1996 Executive Summary

Title: Methods of Classifying Sand Shape and The Effects of Sand Shape on USGA Specification Rootzone Physical Properties

Project Initiation: July, 1996
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Sand shape has been shown to have an influence on soil bulk density, compactibility, total porosity, aeration and capillary porosity, playing surface stability, and root penetration. However, specifications and recommendations concerning the shape of sand for use in USGA rootzone mix construction is lacking. The purpose of this project is to determine a fast, inexpensive and quantitative way to determine the shape of sands used in putting green rootzone mixes. In addition, we will determine the effect of shape on rootzone mix physical properties.

Our methodology for determining sand shape involves visual and mechanical assessments. The visual methods being tested include the Riley sphericity index and a Krumbein roundness chart. These methods are subjective. Another way for determining sand shape may be through the use of the shape analysis software program ArcInfo. This software was developed for global information systems and land analysis. ArcInfo determines the number and lengths of arcs required to outline the sand grain silhouettes, as well as perimeter lengths, volume and axis lengths. The various parameters are compared to standard sand grain values from Figure 1 of the USGA Specifications.

Mechanical methods being tested include: 1) Direct shear method - this determines the amount of sidewards force (shear force) required to cause the sand to slide over itself while a static downward force is being applied. An angular material should require more shear force than a round material. So far we are finding that mixtures of sand sizes and compaction help to delineate between round and angular sands; 2) Rotatable drum method - this method determines the critical angle that an uncompacted sand can reach before it begins to avalanche. Our angular sand has a greater critical angle than the round sand, but further testing is still needed to maximize these differences; 3) Dense soil angle of repose - In this technique the sand is compacted with a vibrator and then tilted until it fails at some critical angle. As in the rotatable drum method, the critical angle should be related to the surface characteristics of the sand. We are currently building the apparatus required to perform this test; and 4) The cone penetrometer - The force required to push a cone shaped tip into a confined sand sample is measured. An angular sand should offer more resistance. We have not begun testing this method yet.

We are also determining the physical properties of the sand materials as outlined by USGA specifications while visual and mechanical tests are being performed. Recently we have completed USGA testing on the round and angular sands when mixed with different proportions of fine or coarse peat, as well as with small amounts of a silt loam soil. These results have not been analyzed yet.

1996 Annual Progress Report

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Objectives

Sand shape has been shown to have an influence on soil bulk density, compactibility, total porosity, aeration and capillary porosity, playing surface stability, and root penetration. However, specifications and recommendations concerning the shape of sand for use in USGA rootzone mix construction is lacking. The current recommended method for determining sand shape is to compare magnified sand grains to a chart showing different degrees of sphericity and roundness (smoothness). The method is tedious and fairly subjective. In addition, once a sand is classified there are no recommendations to be made concerning the effect of the shape on its use.

The objective of our two-year study is to determine if a simple, inexpensive and quantitative procedure can be used to give a reliable estimate of sand shape. Hopefully, such a procedure could be adopted by laboratories to accurately determine the shape of a bulk sample of sand. At the same time methods for determining sand shape are bieng tested, we will determine the effects of sand shape on rootzone mix physical properties and how USGA specifications might be modified to account for the shape of the sand.

Materials and Methods

Our methodology for determining sand shape involves visual and mechanical assessments. The visual method uses the Riley sphericity index and a Krumbein roundness chart. The sphericity index measures how globe-like a particle is by finding the ratio between the largest inscribing circle that can fill a magnified sand grain and the smallest circumscribing circle around that grain. A perfectly spherical grain will have an index of 1.0. Roundness, or smoothness, is a visual determination comparing the grain surface to a smoothness chart. A round grain may or may not be spherical and a spherical grain may or may not be round. Another way for determining sand shape may be through the use of the shape analysis software program ArcInfo. This software was developed for global information systems and land analysis. In this procedure sand grain images (35 mm slides) are scanned as Tiff images into a PC. The images are edited in Adobe Photoshop or Paintshop Pro to remove background differences. ArcInfo then determines the number and lengths of arcs required to outline the grain silhouettes, as well as determine perimeter length, volume and axis lengths. The ratio is then compared to standard sand grain values from USGA Specifications (Figure 1) and a sphericity and smoothness value assigned. This method will hopefully allow for the analysis of many grains at one time, thus giving a better estimate of the bulk sands shape.

Mechanical methods to be tested include: 1) Direct shear method - this determines the amount of sidewards force (shear force) required to cause the sand to slide over itself while a downward force is being applied. An angular material should require more shear force than a round material due to the frictional resistance of the individual grains towards sliding; 2) Rotatable drum method - this method determines the critical angle that an uncompacted sand can reach before it begins to avalanche. A less smooth and less spherical sand should have a greater critical angle than a smooth, spherical sand; 3) Dense soil angle of repose - In this technique the sand is compacted with a vibrator. The sand is then tilted until it fails at some critical angle. As in the rotatable drum method, the critical angle should be related to the surface characteristics of the sand; and 4) The cone penetrometer - The force required to push a cone shaped tip into a confined sand sample is measured. A spherical, round sand should offer less resistance than a non-spherical, non-round sand.

While these mechanical tests are being conducted on our sands we will also determine the physical properties of the sand materials as outlined by USGA specifications. At the end of our study we will be able to state if any of our methods can accurately determine shape and how shape relates to the physical properties of the rootzone mixes.

Results and Discussion:

Currently we have focused our attention on the 0.25 to 0.5 mm fraction of a round sand from U.S. Silica in Ottawa, IL and an angular sand from U.S. Silica in Mapleton, PA.

The physical properties of the materials are shown in Table 1.

Table 1. Comparison of physical properties of 0.25 mm fractions of a round, spherical sand and an angular, non-spherical sand. Compacted data shown in parentheses.

Parameter	**Round Sand**	**Angular Sand**
Bulk density	1.62	1.52 (1.8)
Total porosity (v/v)	39.2	45.8 (16.4)
Aeration porosity (v/v)	33.1	32.2 (4.3)
Capillary porosity (v/v)	6.1	13.6 (12.1)
Ksat. (in./hr.)	74.5	32.9 (12)
Sphericity index	0.87	0.77
Krumbein roundness	0.83	0.57

Table 1 tells us something about the effects of shape on sand physical properties. The round sand has a greater bulk density than the angular sand under uncompacted conditions. This higher bulk density is reflected in a lower total porosity with most of the pore space as macropores (aeration porosity). Initially, the angular sand has a lower bulk density due to a greater total porosity, but a larger percentage of micropores are also observed. After compaction we found that the round sand had remained be essentially unchanged in its physical properties. The angular sand shows dramatic changes though, as shown by the values in parentheses. The bulk density of this material increased to 1.8 while total porosity fell to 16.4% and aeration porosity decreased to 4.3%. Capillary porosity under compaction represents 74% of the total porosity of the angular sand and Ksat fell from 32.9 to 12 in./hr.

Direct Shear Strength Machine

The shear strength machine was used with standard protocols on 0.25 to 0.5 mm round or angular sand having the physical characteristics shown in Table 1. In these tests the sand is placed into a shear strength cell and a downward (normal stress) force of either 30, 60 or 90 pounds is applied. As normal stress increases we observe that an increasing sidewards force is required to cause the upper and lower halves of the cell to slide. This sidewards force is the shear force. The sand is then repacked and the shear force determined at the next higher normal stress force. A plot of shear stress vs normal stress is developed and the tangent of the angle of the line is the internal friction angle. Table 2 shows expected friction angle values for non-cohesive soils.

Table 2. Approximate expected friction angles of non-cohesive soils under different compaction levels.

Classification	Compaction	Expected Value†
Round - uniform	Light	30
Angular - uniform	Light	34
Round - not uniform	Light	34
Angular - not uniform	Light	40
Round - uniform	Medium	32
Angular - uniform	Medium	36
Round - not uniform	Medium	38
Angular - not uniform	Medium	48

†From B.K. Hough. 1957. *Basic Soils Engineering.* Ronald Press Company.

Table 3 shows that the friction angles obtained for our test materials are within the range of the expected values (Table 1). The greatest differences in friction angles between the round sand and angular sand occurred when (a) the 0.25 mm materials were packed to a bulk density of 1.6; and (b) when a mixture of sand sizes was used at either a bulk density of 1.4 or 1.5.

This initial work seems to indicate that a mixture of sizes may result in the greatest differences in friction angle because of the way in which the particles lock together. However, our results are showing that the round sand has a greater friction angle than the angular sand. This is in opposition to the results we expected. We will continue working with these sands and others to see if this remains the case and also to examine more sand size mixtures and bulk densities to try and maximize differences in friction angles.

Table 3. Internal friction angle values for a round and angular sand under different uniformities and bulk densities.

Shape	**Size**	**Bulk density**	**Friction angle**
Round	0.25 mm	1.4	34.0
Angular	0.25 mm	1.4	35.5
Round	Mix[†]	1.4	39.0
Angular	Mix	1.4	35.5
Round	0.25 mm	1.5	38.7
Angular	0.25 mm	1.5	36.9
Round	0.25 mm	1.6	45.0
Angular	0.25 mm	1.6	36.0
Round	Mix	1.5	39.8
Angular	Mix	1.5	33.7

[†]0.5mm:0.25mm:0.15mm sand in a ratio of 8:10:2

Rotatable Drum

The rotatable drum was constructed in March 1996 according to the specifications of Carrigy (Sedimentology, 14 (1970) 147-158). Our preliminary work with this rotatable drum showed that critical angle and angle of rest were not significantly affected by the depth of sand in the drum. Carrigy also showed this to be the case. We also tested to see if the sand within the drum needed to be remixed between rotations and found no measurable differences without remixing. However, we have decided to remix the sand by rotating the drum 360^0 between each reading.

Table 4 shows the critical angles and angles of rest for our round and angular sand standards. After repeated rotations we are able to obtain an average critical angle that is higher with the angular sand than with the round sand. It appears that about 10 readings are necessary. Angles of rest were equal for both sands. The wide range of values around the critical angle is of concern because of the overlap in the data for the two sands. Further testing with other round and smooth sands will be necessary to conclude whether this procedure will be useful in determining sand sphericity and surface roughness.

Table 4. Critical and rest angles (and range) of a round and angular sand, as determined with a rotatable drum.

Sand Shape	**Critical angle**	**Angle of rest**
Round	46.1 (37-52)	18.3 (12-22)
Angular	49.4 (47-53)	18.5 (14-22)

Computer Imaging

This method was not part of our original proposal, but after several discussions with Dr. Rick Day, Director of the Penn State Land Analysis Laboratory, it seemed that procedures used to analyze land shape from digitized topographical maps and satellite images might be suitable for quantifying the shapes of sands. The advantages would be that many more sand grains can be quantitatively analyzed for sphericity and roundness. Slides generated from microscopic views of the sand grains are scanned to raster TIFF format images, edited to create uniformly colored backgrounds and remove objects not of interest, and converted to an ArcInfo vector format where each sand grain is represented by a polygon. A series of shape parameters are then calculated for each grain. Shape parameters include, but are not limited to: (a) number of line segments defining the polygon perimeter, (b) polygon area, (c) average length of line segments, (d) perimeter length, (e) average angle of deviation formed by two connected line segments, and (f) major and minor axis lengths. Combinations of parameters, such as area/perimeter length ratios, will also be calculated. Algorithms will be applied to "generalize" the shape of each sand grain with pre-determined tolerances that force the graphical appearance to be preserved after generalization. The value of calculated shape parameters will be compared for the ungeneralized and generalized images and should provide an index of grain angularity. Correlations between graphical shape parameters and sand grains of pre-determined shape class will be calculated to determine if the shape parameters can be used to effectively classify sand shape.

To date, we have determined the photographic exposure time and magnification size necessary to produce scannable slides having the least amount of required editing. We have also scanned in the 18 sand images from Figure 1 of the USGA Specifications Manual. These images will be used to test the ability of ArcInfo to quantify shape differences and to test which shape parameters are best for distinguishing between shapes. Once this is determined we will begin quantifying the shapes of our test sands.

Dense Soil Angle of Repose and Cone Penetrometry

Equipment for the DSAR is almost completed. The vibratory box is done and a motorized lift is now being attached that will raise the sample box at the same speed each time we run a sample. We will begin constructing a cone penetrometer this winter.

Rootzone Sand Physical Properties

Physical properties of the two test sands have been determined using USGA methods. We have recently completed testing for the effects of peat and soil on the physical properties of these sands. Each sand was constructed to meet USGA sand size specifications. The soil used was a Hagerstown silty loam (27.8% sand, 69.8% silt, 11.4% clay). The soil was sieved to remove particles greater than 2mm. The peat was a reed-sedge peat sieved into two size fractions: 0.25mm to 1.0 mm, and <0.25 mm. We classified these fractions as coarse or fine. The sand:peat:soil treatments tested include:

10:0:0	sand:peat:soil
80:20	sand:peat
90:5:5	sand:peat:soil
80:10:10	sand:peat:soil
70:15:15	sand:peat:soil
60:20:20	sand:peat:soil

Each sand:peat:soil treatment is repeated for each sand shape and peat size. The total number of treatments is twenty-two (2 sands x two peats x 5 combinations, plus the two sands alone). Duplicates of each treatment were constructed. The data for this experiment has been collected, but not analyzed yet.