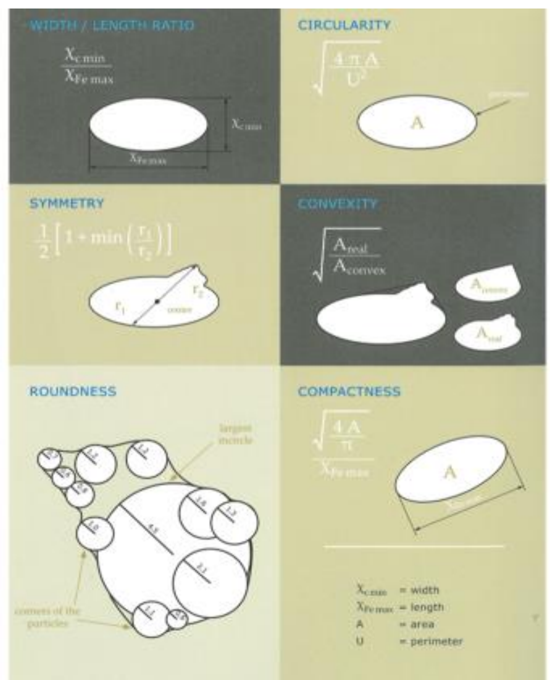
Evaluation of the Retsch Technology Camsizer P4

to assess the shape of crushed particles proposed to be added to natural sand fine aggregate used in Portland Cement Concrete

Final Report
October 2021



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16. Abstract

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Samples were analyzed from glacial and river sand pits, crushed carbonate manufactured sands, crushed rhyolites, and frac sands. The natural sands (deposits from erosional processes) were from established sand pits from multiple rivers and streams in Iowa flowing through multiple Iowa landforms. Analyses of uncrushed, crushed, and mixes were evaluated to determine particle shape.

The aspect ratio and roundness, along with other shape and size characteristics were determined for each particle. The image analysis of particle shape from the Camsizer P4 was compared to Fine Aggregate Angularity results using AASHTO T 304 “Uncompacted Void Content of Fine Aggregate”. A geologic application of particle shape was also investigated to determine the influence of river travel distance and Iowa landforms on particle shape.

The Camsizer P4 was found to be a very powerful and useful tool to evaluate particle shape (angularity and roundness) of fine-aggregate sands for use in Portland Cement Concrete. Particle shape is known to directly relate to the flowability and workability of concrete.

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Abstract

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Introduction

An aggregate Producer is using sand from the Mississippi River to supply fine aggregate to the I-74 bridge. We have been asked by the Iowa Limestone Producers Association (at the request of this Producer) to consider the addition of crushed stone (both coarse and fine) to the fine aggregate and have also requested we consider a specification change to allow crushed gravel to replace “some” fine aggregate. Our specifications are currently worded to prevent deleterious material and angular particles by requiring “Natural sands resulting from disintegration of rock through erosional processes.”

We have great concerns for the following reasons: 1) The potential for loss of concrete workability due to the fractured particles; 2) there is little control of the portions of crushed vs uncrushed aggregate; 3) the only way the DOT has of measuring particle shape and angularity (hence workability) is through an indirect test that estimates the voids produced when angular particle stack when dropped from a set distance.

Objectives

The main objective of this research is to develop a new test method for particle size and shape analyses using an instrument called the “Retsch Technology Camsizer P4”. This instrument uses advanced image analysis technologies to measure particles between 0.02 to 30.0 mm. Captured images contain information about particle size, shape, density, transparency, and number particles in each size fraction.

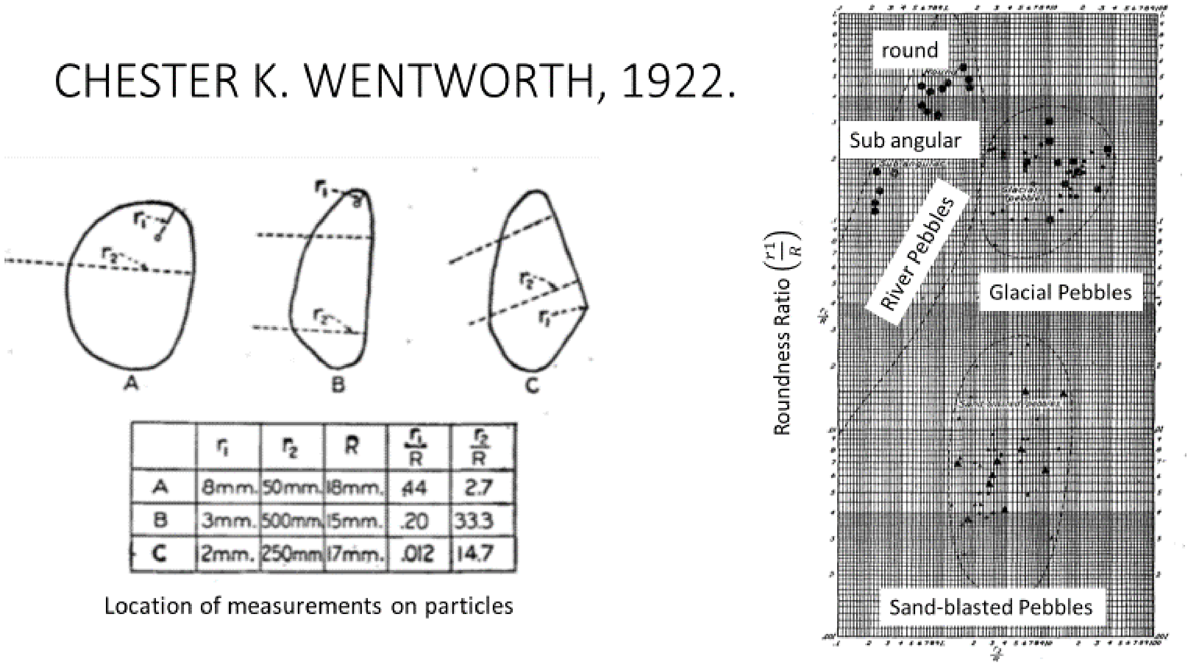
From this research, a method to evaluate particle shape of fine aggregate will be developed. It is anticipated that the use of crushed particles will be considered as a supplement to natural fine aggregate (sand) used in Portland cement concrete. This most certainly will have an effect on the flowability and workability of concrete in both pavements and structures.

Analyses of uncrushed, crushed, and mixes were evaluated to determine if particle shape measurements can be used in the evaluation of fine aggregate approvals. From this it is anticipated that a new specification can be written to classify fine aggregate on particle shape. In doing so, limits may be placed on such properties as angularity and elongation to minimize concrete workability problems detrimental to a pavement's or structure's durability.

As a secondary objective, the variability of fine aggregate from different geologic environments will be evaluated. This may produce a tool to both provide a prediction of fine aggregate characteristics and provide additional information about the environment of deposition.

Background

The first use of particle shape in the analyses of geologic environments was performed by Chester Wentworth at the Department of Geology of the State University of Iowa (now the University of Iowa) in the early 1920's. Before 1920, attempts to establish criteria to distinguishing beach pebbles from those formed by rivers, glaciers, or wind or resulting from weathering were not working. Wentworth was the first to establish a particle shape measurement system. Roundness ratio, (r^1/R), where r^1 is the radius of curvature of the sharpest edge and R is the mean radius of the pebble (Figure 1). Flatness ratio (r^2/R) where r^2 is the radius of curvature in the most convex direction on the flattest developed face or portion of the surface, and R is the mean radius of the particle (Wentworth, 1922a) [1]. Using this system, Wentworth was able to classify the geologic origin of pebbles by their shape (Wentworth, 1922b) [2].



	r_1	r_2	R	$\frac{r_1}{R}$	$\frac{r_2}{R}$
A	8mm.	50mm.	18mm.	.44	2.7
B	3mm.	500mm	15mm.	.20	33.3
C	2mm.	250mm	17mm.	.012	14.7

Figure 1. The first use of particle shape in the analyses of geologic environments was performed by Chester Wentworth at the Department of Geology of the State University of Iowa in the early 1920's. From Chester K Wentworth, 1922 [1,2].

Methods of particle analyses

The American Association of State Highway and Transportation Officials (AASHTO) has been developing a test method to determine the shape properties of aggregate particles known as the *Standard Method of Test for Determining Aggregate Shape Properties by Means of Digital Image Analysis*, AASHTO Designation: T 381-181 [3]. The importance of this method is based on the observation that shape, angularity, and surface texture of aggregates directly affect the engineering properties of highway construction materials.

This Camsizer test method uses a high-speed photography that can provide the required resolutions over the range of particles being analyzed. For coarse aggregates, the shape properties include gradient angularity, sphericity, texture, and flat and elongated value. For fine aggregates, the shape properties include angularity and particle profile.

Previous studies have attempted to use image analysis to determine particle shape to evaluate breakage, abrasion, and polishing (e.g., Moaveni, M., and others 2014) [4] but they admit “little research has examined the effect of aggregate degradation on altering shape characteristics of the aggregates”.

A report was done for the Michigan Department of Transportation by the University of Michigan to evaluate methods and commercial systems for particle size analyses (Brant, N. J., and others, 2011) [5]. In this report they identified 6 methods of particle size analyses which utilized different approached to size determination. These included: 1) Sieving, 2) Sedimentation, 3) Electrical Sensing Zone (ESZ), 4) Laser Diffraction, 5) Single Particle Optical Sensing (SPOS), and 6) Image Analysis.

Each these techniques analyzed particles based on different principles of measurement and thus each define particle size differently. Generally, these techniques will produce the same measure of size only for perfectly spherical particles. This study emphasized two things: 1) there are multiple ways to define particle “size” and “shape” and 2) image analysis with the Camsizer appeared to be the best approach to size analyses.

Given the capabilities of the Camsizer for size and especially for characterization of various features of particle shape it was decided to determine if the Camsizer could distinguish sand-sized particles of crushed gravel from natural sand using particle shape characteristics.

Principles of operation of the Camsizer P4

The Camsizer P4 uses two cameras that operate during measurement [6]. The Basic camera analyzes larger particles, while the ZOOM camera captures smaller particles (Figure 2). Particles fall in front of a LED-lit screen. The percent of the screen “covered’ by particles is set by the operator and controlled by the amount of vibration of the delivery shoot. This procedure ensures optimum measurement conditions for all particle sizes in a distribution. Each individual particle is scanned 65 times as it falls in front of the camera. The captured images are analyzed to determine characteristics of particle shape, size, and number. Using two cameras allows the CAMSIZER to process a wide particle size range, from 0.03 to 30.0 mm.

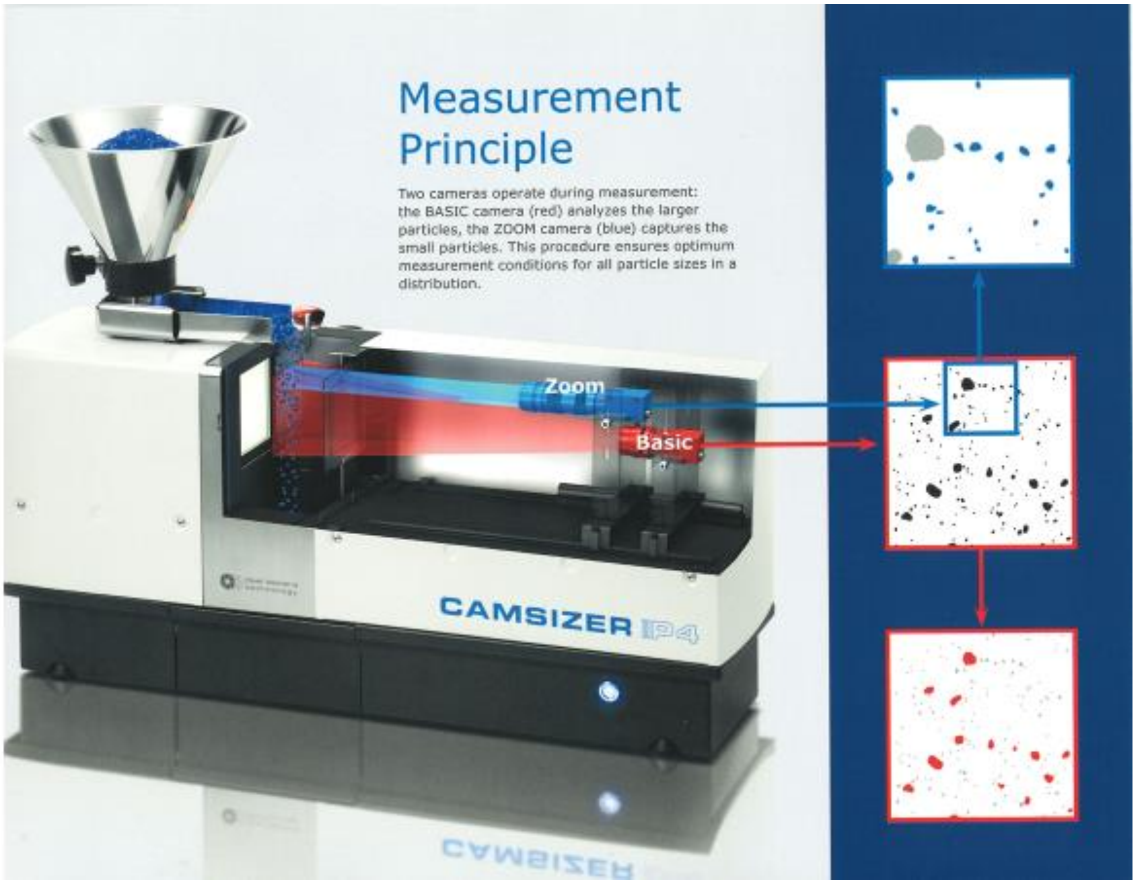


Figure 2. Camsizer configuration showing the two cameras and LED backlite screen. From Retsch Technology, [6]

Shape Characteristics using the Camsizer P4

The Camsizer P4 can determine a wide variety of particle shape characteristics. Below are some of the characteristics that are potentially useful in identifying crushed sand-sized particles [6,7].

Aspect ratio: The ratio of $X_{Fe\ min}$ (minimum particle diameter) and $X_{Fe\ max}$ (maximum particle diameter). These values can be based on number, area, or volume.

$$X_{Fe\ min} / X_{Fe\ max}$$

Roundness: Roundness is based on the radius of small circles outlining projections from the surface of a particle divided by the radius of the largest circle that will fit within the projection of the particle shape. See Figure 3 for an illustration.

Sphericity: Sphericity is calculated from the perimeter *P* and area *A* of the particle projection. A perfect sphere would have a sphericity equal to 1. In all other cases, the sphericity is < 1.

$$SPHT = 4\pi A/p2$$

Symmetry: Each particle is scanned in up to 64 directions. For each of the 64 directions, the distances r_1 and r_2 between the center of the area *C* to the particle borders are recorded to calculate the symmetry. The *Symm* value is the smallest of all measured symmetry values. For asymmetrical particles the value is <1.

$$Symm = \frac{1}{2}\,[1 + \min(r_1/r_2)]$$

These shape characteristics can be seen graphically in Figure 3. The two shape characteristics used most commonly in this study were Roundness and Aspect Ratio.

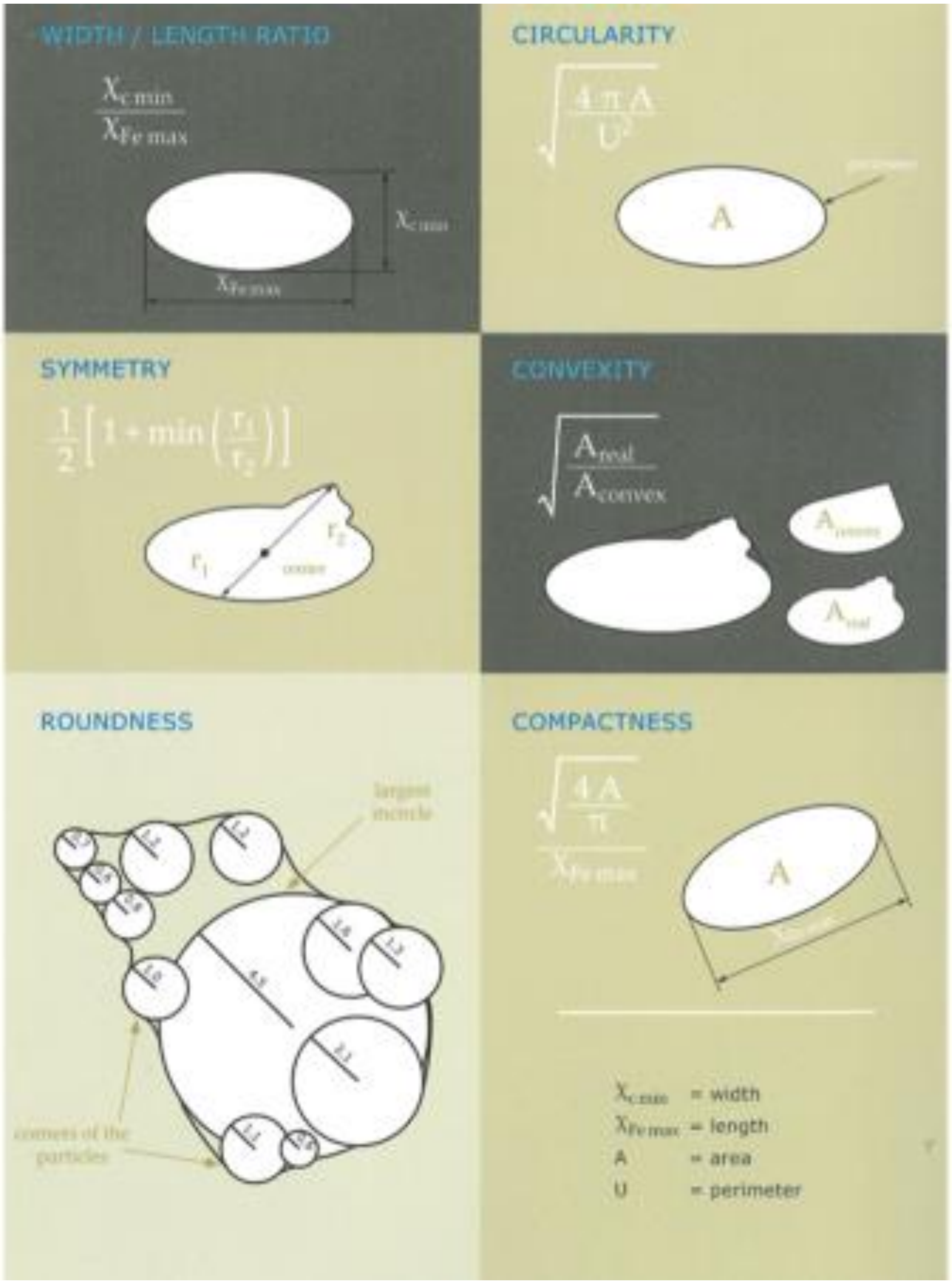


Figure 3. Some particle shape features that can be determined on individual sand grains using the Camsizer P4. From Retsch Technology, [7].

Samples and Sampling

To evaluate the capabilities of the Camsizer P4, multiple types of fine aggregate samples were obtained that were meant to evaluate the differences in shape characteristics between particles produced by natural erosional processes from those that were produced by mechanical crushing and particle fracture processes. These samples included:

- Natural Sands for around the state of Iowa
- Rhyolite Samples from crushing igneous (granitic) rocks
- Frac Sands used for their uniform size and roundness properties
- Crushed Limestone Samples (Mansand) produced from a variety of crushers. The mansand samples were critical in producing "angularity calibration curves" to evaluate Camsizer shape analyses for Fine Aggregate Angularity test results.

Natural Sand

Sand samples were collected over several years during annual sand and gravel source evaluation. The Iowa Department of Transportation has almost 450 approved sand and gravel sources in Iowa and surrounding states. Below is a map showing the location of sand samples produced by natural erosional process used in this study (Figure 4). The base map shows landform features of Iowa. Most sources are either the product of glacial process or that of glacial outwash and fluvial (stream and river) process.

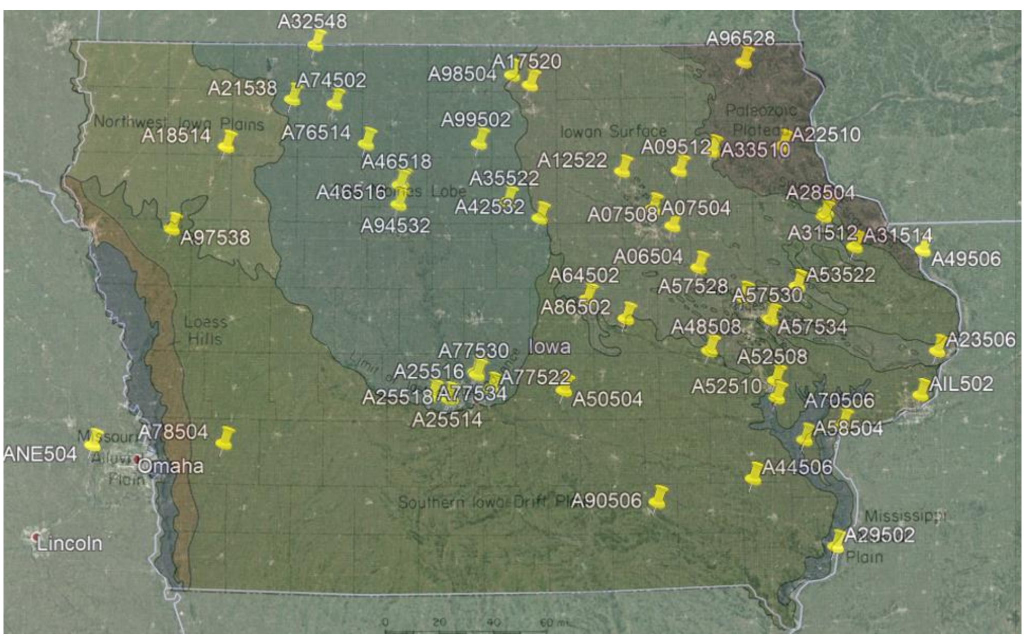


Figure 4. Landform map of Iowa and surrounding states showing Camsizer sample location collected early in the evaluation process. The numbers next to the push pins shows the "A-number" unique to each sand pit location.

Rhyolite samples

Two rhyolite samples were obtained from Trap Rock and Granite Quarries (AMO058) and Iron Mountain Traprock Co (AMO022) located in the St. Francois Mountains of southeastern Missouri (Figure 5). Most of the area is formed from Precambrian igneous rocks. These are seen as a series of granite plutons that are "ringed" with rhyolite flows. Rhyolites have the same chemical composition as granite but are much finer grained having been extruded at shallower depths and having cooled much more quickly.

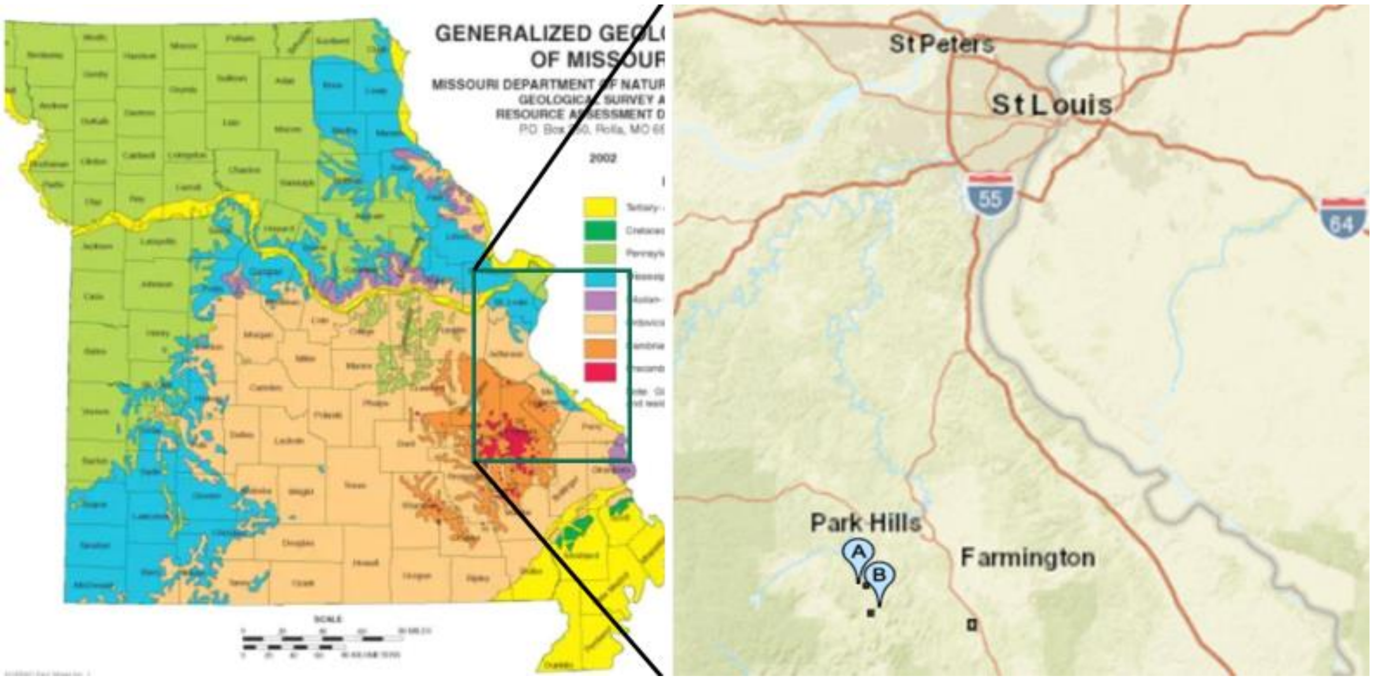


Figure 5. Generalized geologic map of Missouri with the granites and rhyolites of the St. Francois Mountains in red and orange. Location of the two rhyolite quarries are (A) Trap Rock & Granite Quarries and (B) Iron Mountain Trap Rock in the second image.

Frac Sand Samples

Samples of St. Peter Sandstone were obtained from Pattison Sand Company in Clayton County, Iowa, where they mine both "frac sand" and DOT approved aggregate (A22090). The St. Peter Sandstone is Ordovician in age and is used in commercial applications because of the relatively uniform size and shape of its sand particles.

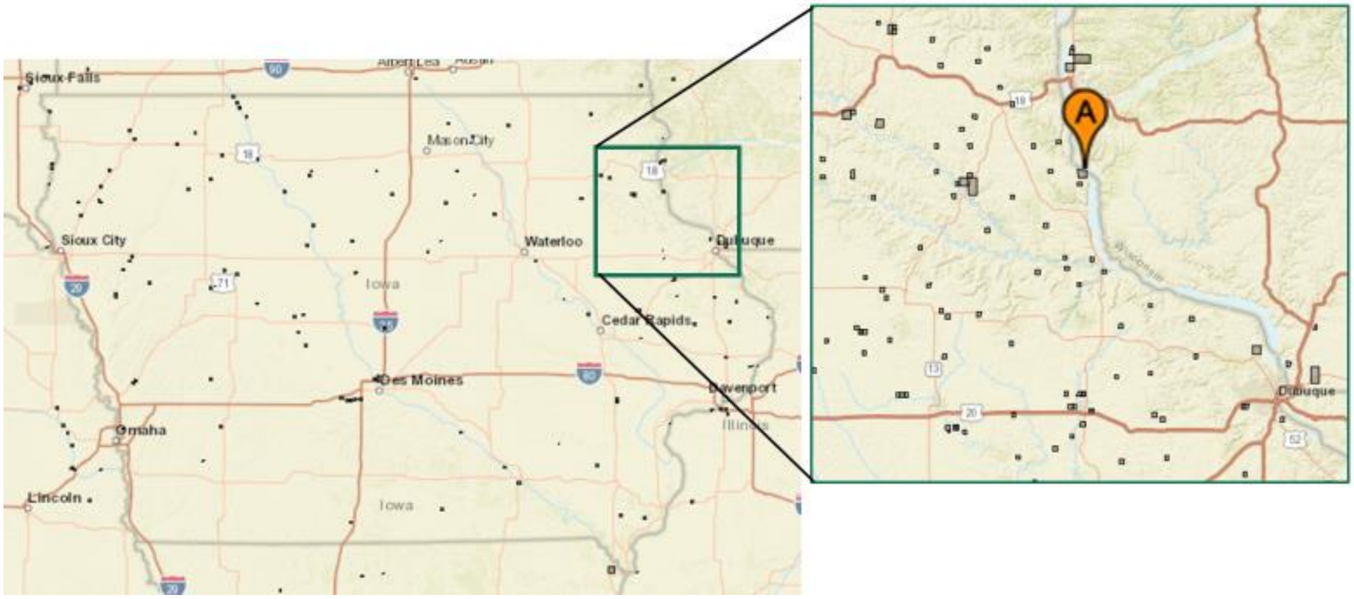


Figure 6. Source of the frac sand samples (A) in Clayton County Iowa.

Crushed Limestone Samples (Mansand)

Crushed Limestone Samples were collected from six sources (Figure 7): Cedar Rapids Quarry; Sully Mine; Durham Mine; Fort Dodge Mine; Pederson Quarry; and Ferguson Quarry. These sources represented different primary and secondary crusher combinations (Table 1). The effect of crusher type on particle shape and a comparison of the Camsizer to the Fine Aggregate Angularity test will be discussed in the section titled "*Comparison of Camsizer Shape Analyses to Fine Aggregate Angularity".*

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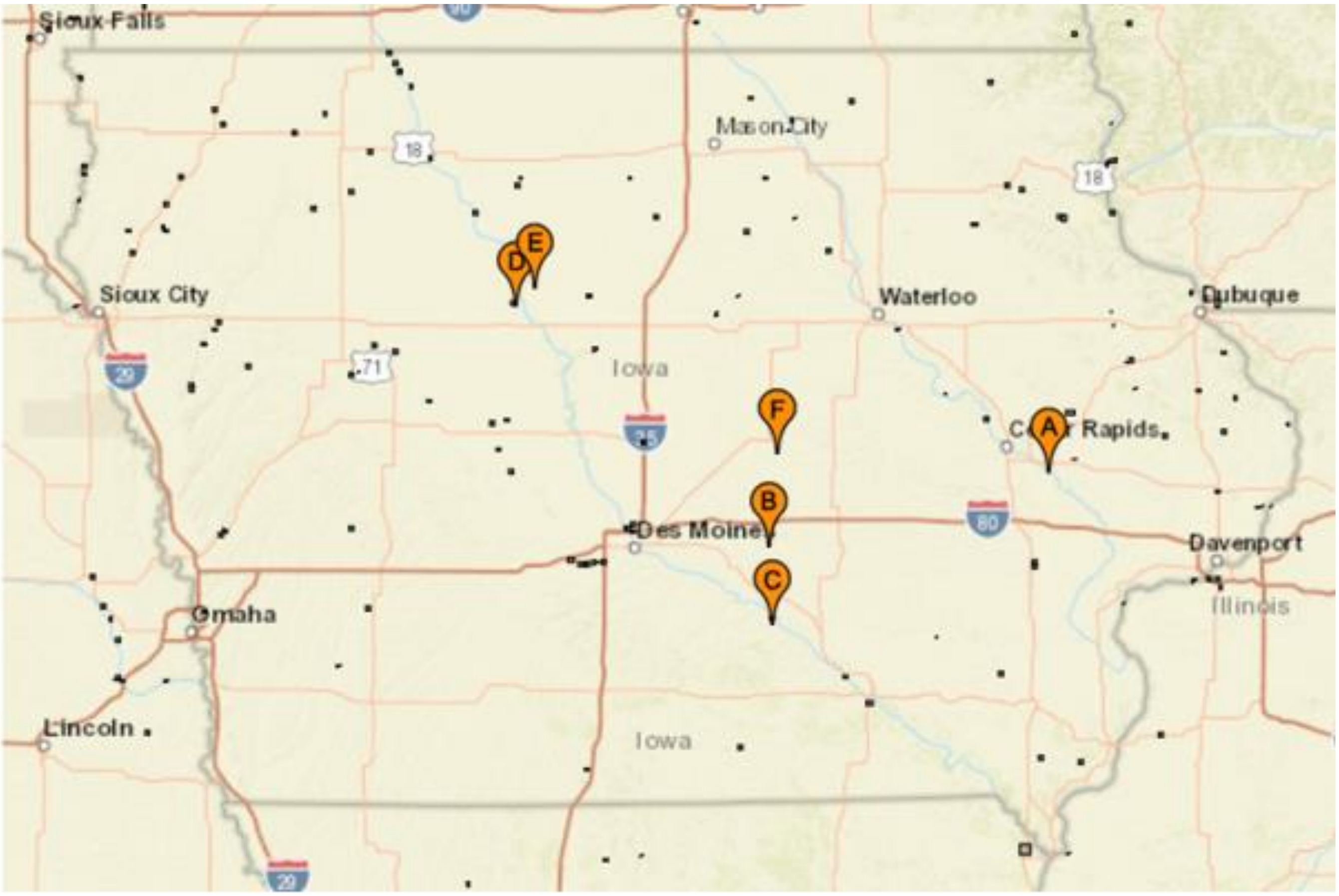

Figure 7. Sample locations of crushed limestone (mansand) used in the comparison study of Camsizer shape results to Fine Aggregate angularity tests. A = Cedar Rapids Quarry; B = Sully Mine; C = Durham Mine; D = Fort Dodge Mine; E = Pederson Quarry; F = Ferguson Quarry.

Results and Discussion

Overview of Fine-Aggregate Sample Results from the Camsizer P4

Figure 8 shows the relationship of aspect ratio to roundness of different particle types as determined by the Camsizer P4. Numbers approaching 1 are more round and more cubic. Numbers closer to zero and more angular and elongated. As can be seen from this graph, Camsizer shape analysis can distinguish the major classes of sand-sized particles analyzed in this study by simply analyzing their roundness and elongation. It was also able to determine the difference of the shape characteristics based on the size fraction of the sample. It appears that both the smaller sizes of Frac Sands (very round sand particles) and Rhyolite sands (crushed igneous particles) were more elongated and angular, while the larger-sized fractions were more rounded and cubic. Limestone ManSands also formed a district group and could be separated by crusher type. This will be discussed in more detail in the *Comparison of the Fine Aggregate*

Angularity Test to the Camsizer Shape Analyses. Natural sands formed from glacial and stream erosional process also formed a distinct group. These will also be discussed in a later section of this report (Geological applications of the Camsizer P4).

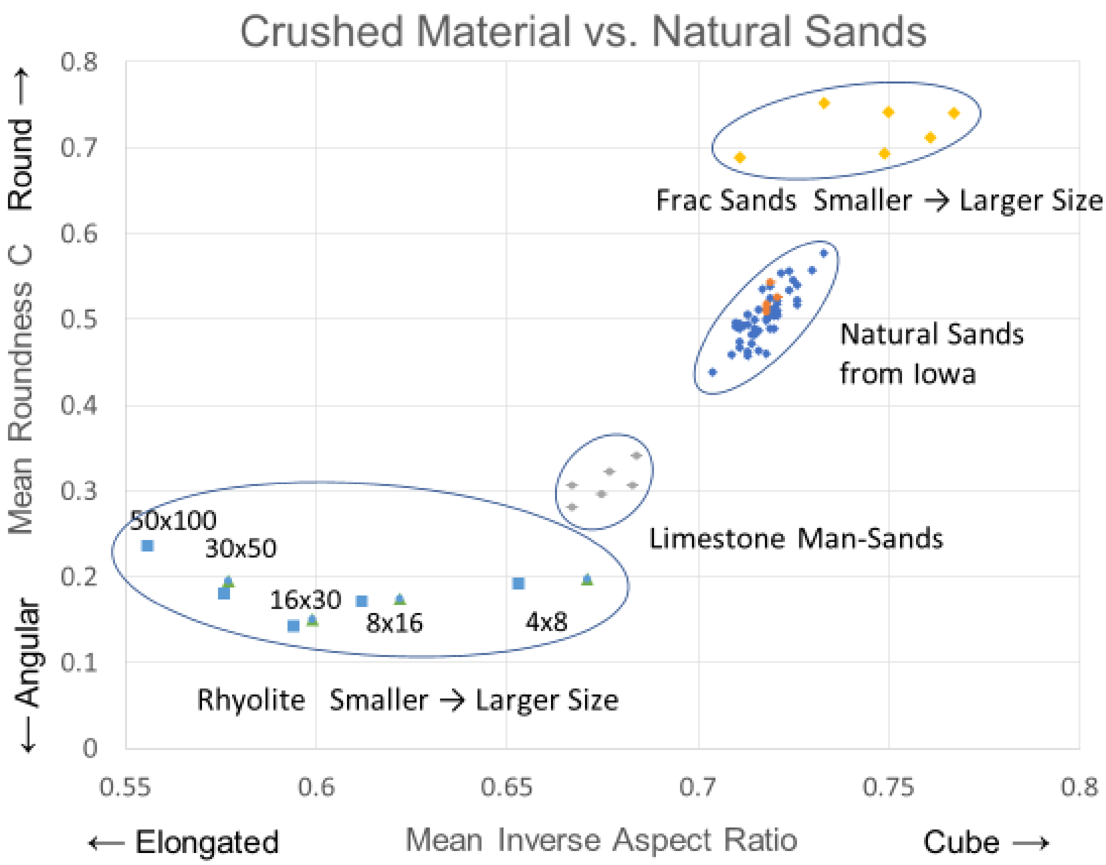

Figure 8. Graph showing the relationship of Aspect Ratio to Roundness for samples of both crushed stone (Rhyolite and Limestone ManSands) to Natural Sands (from erosional processes) and Fractionation Sands.

Comparison of the Fine Aggregate Angularity Test to the Camsizer Shape Analysis

AASHTO test T304 (*Uncompacted Void Content of Fine Aggregate* [8]) is used to determine the void content in a graded sample of fine aggregate. This test is sometime referred to as the "Fine Aggregate Angularity test" (FAA). This test is commonly used in conjunction with other HMA (Hot Mix Asphalt) test methods to aid in determining mix designs for HMA projects.

This test has been adapted for a large Iowa DOT PCC project as a standard method to determine the number or proportion of crushed particles to be allowed in fine aggregate when used in Portland cement concrete (PCC). Prior to the construction of the new I-74 bridge over the

Mississippi River, crushed material was not allowed by specification in fine aggregate used in PCC. Until a new specification could be written that set requirements on proportioning of crushed particles, the only controls relied on limits using the FAA test. Although this test only indirectly measures particle shape characteristics, it has been the only test in common use that could generate some sort of shape information.

One of the principal goals of the Camsizer evaluation was to compare test results from the FAA test to direct particle shape determination using the image analysis capabilities of the Camsizer P4.

Summary of AASHTO T 304 Uncompacted Void Content of Fine Aggregate

The purpose of *AASHTO T 304* is to determine the loose uncompacted void content of a sample of fine aggregate. The test method states that on any aggregate of known grading, the void content provides an indication of the aggregate angularity, sphericity, and surface texture and can be compared to other aggregates of the same grading [3].

For the test, a 100-mL calibrated cylindrical measure is filled with fine aggregate from a funnel at a fixed height (Figure 9 shows a cross section of the delivery funnel). The cylinder with the fine aggregate is struck off and the mass is determined by weighing. Uncompacted void content is calculated as the difference between the volume of the cylindrical and the absolute volume of the fine aggregate collected in the cylinder. Uncompacted void content is calculated using the bulk dry specific gravity of the fine aggregate. Two runs are made and averaged.

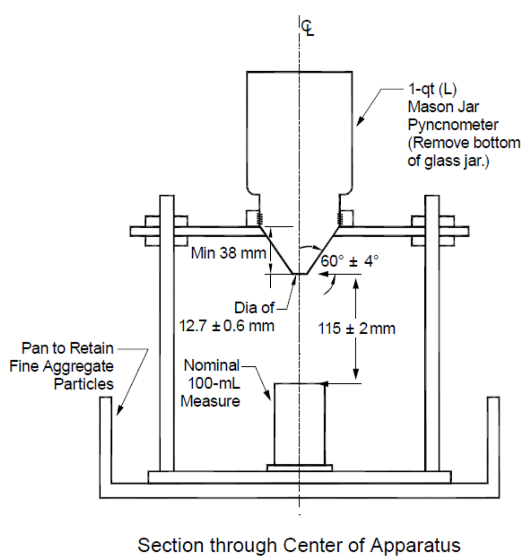

Figure 9. Cross section of the funnel used to drop a fine aggregate sample into a cylinder from a set height to determine the number of voids in the fine aggregate sample.

Sample Preparation for Comparative Particle Shape Testing.

Crushed aggregate samples were collected from sources described earlier under section "Samples - Crushed Limestone Samples (Mansand)" of this report. These samples consisted of "manufactured sand" or "mansand" which is commonly made from crushed carbonate rock. For the purposes of this study, crushed carbonate was used as opposed to a crushed gravel or igneous rock because a variety of shapes and crusher types could be used. A discussion of the influence of crusher type on particle shape can be found in Heckel and others [9] and O'Bryan [10]. Table 1 shows the plant locations and the type of primary and secondary crushers.

Table 1. Types of crushers used to produce the crushed fine aggregate particles.

Plant	Primary Crusher	Secondary Crusher
Cedar Rapids	Impact	Impact and Cone
Sully	Impact	Impact
Durham Mine	Impact	Impact and Small Cone
Fort Dodge Mine	Impact	Impact
Pederson	Jaw Crusher	Hammermill
Ferguson	Impact	Cone and Hammermill

To evaluate and compare the two test methods, calibration curves were made using the crushed carbonate combined with a natural sand in proportions of 0, 20, 40, 60, 80, and 100% mansand. The natural sand used for this study was from Ames South Pit in Story County (A85510).

For the FAA test, set proportions (by weight) are used for each size fraction. These are shown in Table 2

Table 2. Mass of each size fraction of fine aggregate used in AASHTO T 340 [8].

Individual Size Fraction	Mass, g
2.36 mm (No. 8) to 1.18 mm (No. 16)	44
1.18 mm (No. 16) to 600 µm (No. 30)	57
600 µm (No. 30) to 300 µm (No. 50)	72
300 µm (No. 50) to 150 µm (No. 100)	17
	190

The tolerance on each of these amounts is ±0.2 g.

It was suggested by the lead Iowa DOT Bituminous Laboratory Technician that the gradation proportions for the crushed particle gradations be calculated two ways: 1) a fixed gradation used in the AASHTO T 340 test method and 2) an “as received” gradation, reflecting the original “as received” fine aggregate sample gradation. Using Method 2 more accurately reflects the outcome of a blending process where the crushed particles are proportioned with natural sand.

Table 3 shows test results for the Fine two Aggregate Angularity test methods using proportions of crushed particles at 0, 20, 40, 60, 80, and 100 precent crushed particles. The “%Retained” is the as received gradation, the “Set %” is using the AASHTO T 340 gradation shown in Table 2. Both methods have somewhat similar test results.

Table 3. Fine Aggregate Angularity (FAA) results for different aggregate sources using different primary-secondary crusher to produce crushed limestone. The percentages were based on percent mansand with a control sand. % Retained = proportion of mansand based on the as received gradation of the mansand. This method should more accurately represent a blending process. Set% = the wt% to produce the proportions required in the AASHTO Test Method.

Cedar Rapids (Impact-Twin Roll)			Durham (Impact-Small Cone)			Ferguson (Impact-Cone-Hammermill)		
Mansand	%Retained	Set %	Mansand	%Retained	Set %	Mansand	%Retained	Set %
0%	39.7	39.7	0%	39.7	39.7	0%	39.7	39.7
20%	39.7	40.7	20%	40.2	40.7	20%	40.4	40.7
40%	40.5	41.9	40%	40.8	41.9	40%	40.8	41.9
60%	41.5	43.3	60%	41.7	43.3	60%	41.1	43.3
80%	43.0	44.4	80%	43.1	44.4	80%	42.3	44.4
100%	47.2	47.2	100%	45.4	45.4	100%	45.9	45.9

Ft Dodge (Impact-Impact)			Pedersen (Jaw Hammermill)			Sully (Impact-Impact)		
Mansand	%Retained	Set %	Mansand	%Retained	Set %	Mansand	%Retained	Set %
0%	39.7	39.7	0%	39.7	39.7	0%	39.7	39.7
20%	40.6	40.8	20%	40.3	40.7	20%	41.3	41.6
40%	41.5	41.9	40%	41.1	42	40%	43.5	43.7
60%	42.4	43.2	60%	42.2	43.2	60%	45.0	45.9
80%	44.1	44.4	80%	43.4	44.6	80%	47.2	47.6
100%	45.2	45.2	100%	45.9	45.9	100%	49.3	49.3

Camsizer Test Results for Mansand

Samples constructed for the %Retained FAA test were analyzed for shape characteristics using the Camsizer. Although several shape characteristics detailed in the Background Section of this report were determined, it was the roundness C and the inverse aspect ratio that were found to be the most useful. Roundness C evaluates the profile of the particle perimeter by imposing small circles at each particle protrusion. From this, the radiuses of the small circles are divided by the radius of the largest circle that can be imposed in the projection of the particle profile. The other shape property was the inverse aspect ratio, which is calculated by dividing the width of the particle by its length. The Camsizer software calculates the mean value from the number of particles in all particle sizes. Figure 10 shows the mean values of roundness C vs inverse aspect ratio of the six Mansand samples. As can be seen from these results, there is a distinct difference in particle shape derived from different crushers and crusher combinations. Differences between similar crusher types may depend on crusher configuration and wear of the crusher components. Previous studies have also shown these differences (e.g., Hickel, G.C.et. al, 2018; and O'Bryan, 2017) [3,4].

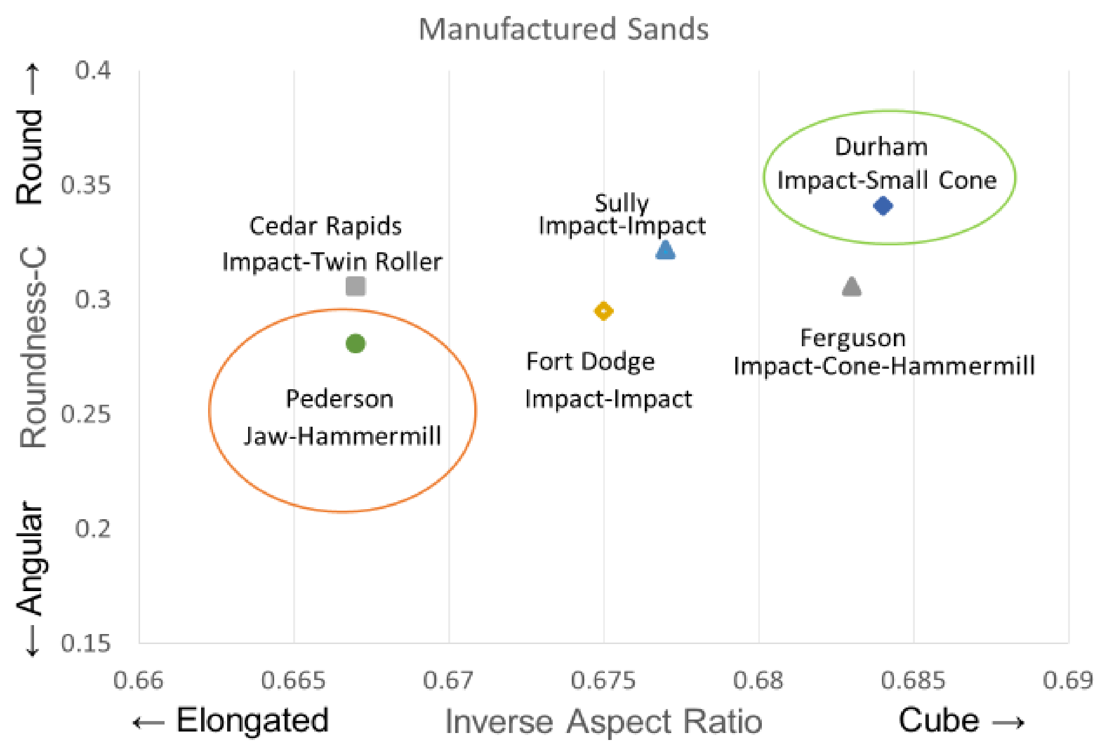

Figure 10. Mean Roundness vs Inverse Aspect Ratio for the six mansand samples of crushed limestone particles. The Impact-Small Cone produced the more round and cubic particles (green circle), the Jaw-Hammermill produced the more angular and elongated particles (red circle).

Figure 10 shows the jaw crusher-hammermill and roller crusher form the most angular and elongated particles. The combination of impact with impact, and impact with cone produce less angular particles. Because the Jaw-Hammermill produced the more angular particles, it was surprising that the impact-hammermill produced more cubic particles that some of the other crusher combinations. Putting the hammermill behind the impact-cone combination must have minimized the shard-shape characteristics of particles from the hammermill.

Figure 11 shows the results of roundness C compared to inverse aspect ratio for each of the crushed stone Pederson mansands. As described above, these samples were produce using “as received” gradations at proportions of 0, 20, 40, 60, 80, and 100 percent mansand in combination with a natural sand from Ames South Pit. As seen from Figure 11the mansand calibration line is very linear. Figure 12 shows the calibration lines for roundness C vs. inverse aspect ratio for the other mansands as well. Table 4 gives the line equations and R^2 factors for each for the mansand calibration lines.

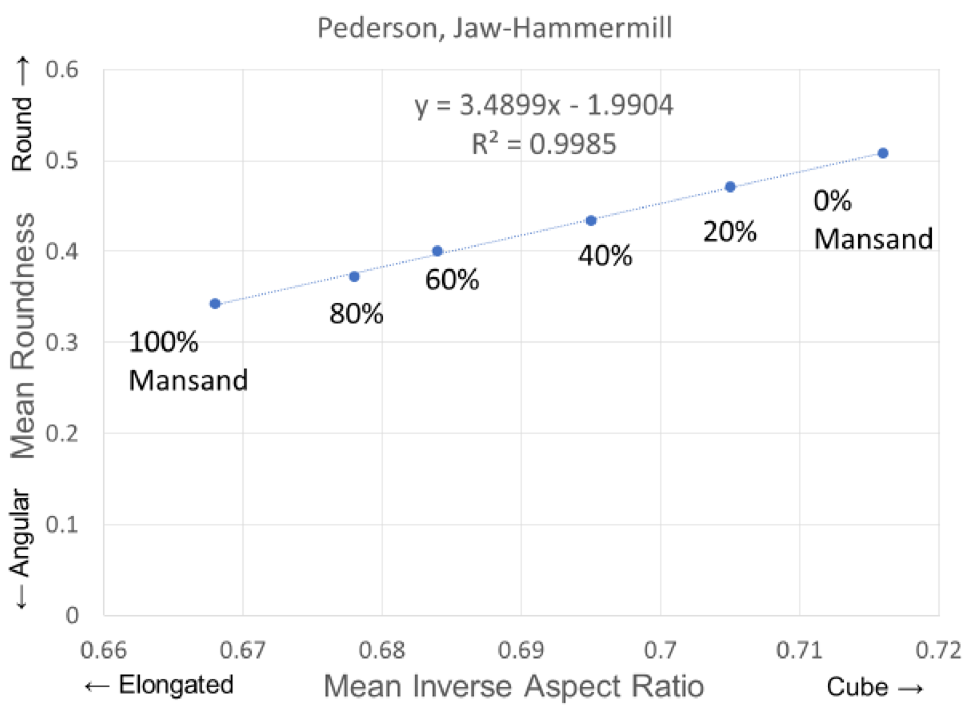

Figure 11. Mean Roundness vs. Mean Inverse Aspect Ratio at different proportions of Pederson quarry mansand. The mansand represents particles with fractured faces.

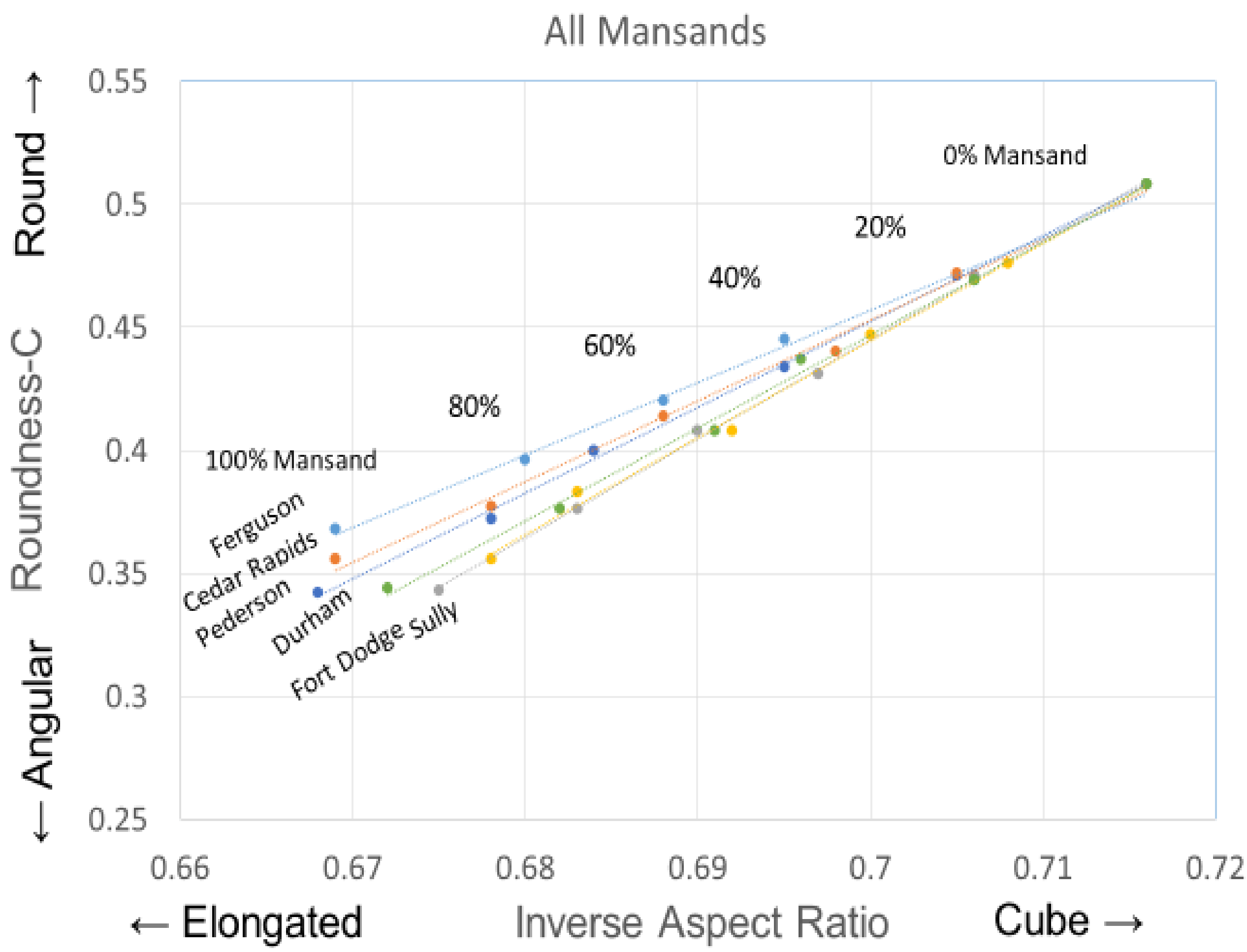

Figure 12. Mean Roundness vs. Mean Inverse Aspect Ratio at different proportions of all six mansand samples proportioned with a natural sand from Ames South pit.

Table 4. Line equations and R^2 values for each of the calibration lines shown in Figure 12.

Source	Crushers	Calibration Equation	R^2 Factor
Ferguson Quarry	Impact Cone-Hammermill	$y = 2.9458x - 1.6051$	$R^2 = 0.9948$
Cedar Rapids Quarry	Impact-Twin Roll	$y = 3.2802x - 1.8432$	$R^2 = 0.9944$
Pederson Quarry	Jaw-Hammermill	$y = 3.4899x - 1.9904$	$R^2 = 0.9985$
Durham Mine	Impact-Small Cone	$y = 3.7812x - 2.1998$	$R^2 = 0.9962$
Fort Dodge Mine	Impact-Impact	$y = 4.0296x - 2.3757$	$R^2 = 0.9988$
Sully Mine	Impact-Impact	$y = 3.4899x - 1.9904$	$R^2 = 0.9985$

Figures in Appendix A show Fine Aggregate Angularity (FAA) vs. Camsizer Roundness and FAA vs aspect ratio for all six mansand (crushed particle) calibrations of set proportions of crushed particles.

Figures 13 through 16 are plots of FAA vs Camsizer Roundness C and FAA vs Inverse Aspect Ratio for proportions of all six mansand samples. Each Figure shows a plot of the data followed by a Figure with a trend line added to model the relationship of FAA to Camsizer shape determination.

Figures 17 and 18 show that the FAA for Sully is anomalously higher than the other mansands comparing roundness and aspect ratio. This is inconsistent with Camsizer data for shape characteristics. The reason for this inconsistency is not obvious.

Figure 19 shows averages of all six mansand FAA data for each proportion of mansand (0 to 100 percent). Both linear and 2nd order polynomial trendlines are shown. It is clear the trend of FAA data is not linear but a 2nd order polynomial. This is also seen in Figure 20 shown without Sully in the average.

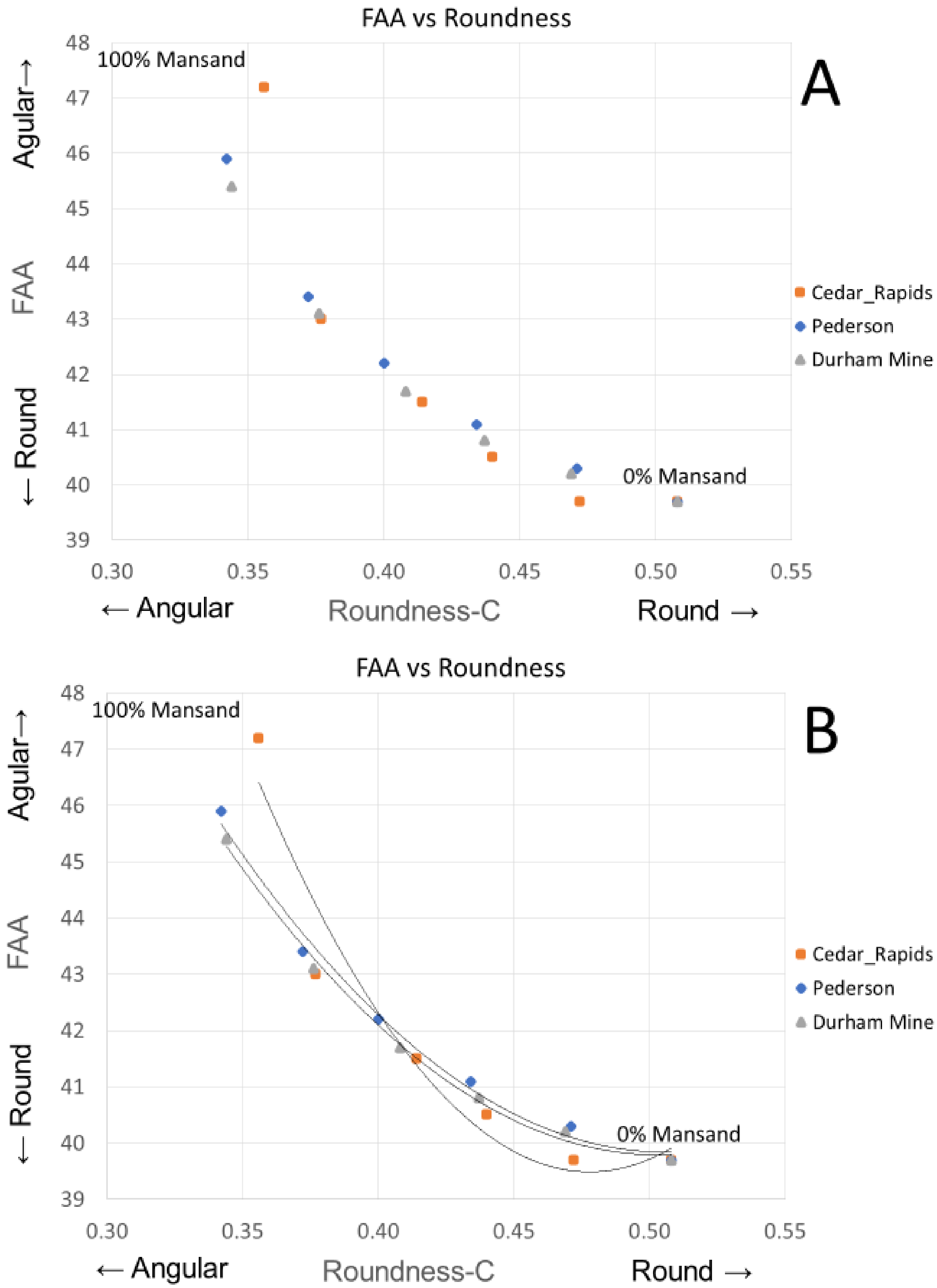

Figure 13. (A) Fine Aggregate Angularity (FAA) vs Camsizer Roundness from 0% mansand to 100% mansand from Cedar Rapids quarry, Pederson quarry, and Durham Mine. (B) Figure 15 A with trendlines added.

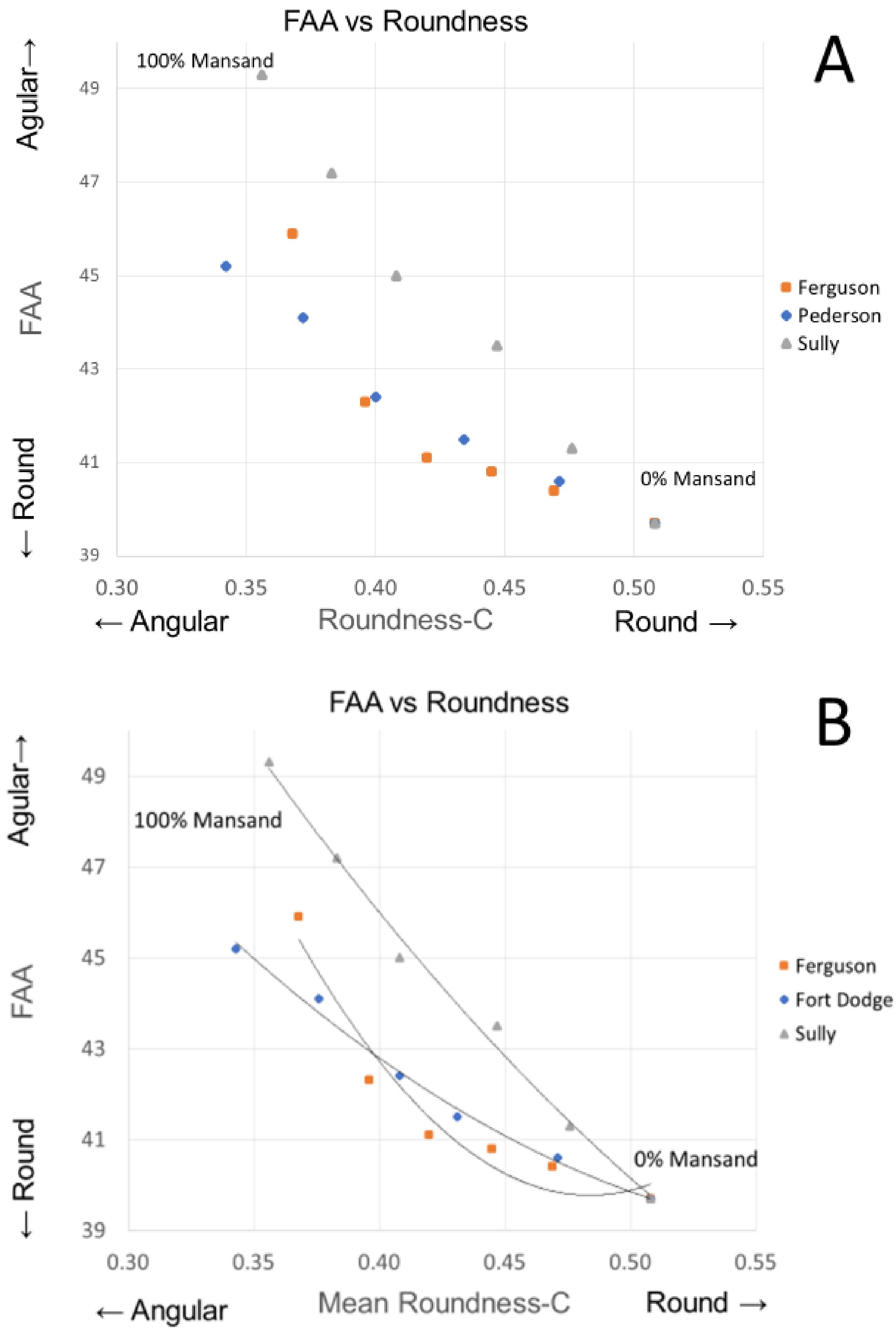

Figure 14. (A) Fine Aggregate Angularity (FAA) vs Camsizer Roundness from 0% mansand to 100% mansand for crushed particles from Ferguson quarry, Fort Dodge Min, and Sully Mine. (B) Figure 17 A with trendlines added.

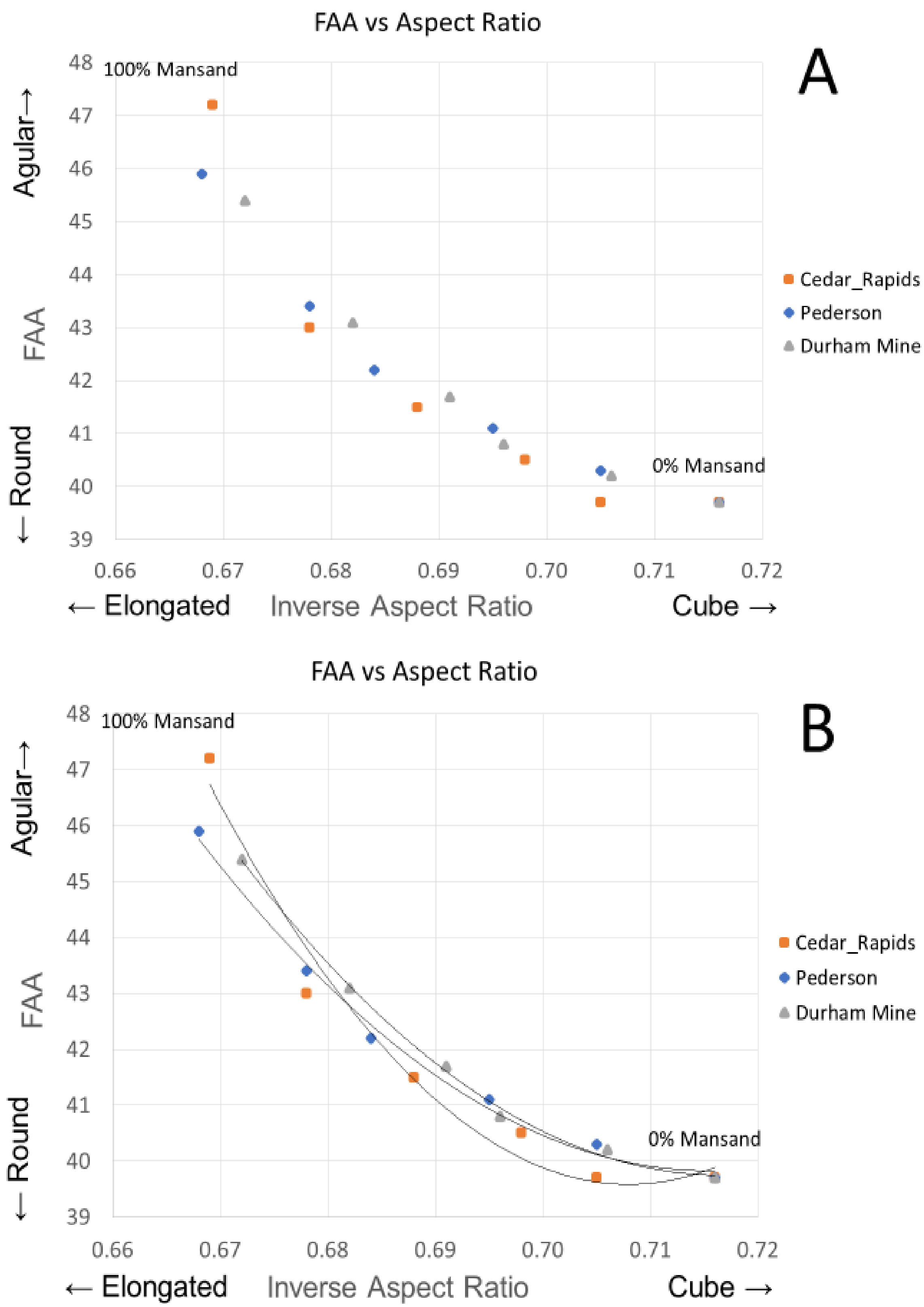

Figure 15. (A) Fine Aggregate Angularity (FAA) vs Camsizer Aspect Ratio using mansand for crushed particles from Cedar Rapids quarry, Pederson quarry, and Durham Mine. (B) Figure 18 A with trendlines added.

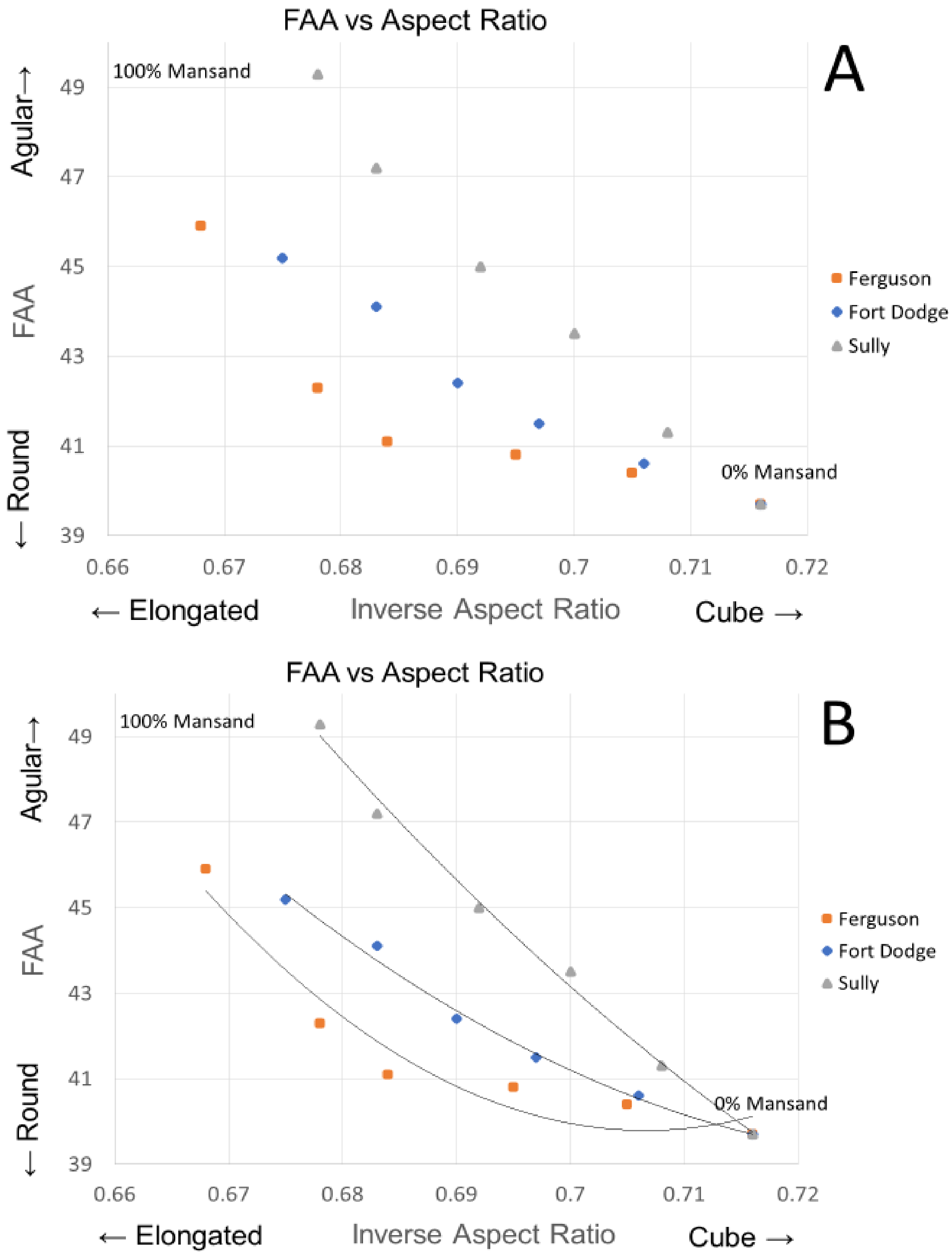

Figure 16. (A) Fine Aggregate Angularity (FAA) vs Camsizer Aspect Ratio using mansand for crushed particles from Ferguson quarry, Fort Dodge Mine, and Sully Mine. (B) Figure 21 A with trendlines added.

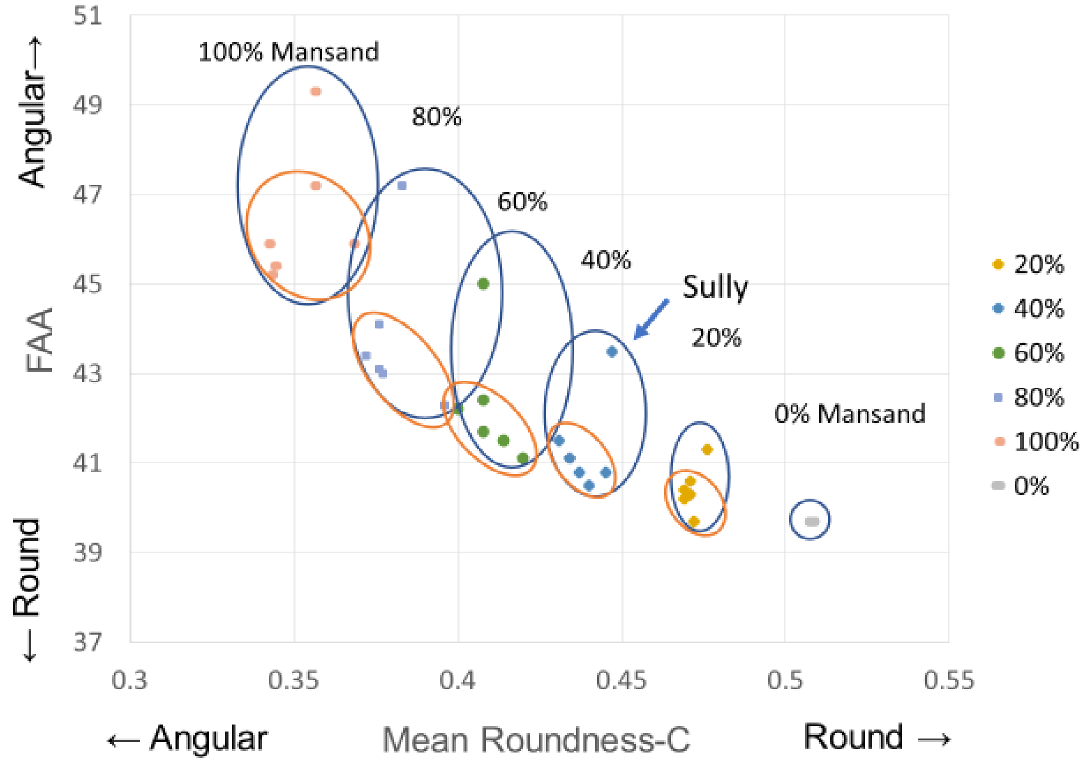

Figure 17. Fine Aggregate Angularity (FAA) vs Camsizer Roundness using mansand for crushed particles from all six mansands.

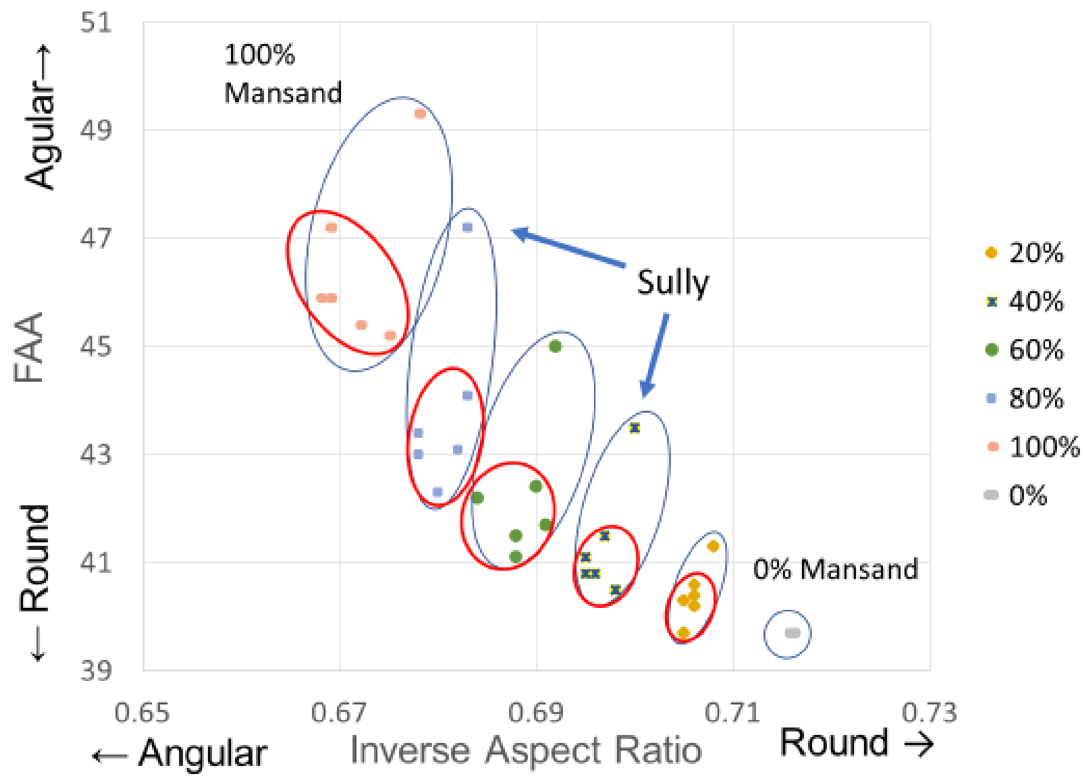

Figure 18. Fine Aggregate Angularity (FAA) vs Camsizer Aspect Ratio using mansand for crushed particles from all six quarries. The Blue circles include the Sully FAA data, the Red circles exclude the Sully data.

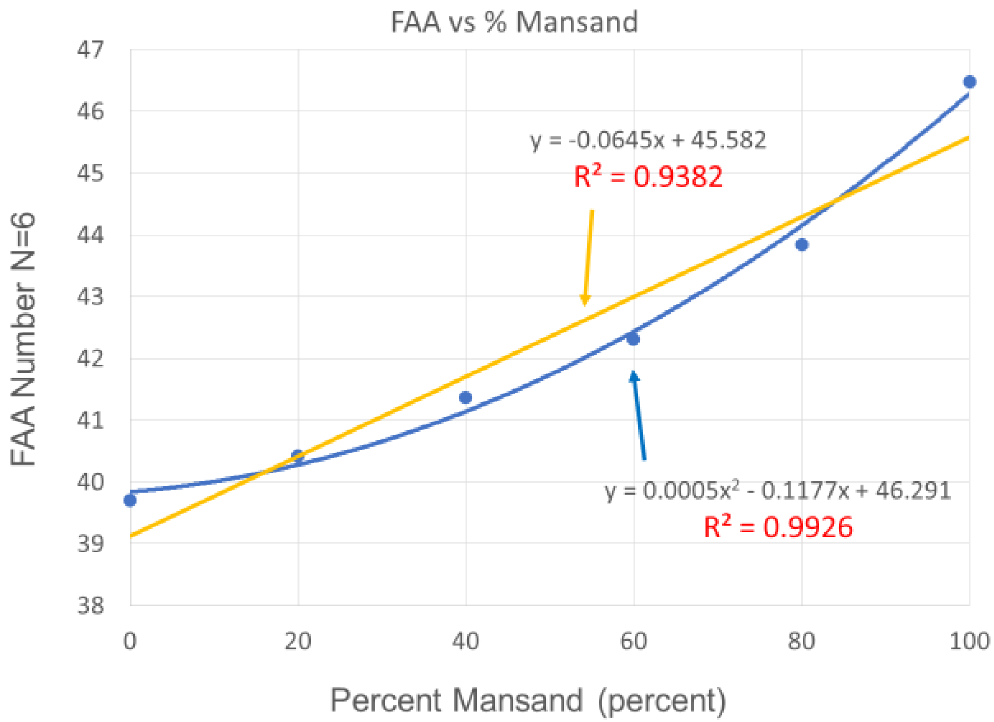

Figure 19. Average of six mansand calibrations plotted with percent mansand vs FAA number. Two regressions are compared, yellow is linear, blue is 2nd order polynomial. The FAA results are not linear but second order polynomial. This indicates that as particle angularity increases the FAA number increases as an exponential function.

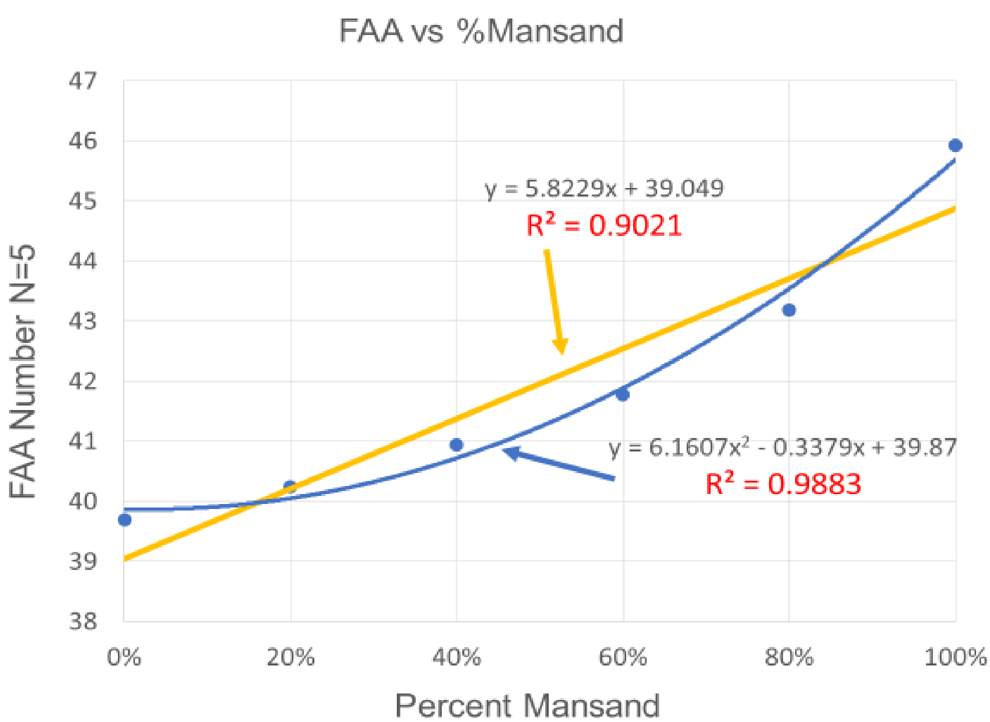

Figure 20. An average of the mansand calibrations plotted without Sully data for percent mansand vs FAA number. The results are the same with or without Sully Mine data.

Correlation of FAA to Camsizer for 20 percent Crushed Particles

At up to about 20% crushed particles, the correlation between the Camsizer and the FAA test correlate reasonably well (Figures 17 and 18). Table 5 shows the correlation between FAA at 20% crushed particles to Inverse Aspect Ratio (IAR) and Roundness (Rd) as determined from the Camsizer shape by image analysis. The average of these six-test result is FAA=40.4; Aspect Ratio=0.706; and Roundness=0.471. The new specification (Iowa DOT IM 409) for the amount of crushed particles that can be added to a natural sand is 20% through a controlled and measured mixing process. The FAA test specification limit in this specification is a FAA of 40.

Table 5. Correlation between FAA (from %Retained) of 20% retained gradation to Inverse Aspect Ratio (IAR) and Roundness (Rd) as determined from the Camsizer P4 shape by image analysis.

	Cedar Rapids Impact-Twin Roll			Durham Impact-Small Cone			Ferguson Impact-Cone-Hammermill		
Mansand	FAA	IAR	Rd	FAA	IAR	Rd	FAA	IAR	Rd
20%	39.7	0.705	0.472	40.2	0.706	0.469	40.4	0.706	0.469
	Ft Dodge Impact-Impact			**Pedersen Jaw Hammermill**			**Sully Impact-Impact**		
Mansand	FAA	IAR	Rd	FAA	IAR	Rd	FAA	IAR	Rd
20%	40.6	0.706	0.471	40.3	0.705	0.471	41.3	0.708	0.471

AVERAGE
N=6 FAA=40.4 AR=0.706 Rd=0.471

Discussion of Camsizer Test Results and Relation to Fine Aggregate Angularity

Chowdhury and others [11] compared the Fine Aggregate Angularity test to multiple methods of shape determination. This comparison included: direct shear test, compacted aggregate resistance (CAR) test, three different image analysis, and visual inspection. They concluded the FAA test method does not consistently identify angular, cubical aggregates as high quality-materials (for HMA). They also concluded the three image analysis techniques appear to be very promising for directly quantifying fine aggregate particle shape.

As discusser earlier, the calibration samples were analyzed for Fine Aggregate Angularity using a modified AASHTO T304 test or the *Uncompacted Void Content of Fine Aggregate* test. These results were compared to Camsizer test results for both Aspect Ratio and Roundness (Figures 5 through 13). These results show that as the amount of angular material increases, the FAA increases exponentially by a second order polynomial (Figure 15 and 16). These results indicate that the Camsizer shape analyses is linear, regardless of particle size or particle shape whereas the FAA test is not.

As a positive result, the FAA does correlate with the Camsizer image analysis at lower amounts of crushed particles. The fact that FAA values increase with greater amounts of crushed particles is not relevant to the use of the test for HMA but needs to be a factor if trying to estimate the percentage of crushed particles in a mix.

Results indicate that the Camsizer can differentiate minor variations in both elongation or aspect ratio and the roundness of particles, as seen in Figure 2. The Camsizer data also indicates using Aspect ratio and Roundness, differences in crusher types can be quantified by particle shape, although this does not take into account factors such as wear of equipment and flow or velocity of material through the crusher.

When “calibration” samples were analyzed with set proportions of mansand or crushed particles the Camsizer shape profiles for roundness and aspect ratio produced linier relationships for each of the crusher types (Figures 3 and 4). At up to about 20% crushed particles the correlation between the Camsizer P4 and the FAA test correlate reasonably well. Table 5 shows the correlation between FAA at 20% crushed particles to Inverse Aspect Ratio (AR) and Roundness (Rd) as determined from the Camsizer P4 shape by image analysis. The average of these six-test result is FAA=40.4; Aspect Ratio=0.706; and Roundness=0.471 (Table 5).

The new specification for the amount of crushed particles that can be added to a natural sand is 20 percent through a controlled and measured mixing process. The FAA test specification limit in this specification is an FAA of 40. The FAA test determination for crushed particles in fine aggregate is close to (but a little higher) for measuring the 20% crushed particles from mansand calibration curves for the FAA determination.

Conclusions from the comparison of Fine Aggregate Angularity test to Camsizer image analysis

- The Camsizer test can accurately measure particle size and shape characteristics of individual sand particles. Individual particles of 50 g of sample (but not limited to) can be analyzed in a matter of several minutes.
- The Camsizer can accurately measure the differences in particle shape in crushed particles produced from different types and combinations of crushers (Figures 10 and 11).
- Camsizer test results are linear when test samples of set proportions of crushed/angular particles are combined with natural sand (Figure 13). The Fine Aggregate Angularity test is not linear, but is closer to a 2^{nd} order polynomial. The more angular particles, the more the FAA deviates from linear with increasing FAA values (Figures 14 through 25).
- Variability between the FAA number and Camsizer image analysis of Aspect Ratio and Roundness is due to the non-linearity of the FAA test.
- Up to about 20% crushed particles, the FAA and the Camsizer correlate reasonably well, but the image analysis of the Camsizer is a direct and better way of measuring particle shape.
- If the FAA test is to be used for the application of testing the amount of crushed particles in a mix for PCC, an “as received” gradation of the fine aggregate should be used as opposed to the “set” gradation used in AASHTO T304.

Application of the Manufactured Sand Calibration to Evaluate a Source with some Crushed Particles

To determine the amount of crushed material that may be in some fine aggregate produced by L.G. Everest, Alex Crosgrove and Robert Dawson (IADOT Construction and Materials) along with Pat Rattenborg (L.G. Everest) had site visits of the Everest sand and gravel production plants at Washta Pit, Cherokee County (A18528) and Hawarden, Sioux County (A84510) on August 13, 2020. These are the only two plants of L.G. Everest which are known to crush oversized rock during fine-aggregate production. When these plants are crushing stone it is for the production of c***oarse*** aggregate and not exclusively for production of fine aggregate. These plants were called into question by the aggregate Producer proposing the specification change to allow crushed particles for the production of fine aggregate for use in PCC. It was determined that the Hawarden Plant does not include crushed particles in material produced for Iowa DOT projects. Analyses of the Washta product is described below.

Washta Production Process

Washta uses both a jaw and cone crusher. Very little material goes through the jaw crusher. The full product is split over a 1" dry screen. The plus 1" goes to a cone crusher. This process is repeated in a closed loop system until all particles pass through the 1" screen. Table 2 contains production data from January 1, 2020, to August 13, 2020, the data of the plant review.

Table 2. Washta Product Report, Year-to-Date 01/01/2020 – 08/13/2020

Wash Plant	Tons	% of Production
1" x No. 4 Washed Gravel	22,920	18%
Washed Concrete Sand	104,400	82%
Total	127,320	100%

Of the 1" Coarse aggregate, 30% of the particles have a fractured surface. Meaning 5.4% of the product has a fracture surface. Six percent (6%) of the 1" particles becomes -3/8 inch which is 0.32% of the total fine aggregate product.

Figure 21 is Pit Run and Stockpile samples from Washta Pit plotted showing the Roundness of particles on the Pederson Mansand Calibration line. The stockpile sample were less angular than the pit run samples. Figure 22 plots Pit Run and Stockpile from Washta Pit showing the aspect ratio of particles. The stockpile samples were less elongated than the pit run samples.

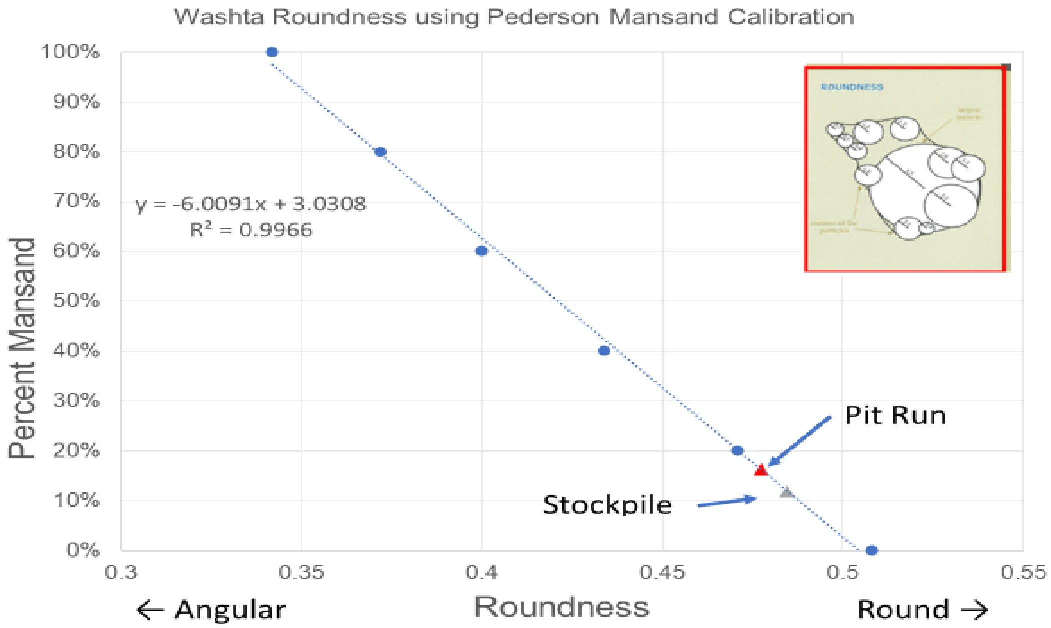

Figure 21. Sand from Washta Pit showing Pit Run and Stockpile samples for Roundness of particles. The stockpile sample were less angular than the pit run samples.

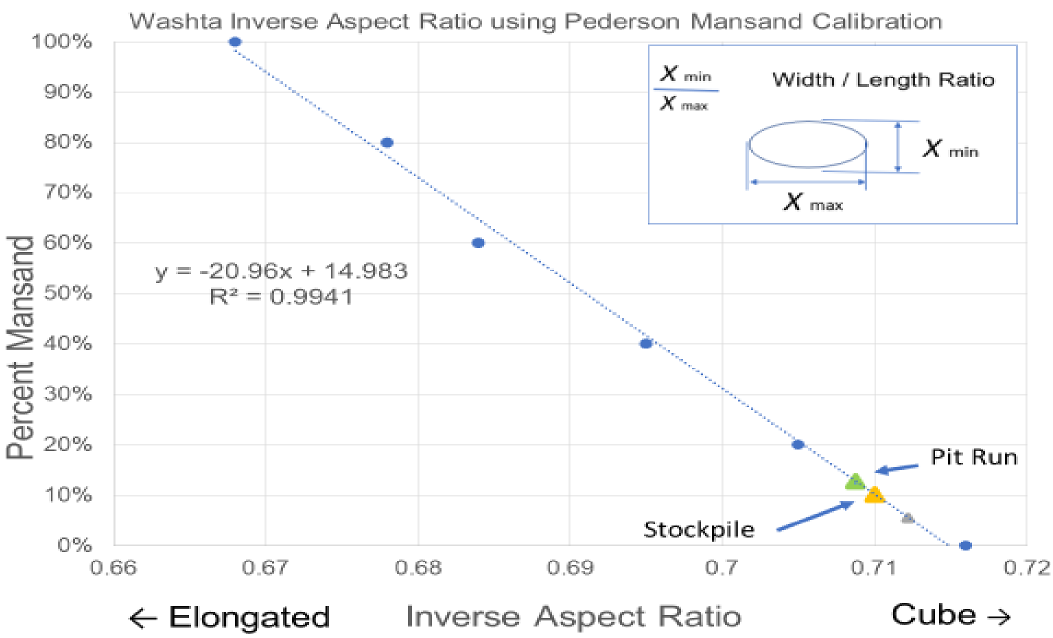

Figure 22. Sand from Washta Pit showing Pit Run and Stockpile samples for the aspect ratio of particles. The stockpile samples were less elongated than the pit run samples.

Use of the Camsizer P4 for Geological Analyses of Sand Particle Shape – River and Stream Particle Shape Analyses.

The Camsizer P4 can determine a wide variety of particle shape characteristics including the inverse aspect ratio and roundness of sand particles. It is anticipated that particle shape can be used to evaluate geological environments. To test this approach to particle shape analyses, sands from Iowa landform environments and the distance from river sources were evaluated to determine particle roundness and elongation and the relationships to the geologic environments.

To determine the distance from a rivers source of a sand deposit, the USGS application Streamer was used (https://txpub.usgs.gov/DSS/streamer/web/). A standard operating procedure (SOP) for Streamer is outlined in Appendix B. A river's source is not the true origin of the sediment that produced a sand deposit. Most Iowa sands were the result of glacial processes and modified by the fluvial or river process after glaciation. Virtually all sand pits in Iowa are located near or along rivers. Measuring the distance of a sand source from the river source is a way of quantifying the effect of natural processes on a particle shape. Figure 23 shows the trace of the Iowa River as determined using the Streamer.

It is recognized that the different landforms (Figure 24) deposited on Iowa bedrock also plays a role in determining a sand particle shape. This is usually the result of landform sediments eroding into rivers streams, contributing to the sediment load of that body of water. Figure 25 shows sand sources along the Iowa River overprinted onto the landform map along the path of the Iowa River.

Figure 26 shows roundness of sand particles from sand pits on the Iowa River in relation to distance from the river source and the landforms of the sand and gravel source. Letters show the source locations from Figure 25. In this figure, four of the sand samples follow a linear trend (A, C, D, and F). The linear trend of these samples becoming more round with the distance from the source of the river indicating that residence time in a fluvial (river) environment has a large contribution to the roundness of a sand particle. The data indicate that, in general, the longer sand particles remain in a river, the rounder they become. Although this is intuitive, it can be quantified based on image particle shape analyses.

Three of the sand samples do not follow this linear trend (B, E, and G). These pits are in unique locations on the Iowa landforms. Even though these samples have not traveled as far from the river source as the linear samples, Figure 25 illustrates that they are more angular than the trend distance would indicate. This figure puts the angularity trend in a better perspective with lower numbers being more angular.

Looking at Figure 25, sample B is from a pit at the edge of the Des Moines Lobe. This location is one of the end moraines of the Des Moines glaciation. Here the glacier continued to pile up rocks as tills with glacial erratics. As new particles or sediments erode from the moraine, although they have been rounded by glaciation, they will not be as “mature” as sediments which have spent considerable time being rounded by water.

Sand Pit E is at the edge of the Iowa Surface and the Southern Iowa Drift Plain. The Iowa Surface formed during the last glaciation, which produced the Des Moines Lobe. Not far from the ice sheet, weathering was due to tundra and permafrost processes. This sand pit is south of the Paha ridges that formed at this time (see Figure 25). Paha ridges, rising ~20 feet above the surrounding landscape, are elongated landforms composed of loess or glacial till capped with loess that formed during development of the Iowan surface. Seasonal freezing and thawing will move these sediments down slope exposing more angular particles.

Sand from Pit G is on the Mississippi Alluvial Plain. This area is composed of alluvium (river sediments) from an older course of the Mississippi River. Sands in this region are likely derived from the sand and cobbles carried by the flow of the paleo-Mississippi river. These sands are in general, more rounded than Des Moines Lobe and ice-marginal sands at the edge of the Des Moines Lobe.

Results of the particle shape analyses of sand pits along the Iowa River indicate that the shape of sand particles is influence not only by the amount of time and distance carried by a river but also by the landforms the river passes through. This relationship can be used to predict shape characteristics along the Iowa River Valley.

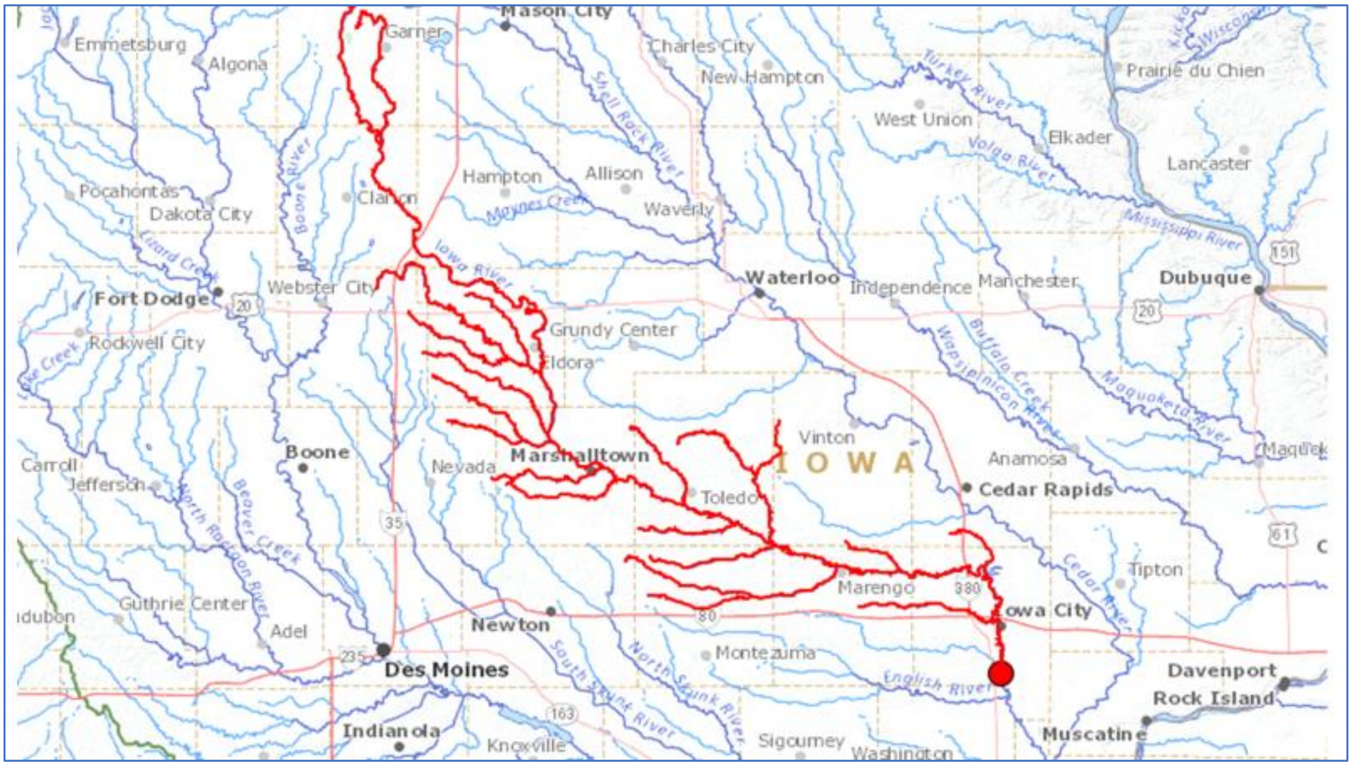

Figure 23. Trace of the Iowa River and tributaries to just below Iowa City. Mapping and calculation of river mileage was done using USGS "Streamer" [12] described in Appendix B.

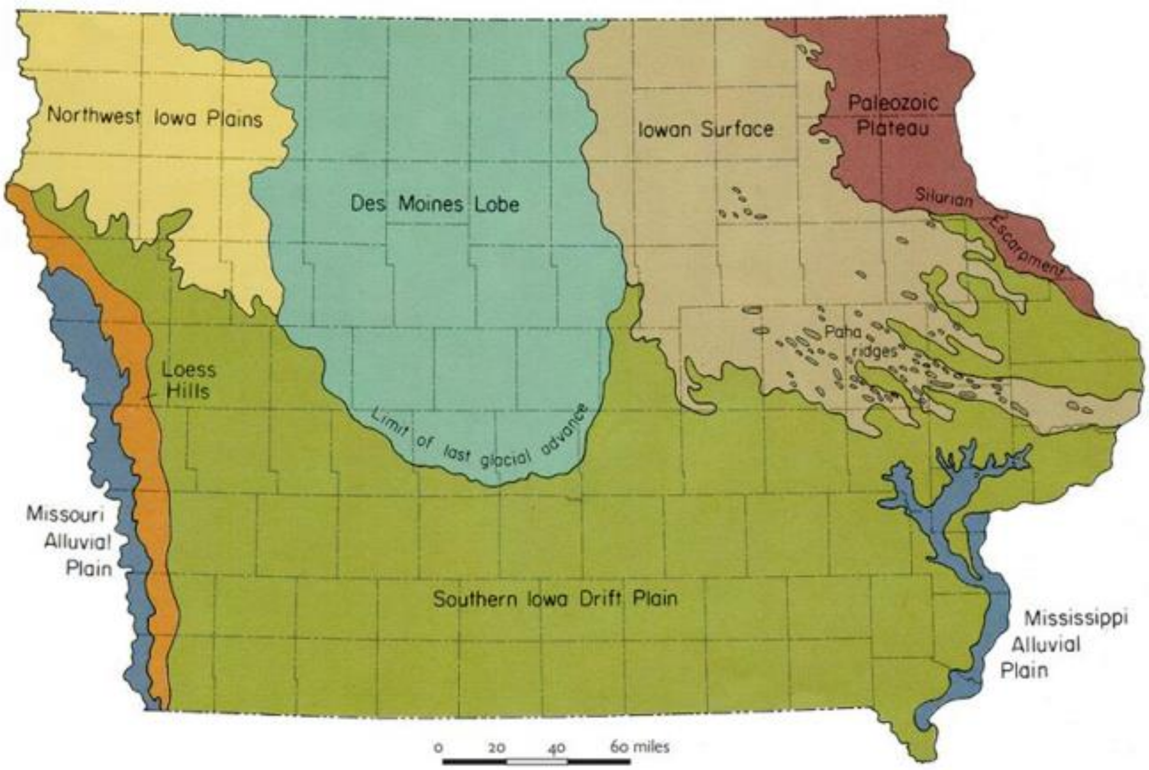

Figure 24. Map of Iowa showing prominent landform features.

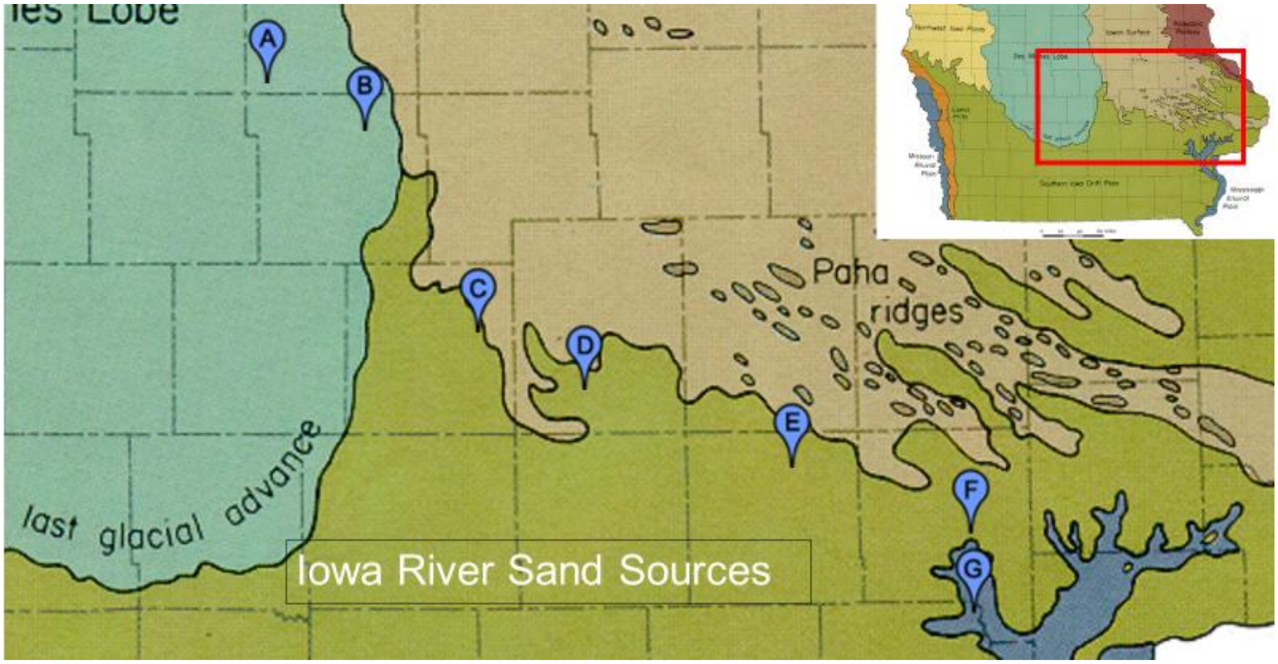

Figure 25. Landforms along the Iowa River with letters representing individual sand and gravel pit locations. These are mapped by distance from source and landforms for shape analyses of the sand particles shown in Figure 26.

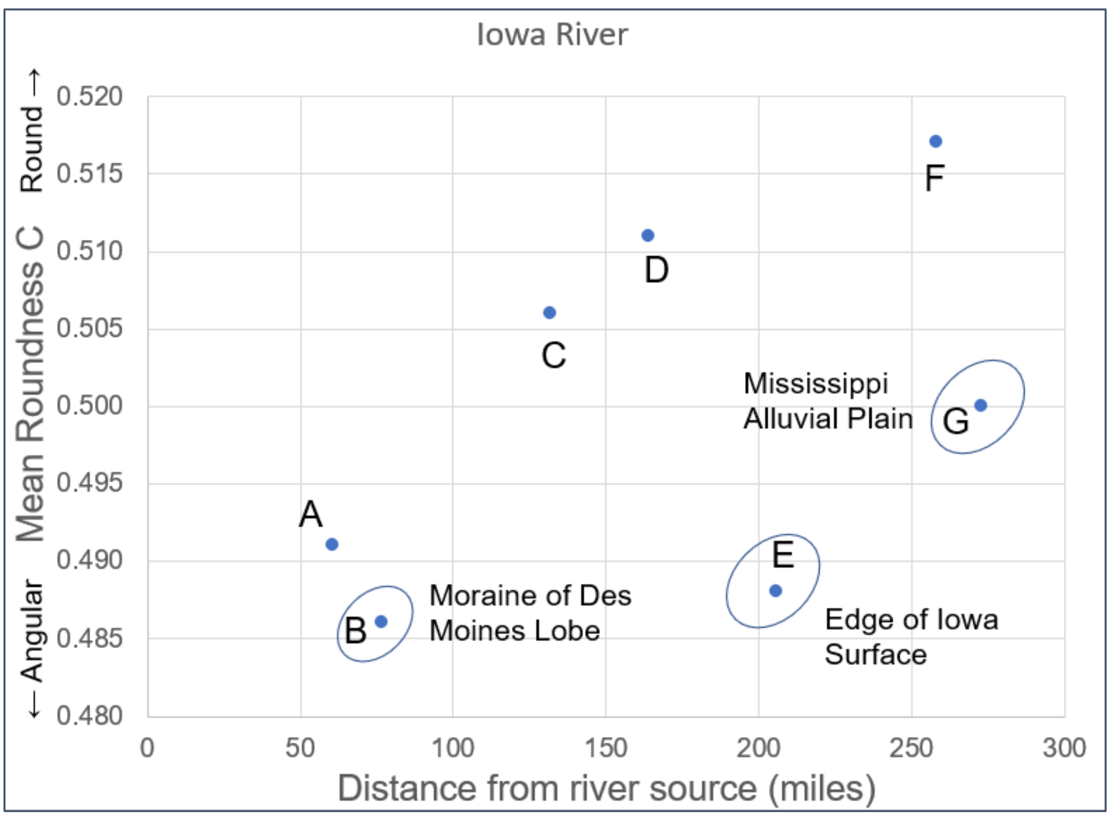

Figure 26. Roundness of sand particles from sand pits on the Iowa River in relation to distance from the river source and the landforms of the sand and gravel source. Letters show the source locations from Figure 25.

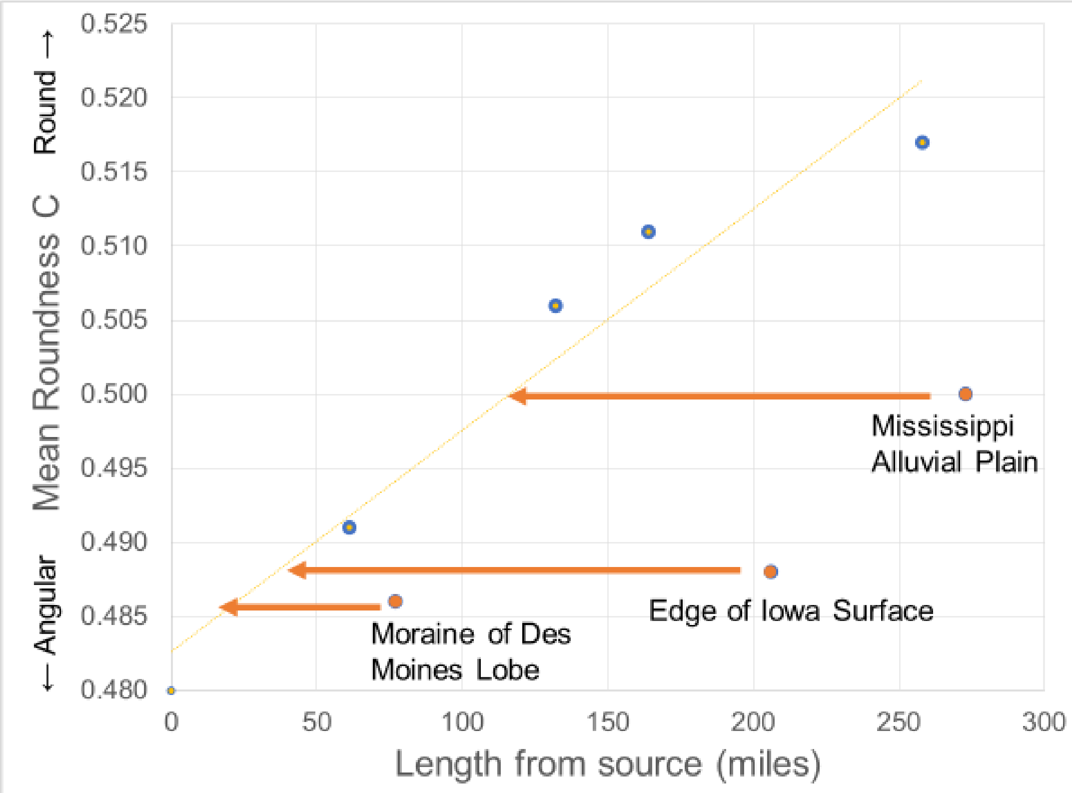

Figure 27. Roundness of sand particles from sand pits on the Iowa River in relation to distance from the river source and the landforms of the sand and gravel source. Letters show the source locations from Figure 25.

Use of the Camsizer P4 for Geological Analyses of Sand Particle Shape – Landforms and Environments of Deposition

Figure 28 shows the relationship between roundness C vs. inverse aspect ratio for natural sands from Iowa. This relationship for all sands measured in this study was shown in Figure 8. Most sands from the Des Moines Lobe are circled in blue, though there are two prominent outliers. Figure 29 shows these two samples. One of the samples was from Wright County, which showed more elongation and poor roundness. Figure 30 is a map of the Des Moines Lobe in Iowa showing the moraines or ridges of accumulated glacial tills caused by either the stalling of the retreat of glaciation or periodic surges of glaciation during glacial retreat. Wright County is shaded in white. The location of the sand pit is located at the point of the arrow in the figure. As seen in this figure, the sand pit is located on the outward side of a lateral moraine. As discussed in the previous section, particles near moraines can be derived from larger particles fractured through the continued deposition of the moraine. Also, proximity to a moraine provides less “mature” particles than those eroded or rounded by prolonged stream flow.

The other outlier, a sample from Pedersen Pit is more rounded and cubic (less Elongated) than the other natural sand samples. Figure 31 is a photograph which shows the geologic relationship of the sand to landform features with the sand *below* the glacial till of the Des Moines Lobe. In this case, the sand was deposited before the advance of the Des Moines Lobe making this deposit older than the deposition of the Des Moines Lobe till. Being deposited before the advancement of the Des Moines Lobe (12,000 to 14,000 years ago) gave much more time for this sand to “mature” (that is, to become rounder and more cubic) than other sands in Iowa.

Figure 32 shows Iowa sands grouped by landforms. The Des Moines lobe sand samples are circled in a dark blue. These sands are geologically recent, being deposited through glacial process and stream flow over the last 20,000 years. Samples from the ice margin of the Des Moines Lobe are circled in red. Ice margin samples are less round (more angular) than other samples from the lobe itself perhaps being derived from the more angular glacial moraine material.

Samples from the Iowa Surface circled in light blue. Sands from the Iowa Surface developed at the same time as the Des Moines Lobe in an environment of permafrost and tundra. In the southern portion of the Iowa Surface, linear ridges caped with loess rise out of the landscape. With rainfall and freeze-thaw, granitic boulders are exposed to weathering.

Samples from the Mississippi Alluvial Plain circled in yellow. This area has a base of alluvium from the ancestral Mississippi River. As seen in samples from along the Iowa River, these sands are more rounded than Des Moines Lobe or Ice Marginal sands.

Samples from the Southern Drift Plane circled in green. The Southern Iowa Drift Plain is formed from a much older glacial surface than the Des Moines Lobe. This area is highly dissected making it much hillier. Sands of this area were transported in more rapidly flowing rivers and streams especially with the melting of the ice flow coming from the retreat of the Wisconsin glacier advance.

Although the groups overlap, the sands tend to occupy unique shapes defined by both the residence time in water, distance traveled, and energy factors of the river. Landforms at the rivers source and path of the river through different landforms are also factors controlling sand particle shape.

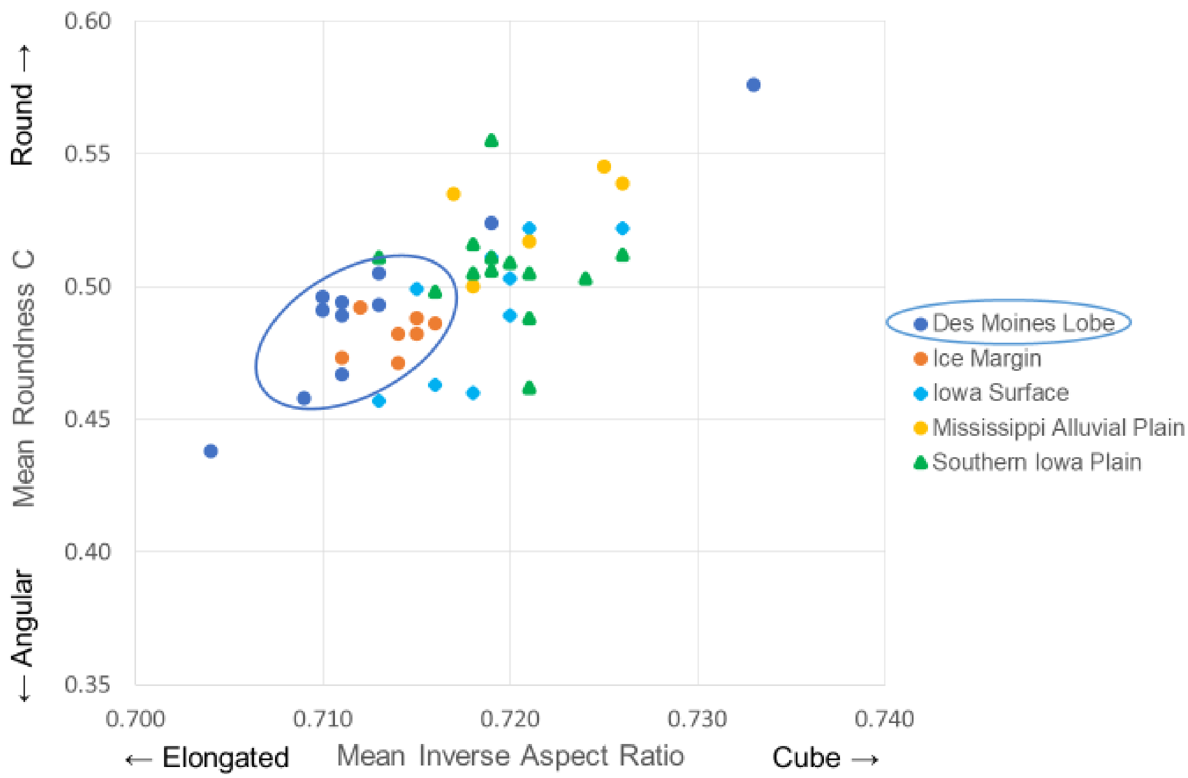

Figure 28. Most sands from the Des Moines glacial lobe are shown in blue.

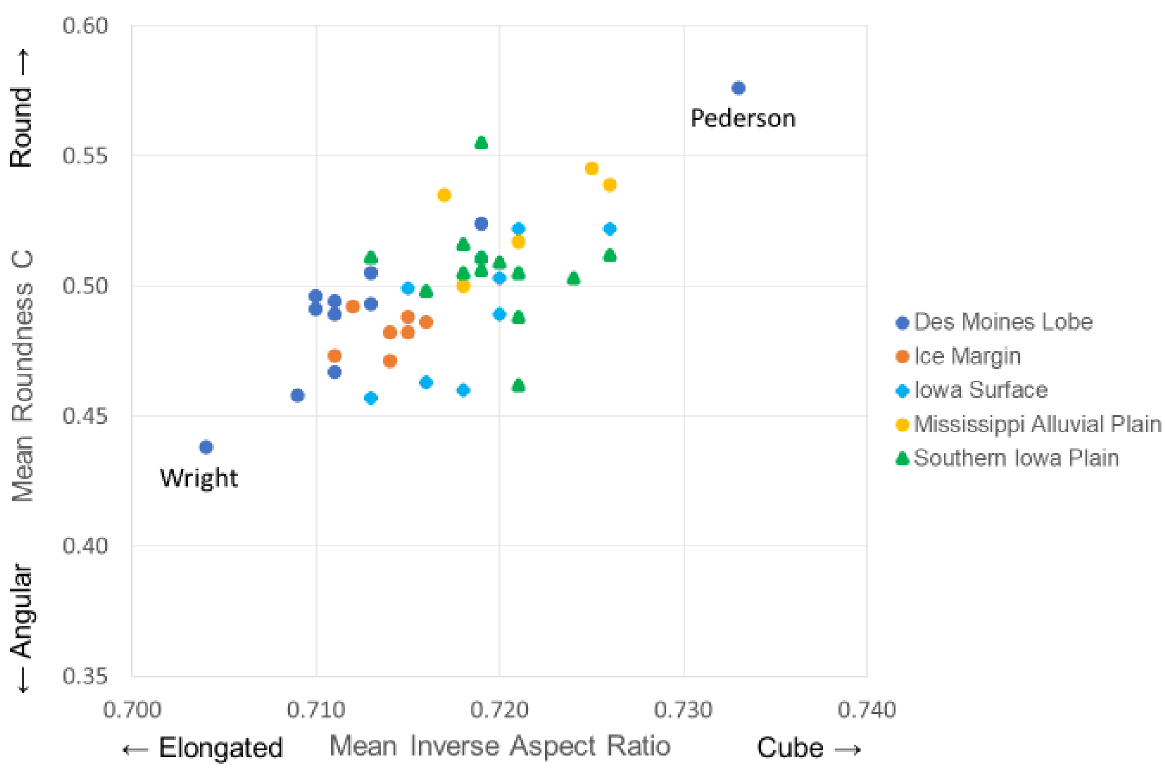

Figure 29. Wright sand from Wright County is an outlier being more angular and elongated than most natural sands.

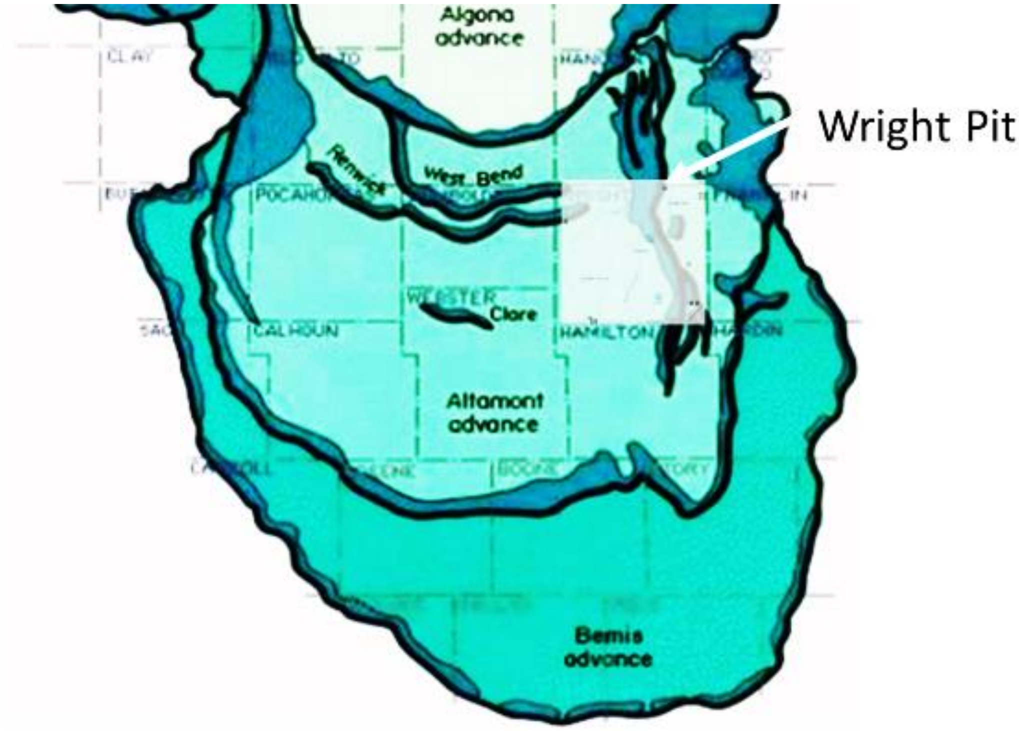

Figure 30. Location of Wright Pit at the very edge of one of the Des Moines Lobe Marginal Moraines. This would be the source of continued ice flow with newly fracture particles.

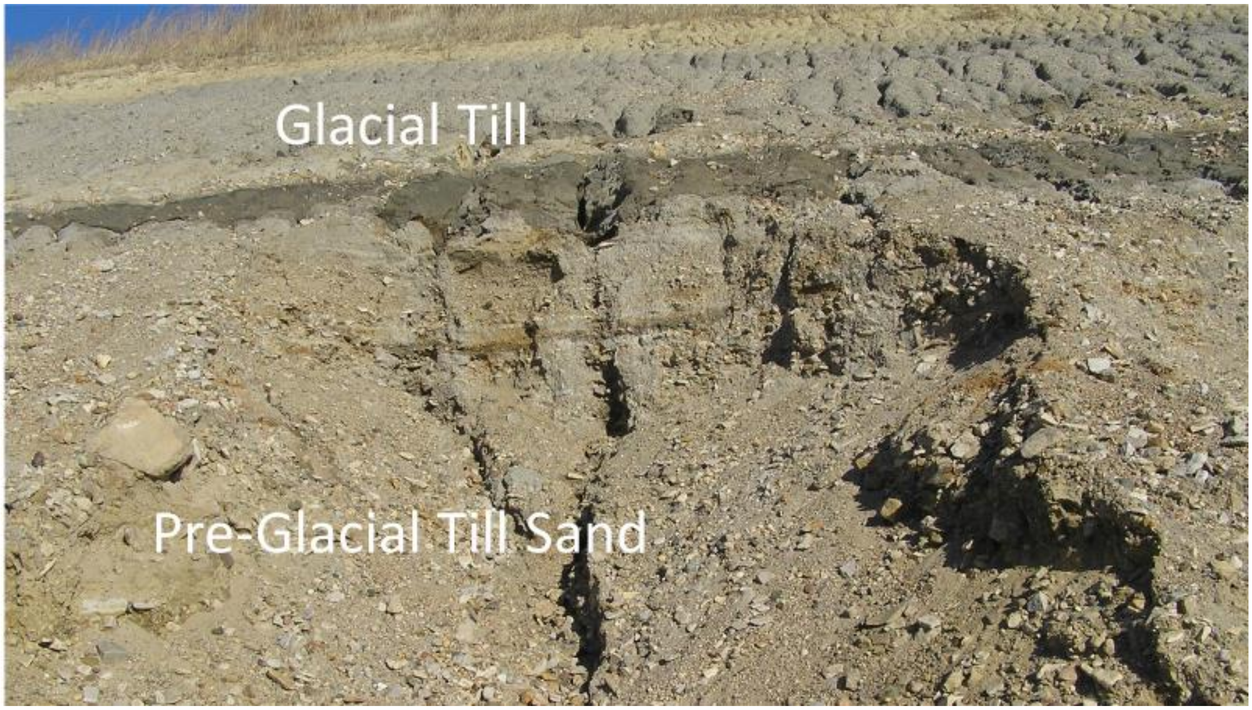

Figure 31. Sand from Pedersen pit located below Des Moines Lobe glacial till making this a sand that is older than 12,000 years.

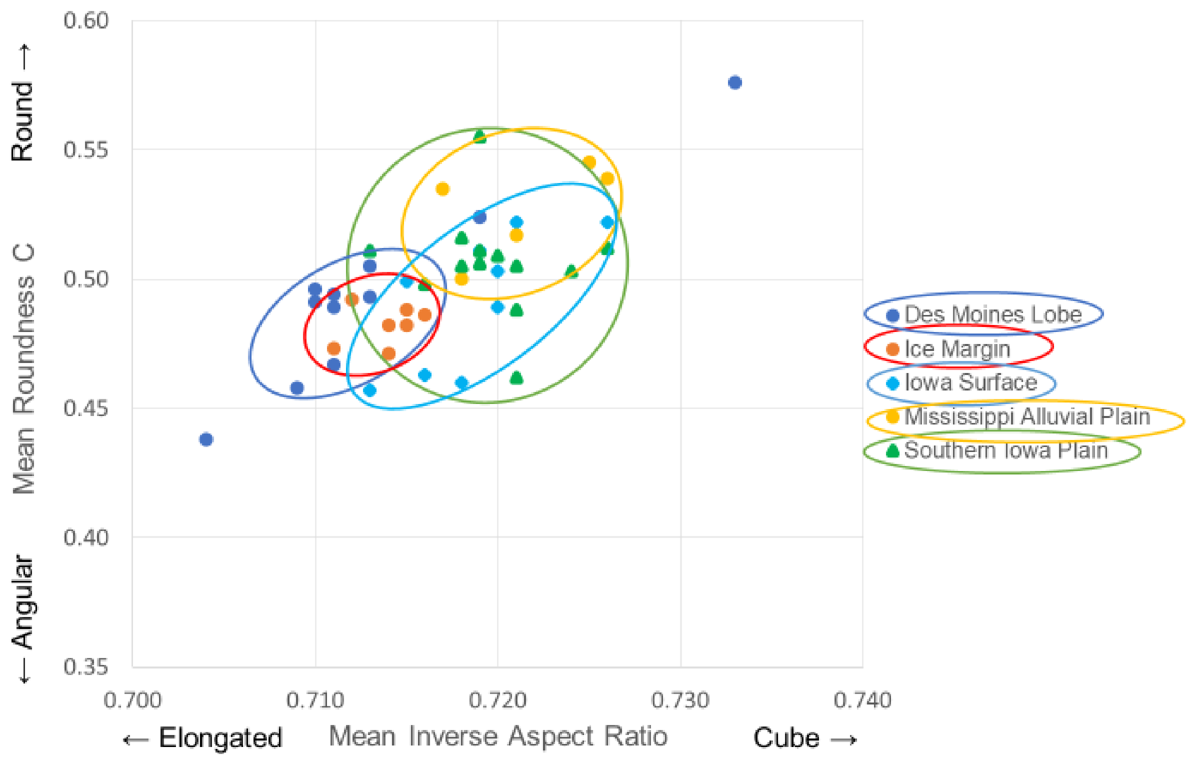

Figure 32. Groups of Iowa sands by landforms. Although the groups overlap, the sands tend to occupy unique shapes defined by both the time, distance, and energy factors of the river as well as the landforms of the rivers source or path of the river.

Conclusions for Use of the Camsizer P4 for Geological Analyses of Sand Particle Shape – River and Stream Particle Shape Analyses

- The Camsizer P4 can differentiate the shape of fine aggregate from different rivers and streams to a certain degree
- Different Iowa Landform Regions can be identified based on image analysis of the sand shape characteristics
- The shape analyses of the Camsizer can be useful in determining the environment of deposition of sand and other fine-grained particles
- The Camsizer will be useful in producing a fine-aggregate quality specification

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Conclusions

Conclusions from the comparison of Fine Aggregate Angularity test to Camsizer image analysis

- The Camsizer P4 can distinguish the difference in particle size and shape characteristics of individual sand particles. Individual particles of fifty grams of sample (but not limited to) can be analyzed in a matter of several minutes.
- The Camsizer can distinguish differences in particle shape in crushed particles produced from different types and combinations of crushers (Figures 10 and 11).
- Camsizer test results are linear when test samples of set proportions of crushed/angular particles are combined with natural sand (Figure 13).
- The Fine Aggregate Angularity (FAA) test is not linear but is closer to a 2nd order polynomial. The more angular particles, the more the FAA deviates from linear with increasing FAA values (Figures 14 through 25).
- Variability between the FAA number and Camsizer image analysis of Aspect Ratio and Roundness is due to the non-linearity of the FAA test.
- Up to about 20% crushed particles, the FAA and the Camsizer correlate reasonably well, but the image analysis of the Camsizer is a direct and better way of measuring particle shape.
- If the FAA test is to be used for the application of testing the amount of crushed particles in a mix for PCC, an "as received" gradation of the fine aggregate should be used as opposed to the "set" gradation used in AASHTO T304.

Conclusions for Use of the Camsizer P4 for Geological Analyses of Sand Particle Shape – River and Stream Particle Shape Analyses.

- The Camsizer P4 can differentiate the shape of fine aggregate from different rivers and streams to a certain degree.
- Different Iowa Landform environments can be evaluated based on Image Analyses of the sand shape characteristics.
- The shape analyses of the Camsizer can be useful in determining the environment of deposition of sand and other fine-grained particles.
- The Camsizer will be useful in producing a fine-aggregate quality specification.

Recommendations

- The Camsizer P4 is a fast, accurate, and direct measurement of particle shape. It would be a very good alternative to AASHTO test T304 (*Uncompacted Void Content of Fine Aggregate* [8]).
- Although not discussed in this report, the Camsizer P4 can be used as a quick, accurate alternative to sieve analyses.
- The Camsizer may be used as a part of new way of evaluating fine aggregate quality.
- Roundness and Aspect Ratio may be used to evaluate the fine aggregate shape of crushed material to determine if it is appropriate for addition to natural sand. Below (Figure 33 and 34) is a proposed recommendation for a Camsizer specification for crushed particles added to a fine aggregate for PCC.

Figure 33 is a plot of Mean Roundness C vs. Inverse Aspect Ratio of natural sands. As a specification, it is proposed that Roundness limits of greater than 0.45 and Inverse AR of greater than 0.700 be used as a limit for particle shape at the addition of 20% crushed particles to a natural sand. One outlier sand was not included. This sample was discussed earlier in this report. Figure 34 shows these same limits on a graph of crushed mansand “calibration” lines.

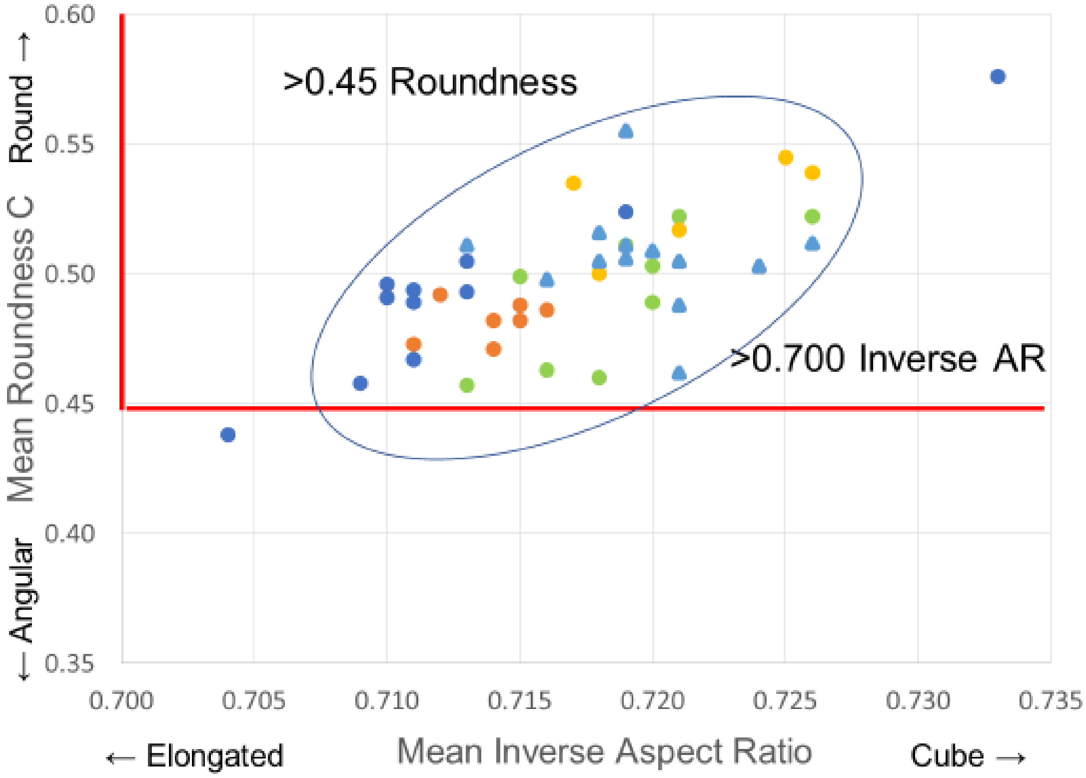

Figure 33. Roundness of greater than 0.45 and Inverse Aspect Ratio of greater than 0.700 is proposed as a specification limit for roundness and elongation of crushed particles when combined with natural sand at 20% crushed particles.

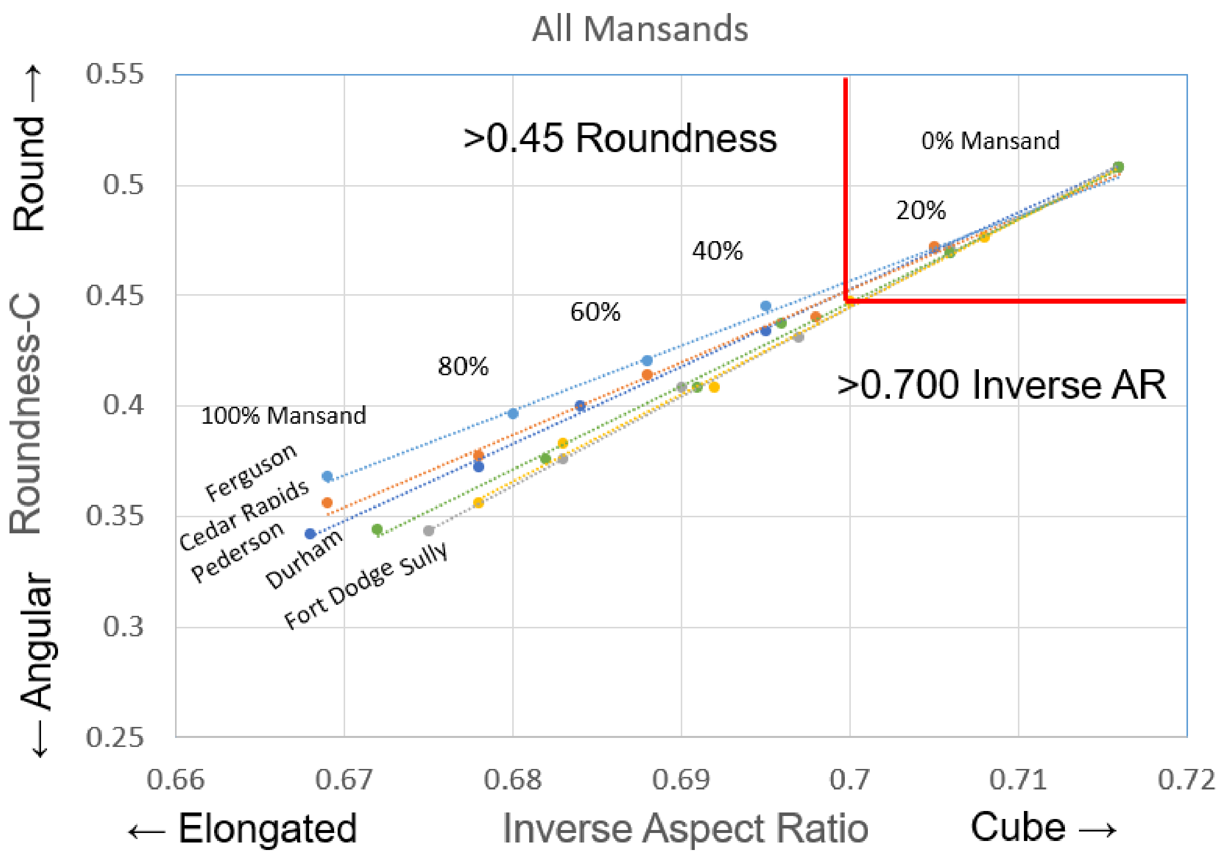

Figure 34. Roundness of greater than 0.45 and Inverse Aspect Ratio of greater than 0.700 is proposed as a specification limit for roundness and elongation of crushed particles at 20%.

References

1. Wentworth, Chester K, *A Method of Measuring and Plotting the Shapes of Pebbles*, Contributions to Geography of United States, 1922, pp.92-102.
2. Wentworth, Chester K, *A Field Study of the Shapes of River Pebbles*, Contributions to Geography of United States, 1922, pp.103-114.
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4. Moaveni, M., Mahmoud, E., Ortiz, E. M., Tutumluer, E., and Beshears, S., *Use of Advanced Aggregate Imaging Systems to Evaluate Aggregate Resistance to Breakage, Abrasion, and Polishing,* Transportation Research Record: Journal of the Transportation Research Board, No. 2401, Transportation Research Board of the National Academies, Washington, D.C., 2014, pp. 1–10.

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6. Microtrac MRB Particle Characterization product description, *Particle size and shape characterization by Dynamic Image Analysis Camsizer P4*,.2021.
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9. Hickel, G.C., Boaventura, G.C., Souza, R.A., Calcada, L.M., Casali, J.M., Betioli, A.M., Oliveira, A.L., *Influence of crusher type in the shape of fine crushed aggregate grains,* Ibracon Structures and Materials Journal, Vol 11, No. 4, August 2018, pp. 902-930.
10. Kurt O'Bryan, Quality aggregates made easy: The ultimate guide to maximizing shape and yield, 2017, https://www.global.weir/newsroom/news-articles/2017/05/23/quality-aggregates-made-easy-the-ultimate-guide-to-maximising-shape-and-yield/
11. Cowdhury, A., Button, J., Kohale, V., and Jahn, D., *Evaluation of Superpave Fine Aggregate Angularity Specification,* International Center for Aggregate Research, Research Report ICAR-201-1, June 2001.
12. USGS Streamer Tool, https://www.usgs.gov/centers/ot-water/science/streamer?qt-science_center_objects=0#qt-science_center_objects,

Appendix A

Camsizer Shape Data by Crusher Type

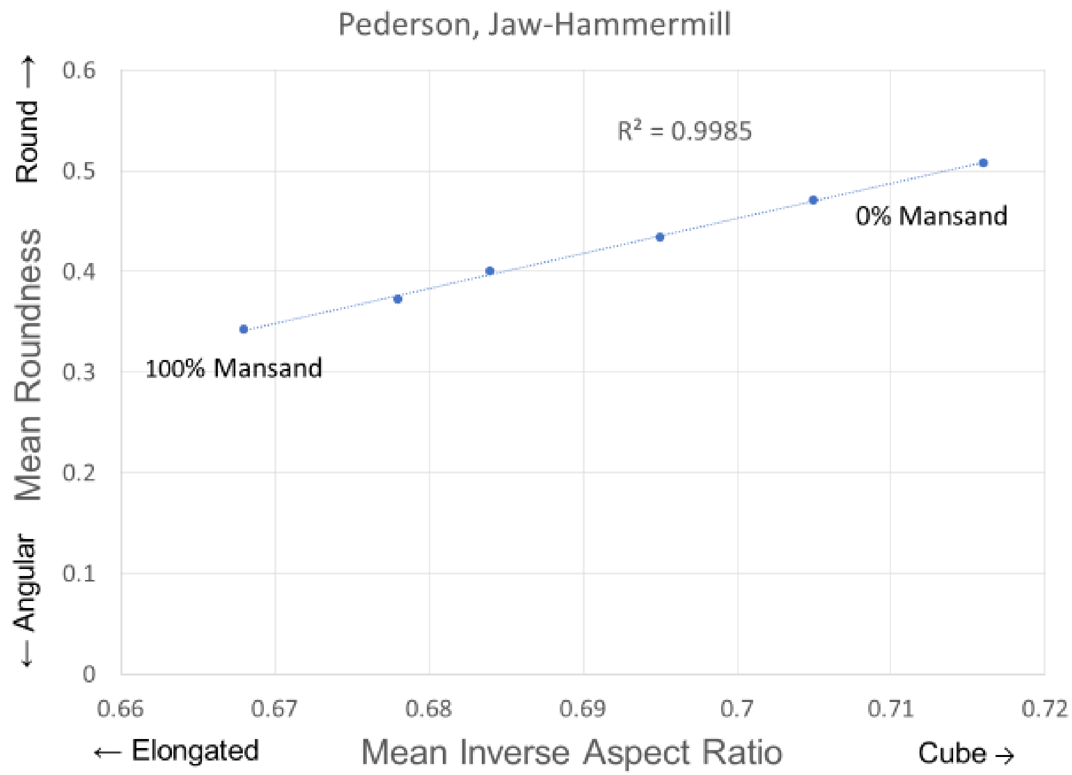


Figure 41. Calibration line using Pederson mansand produced by Jaw-Hammermill crushers.

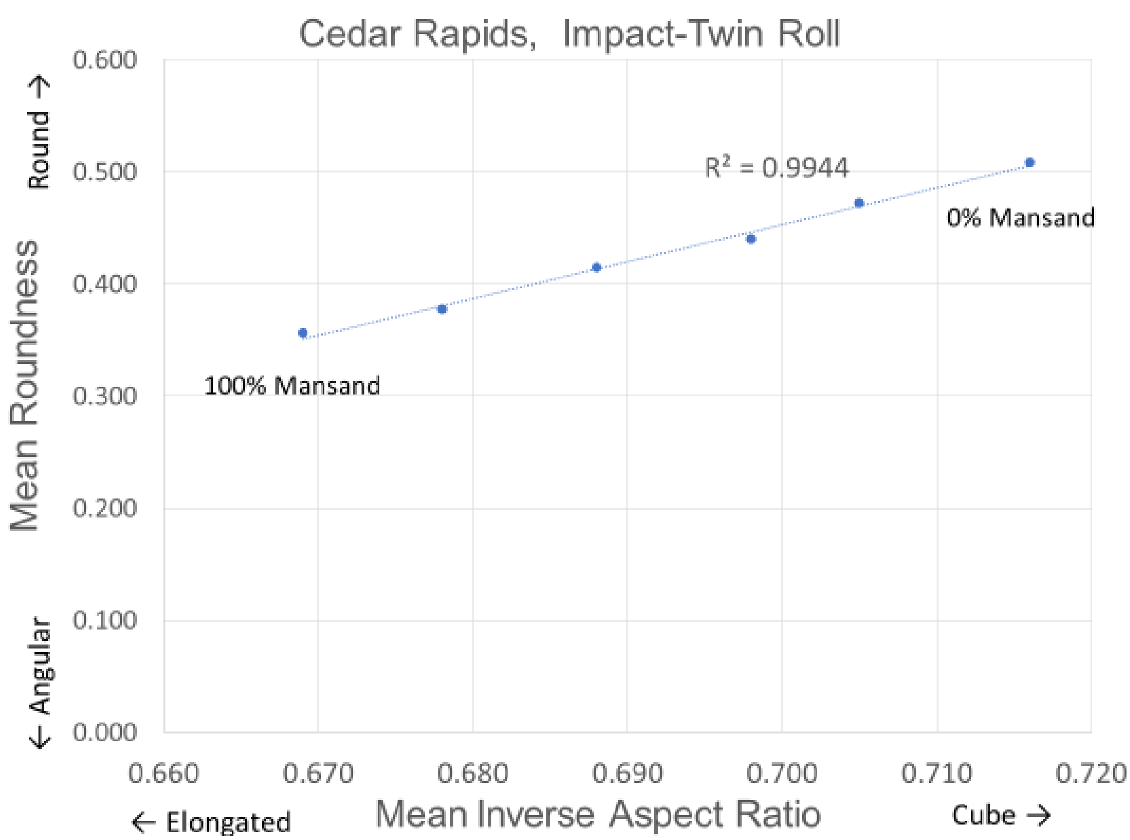


Figure 42. Calibration line using Cedar Rapids mansand produced by Impact-Twin Roller crushers.

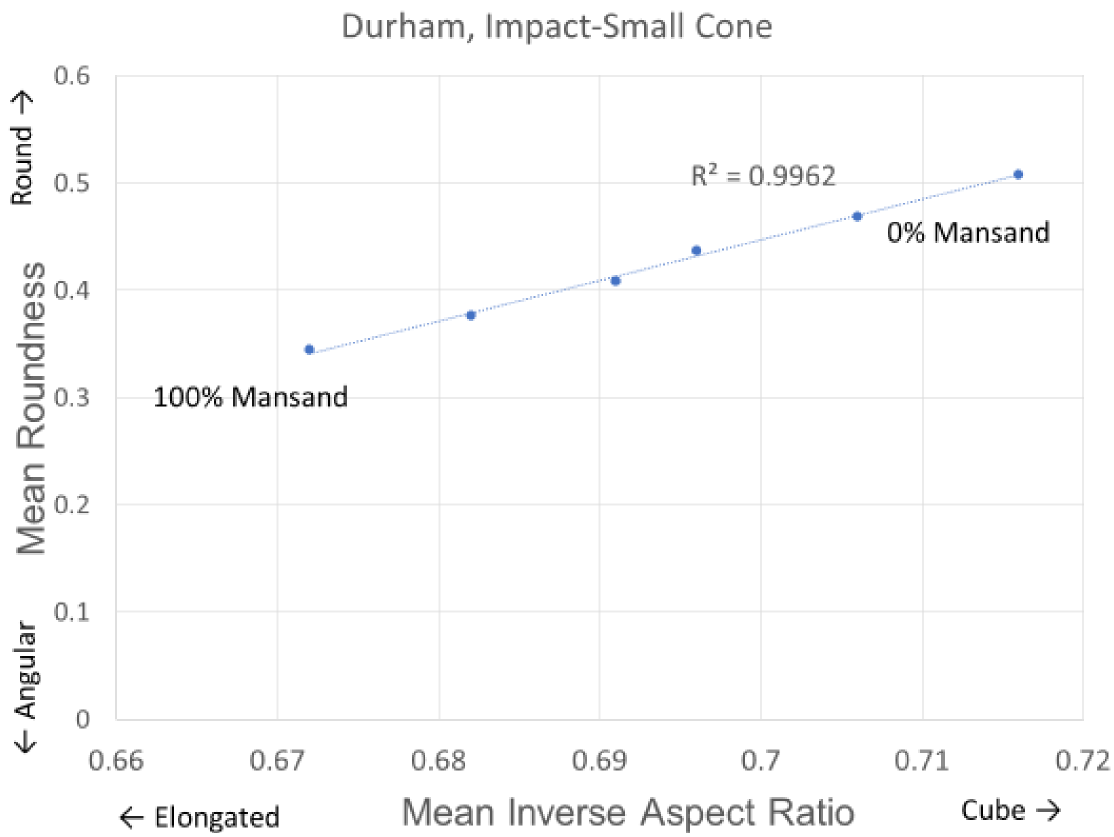


Figure 43. Calibration line using Durham Mine mansand produced by Impact-Small Cone crushers.

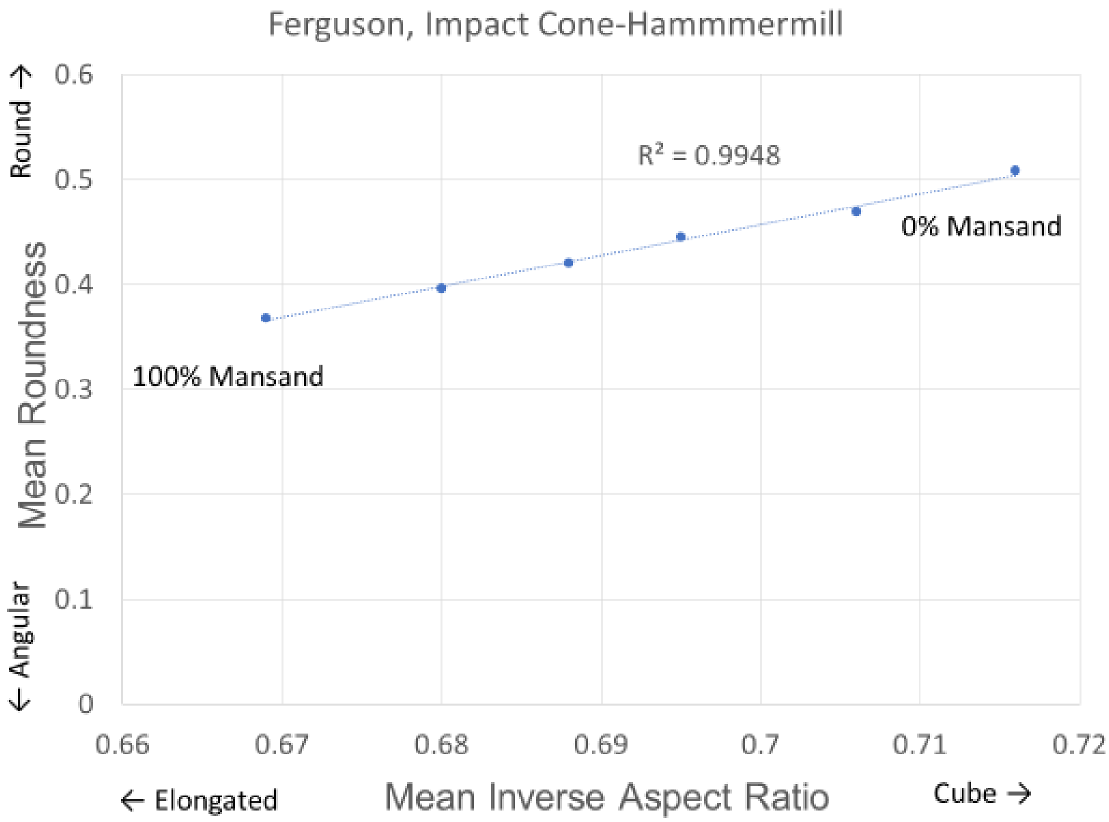


Figure 44. Calibration line using Ferguson mansand produced by Cone-Hammermill crushers.

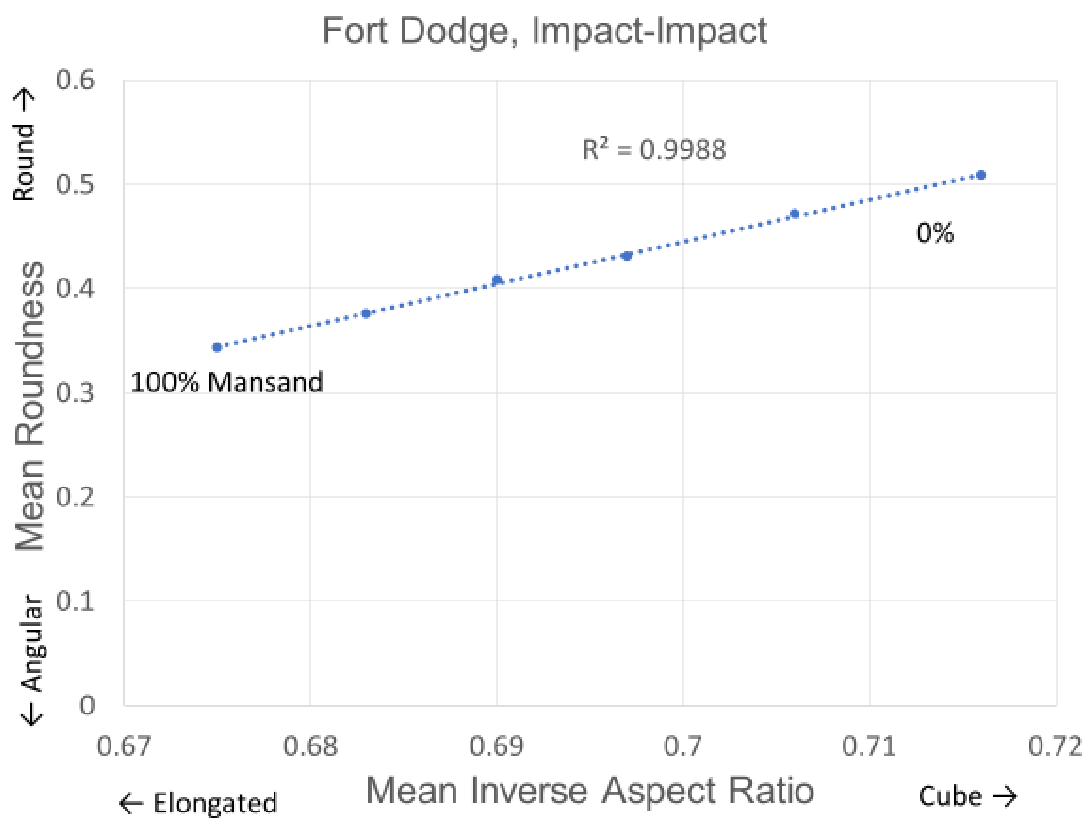


Figure 45. Calibration line using Fort Dodge mansand produced by Impact-Impact crushers.

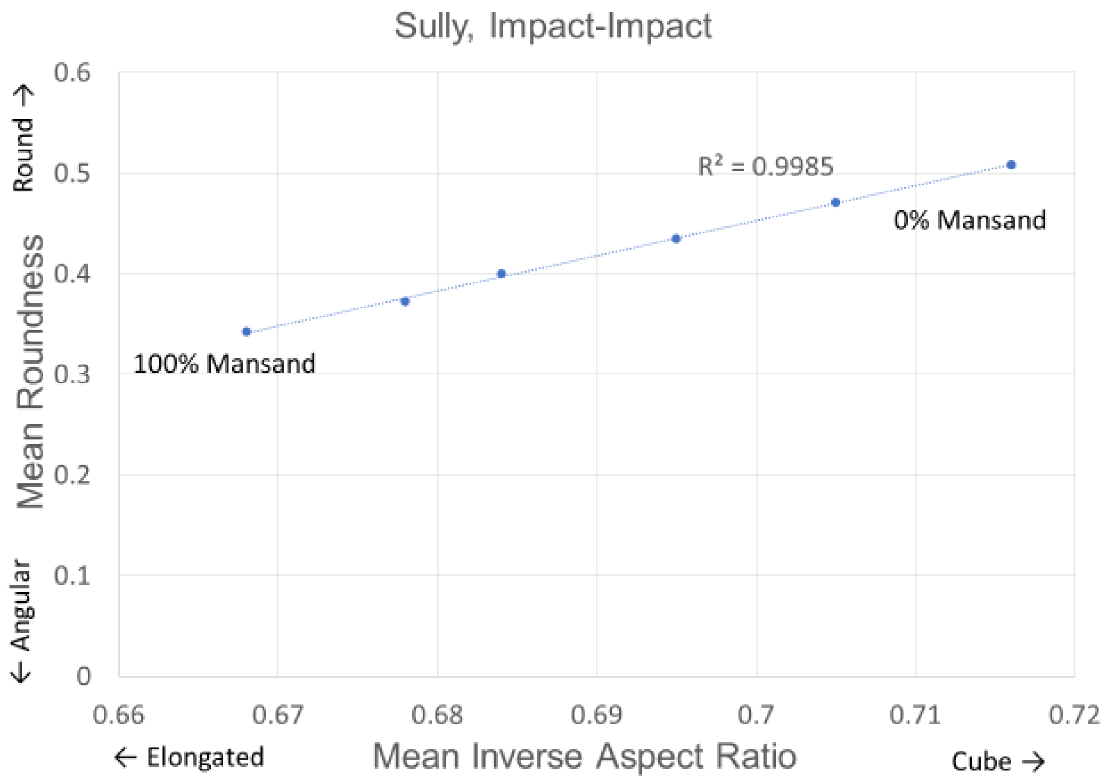


Figure 46. Calibration line using Sully Mine mansand produced by Impact-Impact crushers.

Appendix B

Use of the USGS Streamer Application to determine the Distance of a Sand Pit from the River or Stream Source for Camsizer Additional P4 Data Analyses

Use of the USGS Streamer Application to determine the Distance of a sand pit from the river or stream source for Camsizer P4 Data Analyses

Streamer is an online mapping application developed by the United State Geological Survey (USGS) for mapping downstream and upstream paths rivers and streams in the contiguous US plus Hawaii and Alaska.

This application can be found at: https://txpub.usgs.gov/DSS/streamer/web/. Figure A2-1 gives a short introduction on the home page. Figure A2-2 shows the Trace Downstream or Trace Upstream buttons to determine river miles of any stream or river in the United States. Point the curser on the location to determine nautical milage in either flow direction. To determine a "stretch" of downstream milage use a start point and another at the stopping point. Use the "Trace Report" button to show the milage and other river characteristics. Upstream and downstream examples are shown in Figure A2-3. Determine downstream mileage by subtraction of the start and stop locations. Downstream traces usually end in an ocean or the Gulf of Mexico.

It should be noted that the distance from the river source is a gross simplification of the distance a sediment has traveled. This is especially complicated when numerous tributaries and differences in landforms are involved.

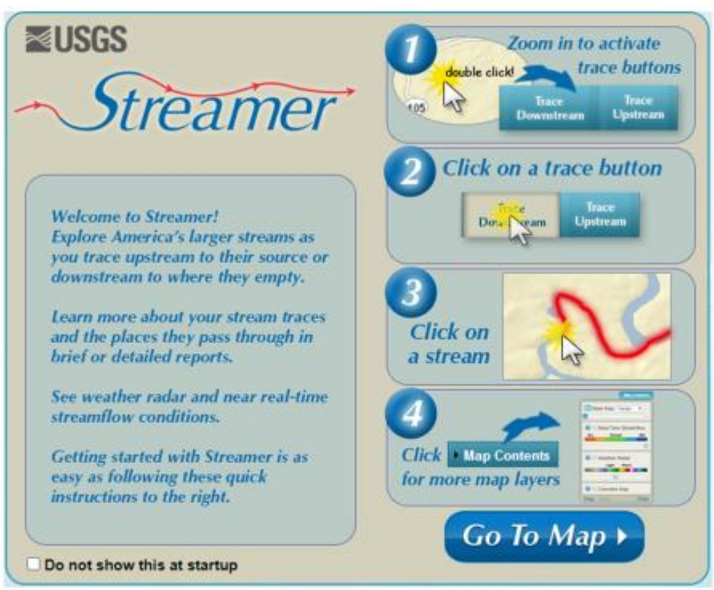


Figure A2-1. Introduction page for the USGS application.

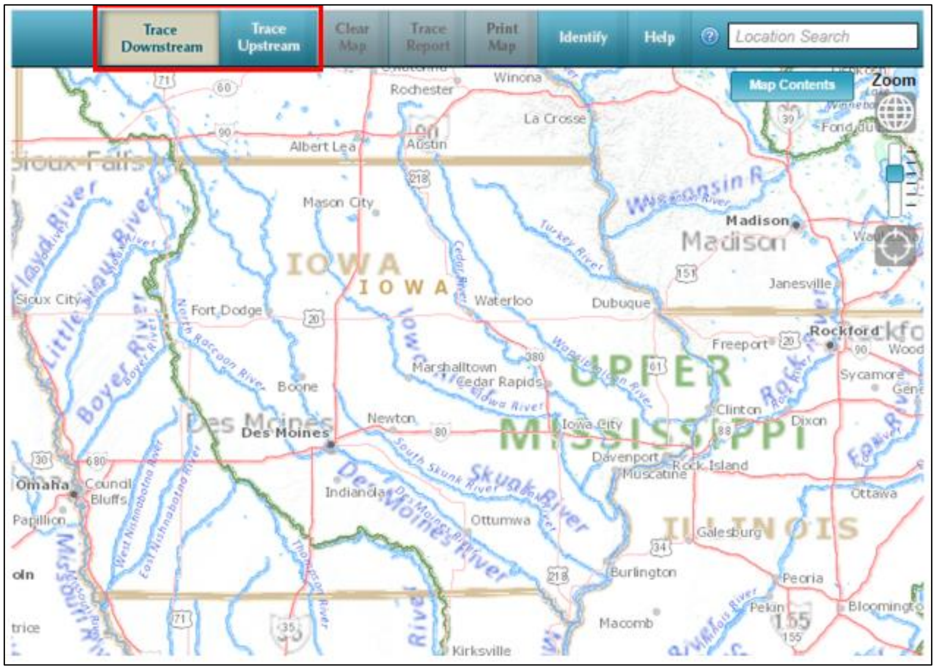


Figure A2-2. Use the Trace Downstream or Trace Upstream buttons to determine river miles of any stream or river in the United States. Point the curser on the location to determine nautical milage in either flow direction.

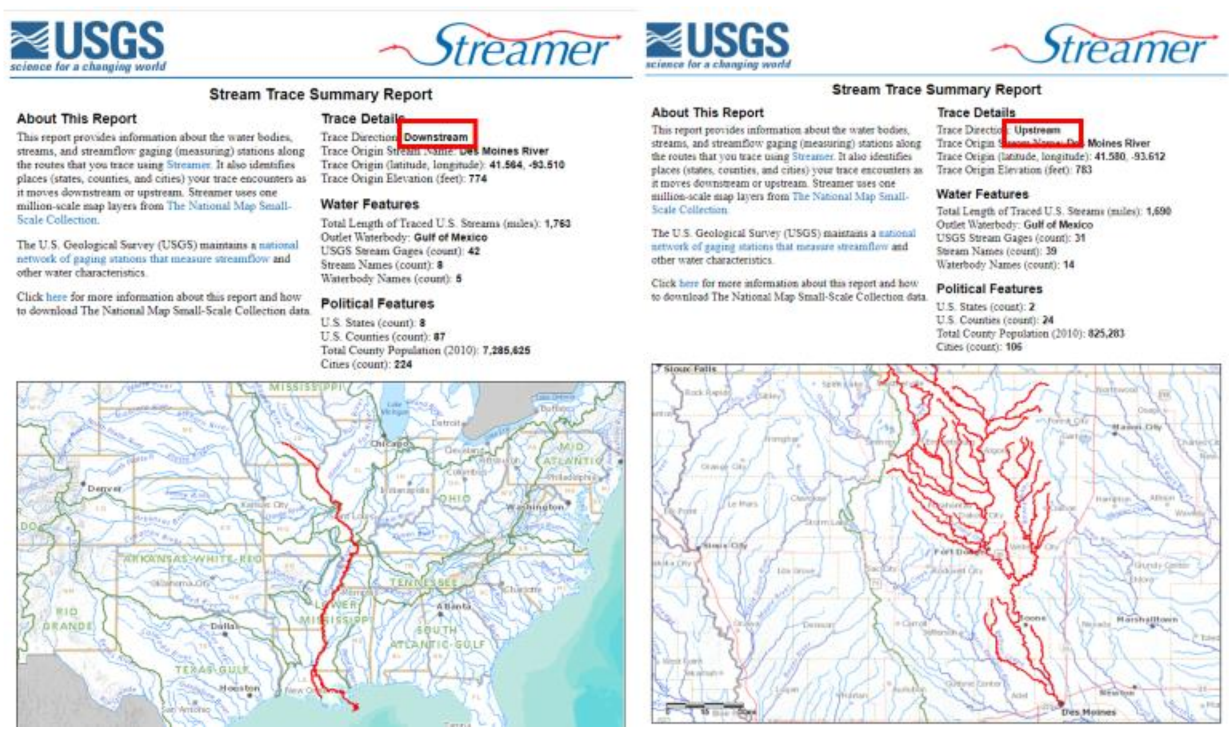


Figure A2-3. Downstream and Upstream mapping of river length and properties. Downstream length is determined by subtraction of starting point and stopping point.

Appendix C

CAMSIZER P4 S.O.P.

CAMSIZER P4 S.O.P.

Table of Contents

Startup

Goal: The overarching goal of the startup would be to ensure the CAMSIZER P4 powers up and loads properly and is ready for operation.

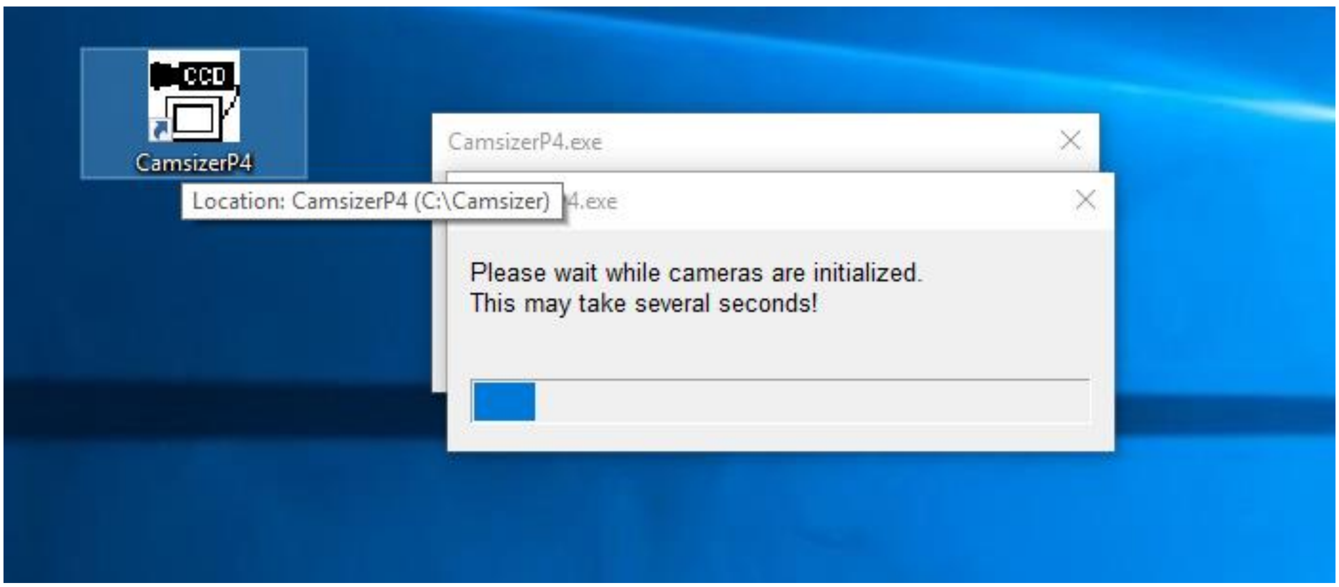
1. Turn on Computer and allow for boot up

2. Turn on Camsizer P4 so the blue light around the power button is illuminated

3. Log onto the computer (if necessary)

   When loaded into the windows boot up the CAMSIZER software by clicking on the CAMSIZER icon

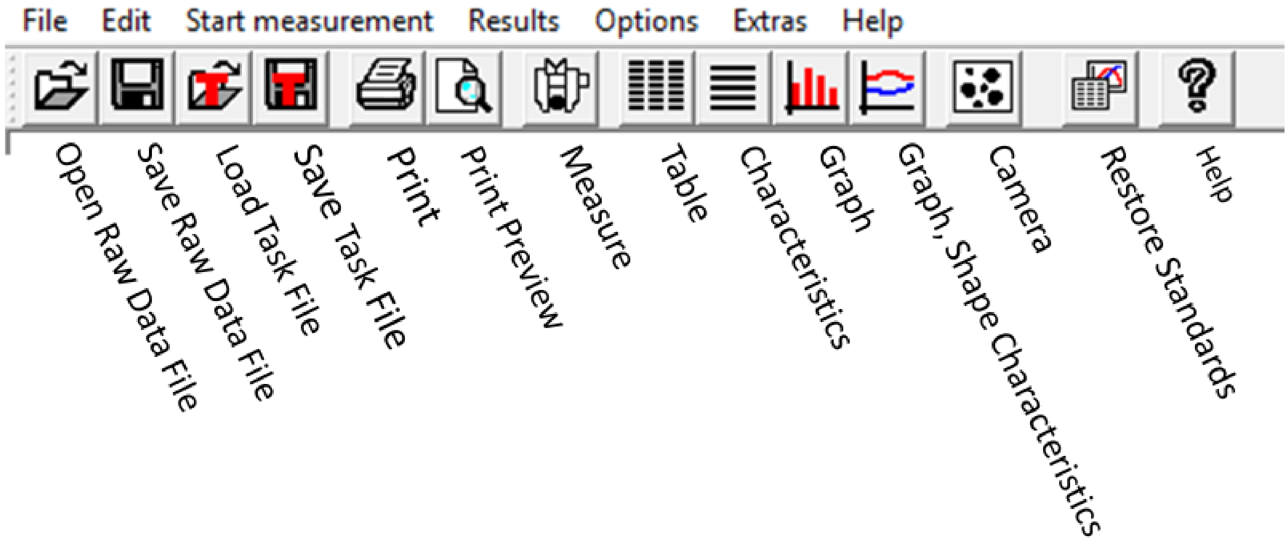
   The software can take up to 1 minute



Appendix C

General Information About the CAMSIZER P4 Software

1. Functions of the main tool ribbon.



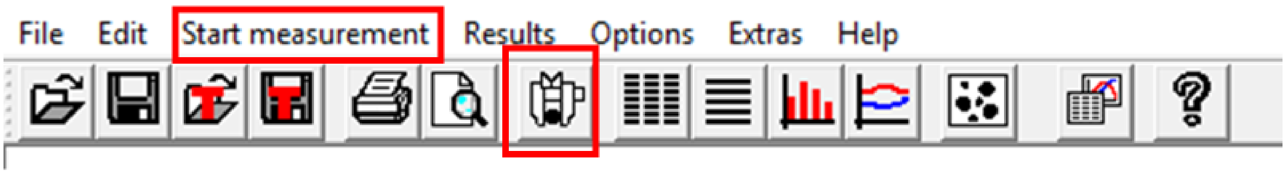
2. Functions of commonly used icons.

Icon	Menu function / description
	∣File∣Read comparison file∣
	∣Edit∣Copy∣
	∣File∣Print∣
	∣View∣Characteristics∣
	Scales the X and Y axis so that the complete measurement range is displayed
	Expands the measurement range in the direction of the X and Y axis
	Linear display of the X axis, linear display of the Y axis
	Logarithmic display of the X axis, linear display of the Y axis
	Logarithmic display of the X axis, logarithmic display of the Y axis
	Adds vertical grid lines
	Removes vertical grid lines
	Adds horizontal grid lines
	Removes horizontal grid lines
	∣View∣Activate/deactivate cross hairs∣
	∣View∣Hand tool∣
	∣Help∣

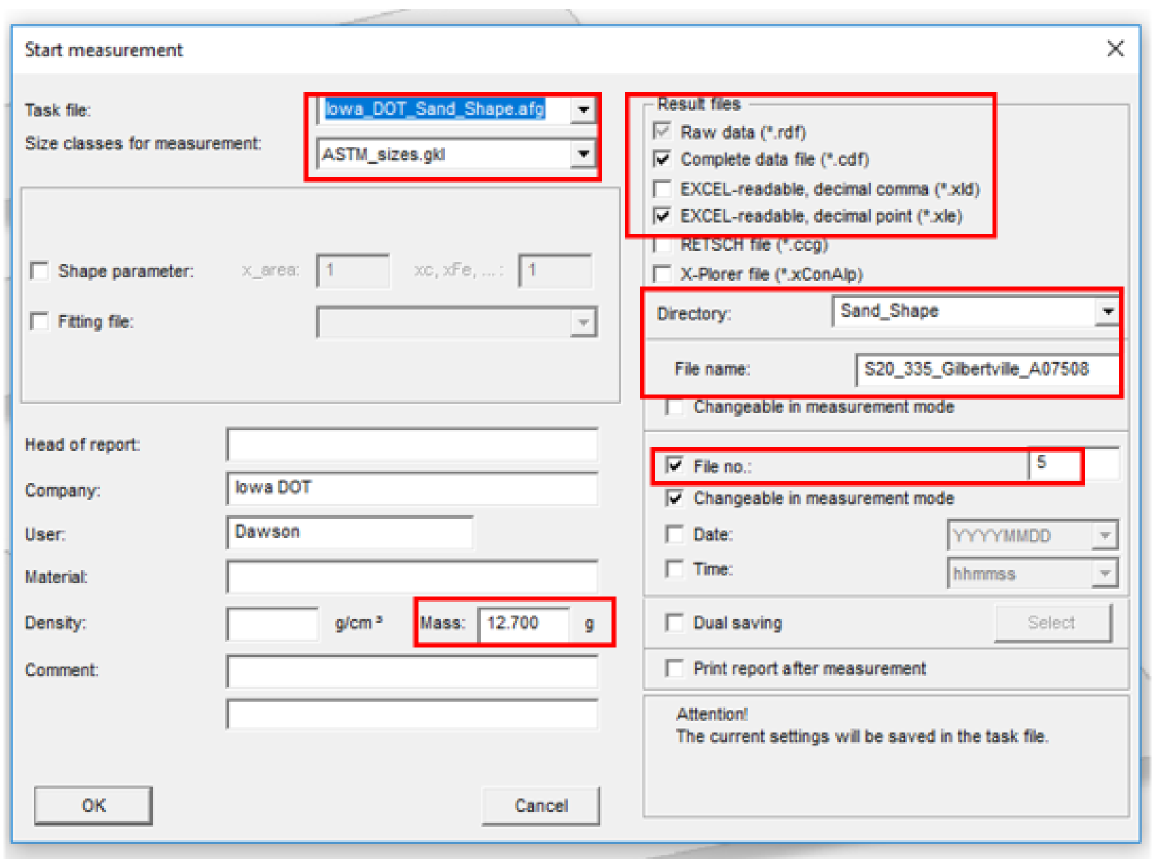
Running a Sample (Sample Measurement)

The sample measurement section is to outline the basic operation of the CAMSIZER for running measurements.

1. Select the "Start Measurement" or the Start Measurement button

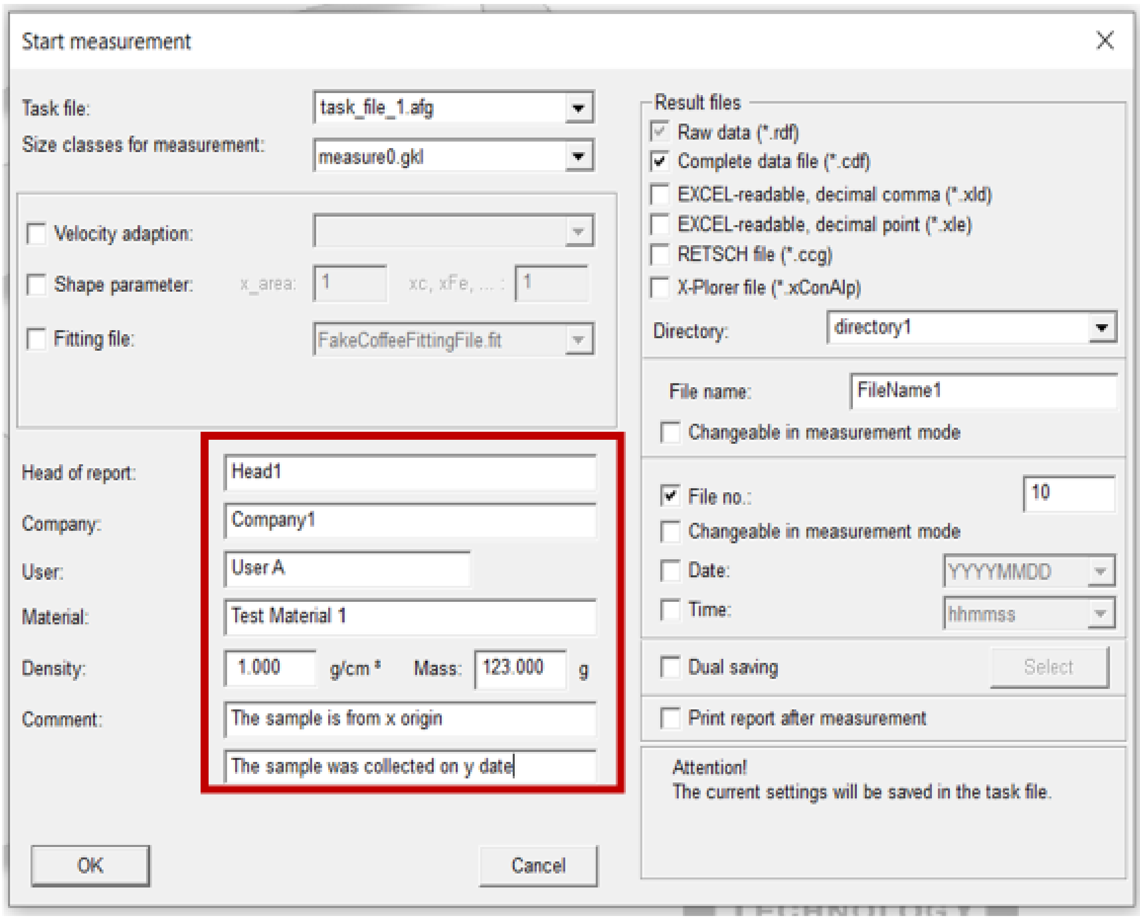


2. Select the task file that corresponds to the sample. ⚠ Note: Data files are stored: E:\Camsizer\CAMDAT\Sand_Shape

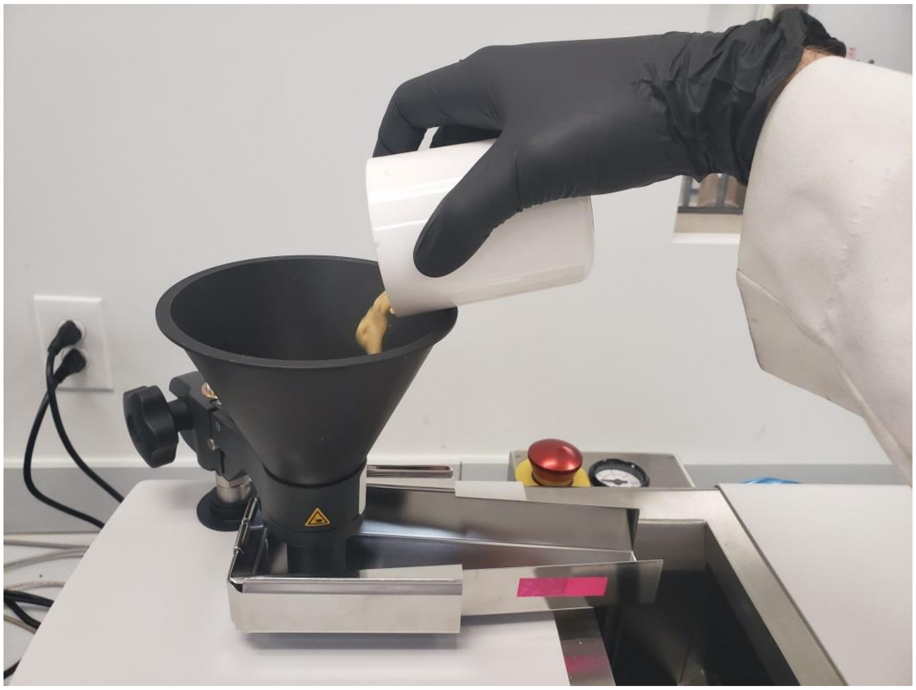


3. Choose Task file (step 2) and Size classes file.
4. Result files: choose Excel readable decimal point (xle). This file type can be read by Excel
5. Change the file name to correspond to the sample that is being tested. Such as: **Source Name_County_ANumbe_Lab Number**. Use under scores to separate information. Do not use (/ \ . -)
6. File no if running a sample multiple times.
7. Double check the directory and types of files that are being saved.

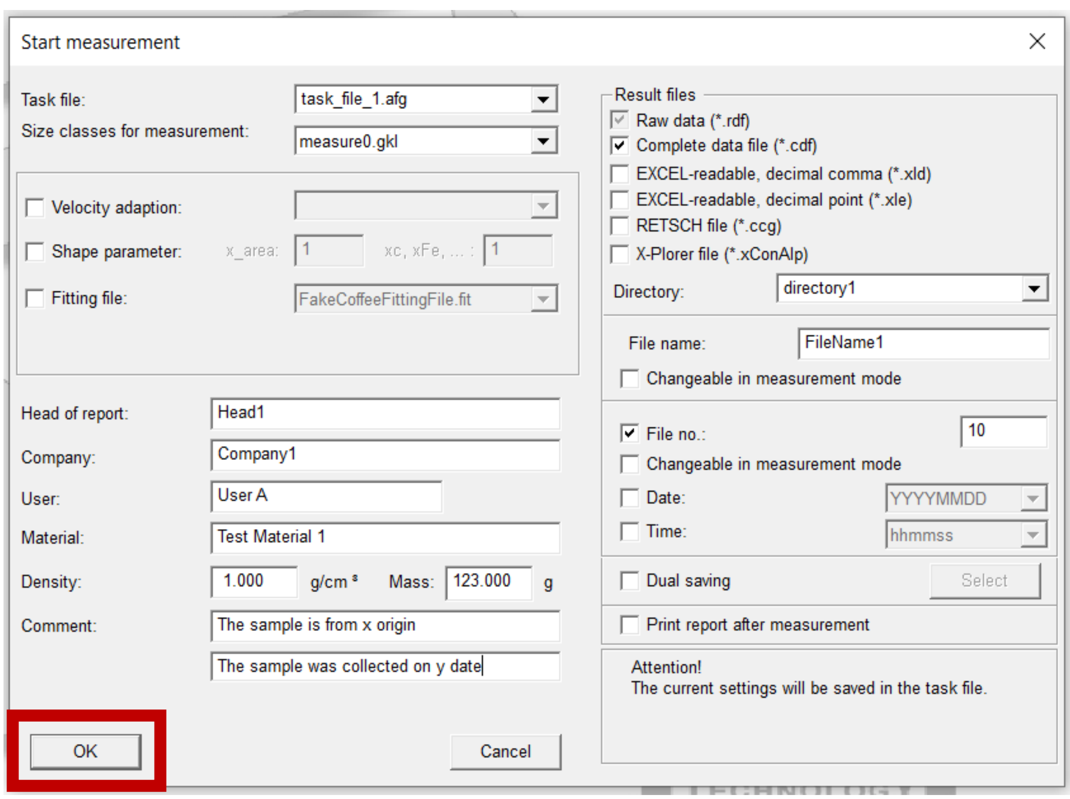
8. Change the sample specific data including the name of the material, operator, company, and any other information that is critical to record on the report file.



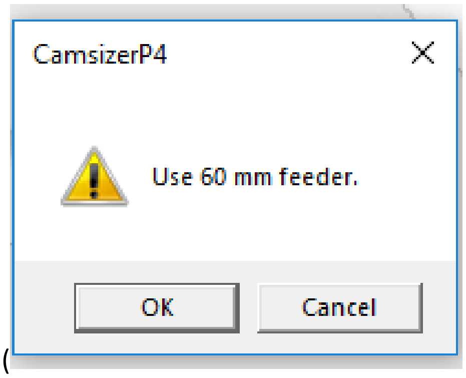
9. Next, load the sample into the funnel



10. After loading the sample into the funnel press "OK" This will initiate the run



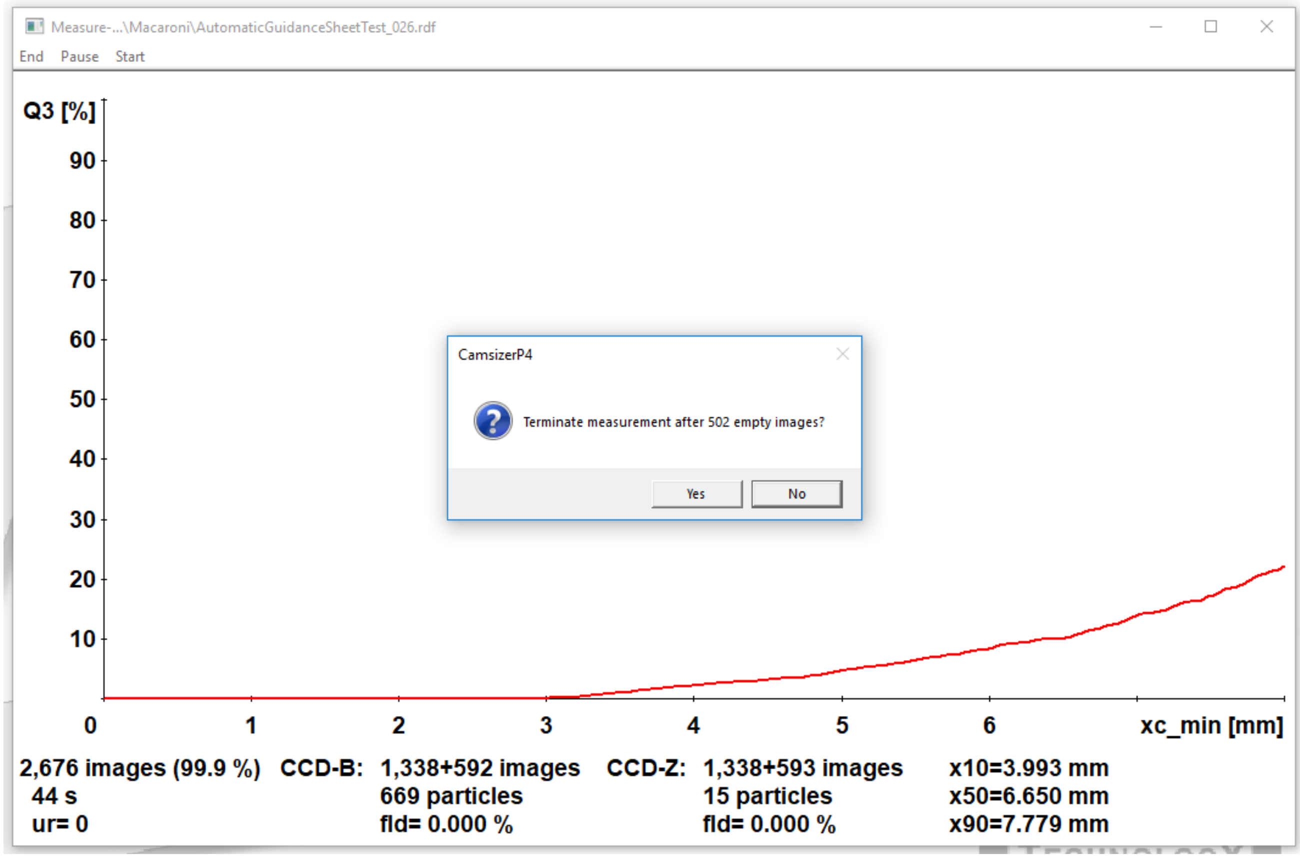
11. There may be prompts following pressing “OK” such as “Please insert guidance sheet”, “Please use XXmm funnel”, or “Please remove guidance sheet”. Follow these instructions if prompted.

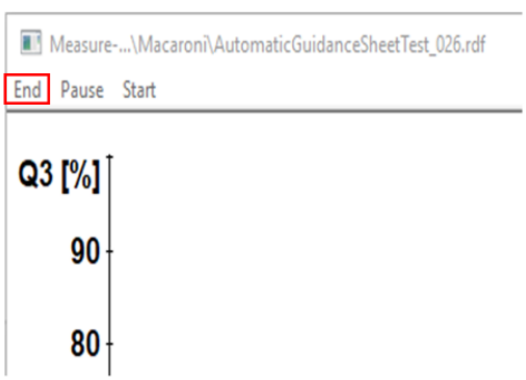


(

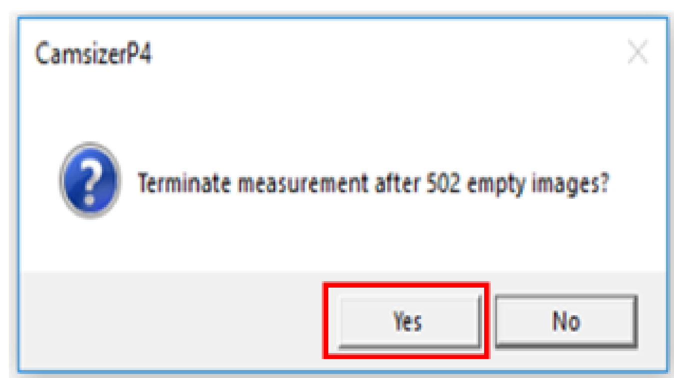
12. The measurement will now run. Following the completion of the run you will hear 3 beeps and will receive a prompt such as “Terminate after 500 empty images.” Check to ensure the funnel and feeder are clear of all debris. If clear, terminate the measurement. If the funnel and feeder are not clear, please continue to measurement and brush remaining sample into the drop shaft. Repeat step 9 until the funnel and feeder are clear of debris.

13. After particles stop passing in front of the LED screen you will see this message.

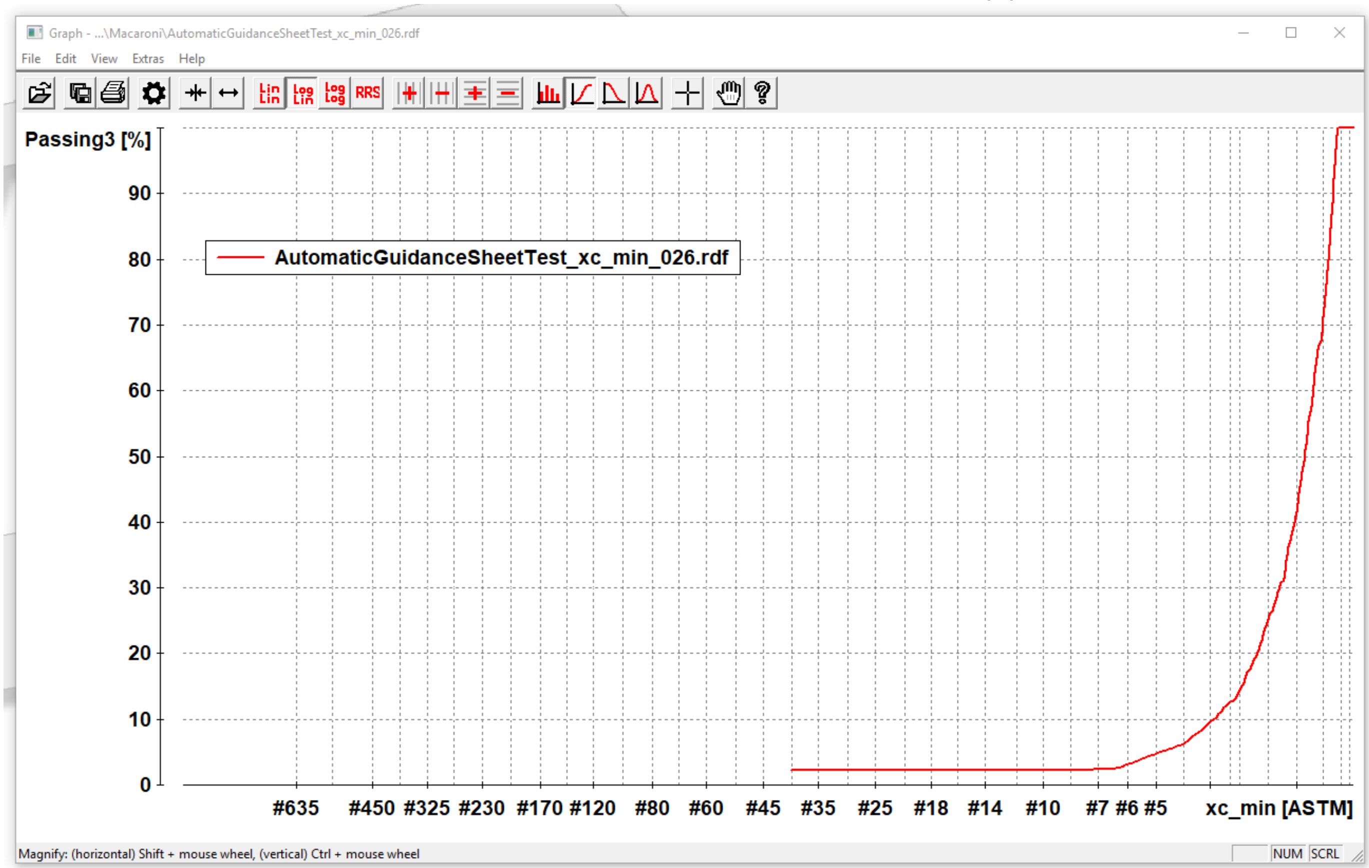




Or



14. You can terminate the measurements in one of two ways. The measurement is now complete.



15. After stopping the measurement, you will see a Graph. It will be % passing, % retained, or the frequency distribution (depending which graph type is selected).

Data Analysis

Data Analysis Help

⚠ For details see the **Retsch** Technology Manual – *Evaluation Software CAMSIZER P4* pages 20 to 144. An electronic copy is available using the CAMSIZER help found on the Tool Bar. 

General Data Analysis

Data analysis is broken down into 4 sections based on the tab being used.

Graph - To access the size graph data click the size graph button as seen below. For options in the size graph tab please proceed to the size graph tab section. 

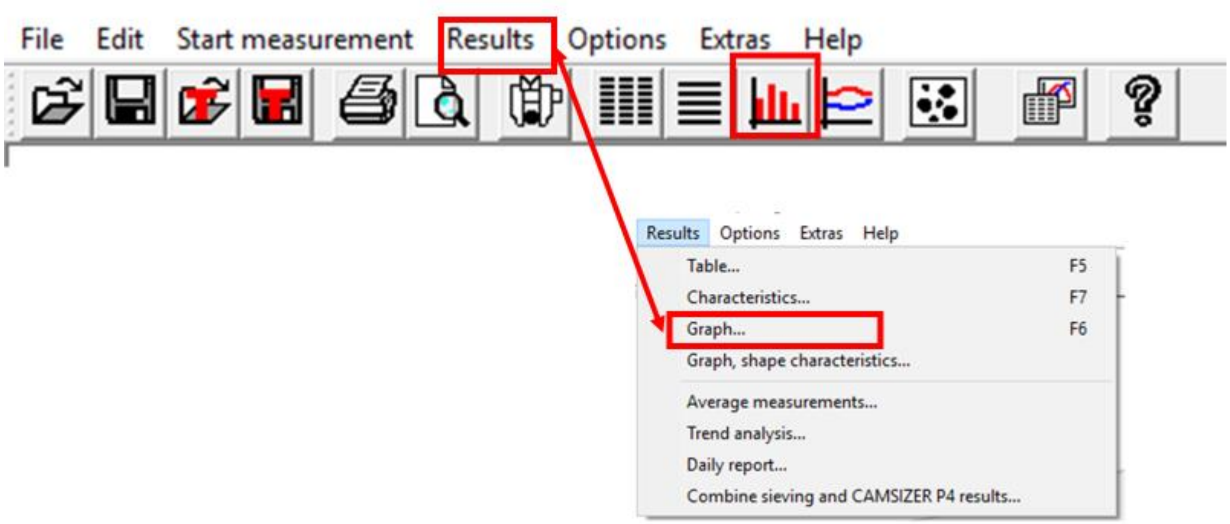
Shape - To access the shape graph data click the size graph button as seen below. For options in the shape graph tab please proceed to the size graph tab section. 

Table - To access the table tab data click the size graph button as seen below. For options in the table tab please proceed to the size graph tab section. 

Characteristics - To access the characteristics tab data click the size graph button as seen below. For options in the characteristics tab to the size graph tab section →View → Characteristics. 

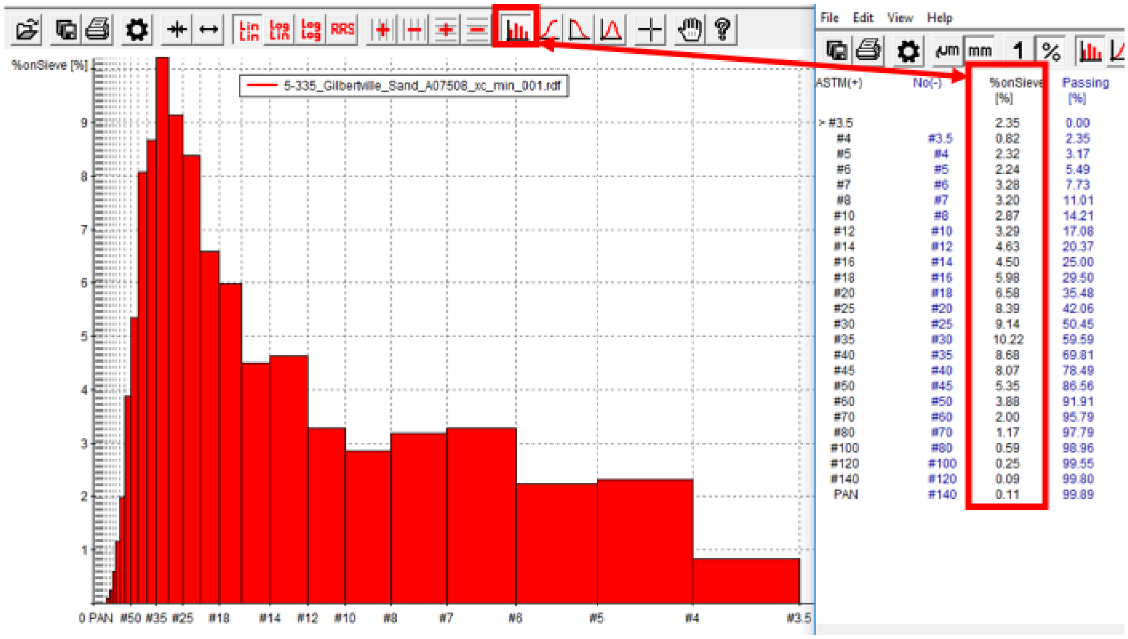
Graph Functions.

Graph Options



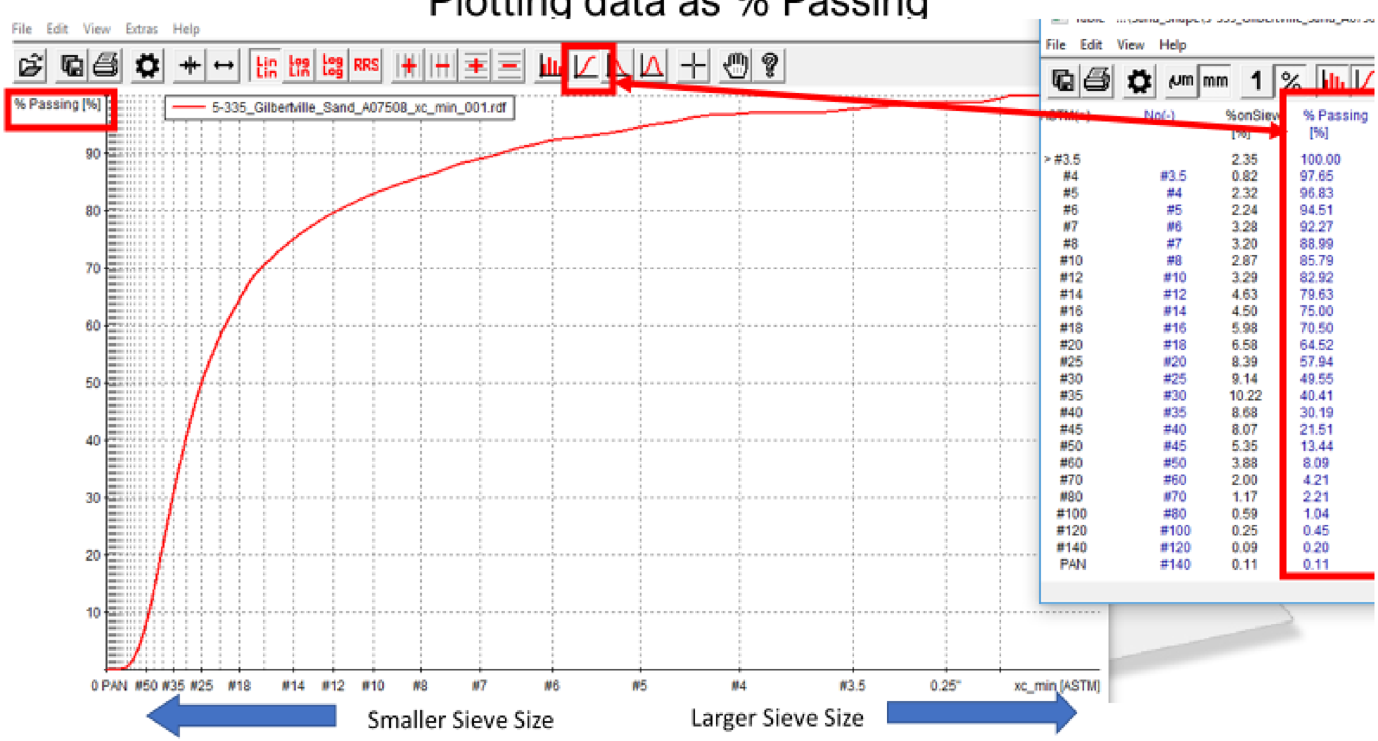
The graph options can be activated by either using the Results pull down the Graph or the Graph button.

Plotting data as % on Sieve

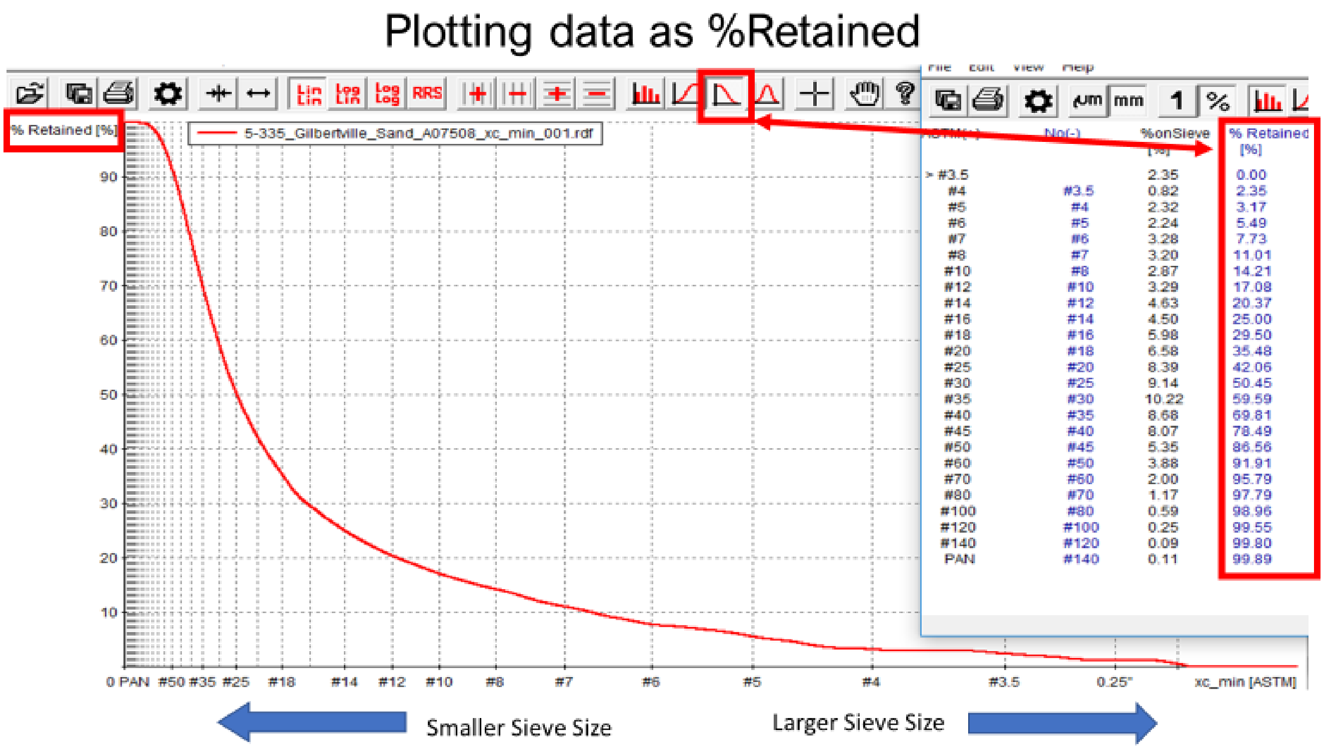


Use this button for percent on each sieve. Included in this figure are the data from Table view for % on each sieve.

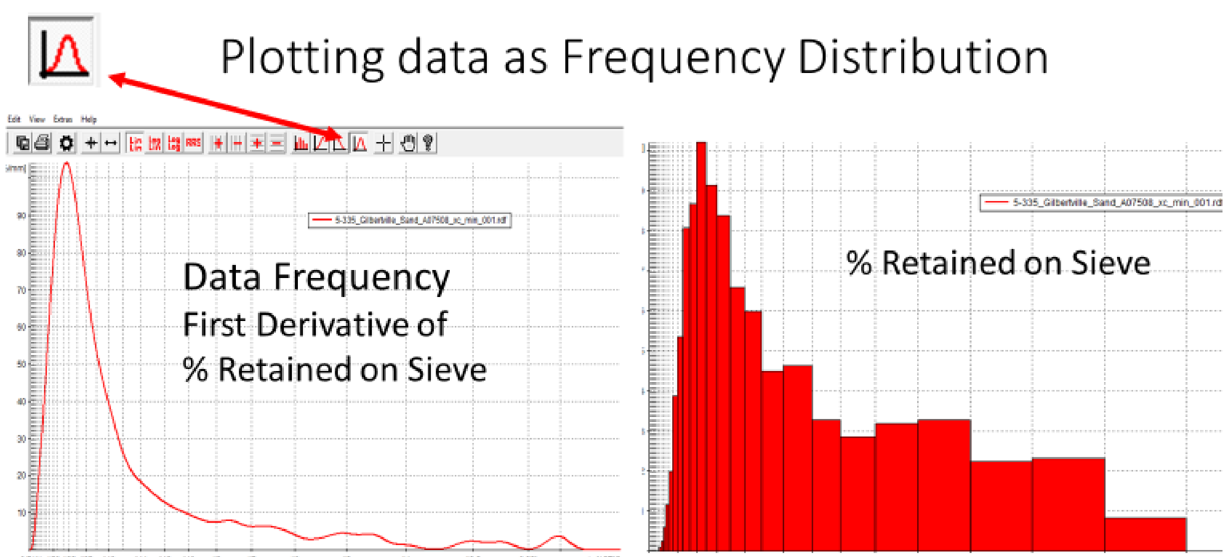
Plotting data as % Passing



Use this button to plot percent passing. Included in this figure are data from Table view for % passing.

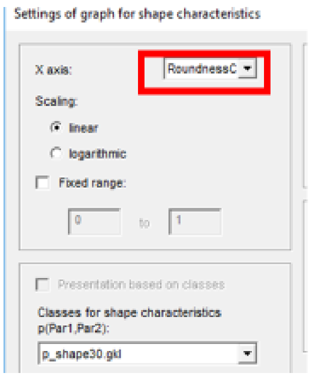


Use this button to plot % retained.

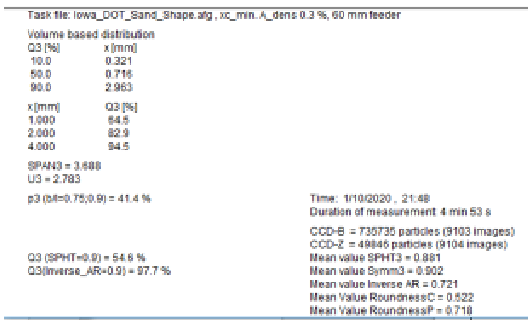


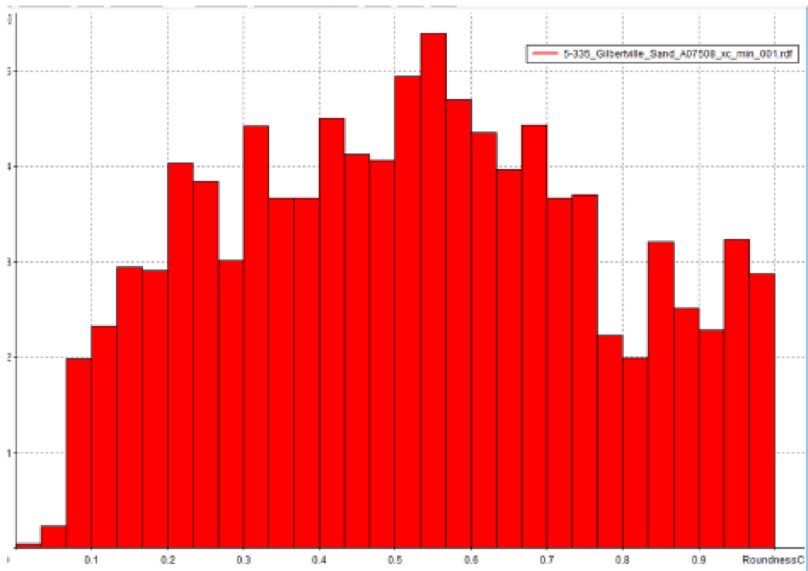
Use this button to plot data as Frequency Distribution. The frequency distribution is determined from the first derivative of the cumulative distribution (Figure to the right, and retained on sieves to the left).

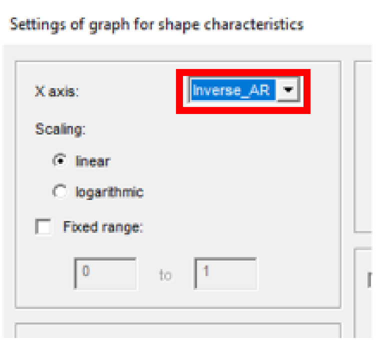
Shape Options



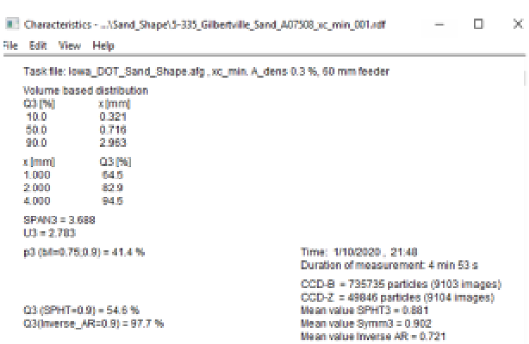
Plotting data as Roundness-C (Circumference)

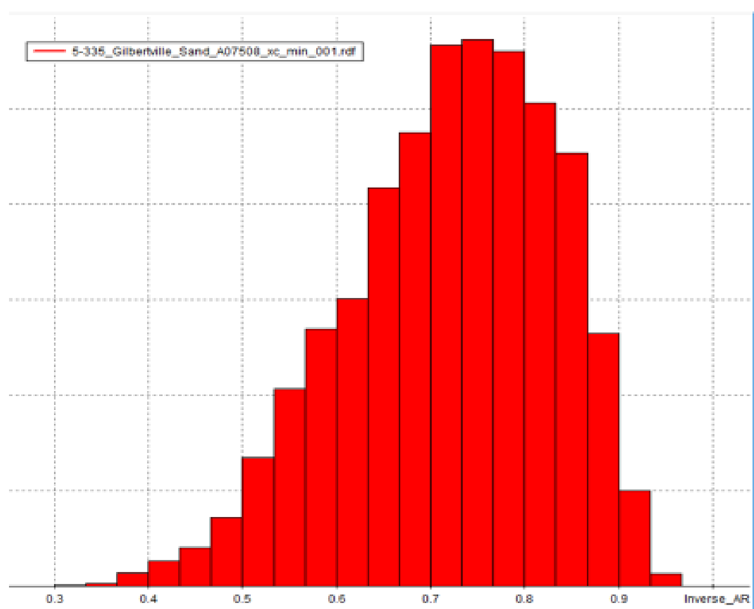




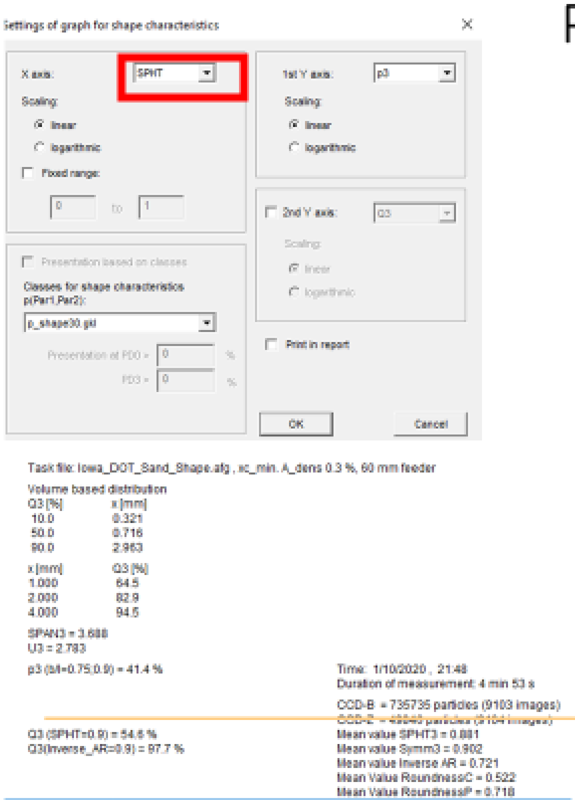


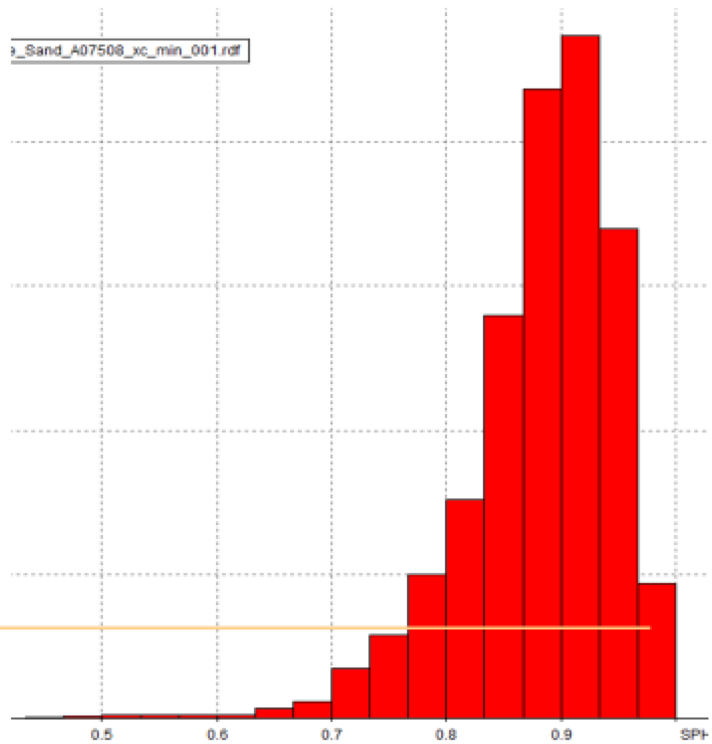
Plotting data as Inverse Aspect Ratio





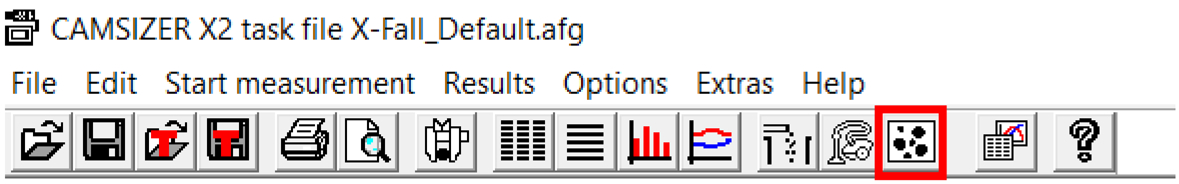
Plotting data as Sphericity



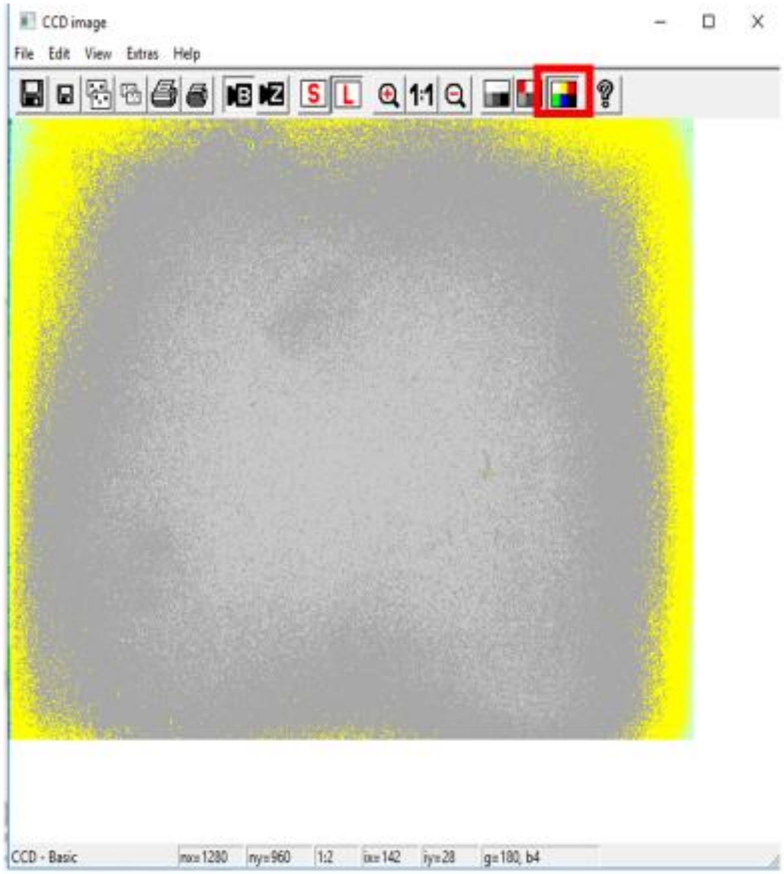


CAMSIZER Cleaning

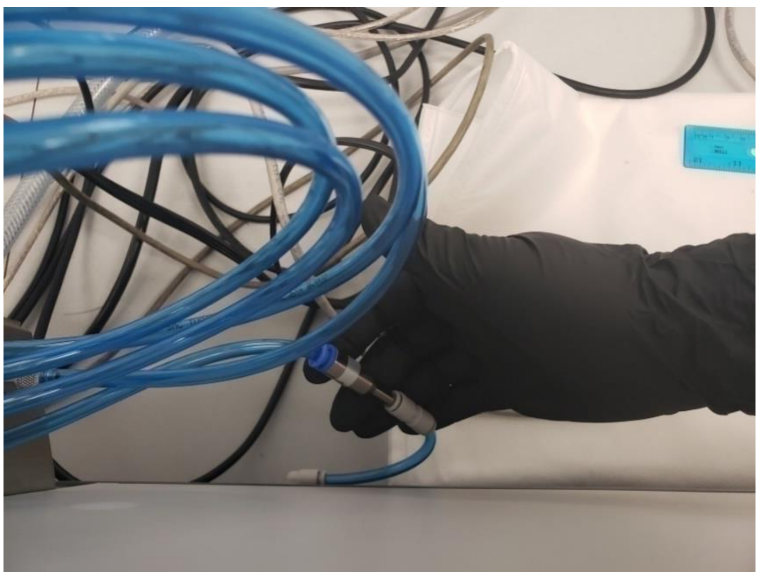
1. General CAMSIZER cleaning
    a. A general cleaning of the surfaces, dropshaft, and collection bin should be completed weekly to quarterly depending on:
        i. The type of materials being tested and their properties (adhesion, size, etc.)
        ii. The frequency of CAMSIZER use
2. Camera screen cleaning
    a. Open up camera screen



    b. Turn on the “colored” view option to identify if there are any particles in the drop shaft



c. Clean the drop shaft by blowing compressed air across the screens.
   i. Compressed air can be accessed via the blue nozzzel on the back of the P4 (as seen below)



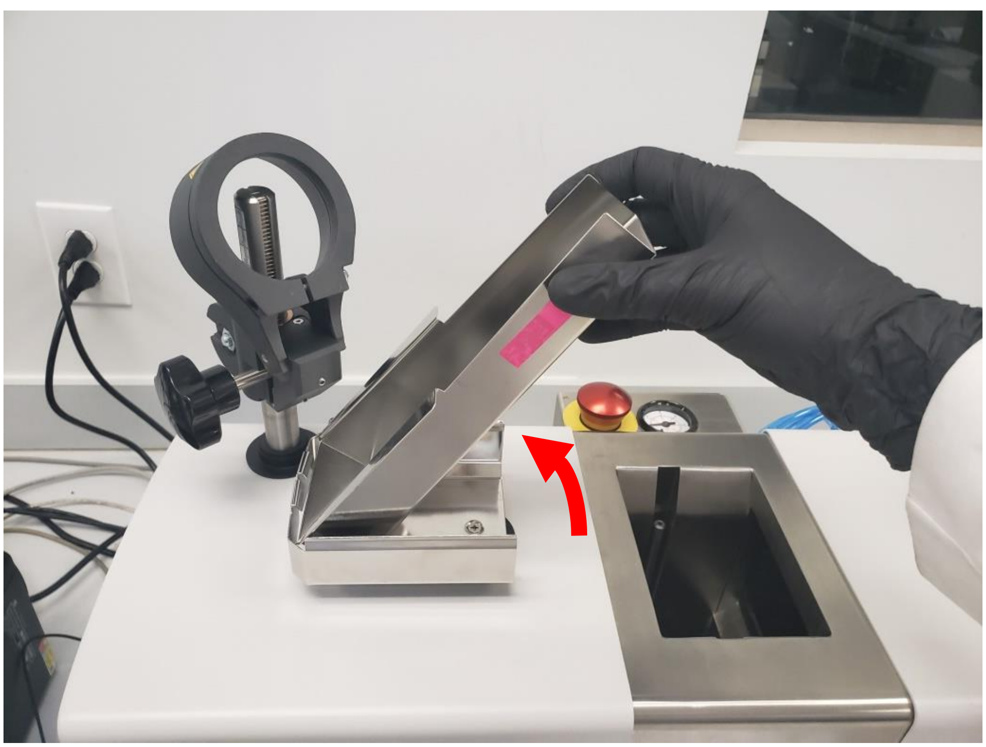
ii. Ensure that the light source (left) and the protective glass screen (right) are both cleaned

d. If the compressed air fails to clean the surface, wipe the screens with a kimwipe with repeated single directional passes. Ensure to clean both the light source (left) and the protective glass screen (right).

e. If dry wiping fails to clean the surface, use a solution such as Isopropanol to clean the screens. Ensure the passing is still single direction. Extra care needs to be taken to ensure there are no steak marks from the cleaning agent.

3. Vibratory feeder & funnel cleaning
   a. Remove the funnel by twisting it out of the funnel holder

   b. Remove the feeder by popping it up out of the feeder holder

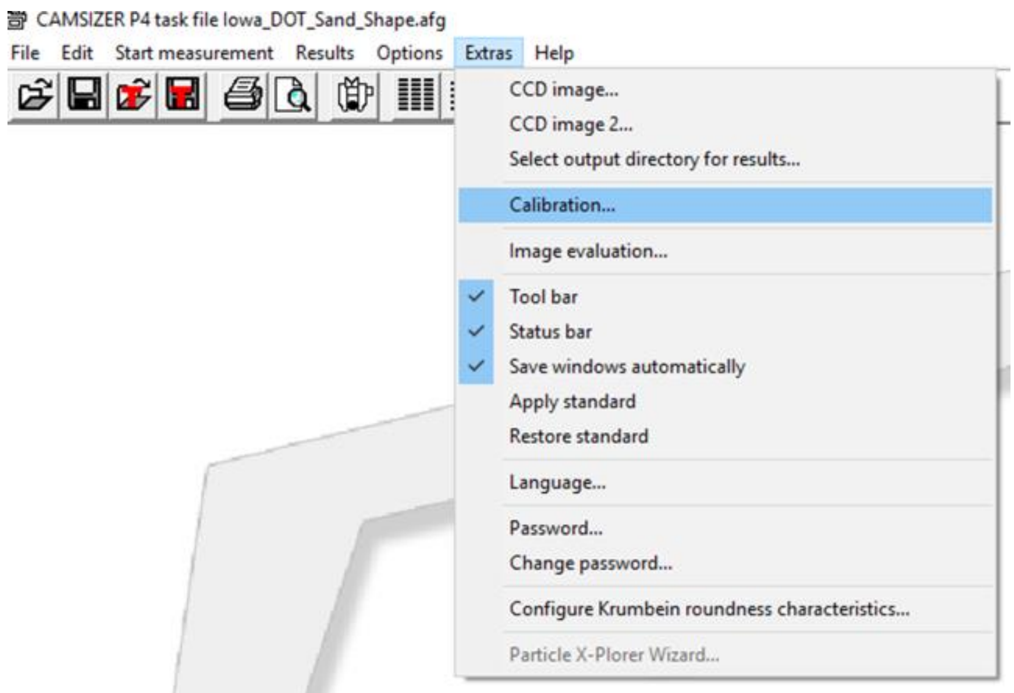


See page 13 for detailed cleaning instructions.

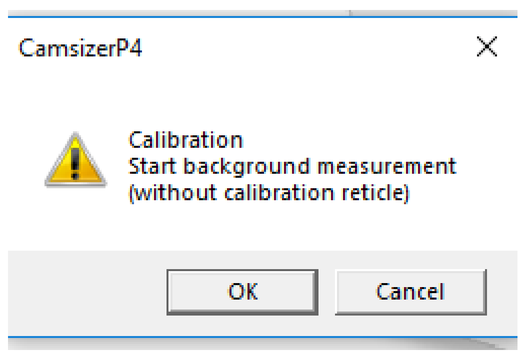
c. Clean both the funnel and feeder with compressed air
d. If cleaning with compressed air is inadequate, clean the surface using a kimwipe
e. If dry kimwipe cleaning fails to clean the surface, clean the feeder and funnel using isopropanol or an equivalent solution and kimwipes
    i. Solution cleaning is recommended at regular interveals to ensure funnel and feeder are clear of contaminations. Weekly to quarterly cleanings are recommended depending on:
        1. The type of materials being tested
        2. The variation of the materials being tested
        3. The frequency of use of the CAMSIZER

4. General CAMSIZER cleaning
    a. As with the vibratory feeder and the funnel a general cleaning of the surfaces, dropshaft, and collection bin should be completed weekly to quarterly depending on:
        i. The type of materials being tested and their properties (adhesion, size, etc.)
        ii. The frequency of CAMSIZER use
    b. The funnel and sample return holder should be cleaned with a dry brush after every sample measurement.

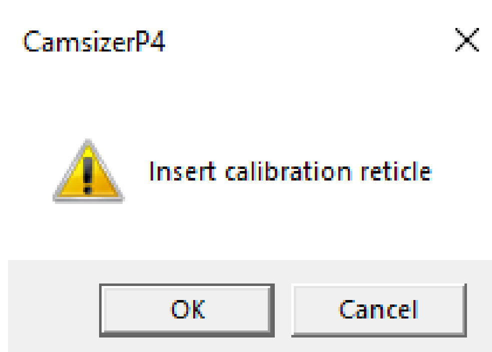
Calibration



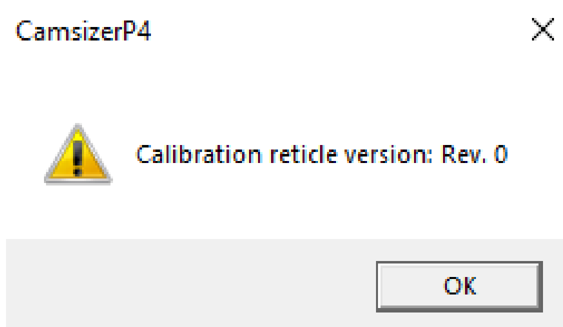
1. Extras → Calibration



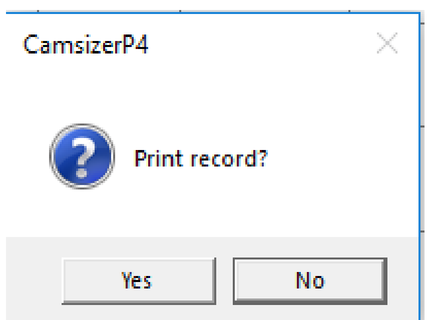
2. OK to background measurement without calibration reticle.



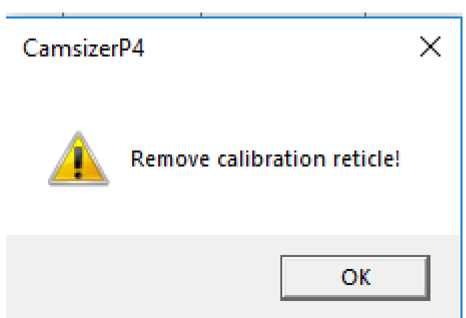
3. Insert calibration reticle when prompted. (Rails may have to be removed from the CAMSIZER before insertion.)



4. Confirm the insertion of the calibration reticle with [OK].



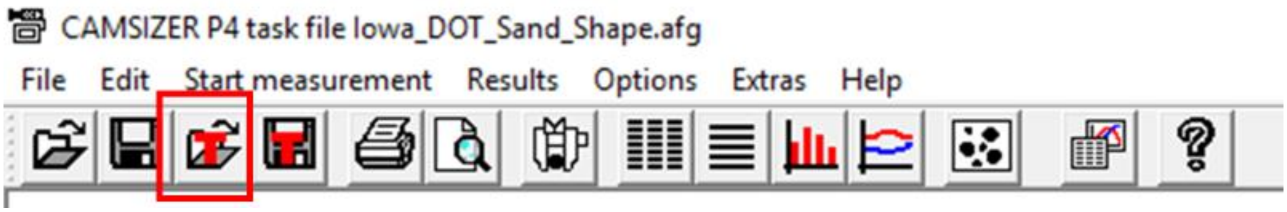
5. Print record

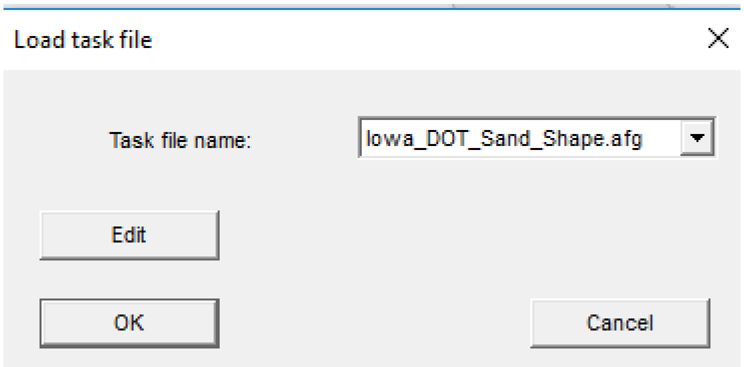


6. Remove calibration reticle when prompted.

Adding Shape Characteristics

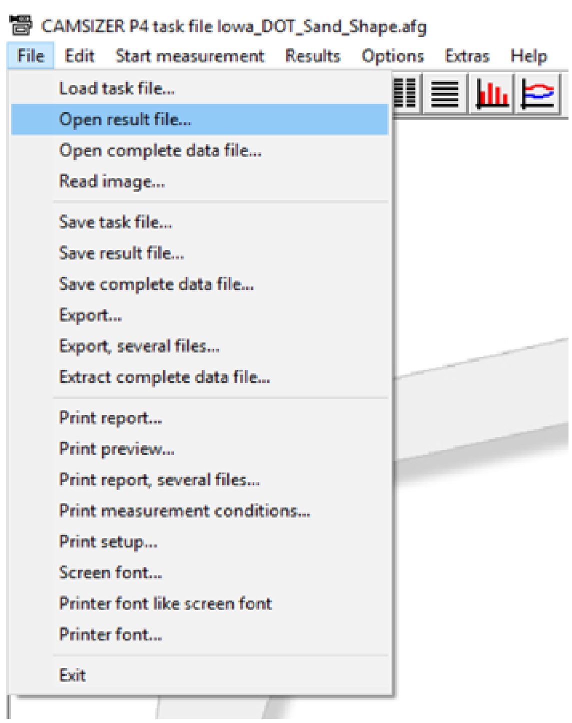
Make sure a Task File is loaded

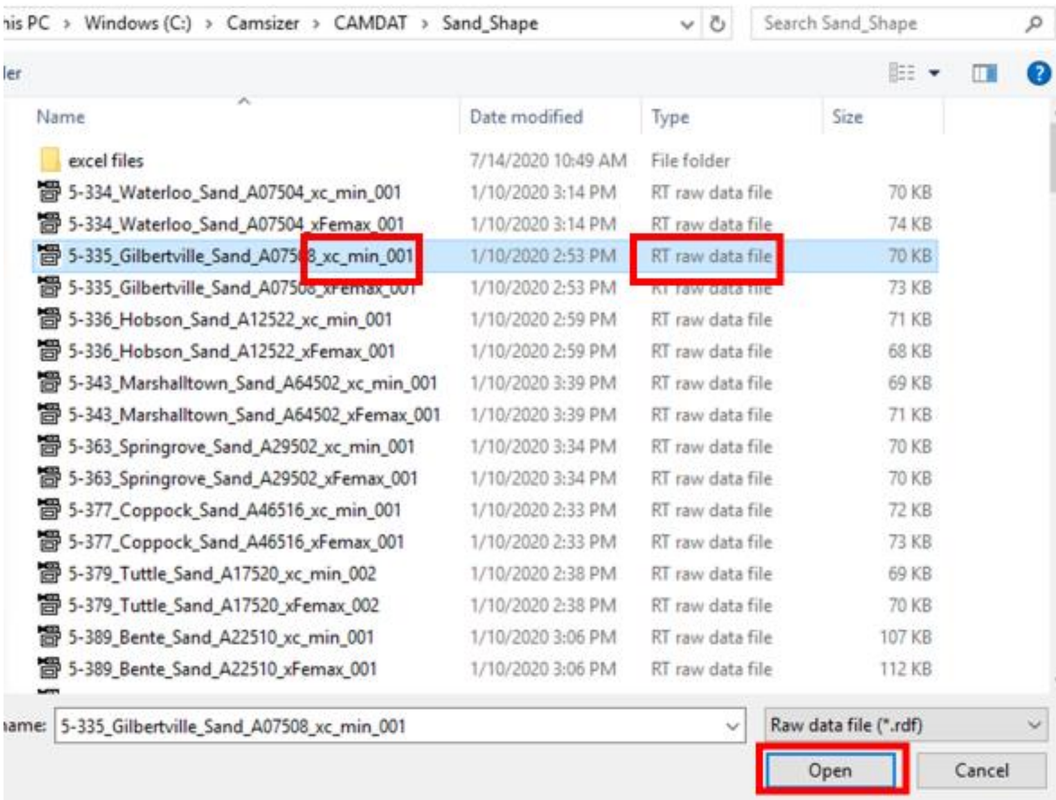


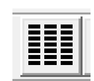


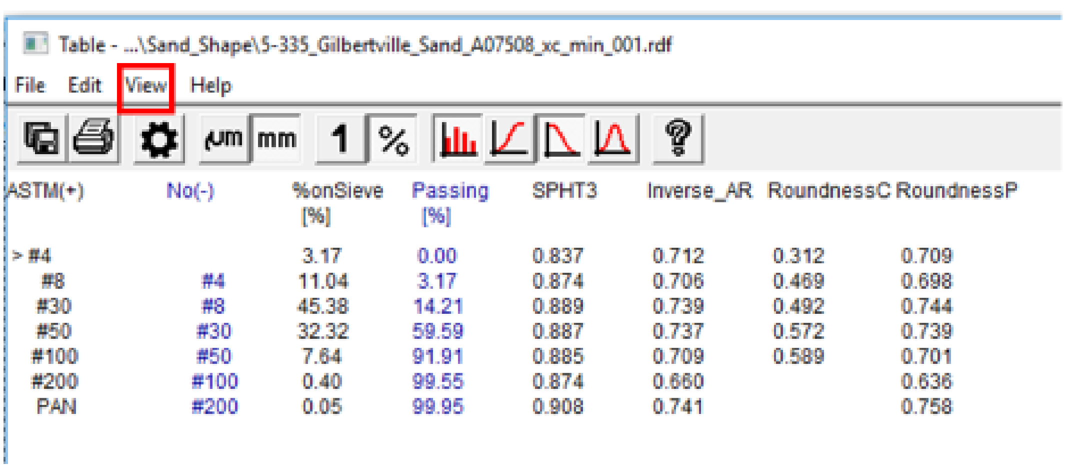
Load a Raw Data File

File → Open result file → Select a xc_min_(some file name).rdf file from your data → OK



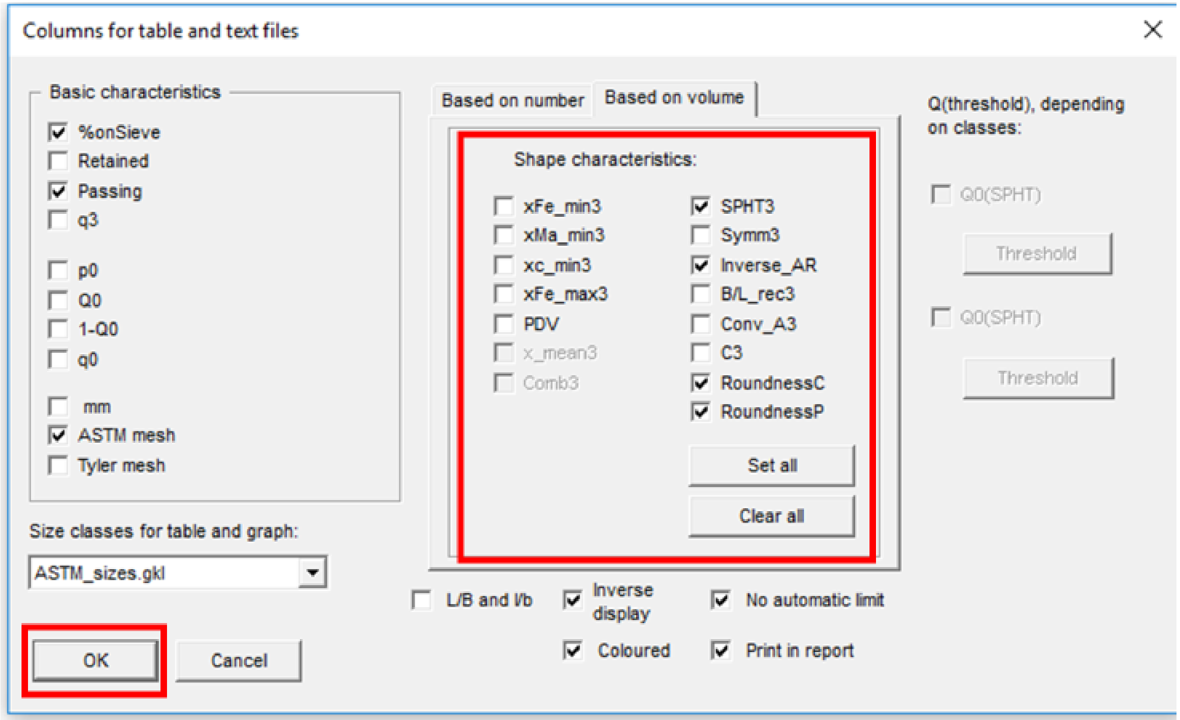


From the Results tab on the main toolbar select Results → Table or use  the Table Button.



ASTM(+)	No(-)	%onSieve [%]	Passing [%]	SPHT3	Inverse_AR	RoundnessC	RoundnessP
> #4		3.17	0.00	0.837	0.712	0.312	0.709
#8	#4	11.04	3.17	0.874	0.706	0.469	0.698
#30	#8	45.38	14.21	0.889	0.739	0.492	0.744
#50	#30	32.32	59.59	0.887	0.737	0.572	0.739
#100	#50	7.64	91.91	0.885	0.709	0.589	0.701
#200	#100	0.40	99.55	0.874	0.660		0.636
PAN	#200	0.05	99.95	0.908	0.741		0.758

From the Table toolbar select View → Characteristics

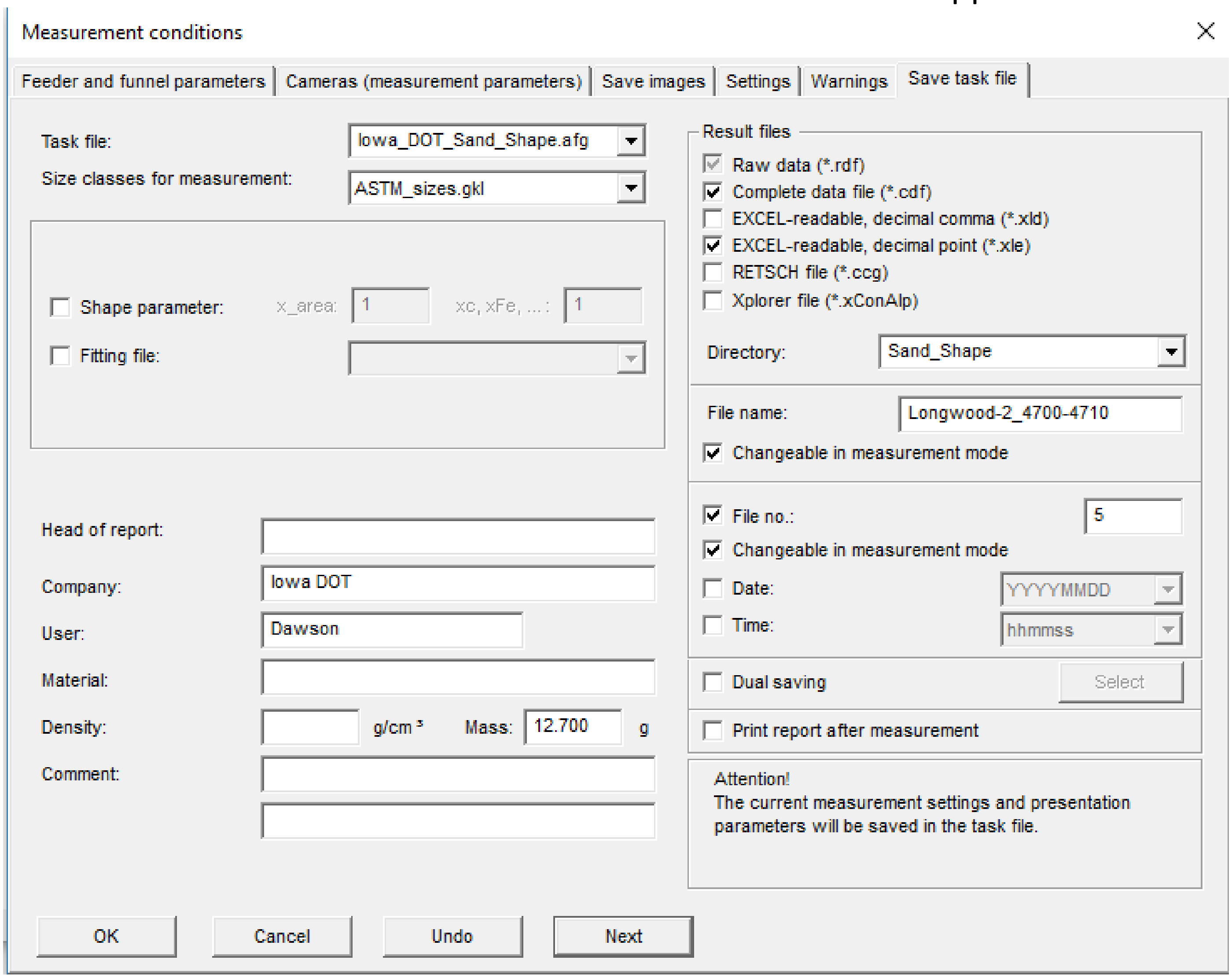


Select the shape value you want (there is a limit of seven (7) including Basic characteristics)

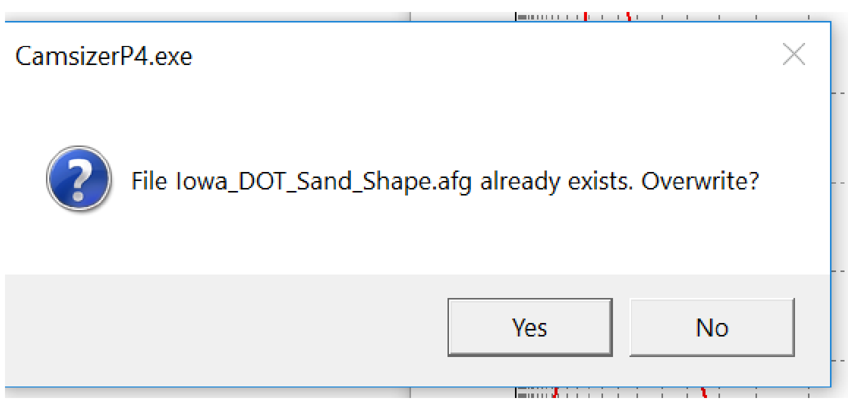
Click OK

Then Save Task using the "Save Task" button 

Save task file



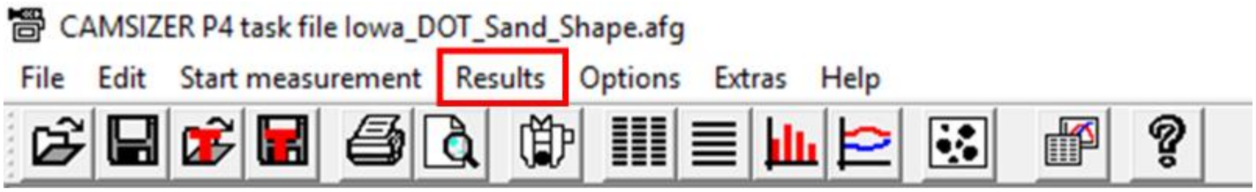
Click OK. It will ask you to Overwrite.



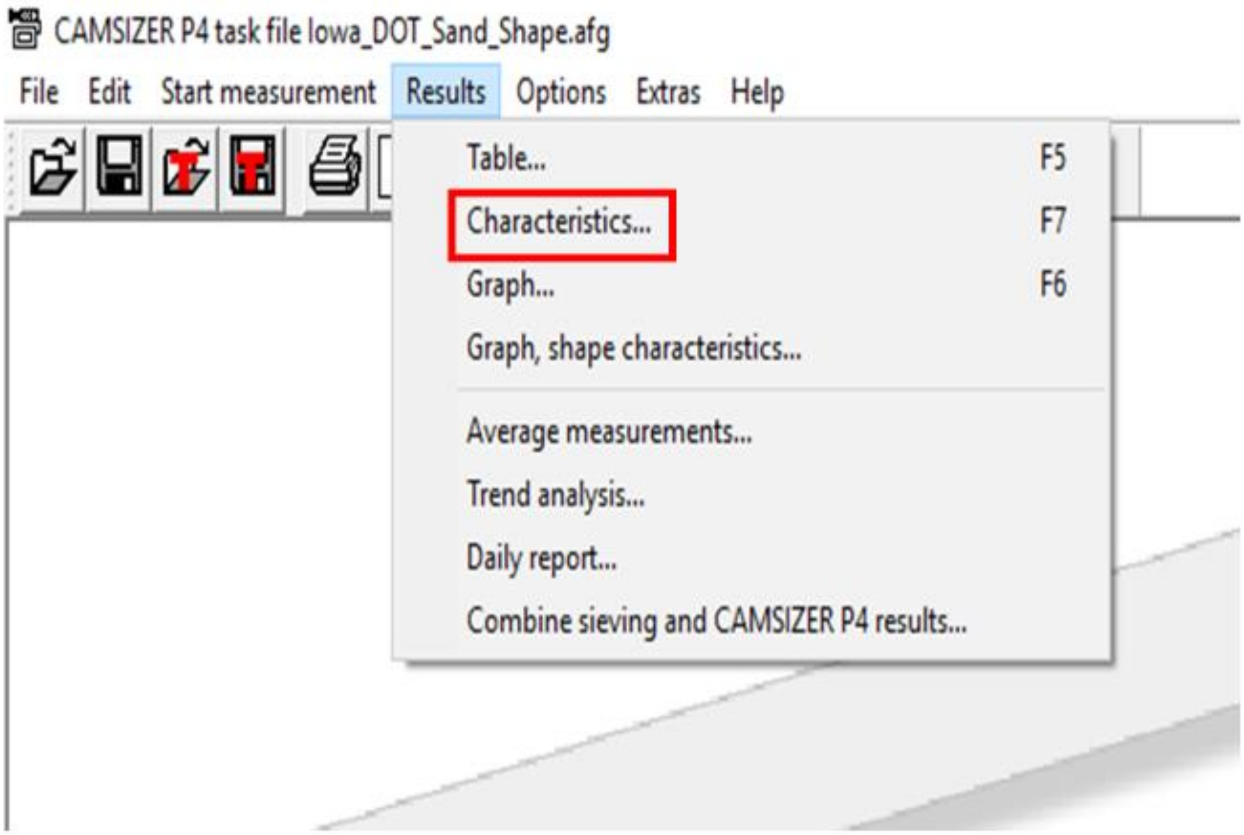
Say yes.

Adding Mean Values to a Table

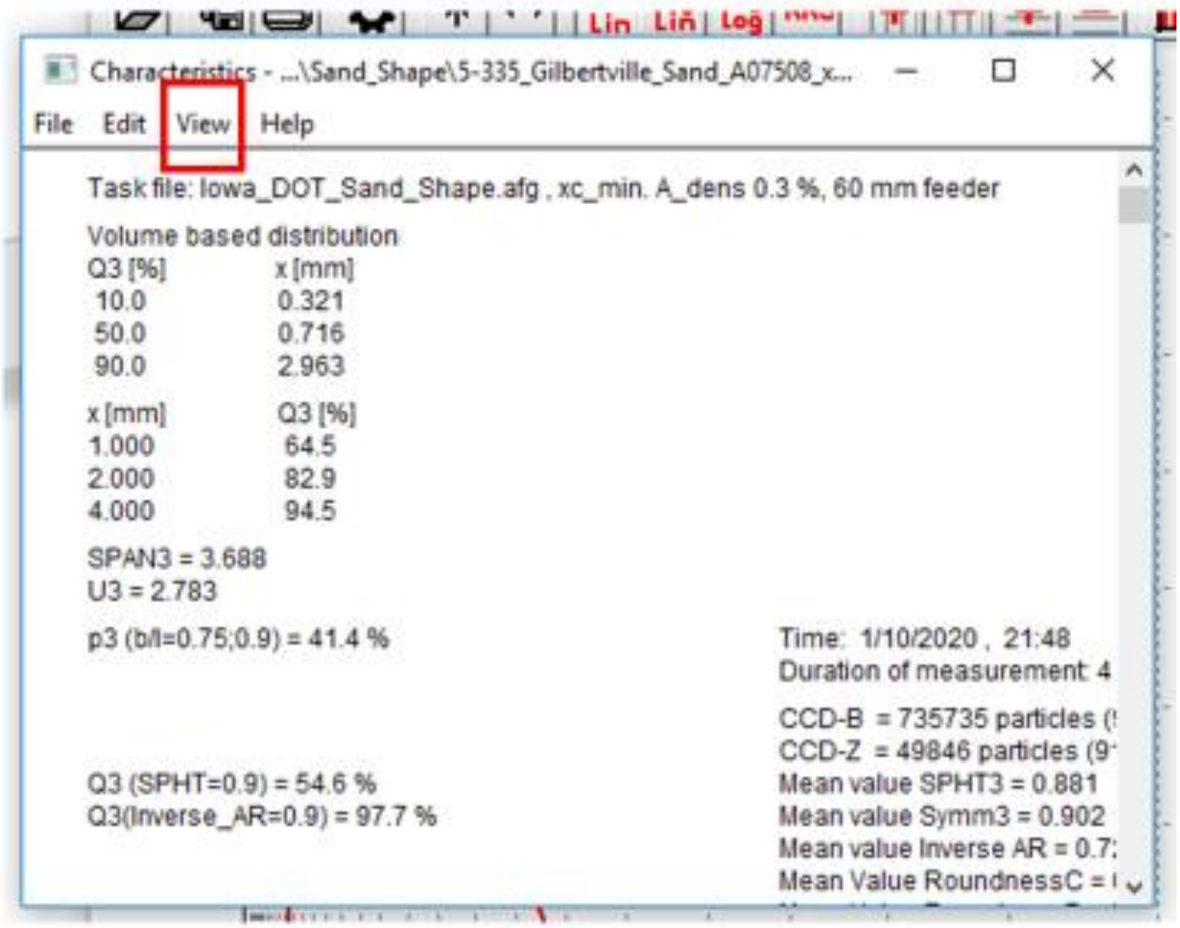
In the Camsizer software go to **Results**



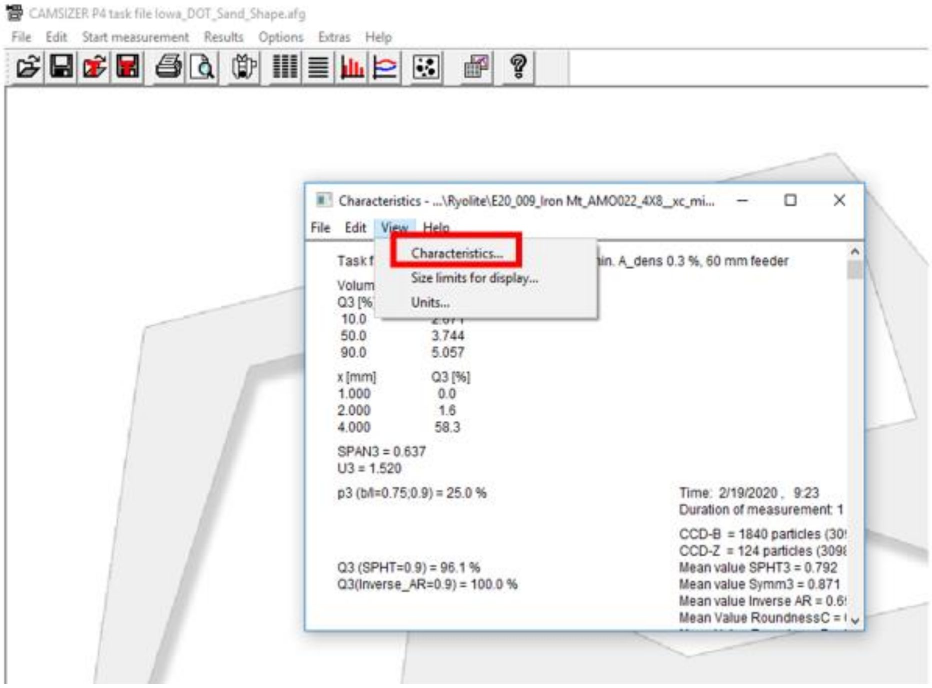
Results → Characteristics →



Characteristics → View

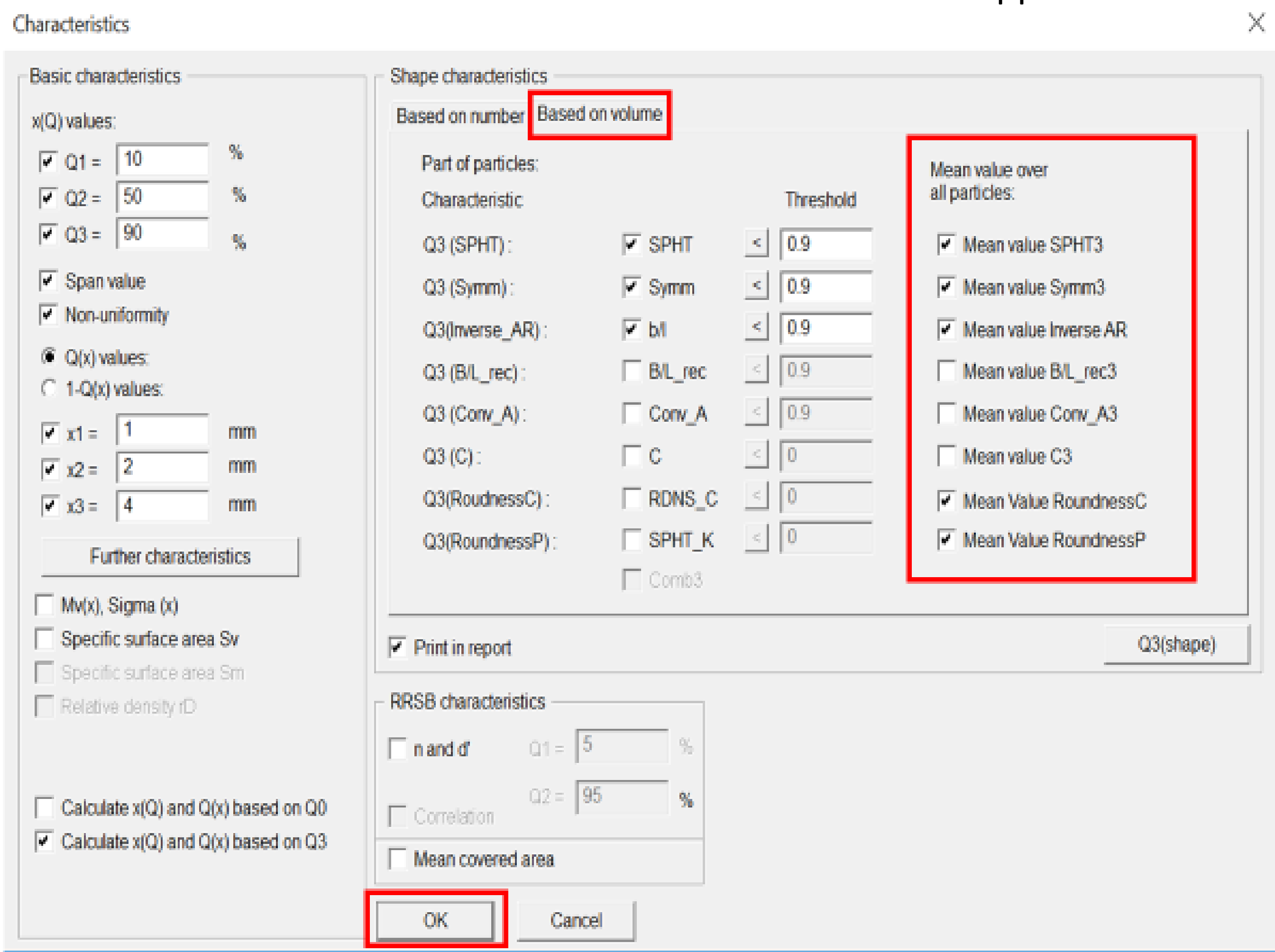


View → Characteristics



.

Use the “Based on volume” tab



Choose the Mean values you want (see next page)

Click OK.

Shape Definitions:

SPHT3 = Sphericity Displays the roundness, Perfect circles or spheres have a sphericity of 1.

Symm3 =Symmetry. Perfect symmetrical shapes have a symmetry equal to 1.

Inverse AR= Length / width the inverse of the aspect ratio.

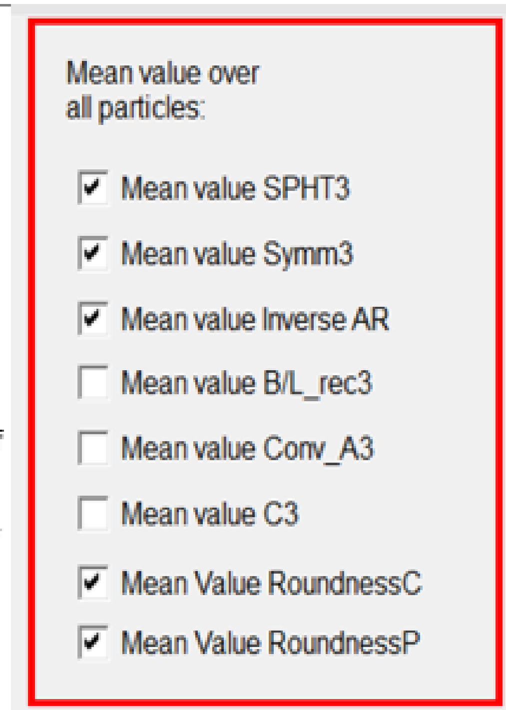
Aspect Ratio = width / length

Conv = Convexity, particle Area and convex particle area. Convex particles have a convexity of 1.

C3 = Circularity, perfect circles or spheres have a circularity of 1.

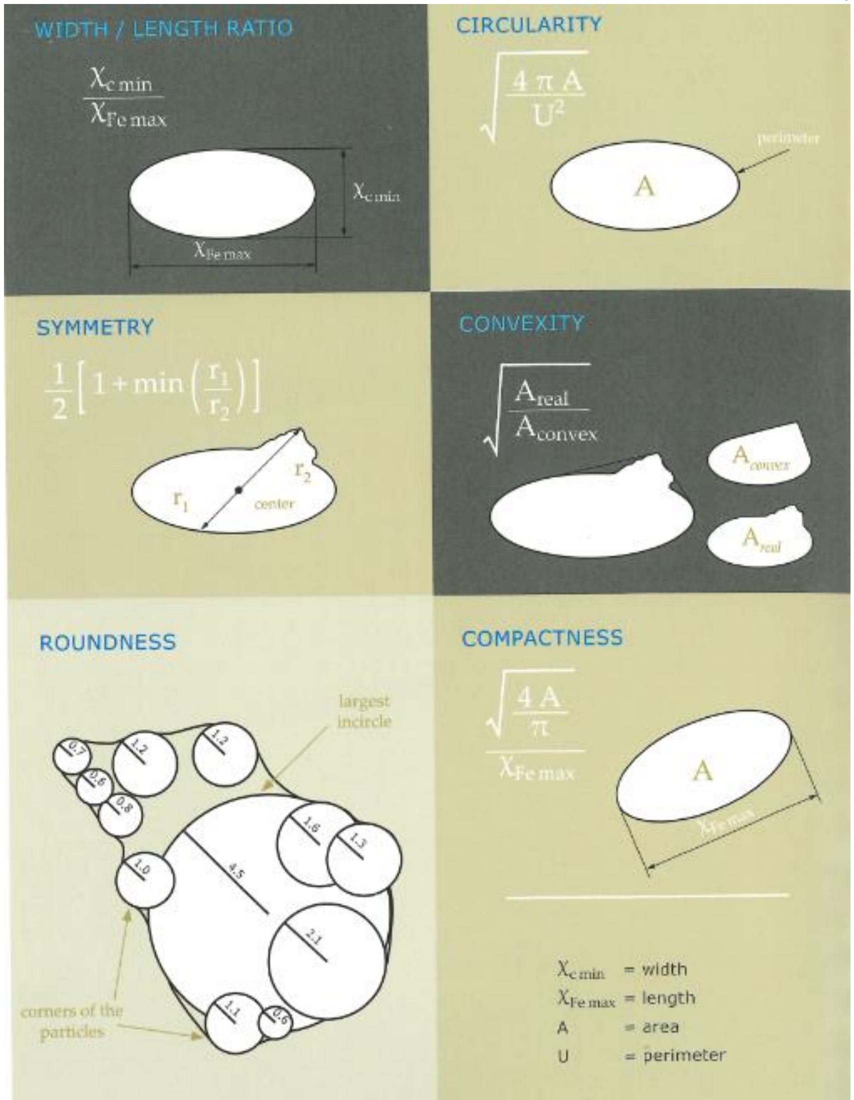
Roundness C = the radius of circles that fit into the corners of a particle divided by the radius of the largest circle that can fit in the particle.

SPHT_K is the box ratio (perpendicular aspect ratio).

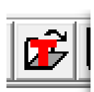


⚠ For details see the **Retsch** Technology Manual – *Evaluation Software CAMSIZER P4* pages 149 to 155. An electronic copy is available using the CAMSIZER HELP found on the Tool Bar.

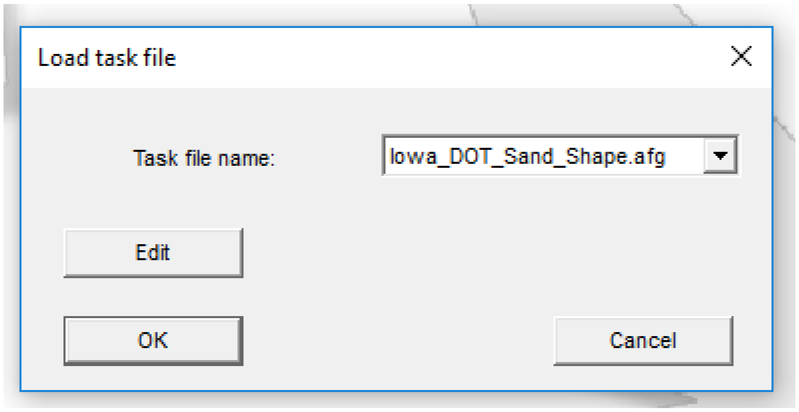
- b/l is Inverse AR (aspect ratio, smallest width / largest length) independent from the angle between xc_min and xFe_max
- RDNS_C = Roundness C
- SPHT is the Area divided by the perimeter
- SPHT_K is the box ratio (perpendicular aspect ratio) in 2D like Inverse AR but perpendicular. Under the microscope that means particles are in the largest stable position. (now Roundness P). SPHT_K is the 2D version of the randomly taken (B/L)rec in 3D
- (B/L)rec is the minimum (xFe1/xFe2) when xFe1 and xFe2 are perpendicular
- (b/l)rec is the minimum (xc/xFe) when xc and xFe are perpendicular



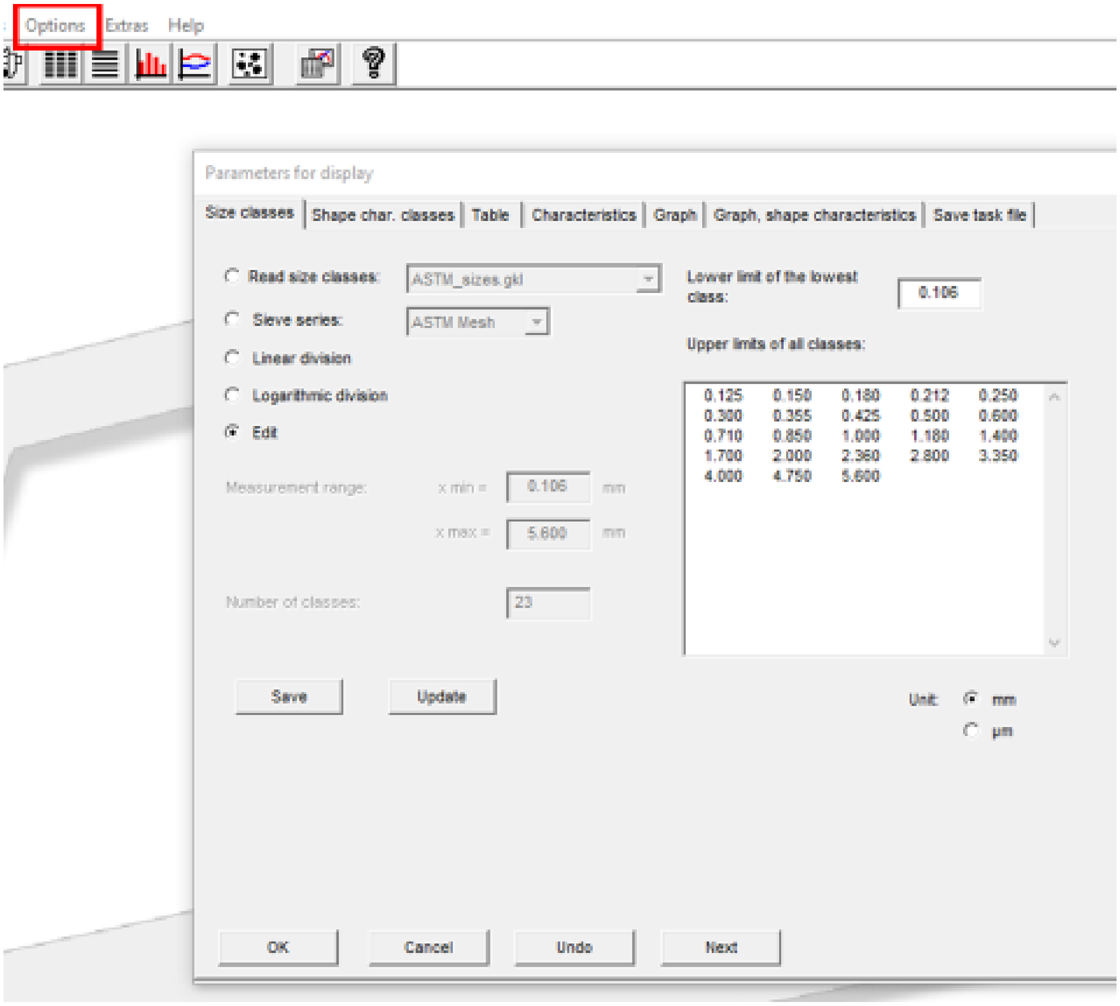
Changing sieve sizes.

Hit the "Open Task" button (3rd  one in)

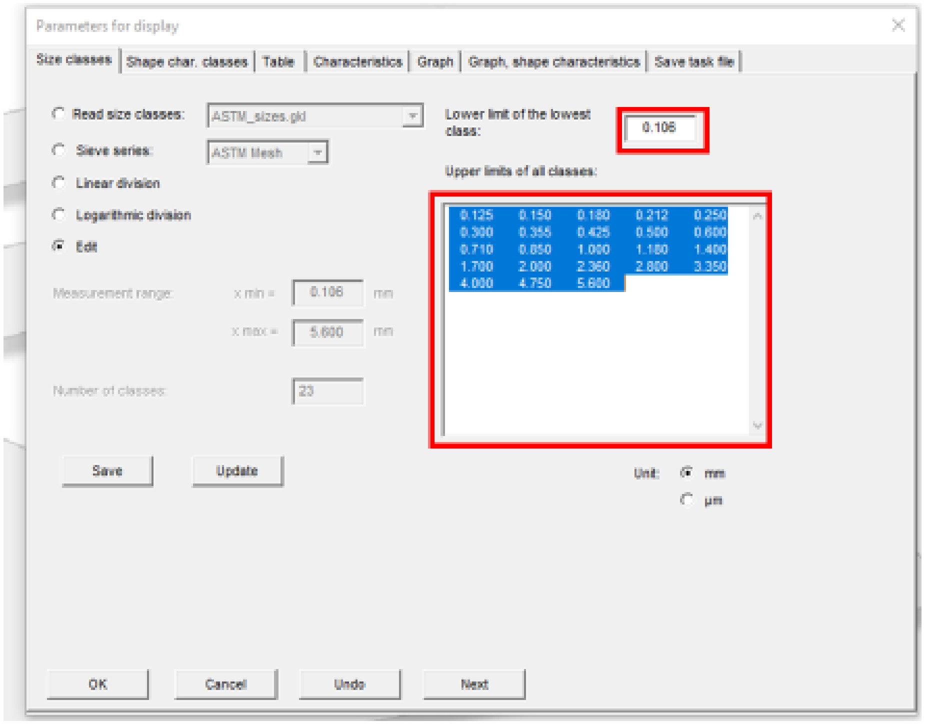
Load Task file. These will be ".afg" files.



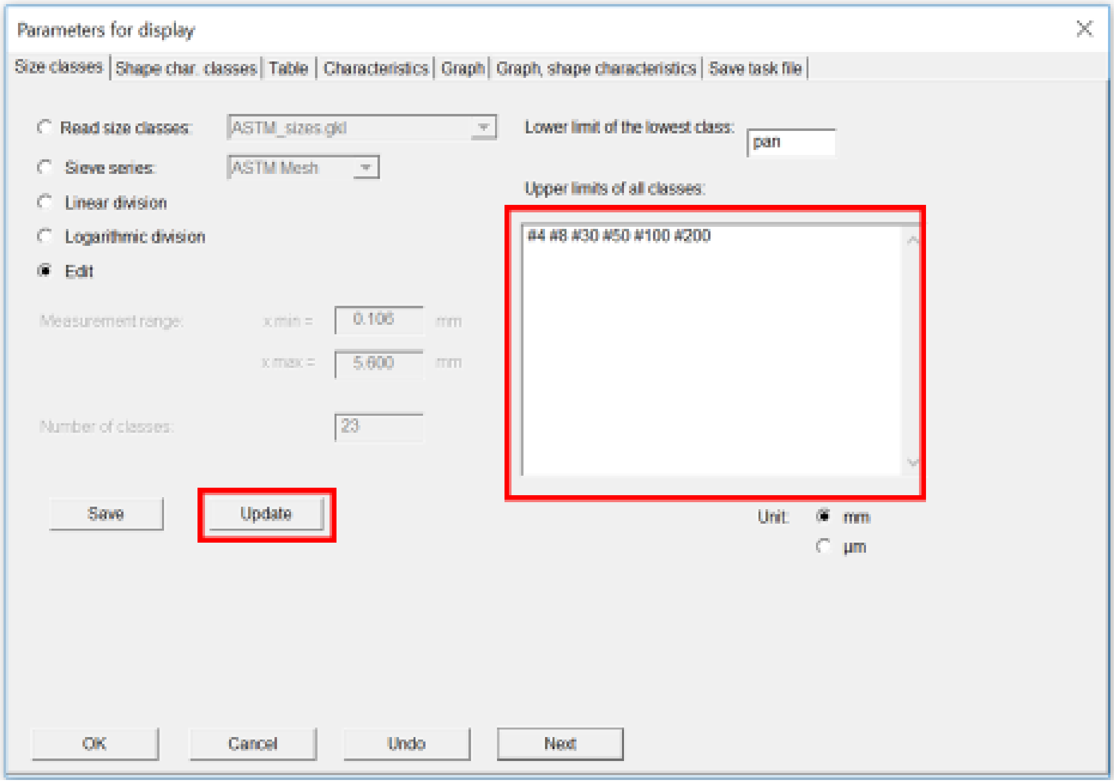
Then Options → Size Classes (If a sieve distribution has already been created, click the "Read size classes", select the size distribution, then save.



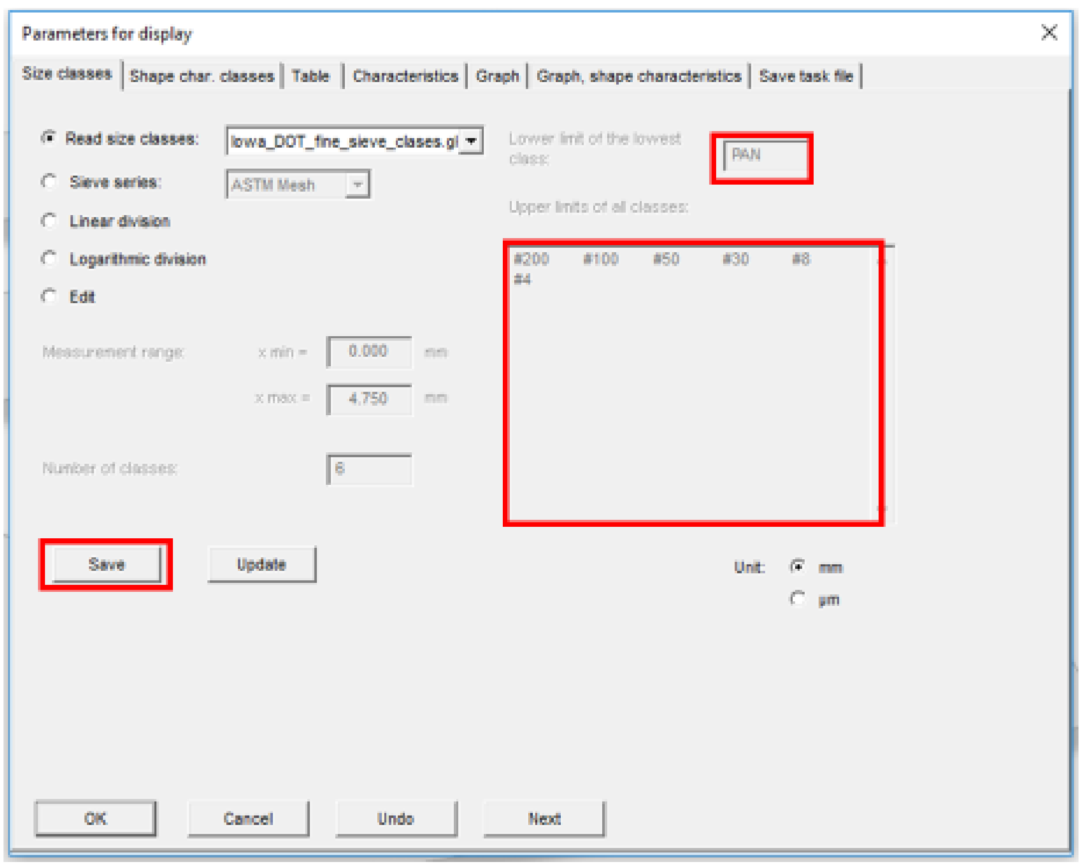
Adding a new sieve distribution:



1) Delete large box. 2) Type in sieve size you want using # and separated by a space. 2) replace the lower limit with “pan”. Then hit update

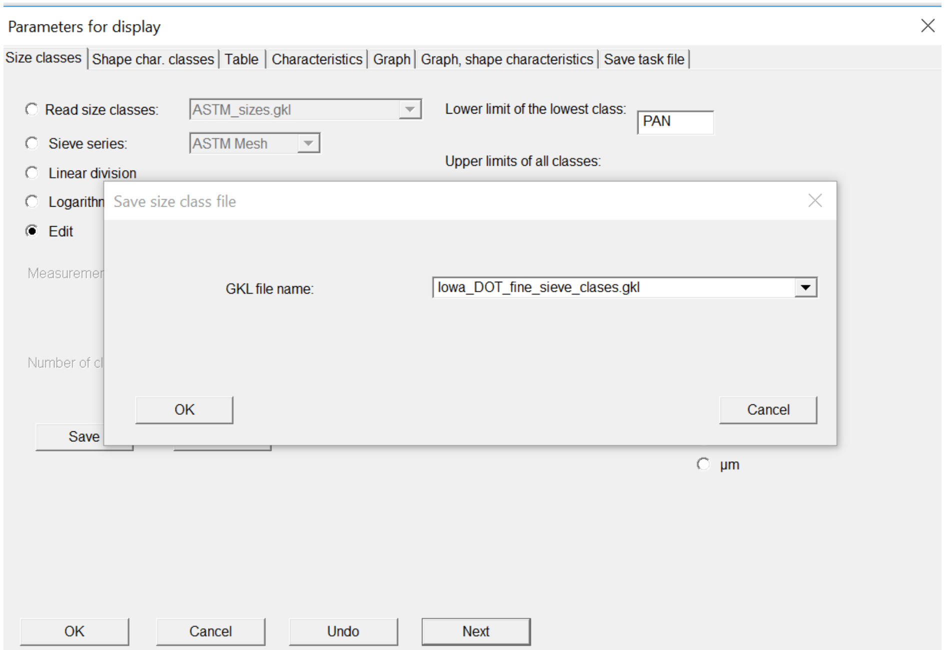


Parameters for display
Size classes | Shape char. classes | Table | Characteristics | Graph | Graph, shape characteristics | Save task file |
Read size classes:
ASTM_sizes.gkl
Sieve series:
ASTM Mesh
Linear division
Logarithmic division
Edit
Lower limit of the lowest class:
pan
Upper limits of all classes:
#4 #8 #30 #50 #100 #200
Measurement range:
x min =
0.106
mm
x max =
5.600
mm
Number of classes:
23
Save
Update
Unit:
mm
µm
OK
Cancel
Undo
Next

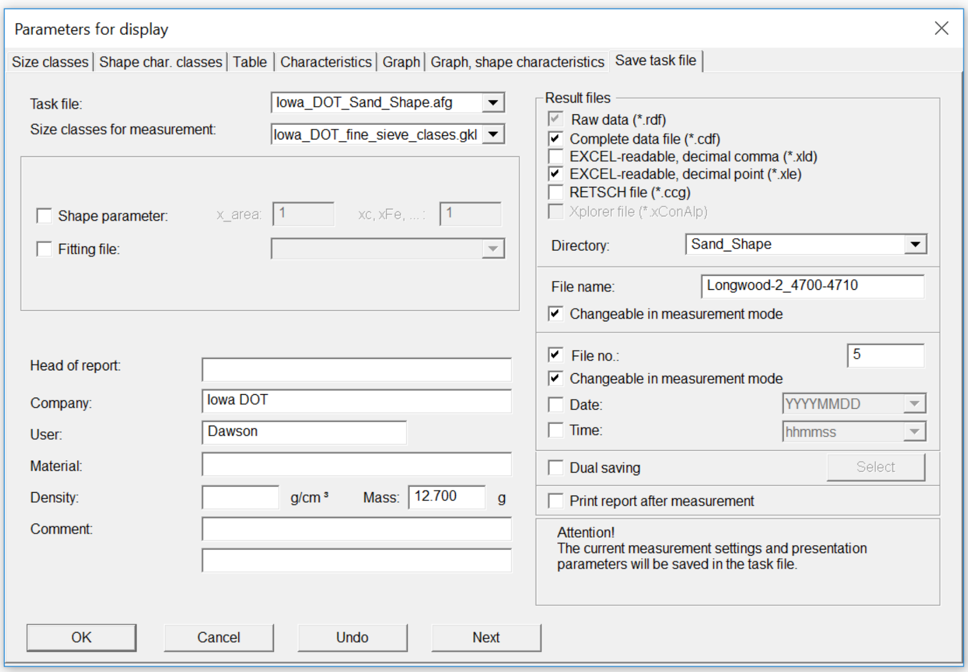


Parameters for display
Size classes | Shape char. classes | Table | Characteristics | Graph | Graph, shape characteristics | Save task file |
Read size classes:
Iowa_DOT_fine_sieve_clases.gl
Sieve series:
ASTM Mesh
Linear division
Logarithmic division
Edit
Lower limit of the lowest class:
PAN
Upper limits of all classes:
#200 #100 #50 #30 #8
#4
Measurement range:
x min =
0.000
mm
x max =
4.750
mm
Number of classes:
6
Save
Update
Unit:
mm
µm
OK
Cancel
Undo
Next

The sieve sizes will be separated by tabs. Hit Save.



Give the new Size Class a new name and hit OK.



Select the Size classes for measurement. Hit OK.

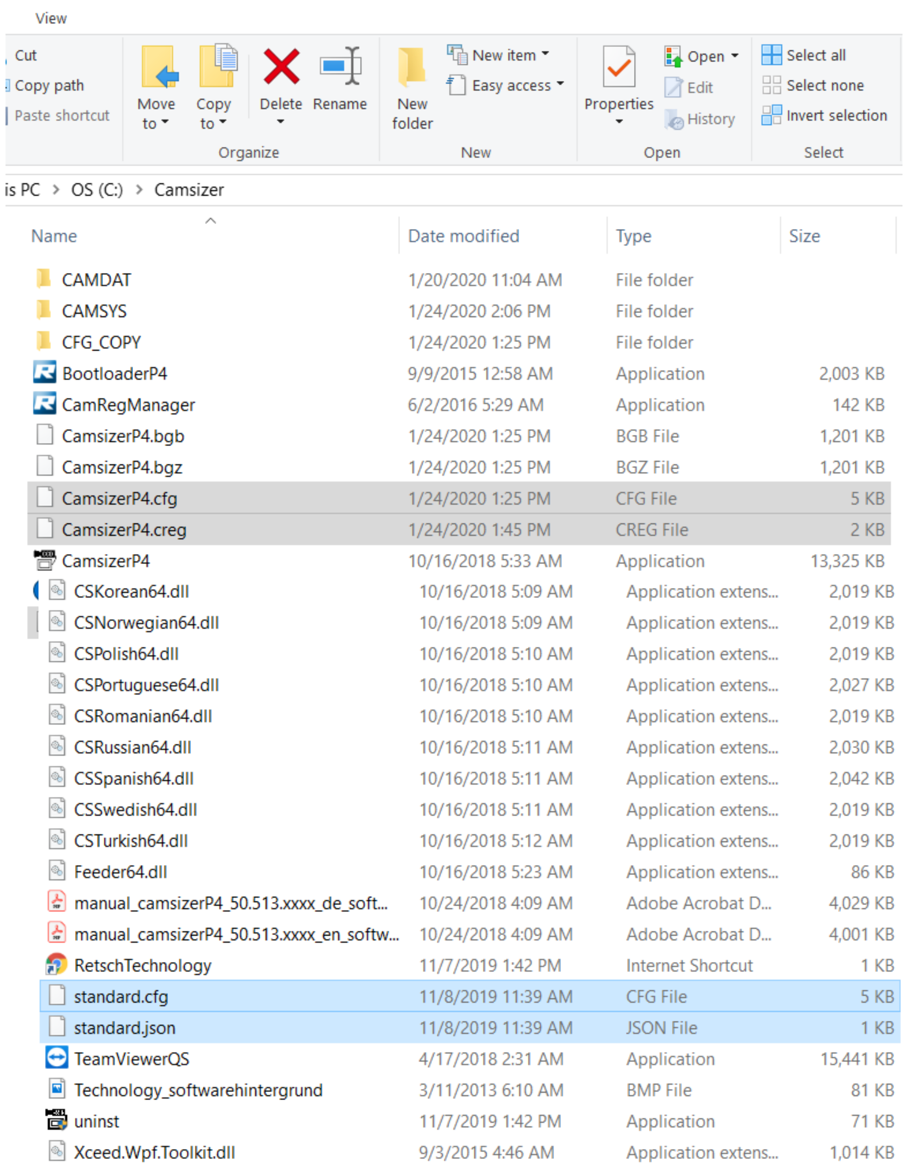
Moving CAMSIZER Software files from one computer to another

These files will rename some of the labels to more recognizable names.

On the CAMSIZER computer navigate to C:\Camsizer

Copy the following files onto your external hard drive:

camsizerP4.cfg
camsizerP4.creg
camsizerP4.json
standard.json
standard.cfg
-



On your computer place the copied files into C:\Camsizer

Appendix D

PROCESSING CAMSIZER DATA TO MAKE SHAPE PLOTS IN EXCEL

Manipulating CAMSIZER data to make shape plots in Excel

These files will rename some of the labels to more recognizable names.

On the CAMSIZER computer navigate to C:\Camsizer

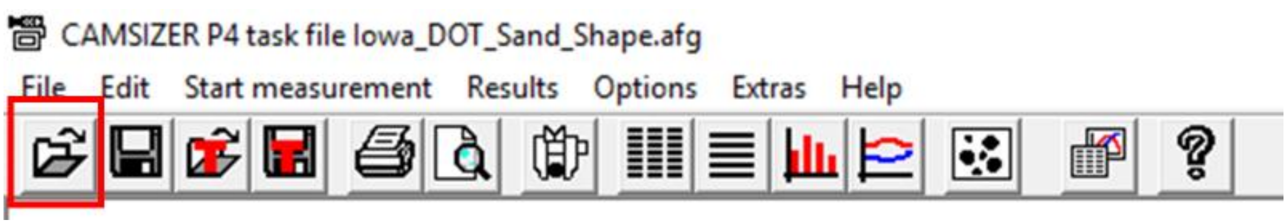
Data is store on a partitioned part of the hard drive called “Particle X-Plorer” then CAMDAT. Select this drive to copy your data. You may want to make sub directories in a locate where you store your data.

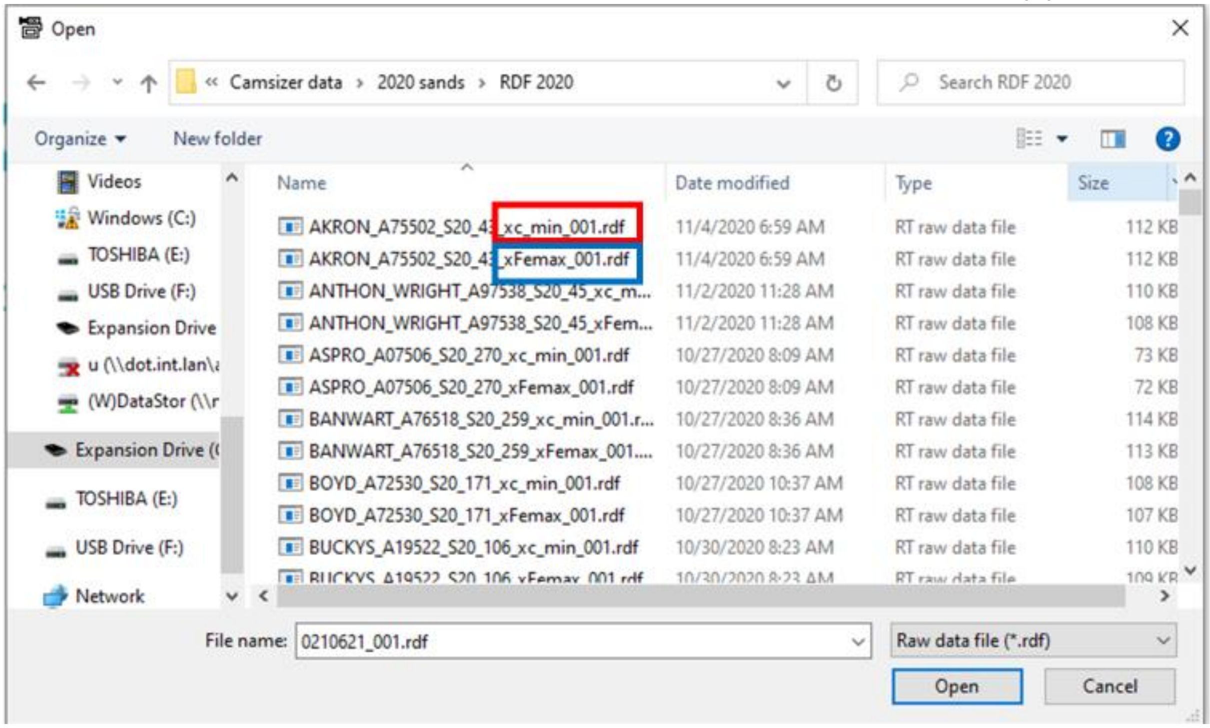
It is important that you know where your data is being stored.

Also, please move your data and working files to a different location such as a flash drive or a network location. Do not store your working files on the Camsizer computer. If you do store data on the Camsizer Computer, you should set up a specific directory with a unique name.

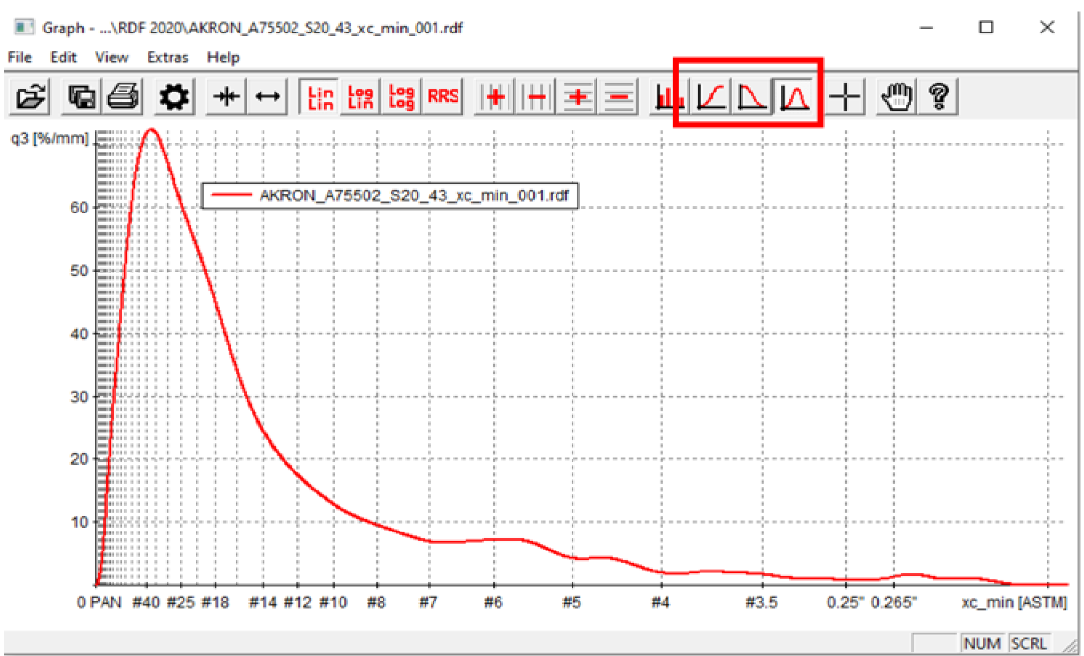
To Begin

Open the “Raw Data File” of the sample you want to plot. Use the open file button and find the directory where your data is stored.

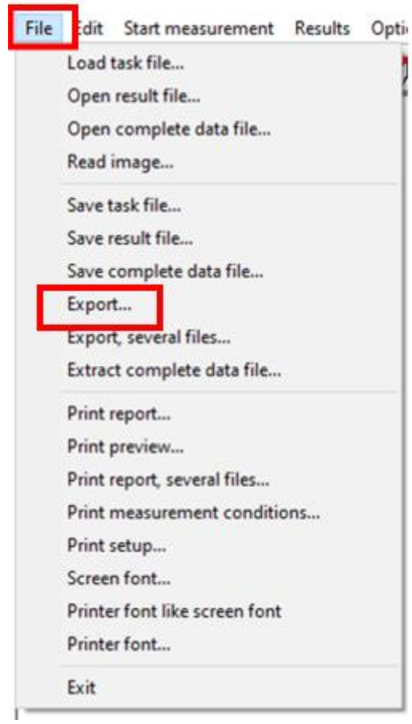




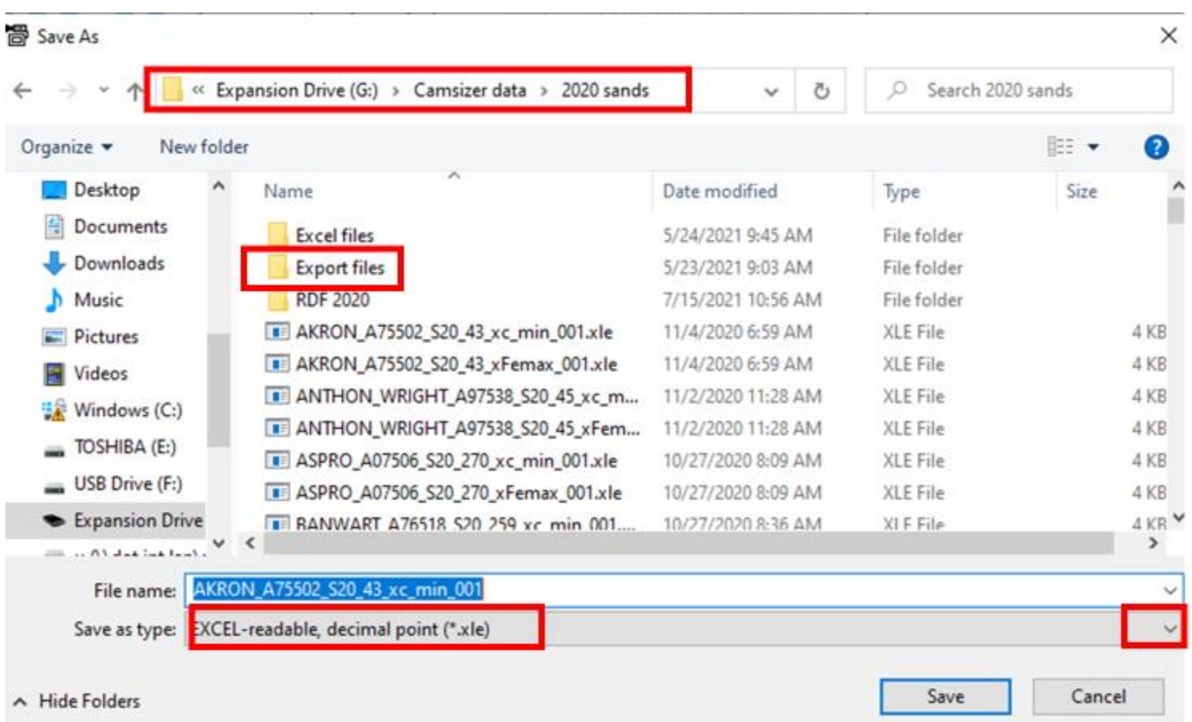
You will get a list of "Raw Data Files" or RDF for the samples you have run. There will be "xc_min" and "xFemax". These file names designate the orientation that the measurements were taken. You can read more about this in the Help Manual found in the Camsizer tool bar. Choose "xc_min" (in red) and not "xFemax" (in blue).



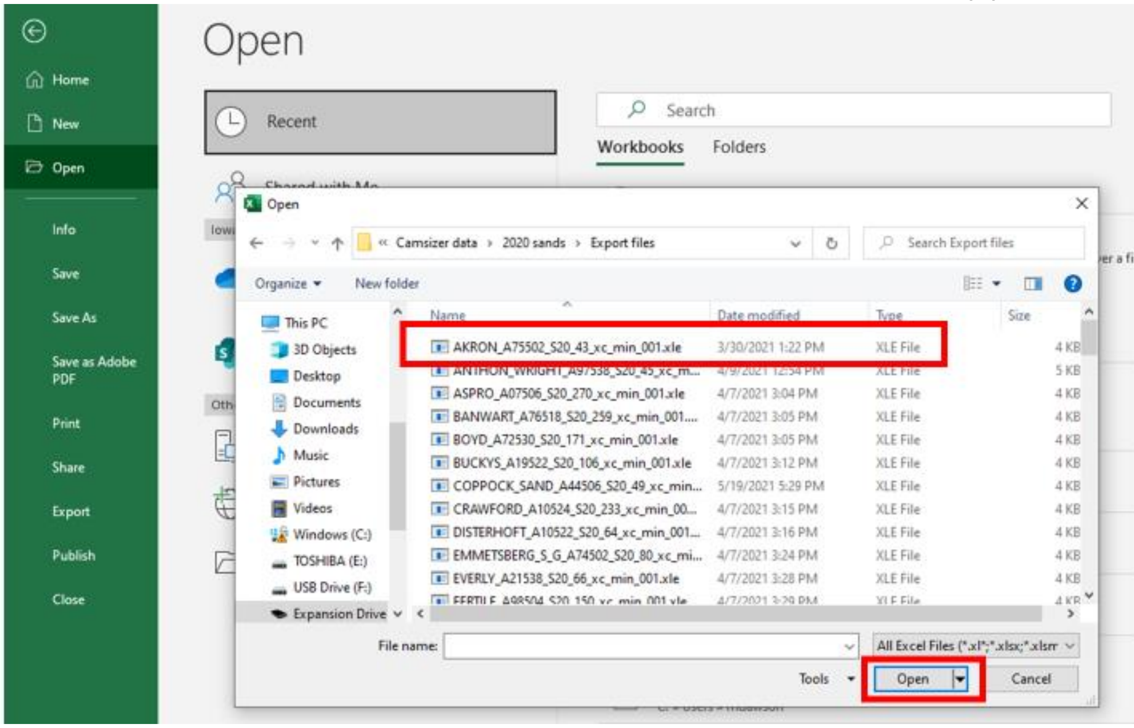
You will see a plot similar to this depending on which of the three modes of size distribution was chosen.



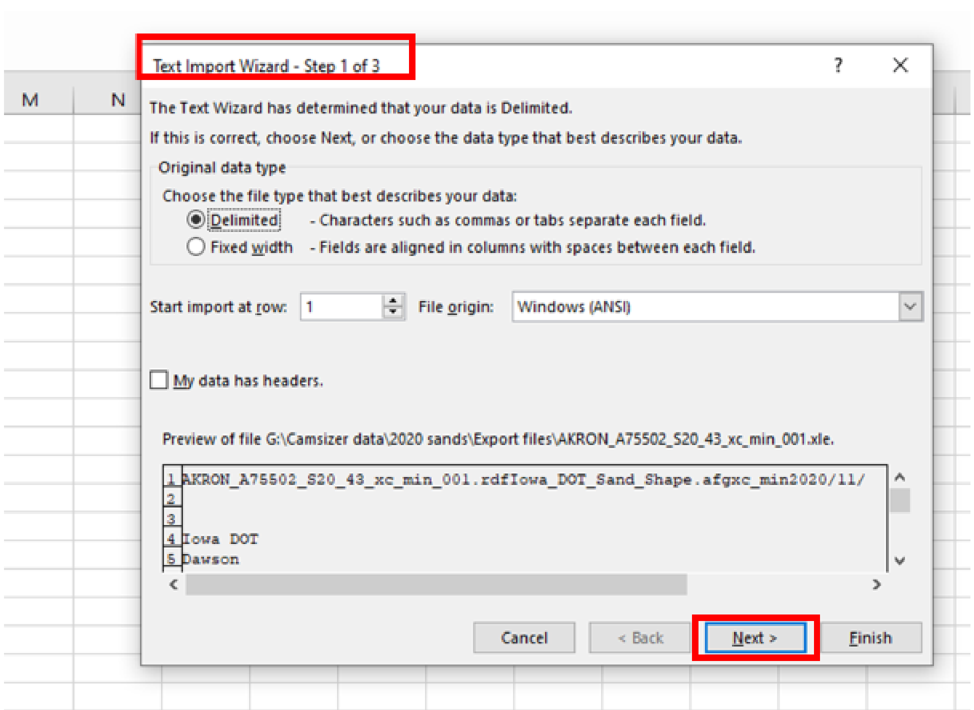
On the Mine Toolbar choose File then Export.



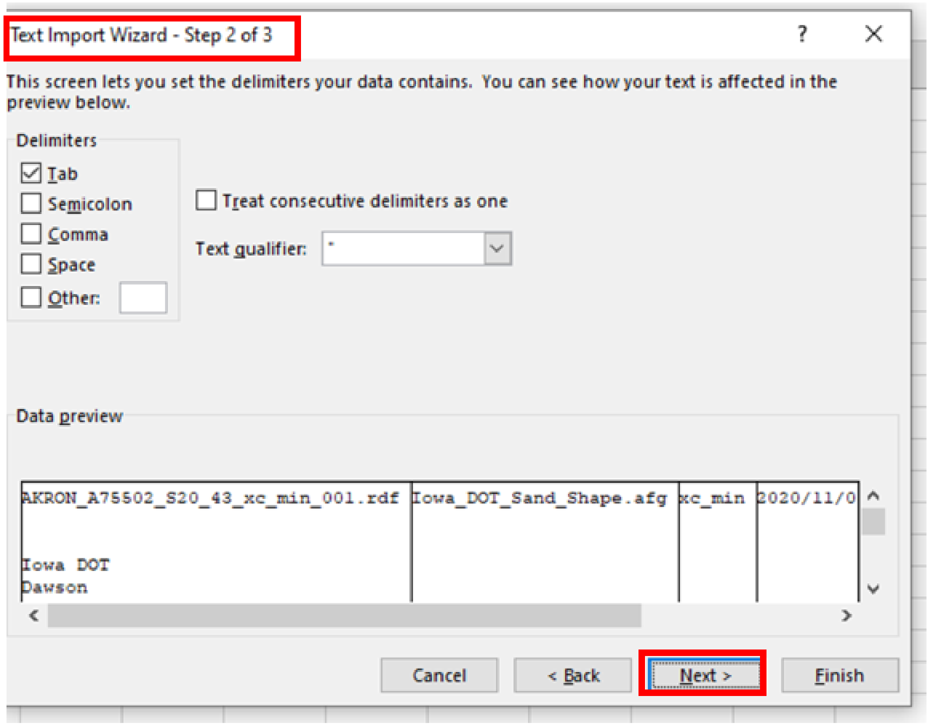
You may want to make a new subdirectory on the drive you are storing your data called export. When you export your files make sure they are in a ".xle" format and not a "xld" format. Use the drop-down box to the right to select the proper format. Excel cannot read the xld format.



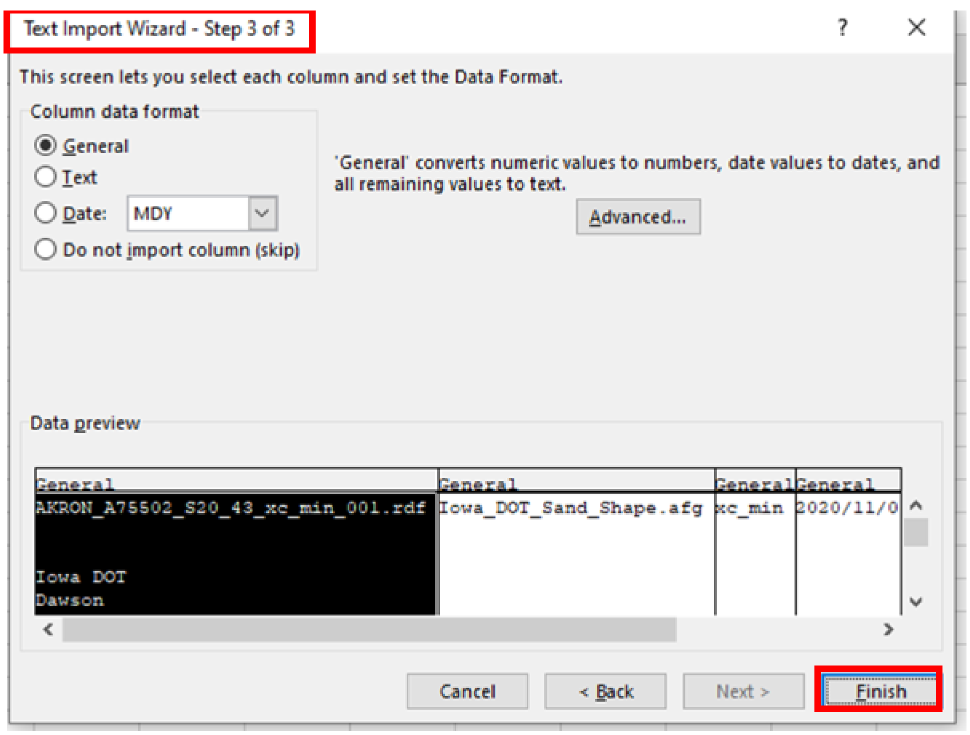
Open Excel and Open File. Choose the sample file you want to open. Then hit Open.



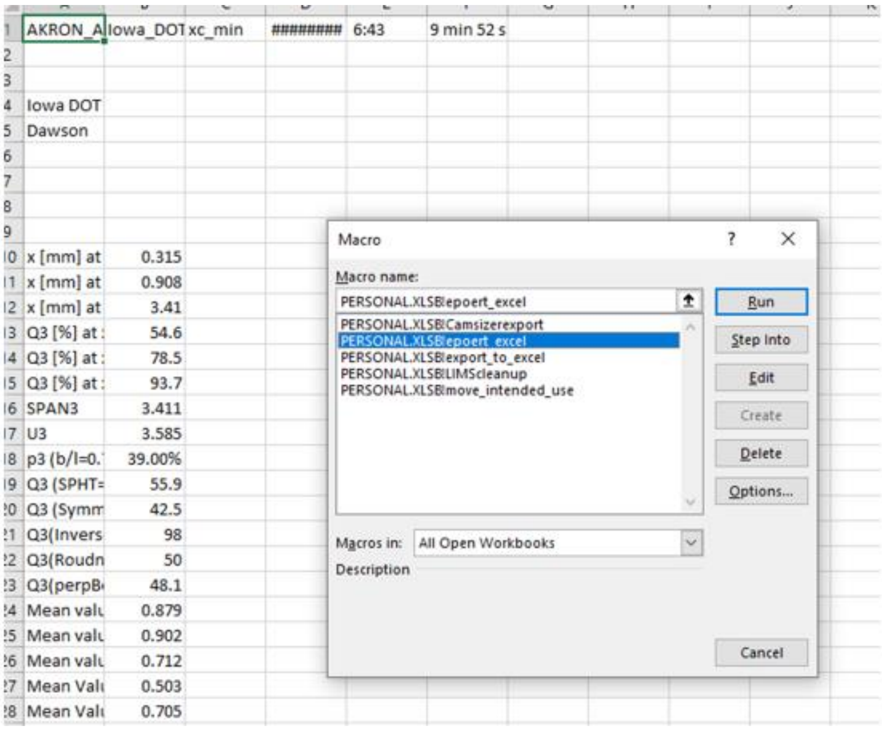
Step 1. The Import Wizard will open to convert the xle file into an excel format. This will take three steps.



On Step 2 the Import Wizard will automatically figure out where the columns should be. If there is a problem, you can click and drag the breaks to the location that works for you. Then just hit next.



On step 3 just hit Finish.



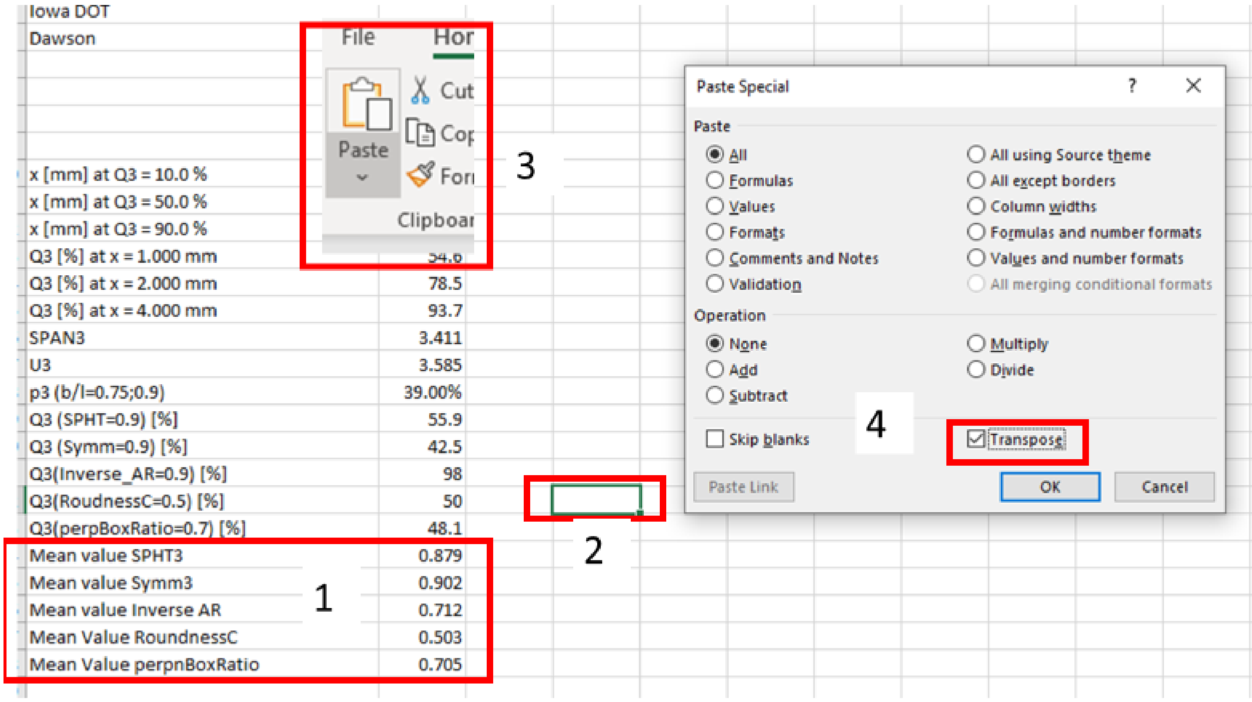
The file has now been imported. You will have to adjust column widths or is you do this once you can write a macro to do the same process over and over in only on step.

x [mm] at Q3 = 10.0 %	0.315
x [mm] at Q3 = 50.0 %	0.908
x [mm] at Q3 = 90.0 %	3.41
Q3 [%] at x = 1.000 mm	54.6
Q3 [%] at x = 2.000 mm	78.5
Q3 [%] at x = 4.000 mm	93.7
SPAN3	3.411
U3	3.585
p3 (b/l=0.75;0.9)	39.00%
Q3 (SPHT=0.9) [%]	55.9
Q3 (Symm=0.9) [%]	42.5
Q3(Inverse_AR=0.9) [%]	98
Q3(RoudnessC=0.5) [%]	50
Q3(perpBoxRatio=0.7) [%]	48.1
Mean value SPHT3	0.879
Mean value Symm3	0.902
Mean value Inverse AR	0.712
Mean Value RoundnessC	0.503
Mean Value perpnBoxRatio	0.705

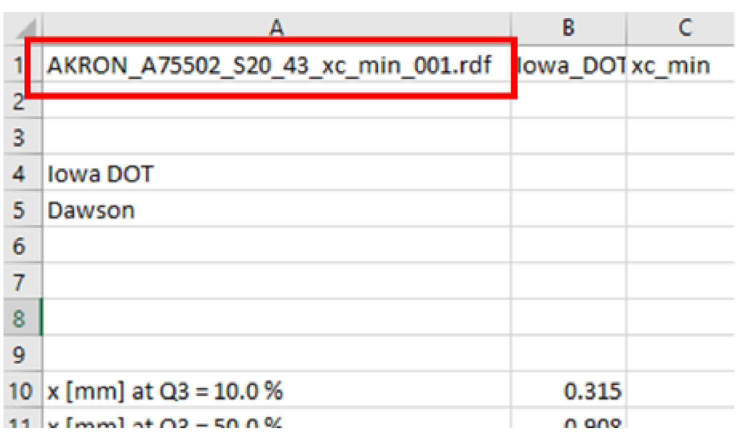
You will need to select the shape properties you would like to use. For what I am working on the Roundness and Inverse aspect ratio are the most useful. Use the help manual to figure out the shape values most useful to you.

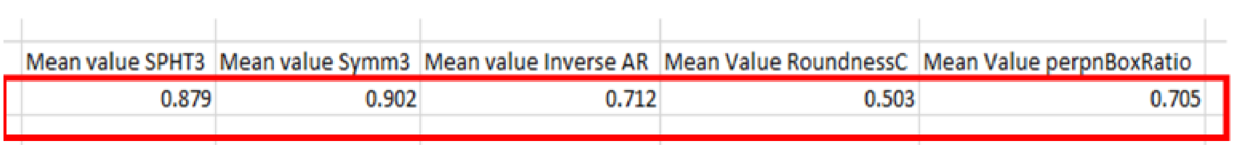
⚠ Remember: The shape properties reported are set up in the program before the sample is tested.

Transposing the data into a more useful format



1.) Select the data you wish to plot. Highlight and copy. 2.) Select a area of the spreadsheet you would like to place the data or on a different spread sheet. 3.) Near the File button will be Paste. Go to "Paste Special" and window 4 will appear. 4.) Click the "Transpose" box then OK.





I like to copy the File Name (Row 1A) and the transposed data into a separate file to make a Master spreadsheet with the File Name in the first column followed by the data.

Appendix D

File Name	A-Number	Mean RoundnessC	Mean RoundnessP	A-Number	Landform	River
S19_321_Tegler_A28504_xc_min_001.rdf	A28504	0.463	0.715	A28504	IS/SIDP	Bear Cr
S20_018_Coots_sand_A06504_xc_min_001.rdf	A06504	0.503	0.718	A06504	IS	Cedar
S-334_Waterloo_Sand_A07504_xc_min_001.rdf	A07504	0.538	0.715	A07504	SIDP	Cedar
S-335_Gilbertville_Sand_A07508_xc_min_001.rdf	A07508	0.522	0.718	A07508	IS	Cedar
S-399_Blairs-Ferry_Sand_A57528_xc_min_001.rdf	A57528	0.512	0.716	A57528	SIDP	Cedar
S19_396_Hess_A57530_xc_min_001.rdf	A57530	0.509	0.719	A57530	SIDP	Cedar
S19_408_Linn_Co_Sand_A57534_xc_min_001.rdf	A57534	0.505	0.717	A57534	SIDP	Cedar
S19_317_Fredonia_A&B_A58504_xc_min_001.rdf	A58504	0.539	0.725	A58504	MAPE	Cedar
S19_163_Lilland_A32548_xc_min_001.rdf	A32548	0.458	0.704	A32548	DL	Des Moines
Emmetsburg_Sand_A74502_xc_min_001.rdf	A74502	0.489	0.705	A74502	DL	Des Moines
S19_162_Miller_A76514_xc_min_001.rdf	A76514	0.494	0.704	A76514	DL	Des Moines
Reigelsberger_Sand_A94532_xc_min_001.rdf	A94532	0.467	0.706	A94532	DL	Des Moines
S-377_Coppock_Sand_A46516_xc_min_001.rdf	A46516	0.496	0.703	A46516	DL	Des Moines
S19_423_EDM_#2_Vandalia_A77522_xc_min_001.rdf	A77522	0.492	0.706	A77522	IM/DL	Des Moines
S19_413_North_Des_Moines_A77530_xc_min_001.rdf	A77530	0.505	0.708	A77530	DL	Des Moines
S19_350_Saylorville_Sand_A77534_xc_min_001.rdf	A77534	0.524	0.715	A77534	DL	Des Moines
S19_415_Saylorcreek_Sand_A77536_xc_min_001.rdf	A77536	0.493	0.707	A77536	DL	Des Moines
S19_354_Wapello_Co_Sand_&_Gravel_A90506_xc_min_001.rdf	A90506	0.498	0.714	A90506	SIDP	Des Moines
McDowell_Natural_A35522_xc_min_001.rdf	A35522	0.491	0.703	A35522	DL	Iowa
S19_380_H_&_M_Farms_A42532_xc_min_001.rdf	A42532	0.486	0.711	A42532	IM/DL	Iowa
S19_367_Disterhoft_A48508_xc_min_001.rdf	A48508	0.488	0.717	A48508	SIDP	Iowa
S19_322_Williams_A52508_xc_min_001.rdf	A52508	0.517	0.72	A52508	MAPE	Iowa

Set up you spread sheet with as many columns with as many variable as you need.