INNOVATIVE SYSTEM FOR SCANNING CONSTRUCTION AGGREGATES USING LASER PROFILING

Hyoungkwan Kim (hyoungkwan@mail.utexas.edu)
Graduate Research Assistant, University of Texas at Austin, TX, 78712, USA

Carl T. Haas (haas@mail.utexas.edu)
Associate Professor, University of Texas at Austin, Austin, TX, 78712, USA

Alan F. Rauch (arauch@mail.utexas.edu)
Assistant Professor, University of Texas at Austin, Austin, TX, 78712, USA

Craig Browne (cbrowne@mail.utexas.edu)
Graduate Research Assistant, University of Texas at Austin, TX, 78712, USA

Abstract: A Laser-based Aggregate Scanning System (LASS) is being developed at The University of Texas at Austin. Using a computer-controlled linear motion slide, a laser line scanner is moved over aggregates spread out on a scanning bed to rapidly gather accurate, three-dimensional data. To analyze the raw data effectively, morphological methods and a group texture analysis method are suggested. In the morphological approach, the aggregate properties of particle size and shape are pursued. The group texture analysis method is suggested as a means to characterize collections of aggregate particles.

Keywords: aggregate, automation, group texture analysis, laser profiling, LASS, morphological method, neural network.

1. INTRODUCTION

Stone aggregates are an essential component in portland cement concrete and asphalt concrete. To achieve high quality construction products, it is essential to analyze aggregates before mixing to ensure suitable properties are obtained, especially with respect to particle gradation, fines content, and grain shape. When the aggregate fails to meet the established material criteria, it has to be discarded, reprocessed, or used for other purposes.

In the United States, it is difficult to acquire data in a timely manner using standard aggregate test methods. For example, the sieve analysis (ASTM C136 [1]) requires a significant amount of time and human intervention. Similarly, the standard test method for flat and elongated particles (ASTM D4791 [2]) requires labor-intensive, manual measurements of individual aggregate particles with a proportional caliper.

Aggregate producing plants need a fast, accurate, and reliable way to characterize their product. In an ideal implementation, aggregate on a production line would be evaluated at different points in the process to provide real-time information on the status of the aggregate. Based on the resulting information, prompt, necessary actions could then be taken to improve the quality of the product.

Increased awareness of the importance of aggregate properties and increased expectation of high quality aggregate products are motivating new developments in aggregate characterization. In particular, recent technological advances in information technology, along with a trend to tighten specifications for aggregate properties, indicate a strong need to develop automated methods to determine aggregate size and shape properties.

This paper describes an aggregate testing system currently under development that relies on laser profiling. The system will be used to examine various approaches to the interpretation of the resulting scan data, including morphological methods and a group texture analysis method. In the morphological approach, standard test methods such as ASTM C136 [1] and ASTM D4791 [2] will be simulated. In the group texture analysis method, efforts will be made to create classes that are representative of the group of aggregates scanned. The system is expected to provide various aggregate properties in a fast, accurate, and reliable manner.

2. RESEARCH BACKGROUND

Gradation and particle shape are two primary aggregate properties. Grain size distribution or gradation data is obtained from sieve analyses as specified in ASTM C136 [1]. Elongation and flatness ratios are based on the three main dimensions of a particle, as defined in ASTM D4791 [2]. If a particle is circumscribed in a virtual rectangular prism of minimum size, then the length, width, and thickness of the prism correspond to the longest, intermediate, and shortest dimensions of the particle, respectively. Elongation is then defined as the ratio of the longest to the intermediate dimension, while flatness is defined as the ratio of the intermediate to the shortest dimension.

Digital image analysis has typically been studied as a means of automating aggregate tests of this type. In this technique, images obtained with a digital camera are processed by computer to determine the shape and size of each particle. Efforts by Maerz and Zhou [4] and Rao and Tutumluer [7] have investigated ways to dynamically obtain three-dimensional particle shape information, such as elongation and flatness ratios, from digital image analysis.

Maerz and Zhou [4] developed a prototype imaging system that can provide particle size and shape information. In their research, a mini-conveyor system was used to parade individual particles past two orthogonally oriented, synchronized cameras. Rao and Tutumluer's [7] research was similar, except that they used three orthogonal cameras instead of two. Rao and Tutumluer [7] argue that relying on only two images could yield unacceptable errors in the determination of shape parameters. While both of these efforts were successful in capturing data on the three-dimensional shapes of particles, both systems were rather slow. The scanning rate in these systems is limited by the need to arrange the aggregate particles in a single line, so that two or three images of a given particle can be taken simultaneously.

Some research has been undertaken to characterize aggregates with the aid of laser technology. Tolppanen et al. [10] and Parkin et al. [6] represent two examples. Tolppanen et al. [10] devised a method that can provide exceptionally detailed information on individual particles. They used a laser line scanner mounted on a three-axis coordinate-measuring machine. High-resolution data could be obtained while the scanner was moving around a particle. A major disadvantage with this system is that significant time is needed to acquire the very detailed data on each particle.

Parkin et al. [6] suggested a three-dimensional aggregate inspection and classification system. In this system, aggregate samples are directed into an inspection chamber where they are digitized by two orthogonal scanned lasers. Fourier transforms and an artificial neural network were suggested as a means to assign a predefined class type to each particle. Unfortunately, the results of this research effort have not been reported.

Following a literature review, site visits to aggregate producing plants, and interviews with experts, information was obtained regarding promising technologies for an automated aggregate testing system. The following criteria were established to judge the most promising technology: accuracy, reliability, processing period per sample, applicable aggregate size range, costs, potential for measuring diverse aggregate characteristics, and so forth. The Analytical Hierarchy Process (AHP) [8] was used to compare different technology options through a systematic approach of selecting, weighting and applying criteria. This formal comparison indicated that digital imaging and laser profiling were the most promising technologies. The laser profiling method was then selected for further development to characterize coarse aggregate.

3. LASER-BASED AGGREGATE SCANNING SYSTEM (LASS)

In an attempt to achieve accurate and rapid measurements of aggregate properties, a laser-based aggregate scanning system is being developed at The University of Texas at Austin. Called the "Laser-based Aggregate Scanning System" (LASS), this machine consists of a horizontal gantry system on which a laser line scanner is mounted. This system is designed to provide maximum flexibility for the study of different lighting schemes, scanner velocities, and so on while repeatedly scanning the same field of aggregates spread out on a table. This arrangement provides a convenient representation of the prototype equipment, where the scanner will be fixed and the aggregates will be spread out on a conveyor belt.

Figure 1 shows the assembled LASS. The principle components of this system include:

- A computer-controlled, belt-driven, linear motion slide with a platform for mounting the scanners. This device is about 2.5 m long and can achieve controlled speeds up to 2.5 m/sec over a horizontal travel distance of about 1.5 m. This performance is sufficient to simulate several possible conveyor belt speeds. This device was manufactured by Parker – Daedal Division.
- A laser line scanner with a scan rate of 50 scans per second, scan width of 120 mm, scan height of 220 mm, and resolution of 0.5 mm. This device was manufactured by MEL (Mikroelektronik GMBH, Germany).
- Personal computer with associated cards, etc. to interface with the scanning and motion control equipment.
- Customized software for integrated control of the linear motion slide and the laser line scanner. This software is being written using the

"LabView" platform, a graphical programming language sold by National Instruments (Austin, Texas) that permits extensive flexibility in this type of application.

Support Frame

Fig... 1. ... gregate Scanning

Linear Motion Slide

After spreading an aggregate sample on the scanning platform, the laser lin... h is mounted on the linear mo...on slide, is passed over the sample. With a vertical sensing field, the laser scanner uses a triangulation method to measure the profile of each aggregate pa...icle as it passes the sensing field. Given the velo... r, relatively accurate aggregate volumetric information can be obtained by integrating the profiles. Since the bottom part of each aggregate can not be scanned, an algorithm is needed to estimate, based on information from the scanned upper half, the shape of the lower half of each particle. Figure 2 shows a three-dimensional representation of scanned aggregates obtained by LASS.

Laser Scanner

Scanning Platform

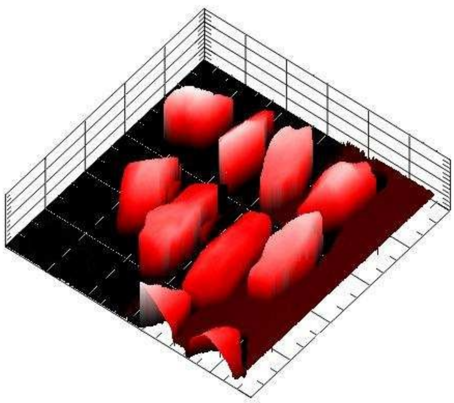

Figure 2. Three-dimensional representation of scanned aggregates.

As mentioned before, Maerz and Zhou's [4], and Rao and Tutumluer's [7] devices are limited in their ability to rapidly acquire data, because only one aggregate particle is scanned at a time. LASS has a 120 mm scan width, which means that as long as the aggregate particles are spread within the 120 mm range, simultaneous scanning of multiple particles is possible. With a resolution of about 0.5 mm in three orthogonal directions, LASS can scan 30 aggregate particles in a second, assuming that the aggregate particles are less than about 10 mm in size.

4. DATA ANALYSIS STRATEGY

From a variety of available methodologies, morphological methods and a group texture analysis method were chosen to analyze the raw scan data. In the morphological methods, efforts are focused on obtaining aggregate gradation and shape properties. The group texture analysis is based on linear transformations and will be used to quantify texture.

4.1 Morphological methods

The word morphology signifies "the form and structure of an object" [5]. Although there are many ways to define this term, morphology is basically related to shape. The digital morphological method is a way to describe or analyze the shape of a digital object [5].

Whether the aggregate property is gradation or particle shape, each particle's data must first be isolated. If the aggregate sample is sufficiently spread apart, a process called region labeling can provide a unique label to each particle. Laser reflectance intensity data and height data will be used as criteria to identify each particle region. Either an 8-neighborhood region identification or the run length encoded data method will be used for this purpose [9].

To extract the three main dimensions of each particle, it is assumed that the aggregates are oriented in the most stable manner. The largest height value can then be considered as the thickness or the shortest primary dimension of the particle. Once the shortest dimension is obtained, calculating the intermediate and longest dimensions becomes a two-dimensional problem. That is, disregarding the height data, the particle image will be projected onto a two-dimensional plane. An algorithm to construct a rectangle that circumscribes the projected image will be developed. The two dimensions of the rectangle will then be the particle's longest and intermediate dimensions, respectively. It is worth noting that the initial assumption conserves significant computing power because the initial three-dimensional problem is transformed into a simpler two-dimensional one.

Gradation, or size distribution information, is another aggregate property that can be obtained using a morphological method. The way sieve analyses characterize aggregate is also based on the size and shape of each aggregate particle. To establish confidence in any automated gradation result, the technique must yield results readily comparable to a conventional sieve analysis [3]. However, this is not as easy as it seems.

To attain results that are sufficiently close to that of a sieve analysis, the data on a given particle must be analyzed to determine two parameters:

- The smallest square mesh opening through which a particle could pass in any possible orientation.
- The weight of the particle, which is generally computed from the estimated particle volume

and the average specific gravity of the aggregate material [3].

This correlation is depicted schematically in Figure 3. It can be said that the particle's two smallest dimensions (width and thickness) govern the smallest mesh opening through which the particle can pass. However, using the width and thickness data alone is not sufficient. As shown in Figure 4, although the width of a relatively flat particle is larger than the sieve size, it can pass the given sieve opening diagonally.

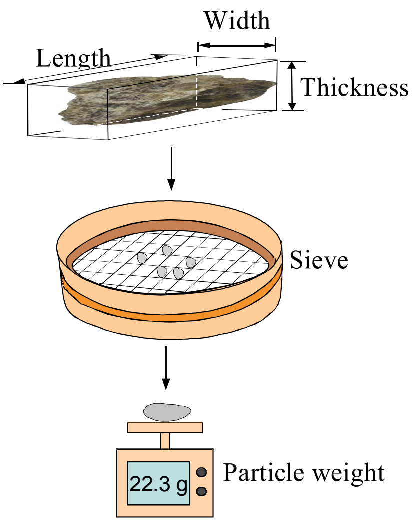

Figure 3. Relationship between three main dimensions of a particle and sieve data.

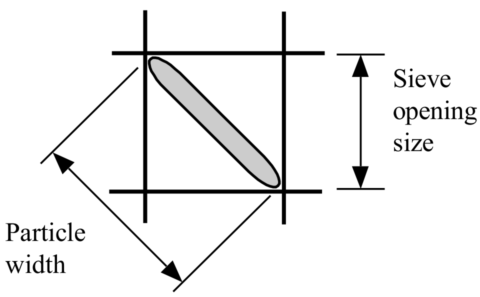

Figure 4. Example of a particle with a width larger than the sieve opening size.

The best way to deal with this problem is to use a projected image of the particle in the length direction, instead of width and thickness. "Virtual sieving" is then performed by attempting to pass the projected image through a square opening of minimum size. Performing this operation a reasonable number of times while rotating the particle by a set increment will provide a result comparable to a sieve analysis.

Specific gravity is another important factor adding to the difficulty in obtaining data that will correspond directly to sieve data. As long as the density of all particles is the same, the percent finer by weight can be accurately computed using particle volumes. However, when the sample includes particles of different minerals, using an average specific gravity may introduce significant error [3].

A tradeoff then arises in this regard. When it is evident that there is a significant difference between a weight-based gradation (sieve analysis) and a volume-based gradation (laser scanner analysis), one may ask how much effort should be made to simulate the conventional sieve results. Indeed, weight-based sieve data became the standard method for characterizing gradation because there was no other practical method to properly measure three-dimensional particle volumes. Ironically, a volume-based gradation would provide a more rational indication of how aggregate particles interact with each other in a three-dimensional way. Experiments are needed to see the magnitude of the difference obtained with each approach.

4.2 Group texture analysis method

In many aggregate test methods, the word "texture" refers to the surface texture of each particle. Indicating surface roughness, texture is measured on a smaller scale than particle angularity. Here, to distinguish the proposed data analysis method from particle surface texture, the word "group" is used with "texture analysis method".

The main objective of performing a sieve analysis is to see how well a group of aggregate particles can be compacted. To determine this property, the aggregate is classified into small size ranges, using a computational or physical division. Ideally, one would characterize a group of aggregates by the way it looks without going through the division process. The group texture analysis method is rooted in this context.

In the machine vision field, texture is defined as "something consisting of mutually related elements" [9]. Namely, texture can mean a combination of texture elements and the relations between each element. When one sees a group of aggregates evenly spread across a plane, one gets a certain impression about the dimensional properties of the particles. If the person sees another group of aggregate that has almost the same aggregate properties, he or she will likely obtain a similar impression. On the other hand, if the person sees another group of aggregate that has different properties, such as gradation and particle shape, there is a good chance of his or her developing a different impression. It is hard to rely on the human eye and one's subjectivity when classifying aggregate. However, if the texture of an aggregate grouping can be quantified, it will be possible to objectively characterize groups of aggregate based on texture.

Linear transformation methods, such as Fourier transforms, will be used to quantify the aggregate group texture. The height data from the scanned aggregate group correspond to the gray level data in a typical two-dimensional digital image analysis. Although the number of required Fourier descriptors is not yet known, a finite number of them will be used to represent the group texture of an aggregate sample.

In this scheme, identical descriptors are not expected to be obtained every time a Fourier transform is performed on the same group of aggregate. The discrepancies will result from irregularities in the texture formed by various aggregate particles. The location and angle of each particle can change freely, depending on how the mix is spread across the scanning bed. In this case, it is necessary to employ an intelligent classifier such as an artificial neural network system.

A neural network system is being considered as a classifier that assigns a class to each group of aggregate scanned. Either a back-propagation method or an unsupervised learning method can be used [9]. In the back-propagation method, well-defined aggregate samples will be used to teach the network how to classify aggregates. It may be possible that standard aggregate properties such as gradation are defined by the outputs of a well-trained neural network. On the other hand, by using the unsupervised learning method, new classes that characterize aggregate can be defined. To demonstrate the validity of these new classes, correlations with existing techniques and properties will need to be studied.

5. CONCLUSION

In this paper, the Laser-based Aggregate Scanning System (LASS), which is being developed at The University of Texas at Austin, was described. LASS, which consists of a linear motion slide, a laser line scanner, and a personal computer system, can rapidly measure various aggregate properties.

To effectively analyze the raw data from scanned aggregate, morphological methods and a group texture analysis are suggested. In the morphological approach, efforts are focused on obtaining aggregate properties based on the size and shape of each particle. Alternatively, the group texture method will be used to characterize groups of aggregate.

Acknowledgments

The authors wish to thank International Center for Aggregates Research (ICAR) for providing the funding that makes this study possible.

REFERENCES

[1] American Society for Testing and Materials. “Standard Test Method for Sieve Analysis of Fine and Coarse Aggregates. C136-A” *Annual Book of ASTM Standards*, ASTM, West Conshohoken, PA, 1999.

[2] American Society for Testing and Materials. “Standard Test Method for Flat Particles, Elongated Particles, or Flat and Elongated Particles in Coarse Aggregate. D4791” *Annual Book of ASTM Standards*, ASTM, West Conshohoken, PA, 1999.

[3] H. Kim, C. Brown, A. F. Rauch, and C. T. Haas. "Technical Aspect of Implementing Rapid Aggregate Gradation" *Proc., 8th Annual Symposium, ICAR,* Denver, Colorado, April. 2000.

[4] N. H. Maerz, and W. Zhou. “Flat and Elongated: Advances Using Digital Image Analysis.” *Proc., 7th Annual Symposium, ICAR,* Austin, Texas, April. 1999.

[5] J. R. Parker. *Algorithms for Image Processing and Computer Vision*, Wiley Computer Publishing, 1997.

[6] R. M. Parkin, D. W. Calkin, and M. R. Jackson. “Roadstone Aggregate: an Intelligent Opto-mechatronic product classifier for sizing and grading.” *Mechatronics,* Vol. 5, No. 5, pp. 461-467, 1995.

[7] C. Rao, and E. Tutumluer. “A New Image Analysis Approach for Determination of Volume of Aggregates.” *Transportation Research Board, 79th Annual Meeting,* Washington, D.C., January 9-13, 2000

[8] T. L. Saaty. *The Analytic Hierarchy Process*, McGraw-Hill Book Company, 1980.

[9] M. Sonka, V. Hlavac, and R. Boyle. *Image Processing, Analysis, and Machine Vision*, PWS Publishing, 1999.

[10] P. Tolppanen, A. Illerstrom, and O. Stephansson. "3-D Laser Analysis of Size, Shape and Roughness of Railway Ballast: Research in Progress." *Proc., 7th Annual Symposium, ICAR,* Austin, Texas, April. 1999.