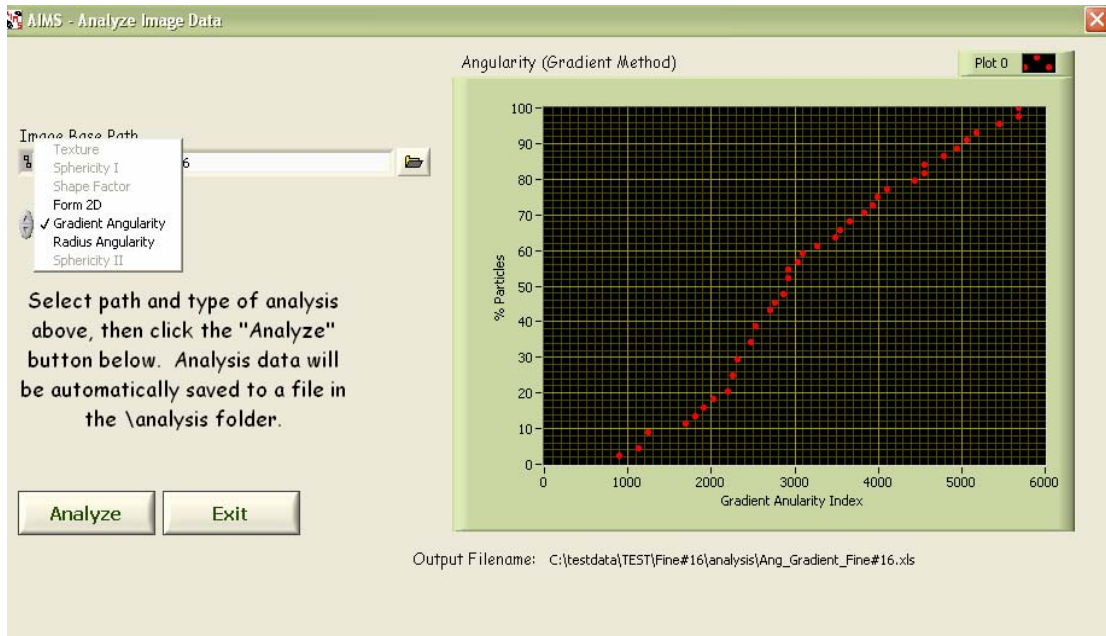


Figure 28. Gradient Angularity Screen for Showing Analysis Type Drop-List.