Characterization of Sand Materials for Golf Course Bunker Use, 2004.
Cale A. Bigelow and Glenn A. Hardebeck

Objectives:

Characterize commercially available sand-sized materials that are being used in golf course sand bunkers for their physical properties and determine if certain physical properties confer increased resistance to golf ball penetration and possibly less sand erosion.

Rationale:

Numerous sand-sized materials are commercially available and marketed for use in golf course sand bunkers. Often a particular sand may be chosen based on subjective characteristics like aesthetic appearance (many golf course architects prefer a bright white sand), or subjective functional characteristics, how a particular golfer perceives the sand to play, firm sand is preferred because it allows the golf ball to sit on top. Sometimes the long-term consequences of these decisions based on subjective criteria may not be immediately realized. A sand that is the desired color but is too coarse or has a predominance of very round particles may necessitate additional labor to maintain playability which increases maintenance costs. From a golf course managers perspective an appropriate sand for golf course bunkers would be one that maintains firmness, drains quickly, does not easily erode from slopes after moderate rainfall or irrigation and is properly sized so that if it is thrown onto the putting surface it does minimal damage to the mowing equipment when picked up during mowing.

How it was done:

This laboratory study was conducted in the laboratory facilities in Lilly Hall, West Lafayette, IN. A wide variety of sand materials were collected from sand suppliers from across the United States. Each sand was analyzed for standard physical properties including particle size distribution using the pipet method and dry sieving (3 replications of 40 g samples), angularity, resistance to penetration with a modified pocket penetrometer (five replications) and angle of repose (three replications of 20 g samples). Additionally, the aesthetic qualities of the sands were determined using a Munsell color chart (data not presented). The properties of these commercially available sands were compared to those of laboratory grade spherical glass beads. Particle size distribution values were used to calculate the Coefficient of uniformity (Cu) and gradation index (GI) for each sand.

Results:

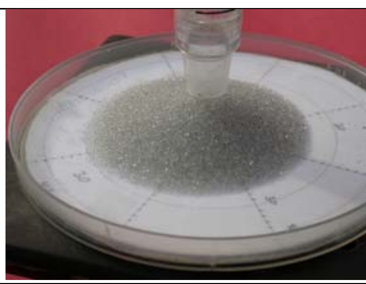
The sands analyzed in this study that are being used for golf course bunkers were extremely variable in terms of all properties measured, particle size distribution, angularity, angle of repose, color, and particle shape (Tables 1 and 2) . Most sands, however, tended to possess mostly angular particles which would be a desirable characteristic for firmness. As expected, all sands were very different from the control sand material, rounded laboratory glass beads. Unfortunately no single sand property or combination of properties measured, particle size distribution as expressed as coefficient of uniformity (Cu), gradation index (GI) or angle of repose, was able to accurately predict sand performance in terms of resistance to penetration (Figures 1-4).

Future studies: Future studies with these sand materials should include laboratory or field observations on the ability of these sands to perform under realistic field conditions like erosion during rainfall and their ability to resist embedding golf balls. Additionally, the effect of sand bunker underlayments on various sand sizes and slopes should be studied.

Acknowledgements

This research was supported by grants-in-aid from the United States Golf Association and the Midwest Regional Turf Foundation. Grateful appreciation is extended to Mr. Edward Gene Walker and Jared Nemitz for their assistance during data collection throughout this experiment.

		
Particle size distribution of each sand was highly variable, however, most sands contained > 90 % (w/w) of their particles between 0.15 and 1.0 mm.	A tremendous variation in color, particle size distribution and degree of angularity was observed.	Each sand's resistance to penetration was measured using a modified pocket penetrometer fitted with a standard size golf ball to simulate "ball-lie".

As expected, angle of repose varied with particle angularity and particle size distribution. In practical terms angle of repose is an important measurement because as the slope of a bunker face exceeds the angle of repose, the sand will be more prone to "slumping" and will migrate off the bunker face resulting in higher maintenance costs. Photos from left to right: round glass beads, angular crushed limestone, and fine textured sub-rounded sand.

Table 1. Particle size distribution of selected commercially available sand materials used for golf course bunkers in the United States.

	Particle size									
	---- mm ----									
Sand source	> 2.0	1.0	0.5	0.25	0.15	0.1	0.05	< 0.05	Cu[a]	GI[b]
	---- g kg -1 ----								--- unitless ---	
Green Plus Sand	6	136	277	454	116	6	5	< 1	2.38	5.24
Tour Grade 535	15	14	58	492	370	28	23	< 1	1.82	2.76
Tour Grade Signature	56	193	190	315	181	23	17	2	3.06	8.89
Tour Grade 50/50	46	192	198	315	200	32	17	1	2.72	8.89
Extra Firm Bunker Sand	1	64	204	342	268	81	48	2	2.85	6.23
Kosse White	2	6	39	376	522	40	13	2	1.47	2.41
Gray Walrath Double Wash	0	17	214	594	146	16	12	1	2.22	3.83
Stone White Sand	0	0	1	350	555	40	14	< 1	1.53	2.53
Crushed Limestone	4	375	559	78	11	3	4	1	1.86	3.53
Caylor White	3	46	202	608	127	9	5	< 1	1.82	3.32
Klassic White	8	77	178	517	209	6	3	2	2.11	4.74
Tan Bunker Sand	3	61	415	406	86	18	10	1	2.43	3.96
Pro White Bunker Sand	0	9	91	659	209	21	10	1	2.50	4.69
# 1600	8	21	116	464	324	40	26	1	2.25	4.17
Autumn Gold	6	46	80	534	302	20	10	2	2.00	3.24
Pro Angle Bunker Sand	10	170	334	287	149	30	19	1	3.33	7.78
USGA Bunker Sand	0	37	228	505	200	19	10	1	2.35	8.41
Shelby Bunker Sand	9	69	312	479	121	6	4	0	2.00	3.79
Florida special	4	32	123	450	329	41	20	< 1	2.20	3.87
Glass beads	0	0	296	704	0	0	0	0	1.61	2.57

[a]Cu (Coefficient of uniformity) = where D60/D10; acceptable value = 2 to 4, higher value = less uniformity, optimum value = 2 to 3, a value < 2 less likely to pack tightly.
[b]GI (Gradation index) = where D90/D10; lower values indicate a higher potential for surface instability, acceptable range 3 to 6, preferred range 4 to 5.

Table 2. Sphericity, angularity, angle at repose and penetrometer values for selected sands.

Sand source	Sphericity	Angularity	Angle at repose	Penetrometer value
			degrees	kg cm-2
Green Plus Sand	Medium	Sub-angular	33.1	1.4
Tour Grade 535	Medium	Sub-angular	30.7	1.2
Tour Grade Signature	Low	Angular	33.9	1.6
Tour Grade 50/50	Medium	Sub-angular	35.4	1.9
Extra Firm Bunker Sand	Medium	Sub-angular	31.6	1.8
Kosse White	Medium	Rounded	30.8	1.7
Gray Walrath Double Wash	Medium	Sub-angular	34.4	2.1
Stone White Sand	Medium	Sub-angular	32.9	1.2
Crushed Limestone	Medium	Angular	34.9	3.3
Caylor White	Low	Angular	32.5	1.4
Klassic White	Low	Angular	34.8	1.8
Tan Bunker Sand	Medium	Sub-angular	34.2	1.5
Pro White Bunker Sand	Low	Very-angular	34.6	2.8
# 1600	Medium	Sub-Angular	30.9	1.6
Autumn Gold	Medium	Sub-angular	30.3	1.8
Pro Angle Bunker Sand	Medium	Very-angular	33.1	2.8
USGA Bunker Sand	Medium	Sub-rounded	30.9	1.0
Shelby Bunker Sand	Medium	Sub-rounded	31.6	1.3
Florida special	Medium	Sub-angular	31.6	1.4
Glass beads	High	Rounded	21.8	0.1

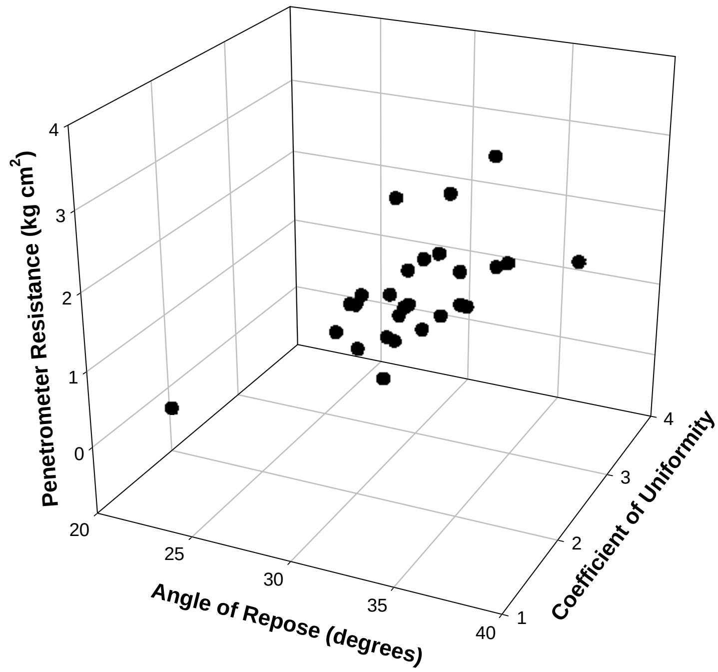


Figure 1. Penetrometer resistance versus angle of repose and coefficient of uniformity.

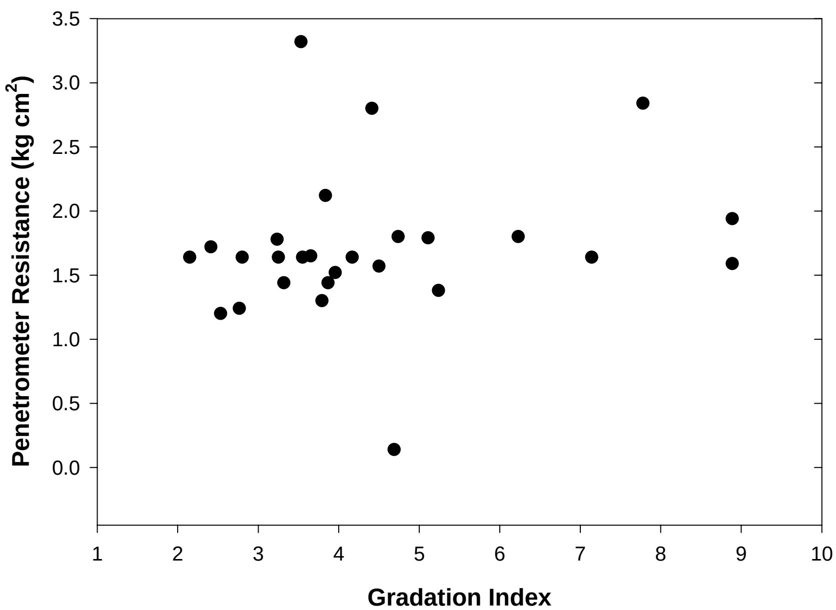


Figure 2. Penetrometer resistance versus gradation index.

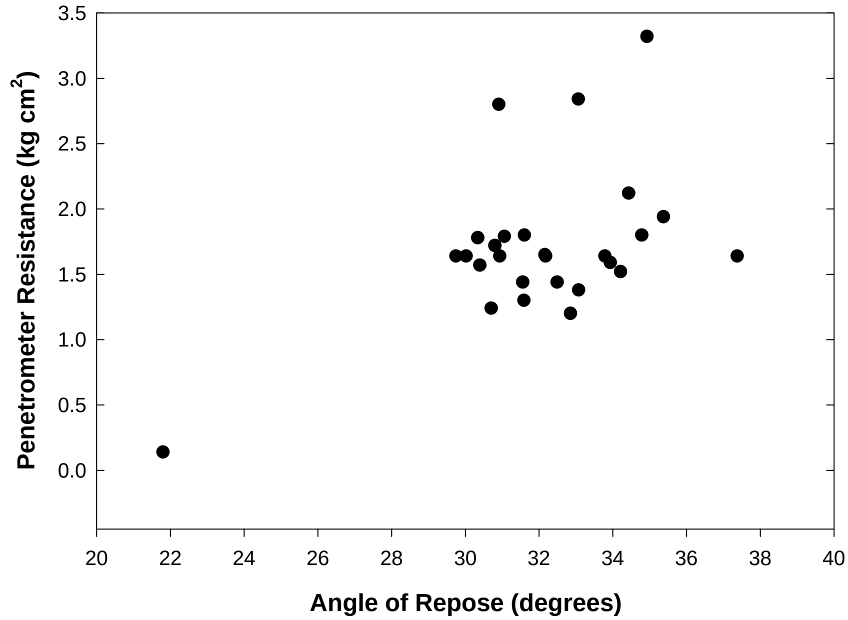


Figure 3. Penetrometer resistance versus angle of repose.

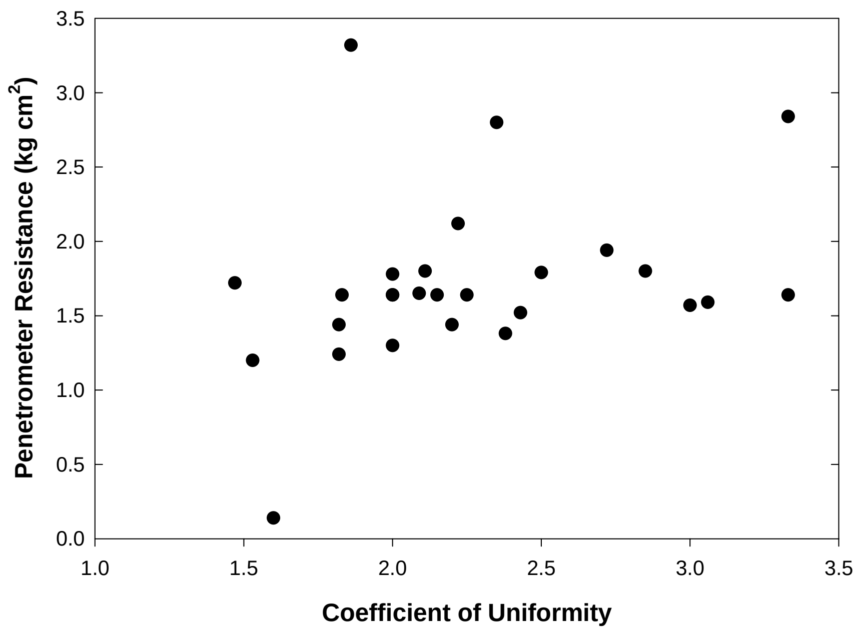


Figure 4. Penetrometer resistance versus coefficient of uniformity.