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## **Flat and Elongated: Advances Using Digital Image Analysis**

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### **Abstract**

Coarse aggregate shape (flat and elongated) is an important issue in the highway industry. Elongated aggregates tend to break down during the asphalt emplacement process. Flat aggregates tend to lay flat, imparting anisotropic properties to the finished product. The new Superpave guidelines call for no more than 10% of coarse aggregates to have aspect ratios greater than 5:1, and there is a possibility of a new standard at 3:1.

Digital image processing is a new approach to measuring these characteristics of aggregates. Currently manual measurements using calipers are employed for flat and elongated. These measurements are not only slow and laborious, but are also highly subjective. Because they are so inefficient and expensive, there tend not to be enough measurements to produce a statistically valid sample.

Two-dimensional shape analysis is possible using such systems as WipFrag or the VDG-40, systems that were originally designed for granulometry rather than for shape measurement. The problem with this approach is that particles tend to lay or fall flat, consequently it is elongation that is measured, rather than the more critical flatness or flat and elongation. This two-dimensional approach has been rejected by the industry as being inadequate.

A new measuring system called WipShape has recently been developed. It images each particle separately, and from two views. A mini-conveyor system has been developed to parade individual fragments past two orthogonally oriented synchronized cameras fed by aggregates from a hopper. This system designed for continuous automated operation, measures flat and elongated aggregates at ratios of 5:1, 4:1, 3:1, and 2:1. Simultaneously it will produce size distribution curves, and shape measurement summaries by size classes.

## **1 Introduction**

### **1.1 Aggregate physical testing standards**

Crushed stone, gravel and sand encompass the bulk of the materials used in highway construction, whether for flexible asphalt, rigid concrete, or unbound pavements. Careful selection of these materials ensures that the pavements will perform as designed, and that the pavements will not suffer from premature deterioration.

Aggregates, consequently, must pass a series of mechanical, chemical and physical tests in order to demonstrate that they will perform satisfactorily, and meet or exceed specifications. Examples of such mechanical tests include abrasion resistance, durability, and resistance to polishing. Chemical tests include sulfate soundness and organic content. Physical tests include aggregate grading (determination of size distributions), aggregate shape, angularity, sphericity, roundness and surface texture.

The test procedures for many of these tests have been well established and are specified, for example, by ASTM standards, AASHTO standards, or Superpave guidelines. In most cases the methods of testing is well accepted by the industry. However, physical testing, such as aggregate grading and aggregate shape has always been a time-consuming, tedious and labor-intensive process. Consequently, these types of tests are often performed reluctantly and infrequently, resulting in test results that are perhaps not statistically representative.

New technologies, such as image processing, promise to increase the efficiency and productivity of such tests. Technologies for generating gradations from images of aggregate material are now commercially available. Technologies for measuring aggregate shape and related parameters are in the process of being developed. This proposal deals with the steps required to bring this technology to common use.

These same techniques can and are being applied to geological materials such as rock. Examples include the use of video gradation techniques for the explosives, mining, and materials handling techniques (Franklin *et al*, 1996; Maerz *et al*, 1996; Girdner *et al*, 1996; Maerz and Zhou, 1999).

A prototype image analysis system for the measurement of flat and elongation of aggregates has been developed (Maerz, 1998), and is described here. When fully developed, this system will be widely used to replace time-consuming subjective manual measurement for aggregate characterization and testing, because of reduced cost, greater objectivity, real time results, and the ability to easily measure enough samples to get statistically valid results.

### **1.2 Impact of image analysis on size and shape measurements**

The potential impact of using image analysis for characterizing aggregate size and shape is immense, in terms of time and cost savings and better characterization of the aggregates.



Figure 1: Proportional Caliper for measuring flat and elongated particles

Taking for example the current methodology for measuring flat and elongated particles, as per ASTM specification D 4791-95 (ASTM, 1995). This involves first obtaining a sample and screening it into the various size fractions. Each piece then needs to be manually handled, by first passing it through one side of the proportional caliper (Figure 1), then rotating it and passing it through the other side. Based on whether the piece passes through the caliper or not it is placed in a separate pile. Each pile, for each size fraction needs to be weighed, and tabulated. If more than one aspect ratio is required, then this procedure must be repeated for each aspect ratio to be measured (3:1, 5:1). If flatness and/or elongation are to be measured individually, the entire task has to be repeated. This task is tedious, and consequently there is a potential for poor implementation and poor results. Because it is labor intensive and time consuming, it is costly. A typical sample may take up to an hour for analysis, and results may not be available for several hours, during which 100's of tons of material may be produced that do not meet specifications. For all these reasons the test is typically underutilized by the industry.

The impacts of a successful image based methodology are numerous:

1. Test results, removed from human subjectivity, will be much more reliable. No longer will the test results vary between operators, or vary based on the disposition of an operator.
2. A greater number of tests will be performed. Faster testing, and the low per unit cost of incremental tests, will result in an increased amount of tests being conducted, allowing better and more statistically valid characterization.
3. Run time adjustments to crushing, screening and other processing equipment will be possible. Because the analysis is quick, a significant reduction of off-specification material can be achieved, and there will be less incentive to pass off-specification material.

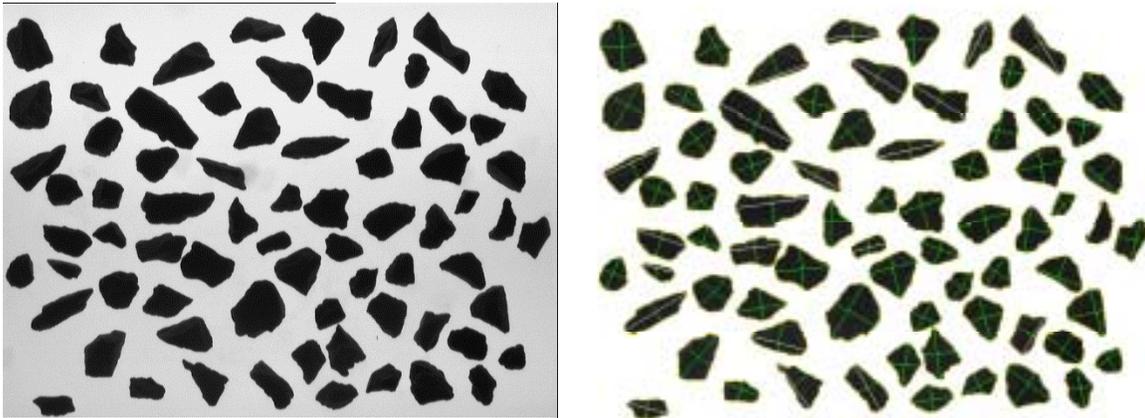


Figure 2. Two-dimensional shape measurements on distributed aggregate samples.

4. There will be a lower burden on operators and testing agencies, resulting from lower per sample testing costs.

Using the proposed imaging methodology, an analysis will be completely automated, requiring only that the operator load the feed hopper with an aggregate material that has been scalped at the #4 sieve size, start the machine, and read the results a few minutes later.

### 1.3 State of the art, new imaging technologies

Currently there are three new classes of imaging technologies currently being developed which purport to measure flat and elongation of coarse aggregates, designed to replace the manual use of a proportional caliper, as per ASTM specification D 4791-95 (ASTM, 1995).

#### 1.3.1 Videograders

The French VDG-40 videograder and the German CPA, are digital optical devices originally designed for determining gradations. They have been purported to be able to measure particle shape in the form of flat and elongation (Weingart and Prowell, 1998). A similar principal has been used by the WipFrag system (Maerz, 1998; Figure 2).

It is, however, doubtful that these devices could successfully determine three-dimensional attributes such as flat and elongation, because of the technology used to present the individual particles to the video camera. In this process the fragments are released by allowing them to slide off of a horizontal cylinder. As a result the individual pieces are all oriented in the same direction, i.e., with a flat side parallel to the plane of the image. Consequently, the methods may well be capable of measuring elongation, but are certainly not capable of measuring flatness, or flat and elongated.

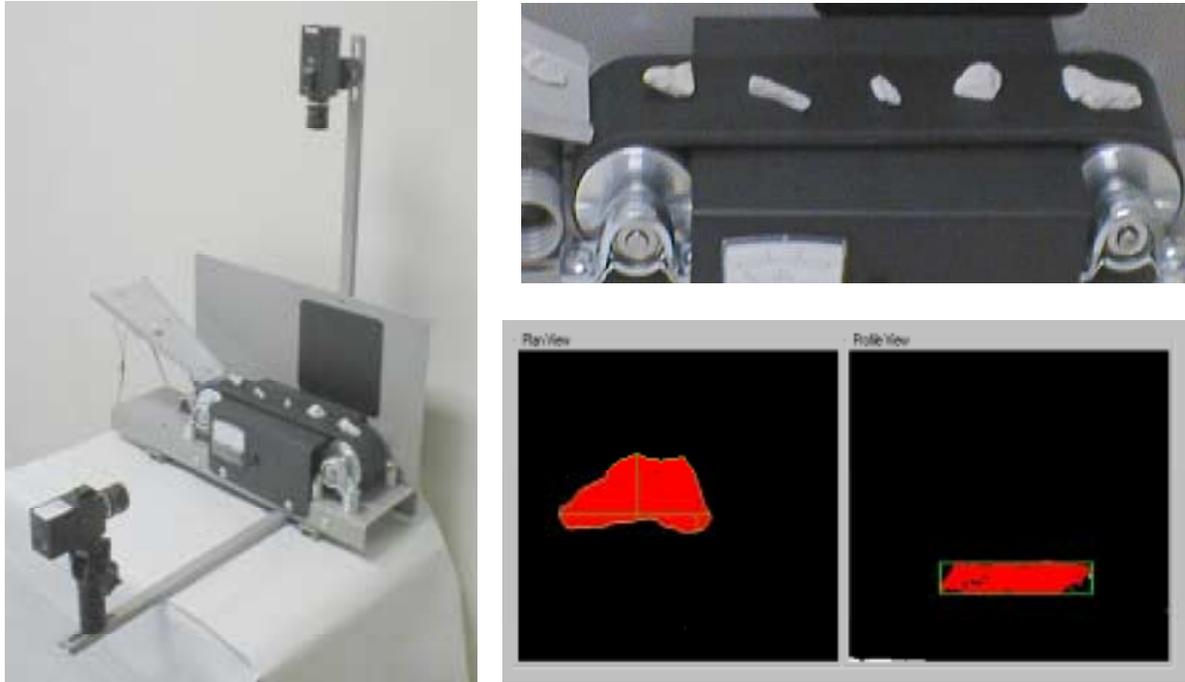


Figure 3. Flat and elongated mini conveyor, with screen dump of the analysis of a single fragment from two views.

### 1.3.2 Three-D static video methods

Several laboratories have developed methods by which particles are stacked in a plexiglas holder, and imaged using two orthogonal cameras, or using a single camera but rotating the holder ( Frost et. al, 1996; Kuo et. al, 1998).

While these methods clearly provide the capability for true three-dimensional measurements, they are still limited because they still rely heavily upon manual intervention to load and reload the holders.

### 1.3.3 Three-D dynamic video method

A method currently under development (Maerz, 1998) uses a moving conveyor to present individual fragments to two orthogonally oriented cameras (Figure 3). When completed, using a specially designed feed hopper, the method will be completely automated.

The status of this system named WipShape is a fully functional prototype for measuring flat and elongated, lacking only the automated feed hopper (Figure 4), and requiring large scale verification studies.

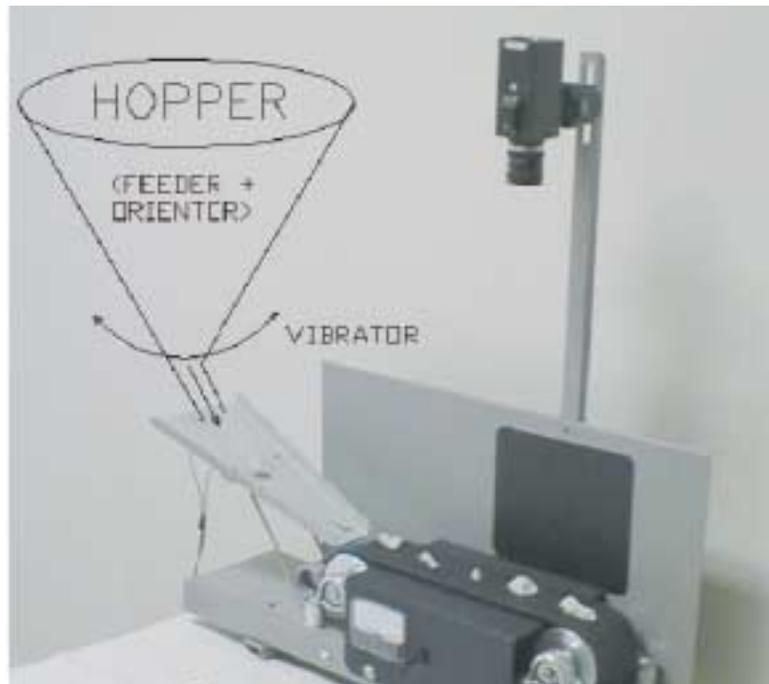


Figure 4. Conceptual drawing of the hopper, feeder, and orientor, for loading aggregates onto the ramp and belt.

## 2. Preliminary verification studies

### 2.1 Manufactured Samples

Preliminary verification studies have been done to test the system. For the purposes of testing, a sample of crushed limestone aggregates was manufactured. Ten aggregate pieces each were selected for each of the 1", 3/4", 1/2", 3/8", 1/4", and #4 sieve sizes (passing) and with flat and elongated ratios of 5:1, 4:1, 3:1, 2:1, and 1:1, for a total of 300 pieces (Table 1).

### 2.2 Process errors

Errors, defined as differences between the manual (proportional caliper and sieve) measurements and image based measurements were found. These reflect different processes and should be thought of as differences rather than errors.

#### 2.2.1 Size measurement

Sieving technology essentially measures the size of the intermediate diameter of the fragment. Given enough time and agitation, the length of the long axis is irrelevant when passing through screens. Consequently, using image analysis, the intermediate diameter is measured and set as the nominal fragment size.

Size/Shape	1:1	2:1	3:1	4:1	5:1
1"	10, 111.70 g	10, 141.94 g	10, 135.88-g	10, 188.81 g	10, 168.74 g
3/4"	10, 79.93 g	10, 76.16 g	10, 58.07 g	10, 96.73 g	10, 82.98 g
1/2"	10, 26.50 g	10, 21.63 g	10, 22.30 g	10, 24.20 g	10, 29.91 g
3/8"	10, 9.86 g	10, 14.76 g	10, 14.34 g	10, 11.17 g	10, 9.38 g
1/4"	10, 1.47 g	10, 4.00 g	10, 2.68 g	10, 4.60 g	10, 4.71 g
#4	10, 1.15 g	10, 1.58 g	10, 1.32 g	10, 2.44 g	10, 1.89 g

Table 1. Manufactured sample by size and shape in terms of number of pieces and mass per class.

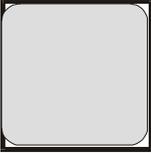
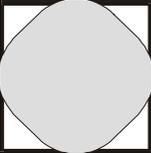
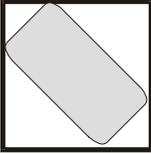
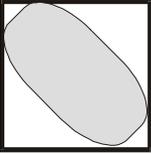
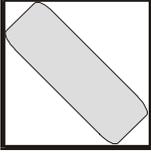
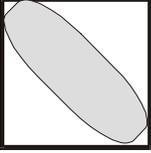
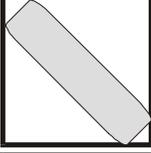
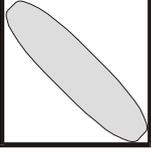
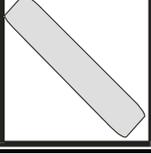
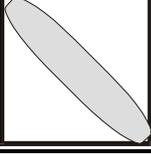
Aspect Ratio	Angular fragments	Maximum Size	Rounded fragments	Maximum Size
1:1		0.75"		0.75"
2:1		0.75"		0.86"
3:1		0.83"		0.91"
4:1		0.91"		0.95"
5:1		0.95"		1.00"

Table 2. Simulation of particles passing through a 3/4" screen. This shows that a 1" rounded fragment with a flatness ratio of 5:1 could pass through a 3/4" screen.

This approach works well with equi-granular fragments, but breaks down when flat particles are encountered. Because the sieve openings are square, there can be a tendency for flat particles, especially those with rounded edges to pass diagonally though the sieve. Table 2 shows this as graphic simulation, indicating that particles with a 5:1 ratio can

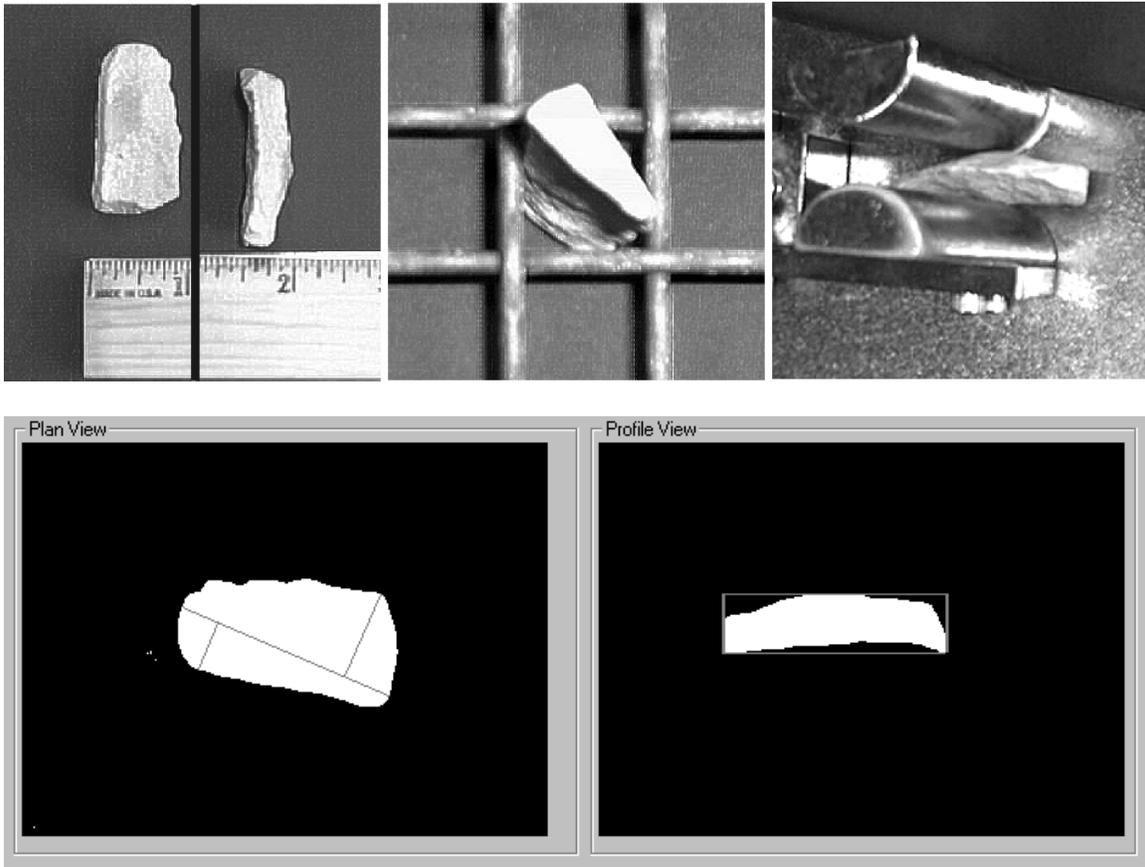


Figure 5. Example of a fragment (top left) with an intermediate diameter of 1" that, because of flatness, passes through a 3/4" sieve (top center). Because of the curvature of the specimen, it has a measured flat and elongated value of 4:1 when using a proportional caliper (top right), but 3:1 using the imaging techniques (bottom).

pass through a sieve screen size that is 75% of the actual nominal size of the particle. Figure 5 shows a particle that has an intermediate diameter of about 1", but fits through a 3/4" screen.

### 2.2.2 Shape measurement

Shape measurements also vary between the proportional caliper measurements and the image analysis results. For the particle of Figure 5, image processing indicates a flat and elongation ratio of 3:1, but because of the curved nature of the fragment, it will pass through the platens at the 4:1 ratio on the proportional caliper.

Size	Pieces	2:1	3:1	4:1	5:1
1.0"	51 54.5%	39 47.6%	28 37.8%	17 24.0%	9 11.6%
3/4"	59 30.9%	45 25.0%	34 18.6%	20 11.8%	11 6.0%
1/2"	45 8.3%	33 6.7%	21 5.2%	9 2.1%	2 0.3%
3/8"	54 4.6%	45 4.2%	31 3.0%	21 2.0%	10 1.0%
1/4"	39 1.1%	32 1.0%	24 0.8%	15 0.5%	11 0.4%
#4	50 0.7%	40 0.6%	30 0.5%	19 0.4%	8 0.2%
Total	300 100.0%	236 85.1%	170 65.9%	103 41.0%	52 19.5%

Figure 6. WipShape output for the sample described in Table 1, showing number of fragments and weight percent as a function of size passing and cumulative flat and elongation ratio.

## 2.3 Comparison to manual measurements

### 2.3.1 Manufactured sample

Figure 6 shows the analysis of the manufactured sample of Table 1. Table 3 shows the percentage point differences between the weight percent of the two analyses.

The results show that there are differences between the manual measurements and the image measurements, most likely reflecting the differences in processes described earlier in this paper.

The most significant difference seems to be the under estimation of 5:1 and 4:1 particles and the overestimation of 3:1 particles using image analysis. Another factor that emerges from this analysis is that the largest fragments dominate by weight, and that if a sample had a significant fine component of flat and elongated, but none in the coarse fraction, the flat and elongation would not be reflected in the overall results.

In this difficult sample, revealed by the variability in individual sizes and shapes, the results are not unreasonable.

Size/Shape	1:1	2:1	3:1	4:1	5:1
1	8.27	10.51	10.06	13.98	12.49
3/4	5.92	5.64	4.30	7.16	6.14
1/2	1.96	1.60	1.65	1.79	2.21
3/8	0.73	1.09	1.06	0.83	0.69
1/4	0.11	0.30	0.20	0.34	0.35
#4	0.09	0.12	0.10	0.18	0.14
total	17.07	19.25	17.37	24.28	22.03

Size/Shape	1:1	2:1	3:1	4:1	5:1
1	6.90	9.80	13.80	12.40	11.60
3/4	5.90	6.40	6.80	5.80	6.00
1/2	1.60	1.50	3.10	1.80	0.30
3/8	0.30	1.30	1.00	1.00	1.00
1/4	0.10	0.20	0.30	0.10	0.40
#4	0.10	0.10	0.10	0.20	0.20
total	14.90	19.30	25.10	21.30	19.50

Size/Shape	1:1	2:1	3:1	4:1	5:1
1	1.37	0.71	-3.74	1.58	0.89
3/4	0.02	-0.76	-2.50	1.36	0.14
1/2	0.36	0.10	-1.45	-0.01	1.91
3/8	0.43	-0.21	0.06	-0.17	-0.31
1/4	0.01	0.10	-0.10	0.24	-0.05
#4	-0.01	0.02	0.00	-0.02	-0.06
total	2.17	-0.05	-7.73	2.98	2.53

Table 3. Summary of the measurement results. Top: Manual caliper results, percentage by weight. Middle: Image analysis results, percentage by weight. Bottom: Difference in percentage points.

### 2.3.2 University of Illinois Study

In a study recently completed by the University of Illinois, samples of rock composed of 9231 fragments with a total mass of 10,647.8 g, supplied by the Illinois Department of Transport (IDOT) were analyzed using the WipShape imaging system. Aggregate pieces were laid down on the belt manually at an average rate of about one fragment every 1.6 seconds. The samples had been previously measured for flat and elongation using the proportional caliper, both by University of Illinois personnel and by IDOT personnel.

The results in Table 4 show that the imaging system results are very close to the results from the manual measurements, especially at the 3:1 ratio. One sample, #52 showed greater error than the rest. This sample contained significant amounts of very dark rock that proved difficult to resolve on the image analysis system.

Sample #	# of particles	Total weight
#62A	1036	1891.4 g
#161	1020	2791.9
#85	739	2596.9
#52	2868	1218.7
#93	1804	1016.5
#86	1764	1132.4

Sample #	IDOT weight %	U. of Ill. weight %	WipShape weight %	U. of Ill. count %	WipShape count %
#62A <3:1	56.7	61.5	66.5	54.5	66.1
>5:1	4.3	2.5	2.1	4.3	3.6
#161 <3:1	89.8	90.7	89.4	83.6	84.1
>5:1	0.6	0.2	1.0	0.5	4.1
#85 <3:1	96.7	97.6	97.1	95.5	94.5
>5:1	0.0	0.0	0.0	0.0	1.8
#52 <3:1	82.9	82.7	71.5	76.2	71.5
>5:1	2.3	1.4	6.6	2.5	8.7
#93 <3:1	90.3	89.8	89.0	83.5	86.4
>5:1	0.8	0.6	1.5	1.1	2.7
#86 <3:1	86.8	88.1	87.5	80.9	84.7
>5:1	1.1	0.4	1.4	0.7	2.0

Table 4. Top: Size of IDOT samples. Bottom: Comparison of IDOT, University of Illinois, and WipShape flat and elongated measurements for <3:1, and >5:1 in terms of weight percentage and count percentage.

### 3. Summary and conclusions

This paper describes a new method of measuring the shape of aggregate particles. Using digital image analysis, the analysis is faster and less subjective than manual measurements.

The long term implications of this technology will be higher reliability, increased testing, quick process control adjustment to reduce off-specification material, and significantly lower testing costs.

Preliminary studies of this emerging technology show that the results can be very close to that of manual measurement. As this technology is still in its infancy, further work will improve its reliability. As well, work is needed to improve the speed of processing, and to completely automate the system by adding a feed hopper.

Further studies will also be able to determine whether current flat and elongated standards are adequate or if they could be improved by utilizing measurements into more elongation classes or breaking them down by different size classes.

#### 4. Acknowledgements

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