THE LASER-BASED AGGREGATE SCANNING SYSTEM:
CURRENT CAPABILITIES AND POTENTIAL DEVELOPMENTS

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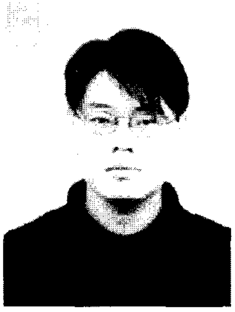

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Abstract

An automated system for scanning and characterizing unbound aggregates, called the "Laser-based Aggregate Scanning System" (LASS), has been developed at the University of Texas at Austin. The system uses a laser profiler to acquire and analyze true three-dimensional data on aggregate particles to measure various morphological properties. Tests have demonstrated that the system can rapidly and accurately measure grain size distribution and dimensional ratios, and can objectively quantify particle shape, angularity, and texture in a size invariant manner. In its present state of development, the LASS machine is a first-generation, laboratory testing device. With additional development, this technology is expected to provide high-quality, detailed information for laboratory and on-line quality control during aggregate production.

Keywords: aggregate, angularity, automation, laser profiling, particle descriptors, particle shape, sieve analysis, texture

Introduction

Increased awareness of the importance of aggregate properties, coupled with increasing expectations for high quality aggregate products, are motivating new developments in particle characterization. In particular, recent advances in computer and sensing technologies, along with a trend to tighten specifications for aggregate properties, indicate a strong need to develop automated methods to measure aggregate properties (Kruse 1999).

A prototype machine called the "Laser-based Aggregate Scanning System" (LASS) was developed for characterizing aggregates. Using laser profiling, digital image analysis, and signal processing methods, this system can measure various morphological properties of aggregate particles in an accurate, three-dimensional (3D) manner. After the LASS hardware and software architecture is briefly described, results are presented from studies to evaluate the capabilities of the system to determine the size, shape, and texture of aggregates. Finally, potential laboratory and field applications of the technology are addressed.

Laser-based Aggregate Scanning System (LASS)

The LASS consists of a laser line scanner, a linear motion slide, and a personal computer (Figure 1). To acquire 3D surface data on an aggregate sample, the laser scanner moves on a horizontal gantry (the linear motion slide) and passes over particles scattered on a platform. This arrangement provides a convenient representation of the system as it would be installed in the field, where the aggregates would be spread out on a conveyor belt with the laser scanner fixed above.

After the 3D aggregate data is acquired, data analysis begins. Since randomly scattering an aggregate sample is likely to result in numerous particles that are touching each other, a segmentation algorithm was developed to digitally separate individual particles in the scan data. Data points on each particle are then analyzed to obtain properties such as grading, dimensional ratios, shape, angularity, and texture. More details on the LASS hardware and software architecture can be found in Kim et al. (2001a; 2001b; 2002).

Measurement of Gradation

In a process called "virtual sieving", each particle's projected image along the longest dimension is incrementally rotated to find the smallest circumscribing rectangle. That rectangle's largest dimension is then assumed to represent the smallest mesh size through which the particle can pass. The cumulative gradation of the aggregate sample is then obtained by sorting the particle data according to the equivalent mesh size, then representing them as cumulative percentages of the total sample volume.

Ten aggregate samples were manually sieved and scanned by the LASS to verify the virtual sieve algorithm. Using aggregate from four material sources, the evaluation test samples were manually mixed to three different gradations. The sample designations are given in Table 1. After the aggregate particles were manually spread on the LASS platform, they were scanned and processed to determine the grain size distribution of each sample. Scanning and sizing took approximately 5 to 8 minutes per kg of sample.

The grain size distributions measured in these tests are plotted in Figure 2. Excellent agreement is exhibited between the manual sieve and the LASS analyses. Note also that the LASS provides a continuous gradation curve across the full range of particle sizes, as opposed to the discrete sieve data representing the quantity of particles in a given size range.

The accuracy of LASS gradation measurements was also compared to that of five other automated grading machines. As described by Browne et al. (2001), evaluation tests were previously conducted on the VDG-40 Videograder, Computerized Particle Analyzer (CPA), OptiSizer PSDA^{TM}5400, Video Imaging System (VIS), and the Particle Size Distribution Analyzer (PSDA). All of these other machines process 2D digital images of falling particles to determine gradation. The same aggregate test samples used in the tests described by Browne et al. (2001) were scanned and processed by the LASS.

To quantify the accuracy of machine-generated gradation curves with respect to standard sieve analyses, Browne (2001) considered different statistics for expressing the overall deviation between the machine and sieve test results. This included the "Cumulative and Normalized Weighted Error" (CANWE), which is computed by summing the weighted, absolute difference between the machine and sieve data in each size range and normalizing with respect to the weights. The weighting factors were defined to represent the number and size of particles in each sieve range. Developed by Browne (2001), the CANWE statistic gives a reasonable measure of the overall accuracy of a machine-generated gradation curve across the full range of particle sizes in a test sample.

The accuracies of the different automated machines, relative to standard sieve data, are plotted in terms of CANWE values in Figure 3. Since CANWE is an error statistic, smaller values indicate better accuracy. The magnitude of CANWE is thus plotted downward in Figure 3, to enhance the perception that shorter bars (closer to zero) indicate better performance. The data in Figure 3 indicates that the LASS exhibited the best accuracy in almost every case, with a few exceptions.

Measurement of Dimensional Ratios

A computer algorithm called the "virtual proportional caliper" was developed to measure particle dimensional ratios with the LASS. This algorithm first finds a particle's shortest dimension, based on the assumption that particles tend to rest flat on the scanning platform. Next, the particle data are incrementally rotated about the axis of the shortest dimension to find the smallest circumscribing rectangle. The results yield the particle's principal dimensions (thickness, width, and length), which can be used to calculate elongation and flatness ratios. In this manner, the LASS can be used as an alternative to tedious, manual measurements with a proportional caliper as indicated in ASTM D4791.

To verify the LASS results, direct manual measurements were made of a collection of stone particles using a vernier caliper (0.025 mm accuracy). Altogether, 200 particles were numbered and measured, each with a longest dimension between 7 and 26 mm. The number of particles was selected to yield statistically valid results given that some variability, related to the positioning and orientation of particles in a particular scan, is expected. To get test samples with a range of particle colors and surface textures, four different aggregates types (limestone, traprock, quartzite, and granite) were procured from different quarries. Fifty particles were randomly selected from each of the four source materials to obtain 200 test particles. The manual measurement of the 200 particles, with the aid of a computer spreadsheet program to calculate the elongation and flatness ratios, required approximately four hours.

After the manual measurements were completed, the particles were scattered on the LASS platform, scanned, and analyzed. The resolution for the X, Y, and Z directions of the scanner were 0.3 mm, 0.3 mm, and 0.5 mm, respectively. It took 70 seconds to scan the 200 particles, and 40 seconds to calculate elongation and flatness ratios.

The LASS determination of the elongation and flatness ratios are compared with the manual measurements in Figure 4. The elongation ratio and flatness ratio measurements obtained from the LASS correlate strongly with the manual measurements, with coefficients of determination of 0.84 and 0.80, respectively.

Particle Descriptors

The LASS software also includes algorithms for computing advanced parameters that represent the shape, angularity, and texture of scanned aggregates. Most research in this area has attempted to define these particle characteristics using different scales for the observed irregularities, but this approach generally suffers from inconsistencies in the way properties on different scales are defined. To provide a more generalized and size invariant approach to 3D particle description, new particle descriptors were developed using a signal processing method called "wavelet transforms" (Kim et al. 2002). Conversion of these transforms to a spherical coordinate system and normalizing with respect to particle radius renders this approach invariant to particle size. The three particle descriptors (shape index, angularity index, and texture index) are defined using six levels of the wavelet decomposition. Custom software was developed to compute the wavelet-based 3D particle descriptors from the LASS data.

To evaluate the potential usefulness of the proposed particle descriptors, 3D data was obtained on particles of rounded limestone river gravel, crushed limestone, crushed quartzite, and crushed granite. The size of the particles used for these tests ranged from 22 to 58 mm in their longest dimension. Each tested particle was scanned twice in opposite directions by the LASS; the two data sets were then merged to minimize possible data loss resulting from "self occlusion" in the laser profiles (Sonka et al. 1999). For 20 particles, it took about 7 to 10 minutes for the data acquisition and merging process and about 25 sec to analyze the data. Approximately, a 0.3 mm/pixel resolution was obtained and, to keep the raw data as intact as possible, signal noise was not removed.

For testing of the shape index, each test particle was visually classified for shape based on its apparent principal dimensions. Twenty particles were identified as equidimensional and another 20 particles as flat or elongated. The average flatness and elongation ratios of the equidimensional group were 1.3 and 1.3, respectively, while those for the flat or elongated group were 2.5 and 2.2, respectively. After the wavelet transform was conducted on data from the 40 particles, the shape indices were calculated for each particle. Figure 5(a) shows excellent correlation between the wavelet shape indices and the visual classifications.

To test the angularity index, 20 round particles and 20 angular particles were selected. Particles that have sharp edges and relatively plane sides with unpolished surfaces (as defined in ASTM D2488) were classified as angular, whereas particles with no apparent edge were considered rounded. As can be seen in Figure 5(b), the computed angularity indices show strong agreement with this visual perception of angularity.

The same approach was taken in evaluating the texture index. Based on the visual inspections with such criteria as the degree of fineness and uniformity, two groups of 20 particles each were formed: one was smooth and the other was rough. Figure 5(c) also shows high correlation between the texture indices and visual classifications, demonstrating that the wavelet-based descriptor is a promising tool to measure particle surface texture.

Potential Applications

The LASS technology produces much more detailed information on an aggregate sample, and in less time, than can be obtained from manual methods. The technology is a rapid, accurate alternative to sieve testing. The LASS device is also an especially fast alternative to manually measuring flatness and elongation ratios with a proportional caliper. More generally, using a wavelet transform technique that incorporates particle information in a comprehensive manner, the LASS can objectively characterize the shape and texture of individual particles. By correlating the quantified particle properties with the performance of construction materials, these 3D particle descriptors could lead to the development of better unbound aggregate, hot-mix asphalt, and concrete mixtures.

While other computerized devices for characterizing aggregate size and shape process 2D digital images, the LASS technology yields true 3D data from each particle. Consequently, the LASS results tend to be more accurate. While processing 3D data can be computationally intensive, the LASS characterizes aggregates in a fast manner by converting the 3D data into an image format.

In its present state of development, the LASS is an excellent research laboratory device for characterizing irregularly shaped stone particles. Before the machine could be used for routine testing in a materials laboratory, however, several improvements are needed. First, an automated mechanism for scattering aggregate samples on a belt, which would then pass beneath a fixed scanner, needs to be built. This system might include a mechanical vibrator to spread particles across the moving conveyor belt. Second, the LASS software needs additional development to simplify the user interface.

The LASS technology is also suitable for field applications, where the device could be employed in a "grading station" (Kim et al. 2000). In some field applications, a LASS device might be deployed to detect variations in the product stream, rather than to perform a complete characterization of discrete samples. For example, material on a crusher discharge conveyor could be monitored directly for variations in the percent passing a certain sieve size, with the information used to detect when crusher adjustments are needed. In this application, not every individual particle would have to be characterized, and a much simpler and faster method of data analysis could be developed for an on-line LASS device. Given the ability to acquire 3D data, it is probably feasible to position the device to scan material piled on a moving conveyor belt and still gather sufficient information to monitor variations in the production stream.

Conclusions and Recommendations

The Laser-based Aggregate Scanning System (LASS) was developed to accurately measure grain size distributions and dimensional ratios, as well as more advanced morphological properties like particle shape, angularity, and texture. Evaluation studies have shown very strong correlations between LASS measurements of these properties and manual measurements (or human visual perceptions). The LASS is a powerful tool for characterizing construction aggregates; the 3D data acquisition capability, along with the efficient analysis algorithms, provides accurate and fast characterization of aggregate particles.

More work is needed to improve the capabilities of the LASS technology. A mechanical sample spreader could be added to the LASS to automate sample handling. It would also be important to make the software more user-friendly. When implemented, the ability to automatically analyze multiple characteristics of an aggregate sample is expected to provide the necessary information needed to optimize quality control during aggregate production.

Acknowledgement

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Table 1. Descriptions of aggregate samples for gradation tests.

Gradation designation	Description of gradation	Sample size(kg)	Material source			
			TX	VA	CA	SD
C-STD	Coarse standard, with most particles larger than 4.75 mm (#4 mesh)	6.0	·	·	·	·
C-SM	Similar to C-STD but with proportionally more smaller particles	6.0	·	·	·	·
C-LG	Similar to C-STD but with particles up to 38 mm (1.5 inch)	15.0	·			
C-RND	Same as C-LG but with mostly rounded particles	15.0	·			

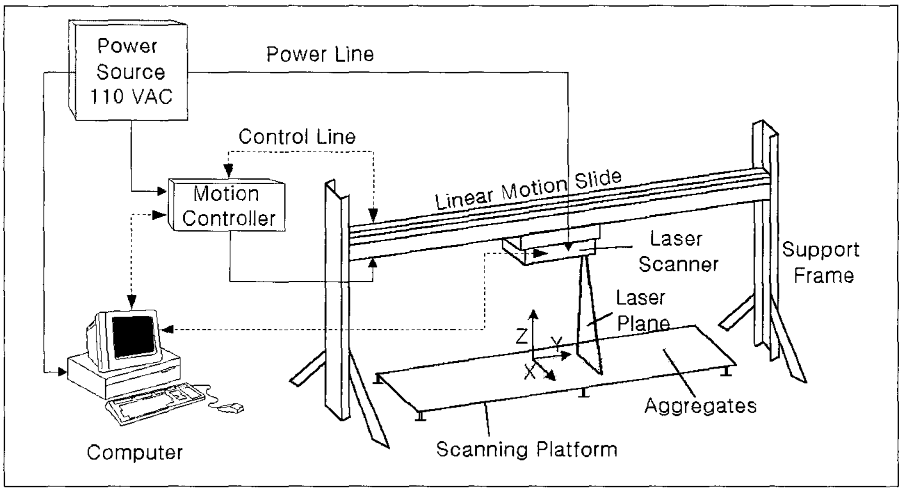


Figure 1. The LASS hardware architecture.

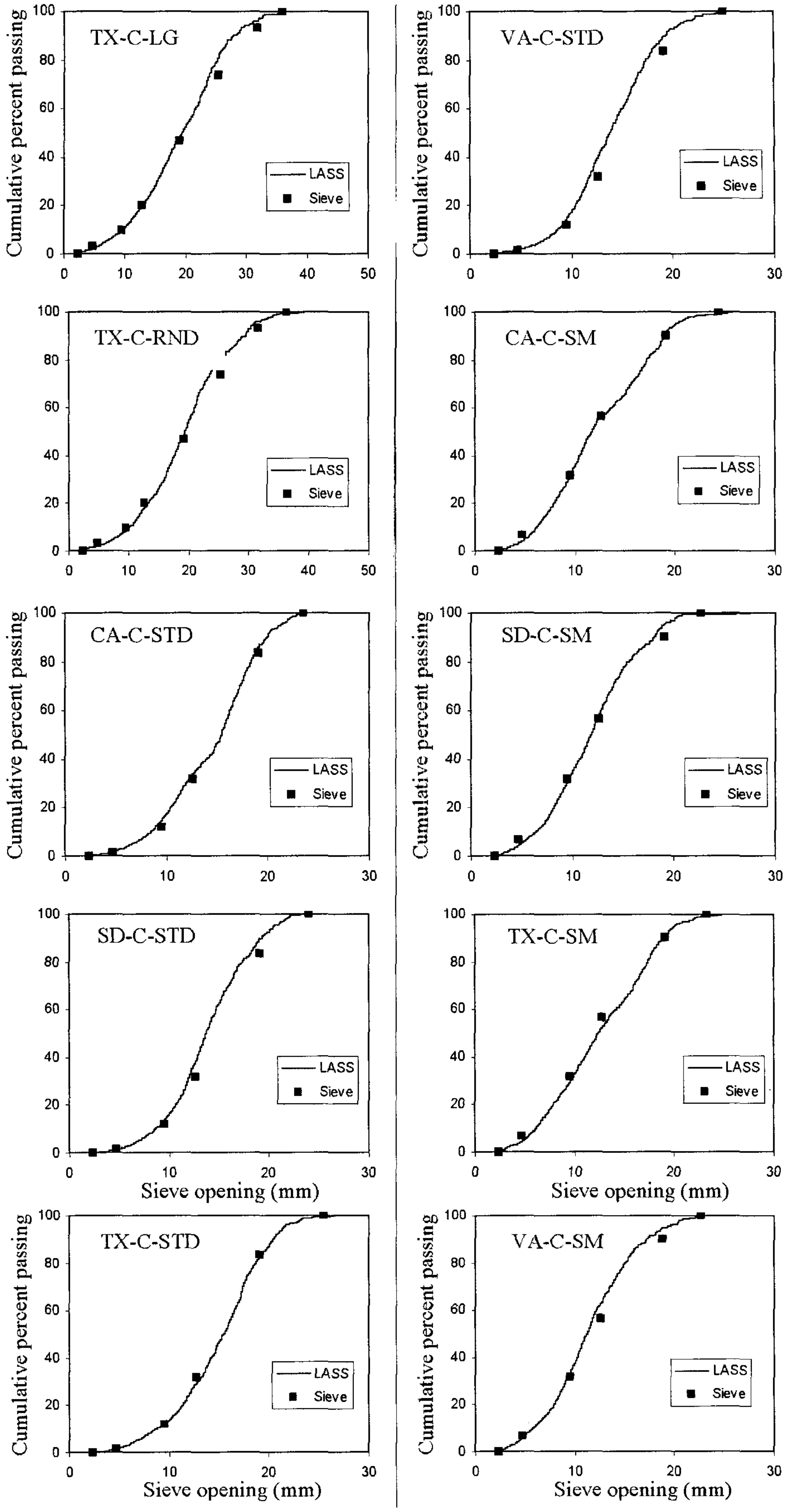


Figure 2. Comparison of size distribution results between manual measurement and the LASS measurement.

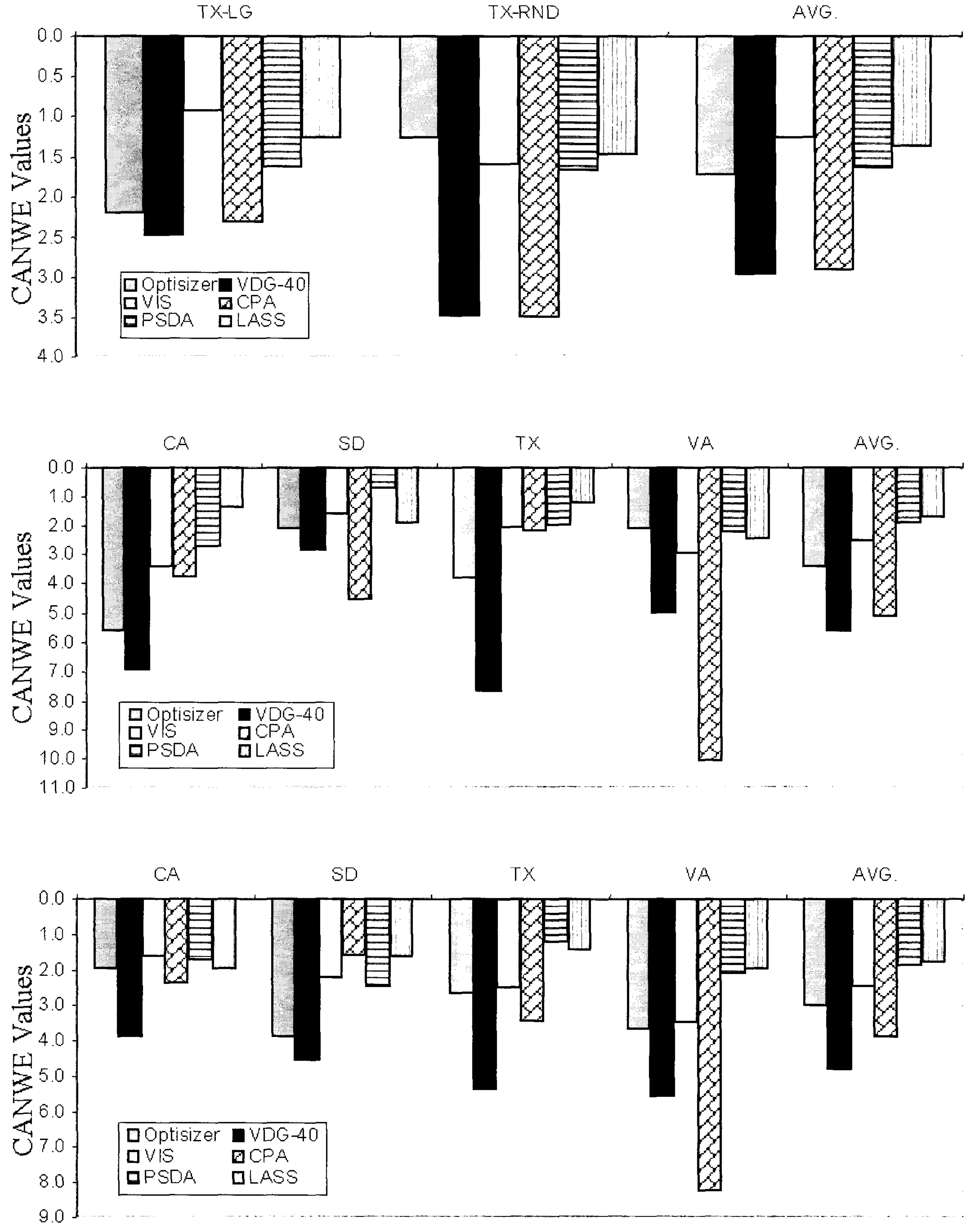


Figure 3. Comparison of machine accuracies in measuring grain size distribution based on the CANWE statistic.

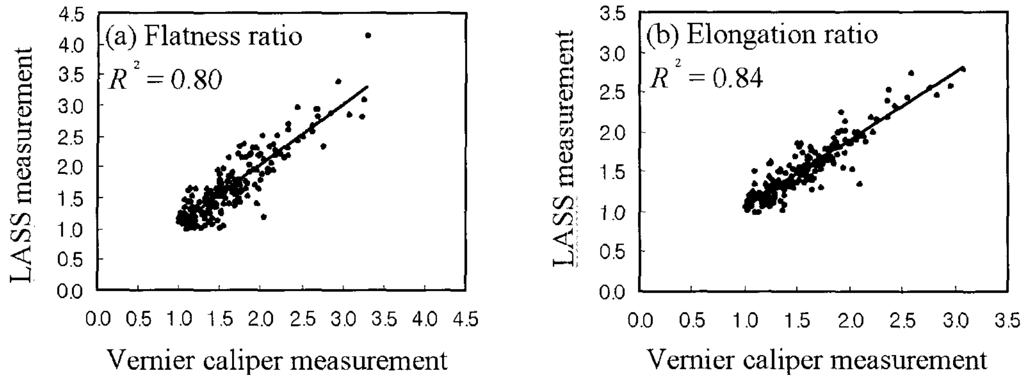
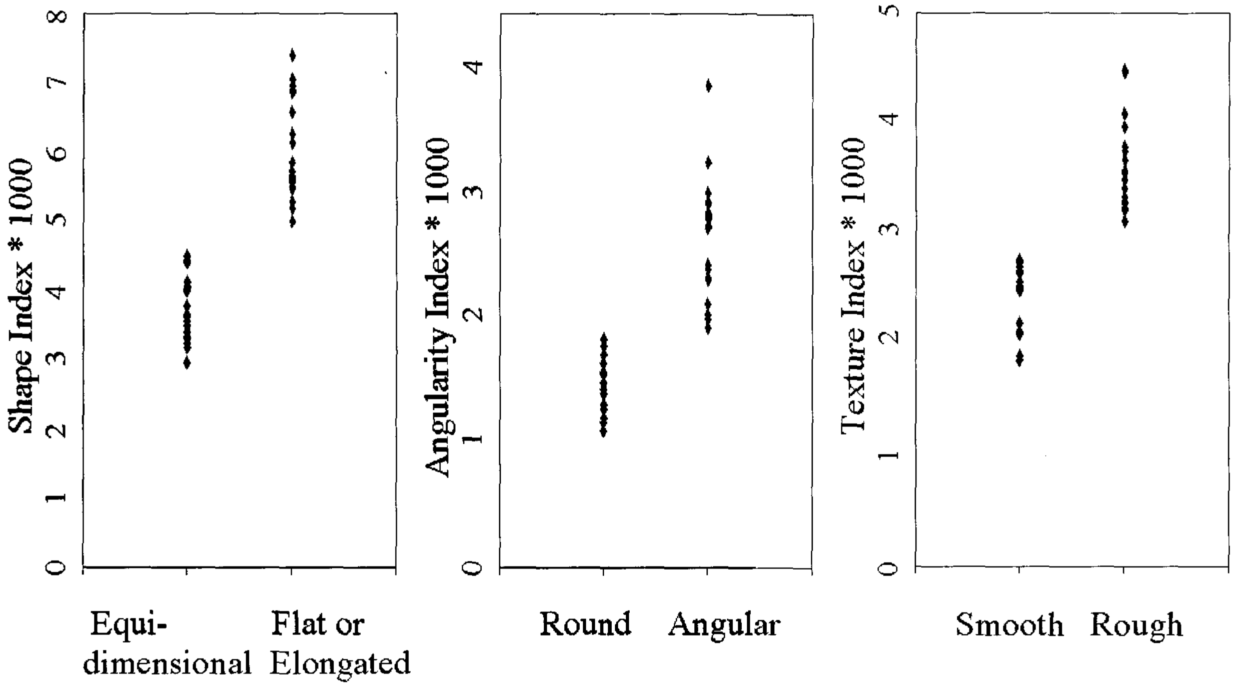


Figure 4.Comparison of the dimensional ratios measured with the vernier caliper measurement and with the LASS.



(a) (b) (c)

Figure 5.Correlation between wavelet-based particle indices and visual inspections.