Quantifying Multiple Components in Reflective Glass Beads Based on Morphological Analysis

Reflective Glass Beads

Highway safety coatings used in highway striping and signage consist of some type of paint containing a carefully blended mix of reflective glass beads. They also contain some portion of sand to provide good traction on the coated surfaces during rain or icing. The beads themselves have to pass Quality Control inspection which consists of meeting specific sizes and shapes along with some strength requirements. Size is important so that the beads show enough of their volume above the level of the coating for capturing and reflecting enough light. Shape needs to be as spherical as possible to form the lens shape needed to reflect the light in the right direction and at a high enough intensity.

Any glass bead mix will contain some beads which fuse together in the manufacturing process. These agglomerates of multiple beads detract from the efficiency of the job of properly reflecting enough light, in the right direction. Too much sand in the mix inhibits light, and too little is unsafe. So the size distribution and the amounts of fused beads and sand need to be measured and quantified to ensure the mix meets the Quality Control specifications.

The technology most employed to measure particle size distribution is Laser Diffraction (LD), well established in industry since the mid 1970's. The newer Dynamic Image Analysis (DIA) has now become the technology of choice for particle morphology, including Sphericity as one of some 30 different size and shape parameters.

Combination Laser Diffraction (LD)/Dynamic Image Analysis (DIA) Technologies

An instrument now offered by Microtrac measures particles using both Laser Diffraction and Dynamic Image Analysis simultaneously, on the same sample, in the same sample cell. The photo below of the "SYNC" shows the system configured for wet analysis along with the dry feeder module. The wet and dry modules are interchangeable.

Figure 1. Synchronous Size and Shape Analyzer: Each measuring unit measures and reports all results simultaneously on the same sample. The instrument pictured measures one sample using both the Laser Diffraction and Dynamic Image Analysis technologies.

The diagrams below show the internal layout of both wet and dry configurations.

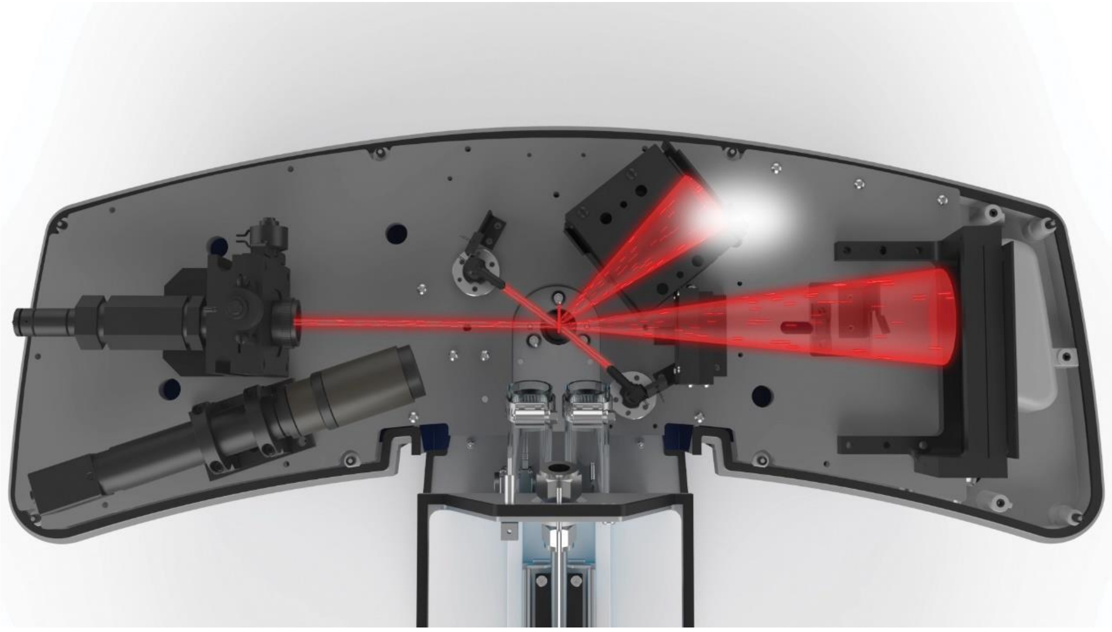


Figure 2. Diagram of Laser Diffraction (LD) Technology: The tri-laser diodes at different angles provide scattered light to the array detectors at angles from 0 to 165 degrees. The blue lasers, at lower wavelengths, detect the smallest particles more accurately.

Laser Diffraction Size Distribution Results

The size distribution report from a Laser Diffraction analysis of a glass bead sample is shown here in Figure 3. This comprehensive report gives the size distribution in both graphical and tabular formats, summary data giving central tendency and span, size percentiles and the SOP settings used for the measurement.

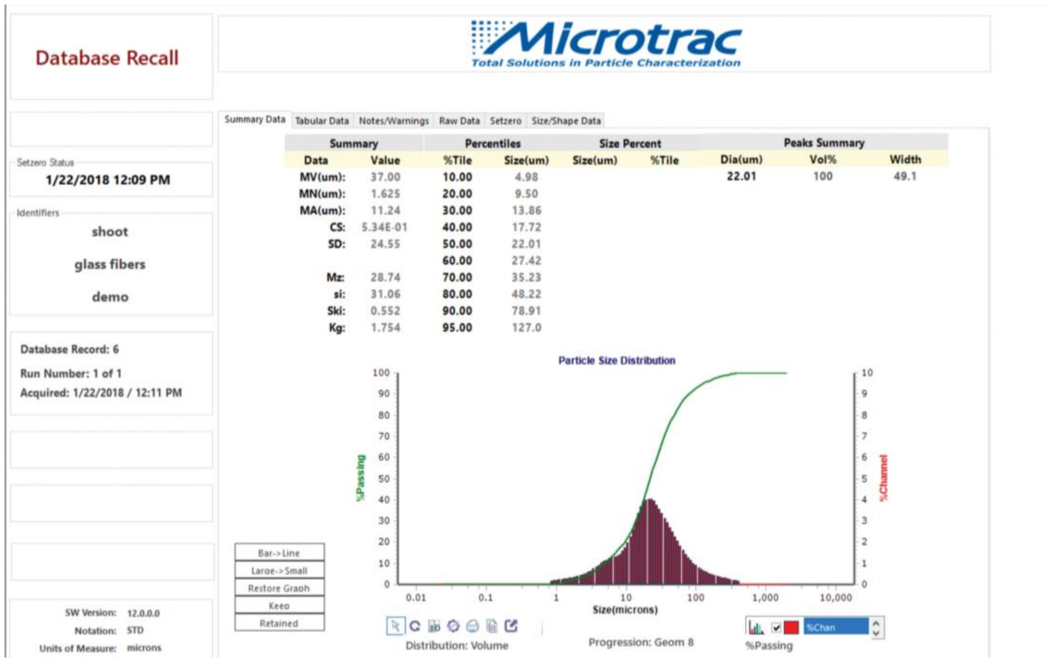
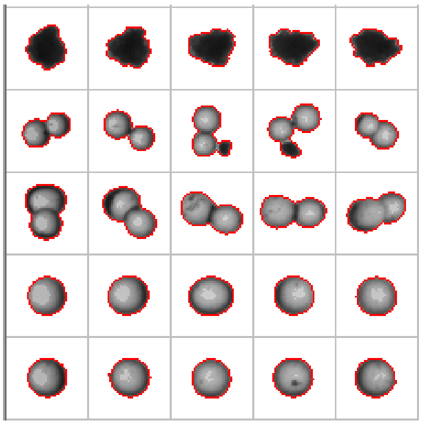


Figure 3. Size Distribution Report: Data is displayed in graphical and tabular form.

Dynamic Image Analysis Results

Example images from the video file of a glass bead measurement show the three major components – sand, fused beads, and good beads here in Figure 4.



Sand

Fused Beads

Good Beads

Figure 4. Reflective Glass Beads Sample: Images selected from the video file of a DIA analysis.

One major feature of the DIA post analysis software is the ability to identify and quantify different components in the sample. Table 1. Below lists the various ways this can be done for the glass bead application.

View Particles Image Video File Search Query Scatter Diagram	Filter Function 7 Different Components Individual or Combinations	X-Y Graph and Table Visual Presentation Quantification

Table 1. Post Measurement Analysis

In View Particles the entire image video file can be shown, sorted on any parameter, in ascending or descending order with parameter value displayed. The file can also be converted directly to a spreadsheet which lists all size and shape parameters for every particle in the sample. The image or data versions can be printed to PDF. This function also offers a Search Query where populations of particles can be isolated based on limits applied to various parameters. A Scatter Diagram feature here also displays where particles are relative to two parameters chosen in the X- and Y-axes. The complete video file saved can also be re-run under different SOP conditions. All post analysis functions will be discussed in more detail later.

Up to seven different components can be quantified using the Filter Function if they display distinct differences in one or more size or shape parameters. This feature can also be used to quantify the portion of off-spec particles in a sample.
The X-Y Graph and Table presents frequency or cumulative distributions for up to any six parameters in all standard formats – volume %, count (number) %, logarithmic, and linear. When the Filter Function has been selected for use in an analysis the filters can be applied to parameter distributions here as desired.

Figure 5. is an example of use of the View Particles feature.

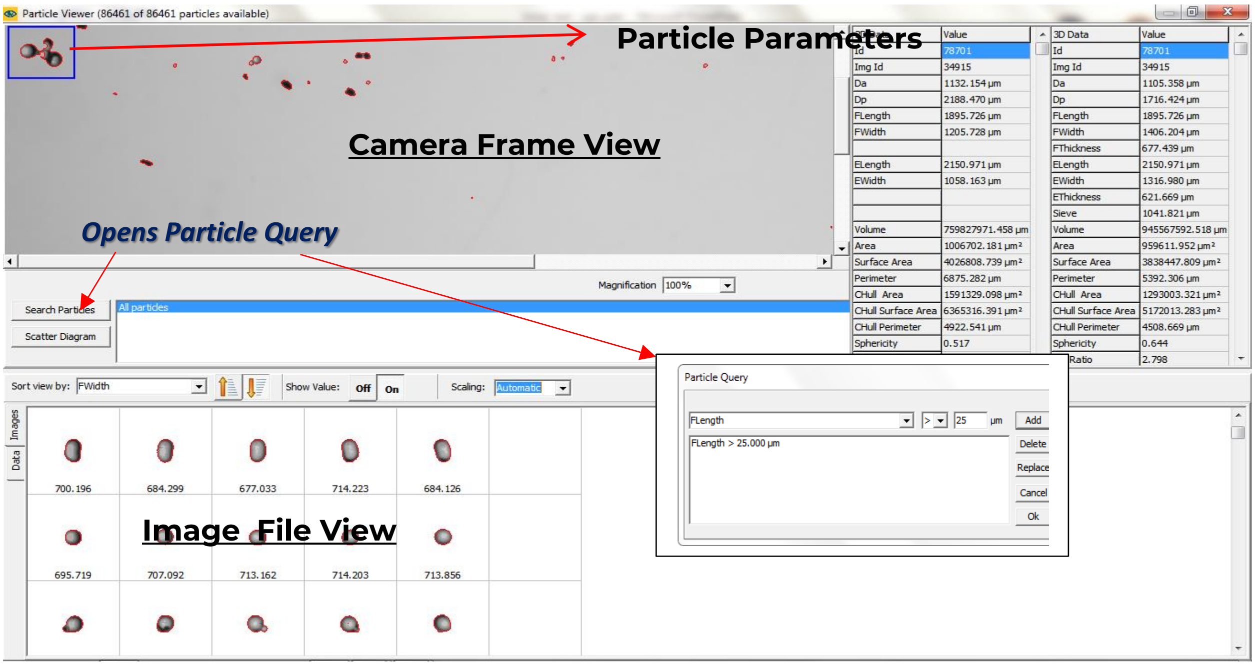


Figure 5. View Particles: Selected (blue box) particle parameters list, search query, camera and image views, scatter diagram selection.

This view particles display is a workhorse of the software for method development. A camera frame view is shown in the upper left, and an image file view in the lower left. This image file view can be scrolled through all 84,000 particles measured in this sample. The file can be sorted on any parameter and the value of the parameter for each image displayed. It can also be exported to a spreadsheet listing the value of all 36 parameters for each particle.
The fused or agglomerate particle in the upper left has been selected in the blue box and all its size and shape parameters are displayed in the list in the upper right.

The Search Particles button on the left opens a particle query window shown below the parameter list on the right. This versatile window is used to create searches for types of components in the sample which match the selection criteria entered in the window. The simple example shown is to select for all particles with a length greater than 25 microns. If this query is selected, the image file will change to display only those particle images in the sample which are greater than a length of 25 microns. More on the search query later. The scatter diagram display can be selected here.

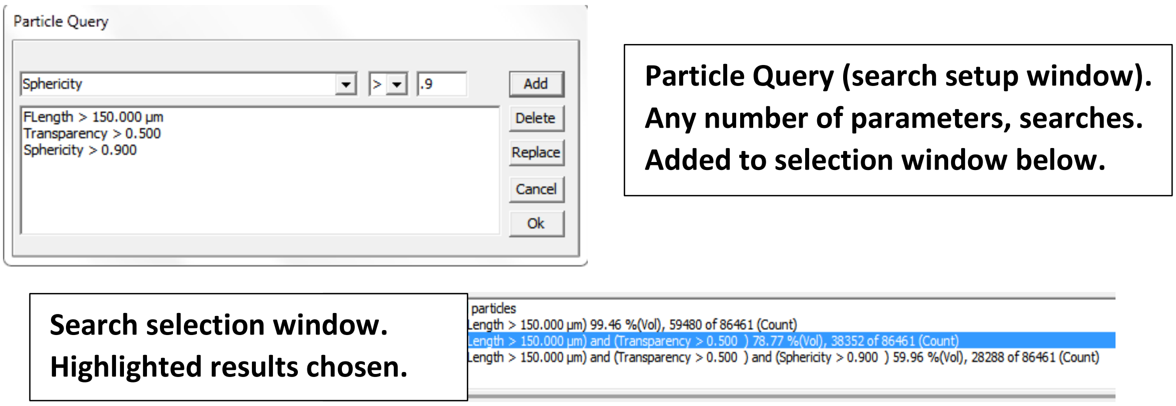


Figure 6. Search Results Selection: Second search results – make up 79% by volume, 44% by Count, of the total sample.

Three different searches were set up using the Particle Query window and were added to the Search Particles window. The second search was chosen to be calculated. Then the image file contains only those particles that match the search criteria, and the results of what proportion those particles are of the total sample.

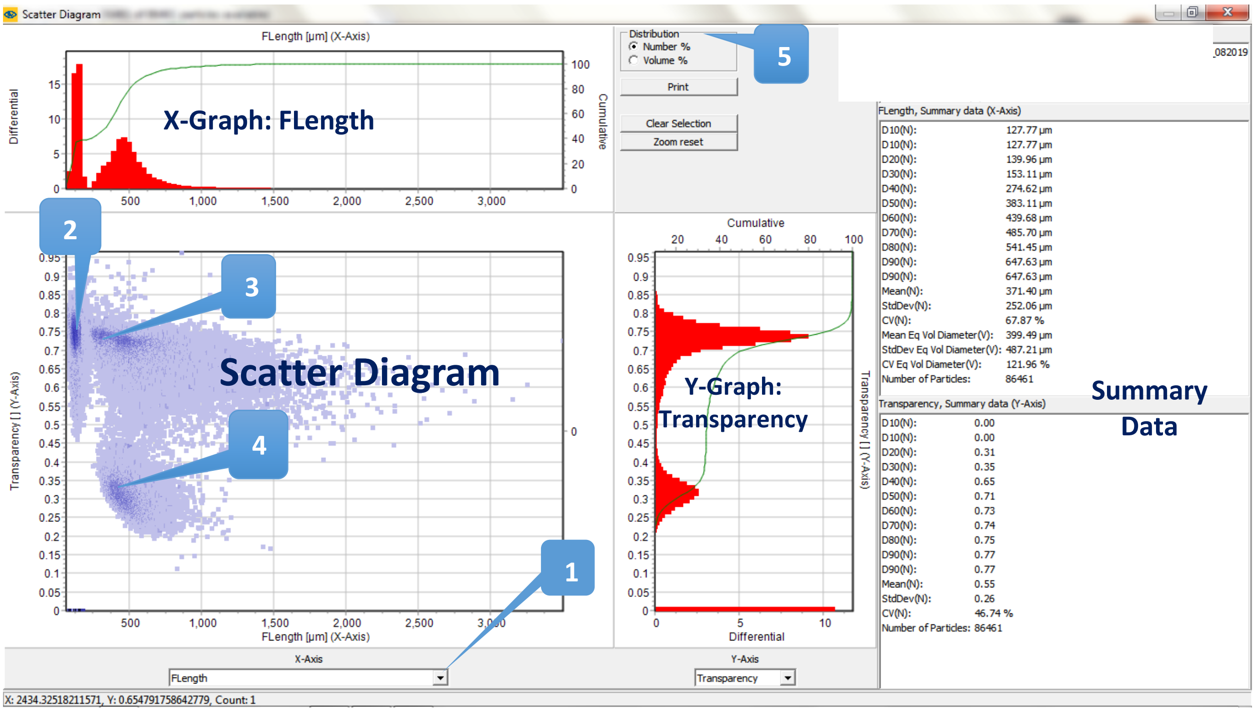


Figure 7. Scatter Diagram: Selected from View Particles display, shows distributions of whatever search has been chosen from the Search Particles window.

Above is the Scatter Diagram which can be opened in the View Particles display just covered. It always displays the distributions of any of the parameters which represent the distribution or sub-distribution selected in View Particles.
This is the Scatter Diagram view for the entire glass bead sample distribution being used as an example.

The Scatter Diagram itself is the diagram in the lower left where the blue dots indicate the location of each particle in the sample with respect to the top red X-axis graph and the right side red Y-axis graph. The darker the blue area, the more dense the population of particles there.
Any of the 30 parameters can be chosen, callout 1, to be plotted on either graph. In this display F or Feret Length is plotted on the X-graph and Transparency in the Y-graph. Transparency is on a scale of 0 to 1 where 1 is a perfectly transparent and 0 is completely opaque.

Looking at the entire sample here is a good way to get started in conducting the particle queries. Here for example we see three areas of high population density – a small size mode at a high transparency, callout 2 in the upper left, a considerably larger sized mode at the same high transparency, callout 3, and a similarly sized mode but at a much lower transparency, callout 4.

The distributions are reported in Number format here, but they can be reported in Volume % also, callout 5. When switched to the volume format, the lowest size mode made up less than 1 % of the total volume of the sample, verifying a small, negligible mode of very fine abraded particles, of little concern. Summary Data for both graphs are listed on the right side of the display.

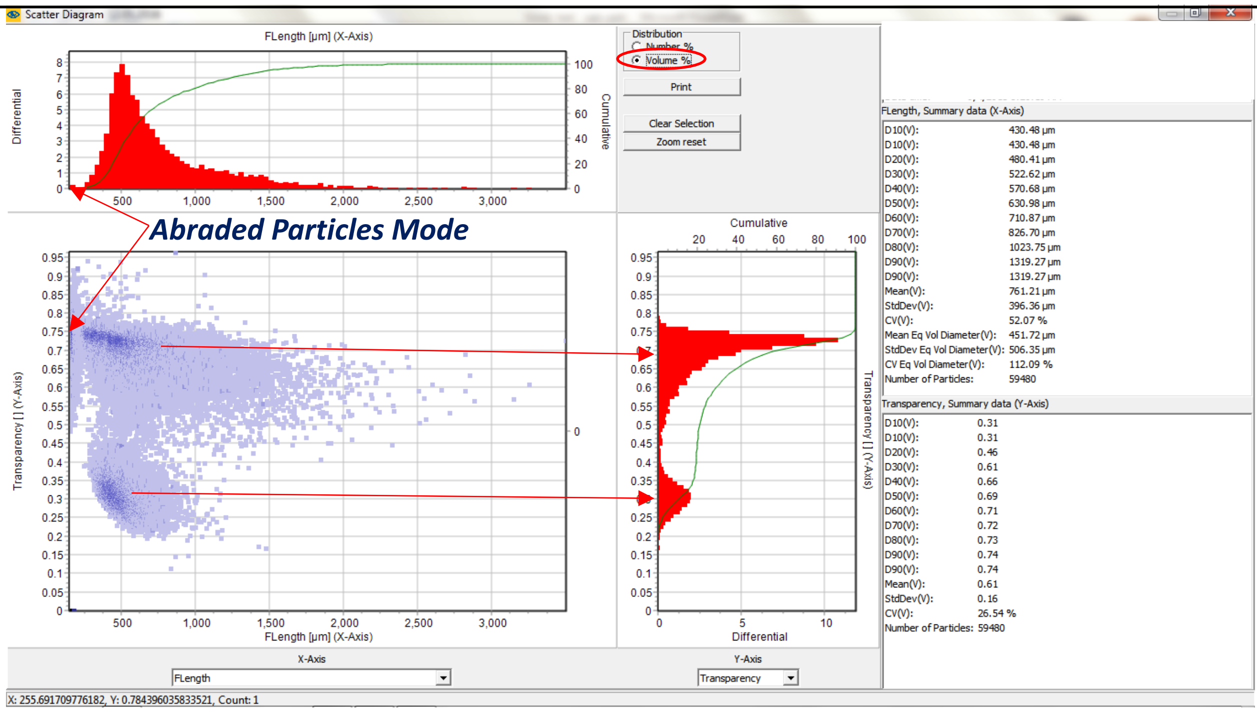


Figure 8. FLength Graph in Volume %: Two high concentration modes at a high Transparency and a lower Transparency.

Here, the same distribution plotted in Volume % format shows that the small abraded particles (dust) mode makes up only a negligible portion of the sample.
The difference in the Transparency of the two concentrated modes can be utilized to isolate, identify and quantify those two different components in the sample.

The Filter Function, display shown below, will be used to quantify the different components. The high Transparency mode is likely made up of glass beads, both good and fused, and the lower mode is likely the sand. We know the fused beads have lower W/L Aspect Ratios than do the good spherical beads. So we can isolate those two populations as well by setting a filter for that shape parameter also.

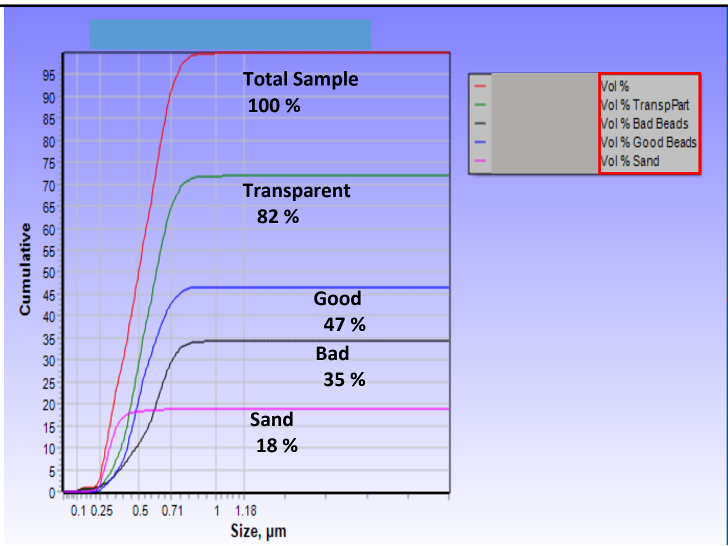
Sieves | Summary Data | Start/Stop control | 3D Tracking | Filter Functions | Particle measurement | Set up for textfile | Advanced SOP Settings

Pre Filter | Post Filter

Filter Set	FMain			F1			F2			F3			F4			F5			F6		
Operator	AND (Class)			AND (Class)			AND (Class)			AND (Class)			AND (Class)			AND (Class)			AND (Class)		
Name										Bad Beads			Good Beads			Sand					
Mode	Passthrough			Include			Include			Exclude			Include			Include			Off		
Depends on		☐ inv		FMain	☐ inv		FMain	☐ inv		F4	☐ inv		FMain	☐ inv		F4	☑ inv			☐ inv	
Value	Min	Max	Seq	Min	Max	Seq	Min	Max	Seq	Min	Max	Seq	Min	Max	Seq	Min	Max	Seq	Min	Max	Seq
Sphericity																					
L/W Ratio																					
W/L Aspect Ratio													0.8	∞	2D						
Ellipse Ratio																					
Compactness																					
Roundness																					
Extent																					
Circularity																					
Solidity																					
Concavity																					
Convexity																					
Transparency							0.6			0	0.4	70				0	0.4	70			
Curvature													0.1		70						
Angularity																					
Krumbein Rnd																					
Da																					
Dp																					
FLength																					
FWidth																					

Table 2. Filter Function: In each filter column limits can be set on any parameters, operators can be AND/OR, Mode can be Include or Exclude. Operation can Depend On the entire sample (F2, F4), or Depend On results of any other filter (F3) or Depend On the Inverse of any other filter (5).

The above filter settings can be selected to become part of the SOP. Then, the various filters can be applied to the measurement results to isolate and quantify the different component populations in the sample. When applied, filter F3 will quantify the Bad (fused) Beads, F4 the Good Beads, and F5 the Sand. Filter F2 quantifies transparent (good and bad) beads.

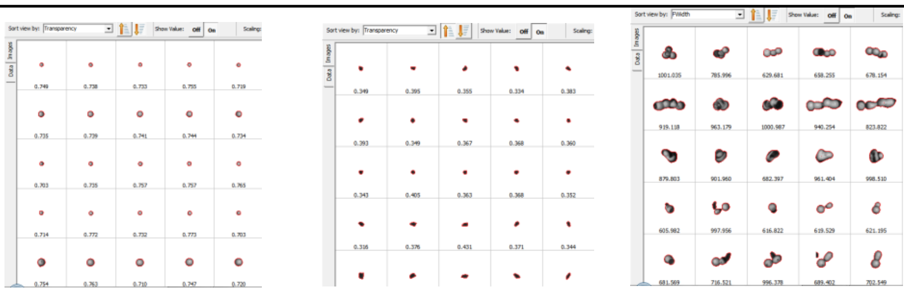


µm	Vol %	Vol % TranspPart	Vol % Bad Beads	Vol % Good Beads	Vol % Sand
1.18	100.00	71.90	34.44	46.65	18.91
1	99.87	71.87	34.35	46.65	18.87
0.71	90.51	64.26	29.14	42.63	18.75
0.5	50.45	29.62	10.94	21.20	18.31
0.355	23.10	7.24	4.09	4.48	14.53
0.25	3.16	1.23	1.14	0.42	1.60
0.15	0.78	0.63	0.59	0.05	0.13
0.1	0.25	0.11	0.11	0.00	0.13

Summary Data

Figure 9. Distributions Graph and Table: Shown as Cumulative Volume % Finer, the various populations of the different components in the sample are given here.

Segments of the image files for each of the component populations are shown below in Figure 10.



Good Beads **Sand** **Bad (fused) Beads**

Figure 10. Components of Reflective Glass Beads Sample: Spherical transparent good beads, blocky opaque sand, fused transparent/opaque beads.

Summary

1. **Reflective glass beads for highway coatings must meet specifications for size distribution and shape.**
2. **Laser Diffraction is an industry standard for measuring particle size.**
3. **Dynamic Image Analysis is now used to measure aspect ratio and transparency, among many other sizes and shapes of particles.**
4. **There is an instrument offered by Microtrac, SYNC, which utilizes those two technologies to simultaneously measure a particulate sample in the same flow stream, in the same sample cell and report a complete size distribution and up to thirty different size and shape parameters.**
5. **Sub-populations of different sample components can be isolated and quantified using the features of the SYNC software.**
6. **The relative proportions of good and fused beads plus sand particles were calculated, all from one sample analysis, for a glass bead sample.**