Effect of Gradation and Particle Shape on Sand Properties as Coverage of Beach Soccer Ground - *Details of a Patent*

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ABSTRACT

Background. Beach soccer is one of the most well-known international sports in the world. The laws of the game were introduced by some associations and today they are covered by FIFA. There are also certain rules for the selection of beach soccer sand, but the specifications are too simple and rough. Thus, a wide range of sand types falls in the acceptable range of FIFA. **Objectives.** In this study, an investigation is conducted to identify the effective parameters of beach soccer sand that affect the acceptability and quality of sand. The aim of this study is to determine which type of sand is more in accordance with the expectations of beach soccer players. **Methods.** This study is based on the results of a survey on 10 players of the national beach soccer team of Iran. The questionnaire includes questions about different aspects of sand quality at a number of beach soccer grounds. The sand samples are consequently compared by considering their gradations and particle shapes. A number of recommendations are presented in order to select high-quality sand for the purpose of beach soccer ground coverage. **Results.** The results are examined using numerical simulations. Finally, after conducting several tests and survey and gathering regional data, a simple and reliable method for ranking sand types used in beach soccer ground coverage is presented. The method can accurately predict the score of each sand sample by using the input data of gradation test, roundness test, and regional data. The sand types are scored according to the level of the match. **Conclusion.** In this manner, the grounds of beach soccer can be standardized using the presented ranking method.

KEY WORDS: *Beach Soccer, Sand Quality, Ranking Method, Gradation, Particle Shape.*

INTRODUCTION

Beach soccer is one of the most well-known international sports in the world. This sport was incorporated into the FIFA structure in 2004 and the first Beach Soccer World Cup was held on Copacabana beach Brazil in 2005 (1). The ground surface of the beach soccer game is covered by sand. Some criteria for the selection of appropriate sand are specified by FIFA. These rules for selection of sand are too simple and rough; therefore, a wide range of sand types with different properties is acceptable with FIFA. For example, according to FIFA (2), some rules for the ground surface are:

The surface should be composed of sand that is level and free of pebbles, shells, and any other objects that could injure the players. For

international competitions, the sand must be fine and at least 40 cm deep. It must be sifted until suitable for play, and must not be rough or contain pebbles or any other dangerous elements; however, it must not be so fine as to cause dust to stick to the skin.

Because of this mode of sand selection, the sand types at different beach soccer grounds have different properties and the beach soccer players do not have similar conditions in the matches. Therefore, the authors have investigated the effective parameters for sand quality using a number of experimental and numerical tests. This study is mainly based on geotechnical methods and concepts. It comprises three steps: i) survey, ii) experimental and numerical tests, and ii) correlation between survey and tests data.

Granular material, like sand, consists of a large number of particles of different shapes and sizes. In the past, several researchers have studied the impact of the size and shape of the sand particles on the global behavior of sand sample. In this section, a number of researches related to this topic are reviewed.

Martins and Barboza studied grain-size properties of sand gravel marine deposits in Brazil. This study focuses mainly on the relationship between grain-size properties and the sedimentary environment. Gradation diagrams are presented for different sand samples (3).

Arasan et al. used image analysis method to determine the grain-size distribution. The effects of particle shape and volume computation techniques on grain-size distribution were also researched. The results indicate that the shape of particles significantly affects the grain-size distribution (4).

Han et al. studied the influence of particle size on soil strength. The soil strength was measured using pullout tests of geocells embedded in the soil. The test results indicate that different types of geocells show different relationships with relative particle size of the backfill and pullout resistance (5).

The maximum friction angle of a sand sample can be correlated with many parameters, such as grain-size distribution (6, 7). Kara et al. investigated the effect of particle size on the internal friction angle of sand. A method is presented to estimate the friction angle using particle-size distribution (8).

The effect of particle size on the mechanical resistance of sand was studied by McDowell and Bolton (9). It was observed that peak resistance is larger for well-graded sand but the ultimate resistance is more or less independent of the initial particle-size distribution.

Cho et al. investigated the effect of particle shape on packing density, stiffness, and strength of sand. Sphericity, roundness, and smoothness were studied in terms of the particle shape (10).

There are many other studies on the different aspects of sand behavior, such as:

- mechanical behavior of sand (11, 12)
- compaction and swelling of sand (13-15)
- sand mixture (16)
- cemented sand (17-27)
- sand strength (28-30)
- frozen sand (31-33)
- sand liquefaction (34-37)
- There are also a few studies on sand used for covering sporting grounds. For example, Crum et al. studied the engineering properties of high sand-content soil used in golf putting greens and sport fields (38). They focus mostly on bearing capacity, porosity, and gradation of such soil. Some data were presented for a number of fields, but there was no clear conclusion.
- ASTM F2396-04 suggests some guidelines for the construction of high-performance sand-based root zones. In this standard, a number of limitations related to particle-size distribution and physical and chemical properties of sand-based root zones are specified (39).
- In earlier studies, no method for the evaluation or ranking of sand for its utilization to cover sporting ground surface—especially beach soccer ground surface—is presented. Therefore, the authors have decided to do a comprehensive study on sand properties to find an evaluation method for sand used to cover beach soccer grounds.

This study is conducted to investigate the effect of the gradation and shape of sand particles on the quality and acceptability of sand as beach soccer ground coverage. A simple and reliable method for ranking and selection of an appropriate sand type

to cover beach soccer grounds and a minimum sand quality are suggested, keeping in mind the levels of beach soccer matches.

MATERIALS AND METHODS

Survey. In the first step, a survey is done, in which 10 beach soccer players of the Iranian national beach soccer team were interrogated about different aspects of sand quality at seven beach soccer grounds. The names of the beach soccer grounds and the average results of the survey are presented in Tables 1 and 2.

The questionnaire has nine questions. Questions 1–8 are related to some unwanted properties of sand samples, such as excessive roughness (coarse sand), excessive fineness (sand that sticks to the players' skin), dust, early fatigue, quick reduction of ball speed, excessive unevenness of ground surface (ball detour), low stiffness of ground surface, and high stiffness of ground surface. Question 9 pertains to the overall acceptability of sand or sand quality. In response to the questions, the players allotted a score between 0.0 and 10.0 for each question.

It can be seen in Table 2 that the seven sand samples have different qualities from the points of view of the beach soccer players (Question 9). Any clear relation between the responses to Question 1—8 and the response to Question 9 (sand quality) is not observed. In fact, Question 9 is the overall result of Questions 1–8.

The validity of the questionnaire is evidenced by the fact that different aspects of sands acceptability are directly addressed. It this study, the split-half method is used to estimate the reliability of the questionnaire.

Table 1. List of beach soccer grounds

	Stadium or Ground Name	Location
Sample 1	Shahrdari (City council)	Iran, Rasht, Roodsar
Sample 2	Park-e-saheli (Beach Park)	Iran, Bushehr
Sample 3	Port Dickson	Malaysia, Sepang
Sample 4	Olympic Village	Thailand, Phuket
Sample 5	National football academy	Iran Tehran
Sample 6	Alghadir Park	Iran, Bandar Abbas
Sample 7	Katara	Qatar, Doha

Table 2. The average results of the survey

	Samp. 1	Samp. 2	Samp. 3	Samp. 4	Samp. 5	Samp. 6	Samp. 7
Q1: excessive roughness	2.10	6.40	3.60	1.60	5.50	6.10	5.60
Q2: excessive fineness	3.10	3.10	6.00	8.55	4.90	3.80	4.60
Q3: dust	2.70	3.60	4.90	1.60	6.60	3.80	3.90
Q4: early fatigue	6.65	6.75	7.00	8.65	6.90	5.80	3.40
Q5: ball speed reduction	6.80	6.40	4.60	3.50	7.15	5.90	3.70
Q6: unevenness	6.30	6.15	6.60	3.50	7.05	6.50	4.80
Q7: ground low stiffness	6.60	5.80	7.50	4.85	5.95	4.90	5.60
Q8: ground high stiffness	2.50	3.80	4.10	2.80	1.45	6.30	5.40
Q9: overall sand quality	8.65	7.10	5.00	8.45	8.10	5.80	8.40

Table 3. The reliablity of questinaires

	Samp. 1	Samp. 2	Samp. 3	Samp. 4	Samp. 5	Samp. 6	Samp. 7
r	0.993	0.890	0.949	0.991	0.982	0.855	0.895
ρ	0.997	0.942	0.974	0.995	0.991	0.922	0.945

* r: reliability, ρ: modified reliability (Spearman-Brown formula)

RESULTS

Gradation Test. The gradation or sieve test is a basic geotechnical test for granular soil types, like sand. The gradation or size distribution has an important impact on the various properties of sand. Therefore, this test is selected to compare

sand samples and to find a correlation between sand quality and its physical properties. The results of the gradation test for seven sand samples are shown in Table 4 and Figure 1. As can be seen in Table 4, some samples with approximately similar particle-size distributions demonstrate different sand qualities. For example, the gradation diagrams of Samples 1, 5, and 6 are relatively similar, but they have different sand qualities, according to Table 2.

Table 4. Results of gradation test

Dia(10%)	Dia(20%)	Dia(30%)	Dia(40%)	Dia(50%)	Dia(60%)	Dia(70%)	Dia(80%)	Dia(90%)
0.079	0.100	0.124	0.149	0.176	0.200	0.224	0.249	0.274
0.206	0.286	0.343	0.385	0.424	0.474	0.569	0.918	1.679
0.186	0.247	0.331	0.483	0.650	0.793	0.944	1.167	1.641
0.155	0.199	0.239	0.291	0.401	0.585	0.759	0.955	1.337
0.099	0.135	0.165	0.187	0.204	0.218	0.233	0.250	0.275
0.096	0.126	0.151	0.169	0.184	0.198	0.233	0.252	0.545
0.182	0.218	0.248	0.283	0.333	0.412	0.530	0.684	0.889

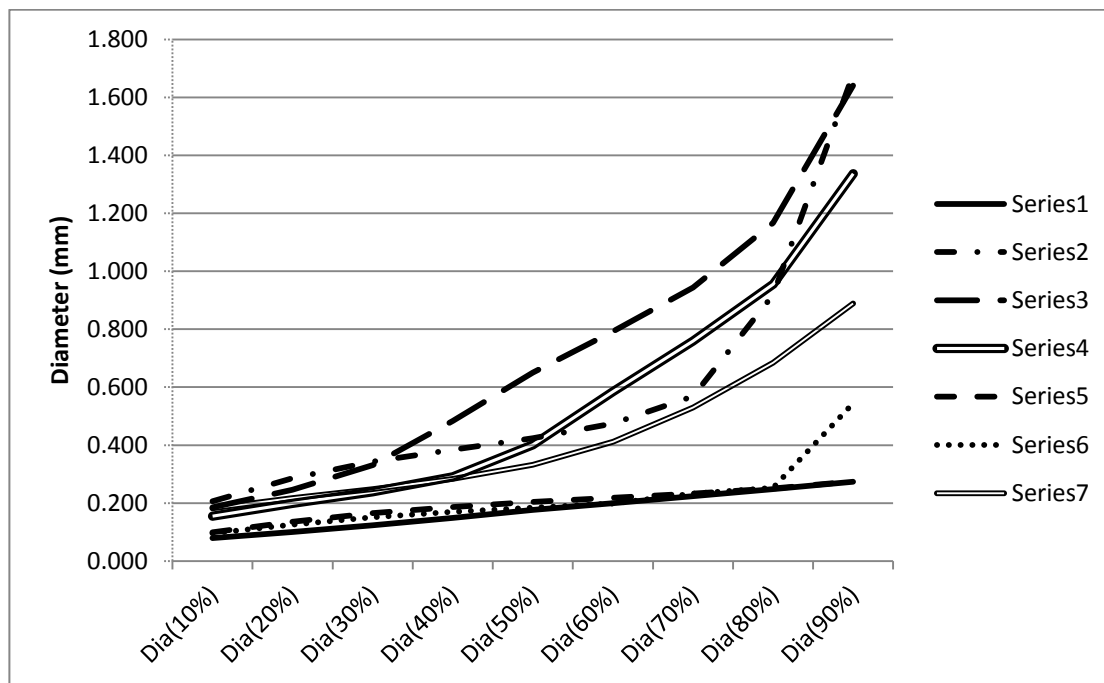* Dia(10%) is the size that 10% of particles are finer.

Figure 1. *Results of gradation test*

In this study, to compare the sand samples more efficiently, the gradation data is scaled so that Dia(10%) and Dia(90%) are reduced to zero (equation 1). In Equation 1, X= 10, 20, …, 90, and i is column no. in gradation table (i= 1, 2, ..., 9). The "new" and "old" subscripts are related to Tables 5 and 4 respectively. The modified data is shown in Table 5. The data presented in the Table 5 are depicted in Figures 2, 3, and 4. The diagrams in Figure 2 correspond to Samples 1, 4, 5, and 7, which have relatively high sand quality (8.65, 8.45, 8.1, and 8.4 respectively) according to Table 2. Figure 3 is related to Sample 2 with moderate sand quality (7.1) and the diagrams in Figure 4 are drawn using the data of Samples 3 and 6, which have relatively low sand quality.

$$Dia.(X\%)_{new} = \left| Dia.(X\%)_{old} - \left(\frac{9-i}{8}\right)Dia.(10\%) - \left(\frac{i-1}{8}\right)Dia.(90\%) \right| \qquad (1)$$

Comparing the scaled gradation diagrams in Figures 2, 3, and 4, it is obvious that there is a clear difference between the diagrams of high-quality, moderate-quality, and low-quality sand. For high-quality sand (Sample 1, 4, 5, and 7), the particle distribution is represented by a smooth bell-shaped diagram with a maximum point in the middle region of horizontal axis. For moderate-quality sand sample, as shown in Figure 3, the maximum point moves to the right, while low-quality sand samples (Figure 4) do not have smooth bell-shaped diagrams.

Table 5. Modified gradation data

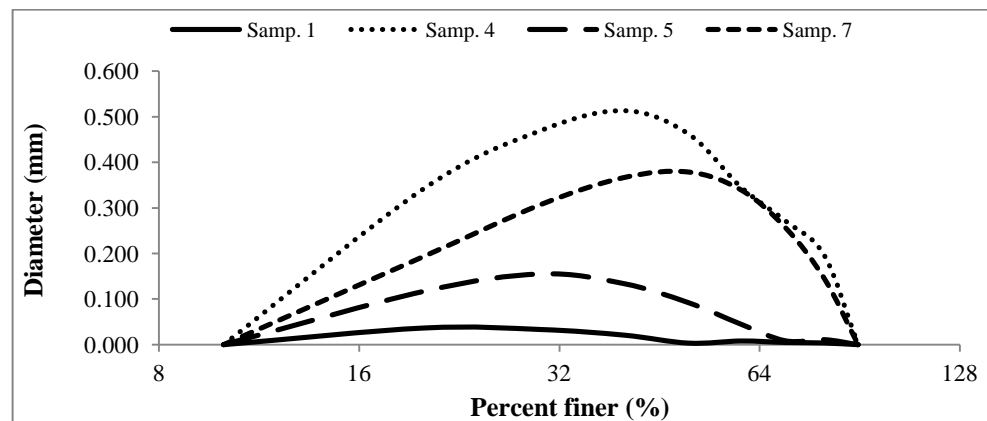| Dia(10%)	Dia(20%)	Dia(30%)	Dia(40%)	Dia(50%)	Dia(60%)	Dia(70%)	Dia(80%)	Dia(90%)
0.000	0.036	0.033	0.021	0.003	0.008	0.005	0.004	0.000
0.000	0.266	0.403	0.493	0.550	0.579	0.566	0.386	0.000
0.000	0.329	0.397	0.339	0.288	0.276	0.261	0.200	0.000
0.000	0.342	0.470	0.513	0.462	0.345	0.271	0.197	0.000
0.000	0.117	0.155	0.134	0.092	0.045	0.008	0.011	0.000
0.000	0.171	0.273	0.359	0.425	0.474	0.462	0.483	0.000
0.000	0.193	0.307	0.366	0.379	0.339	0.256	0.146	0.000

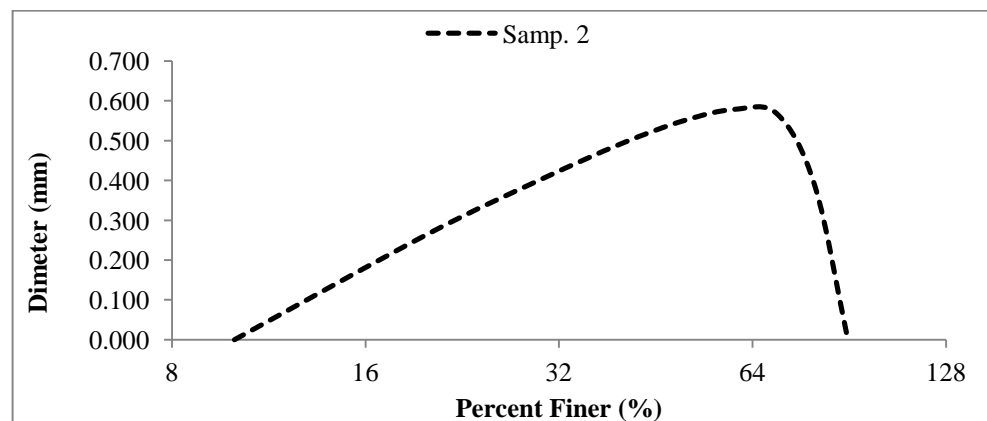**Figure 2.** *Scaled gradation diagrams for high quality sand samples*

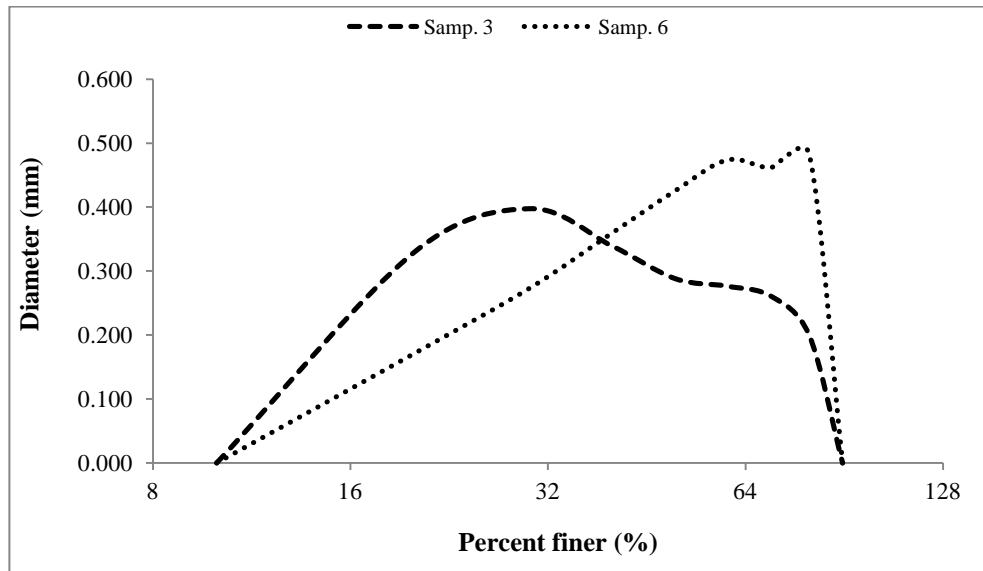**Figure 3.** *Scaled gradation diagram for moderate quality sand sample*

Figure 4. *Scaled gradation diagrams for low quality sand samples*

Particles shape. The shape of sand particles is another factor that can affects the properties of sand sample. In this study, particle shape is studied in terms of two concepts—roundness and sphericity. Roundness represents the degree of angularity of particles, while sphericity is related to overall shape of particles. The sphericity and roundness of sand particles are determined through visual judgment using microscopic images (40, 41). The main idea of these tests is illustrated in Figure 5. The microscopic images used in roundness and sphericity tests are shown in Figure 6.
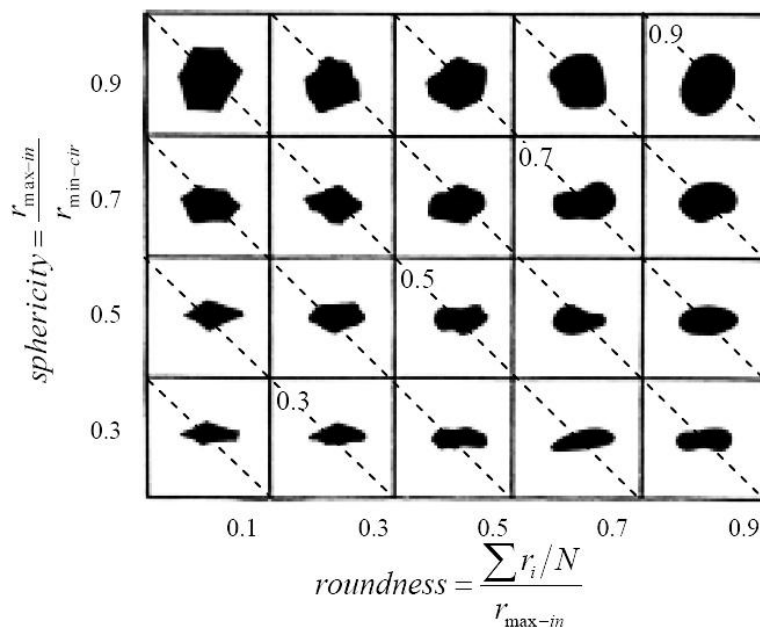

Figure 5. *Sphericity S and roundness R chart. Modified from* (10, 42)

Sample 1

Sample 2

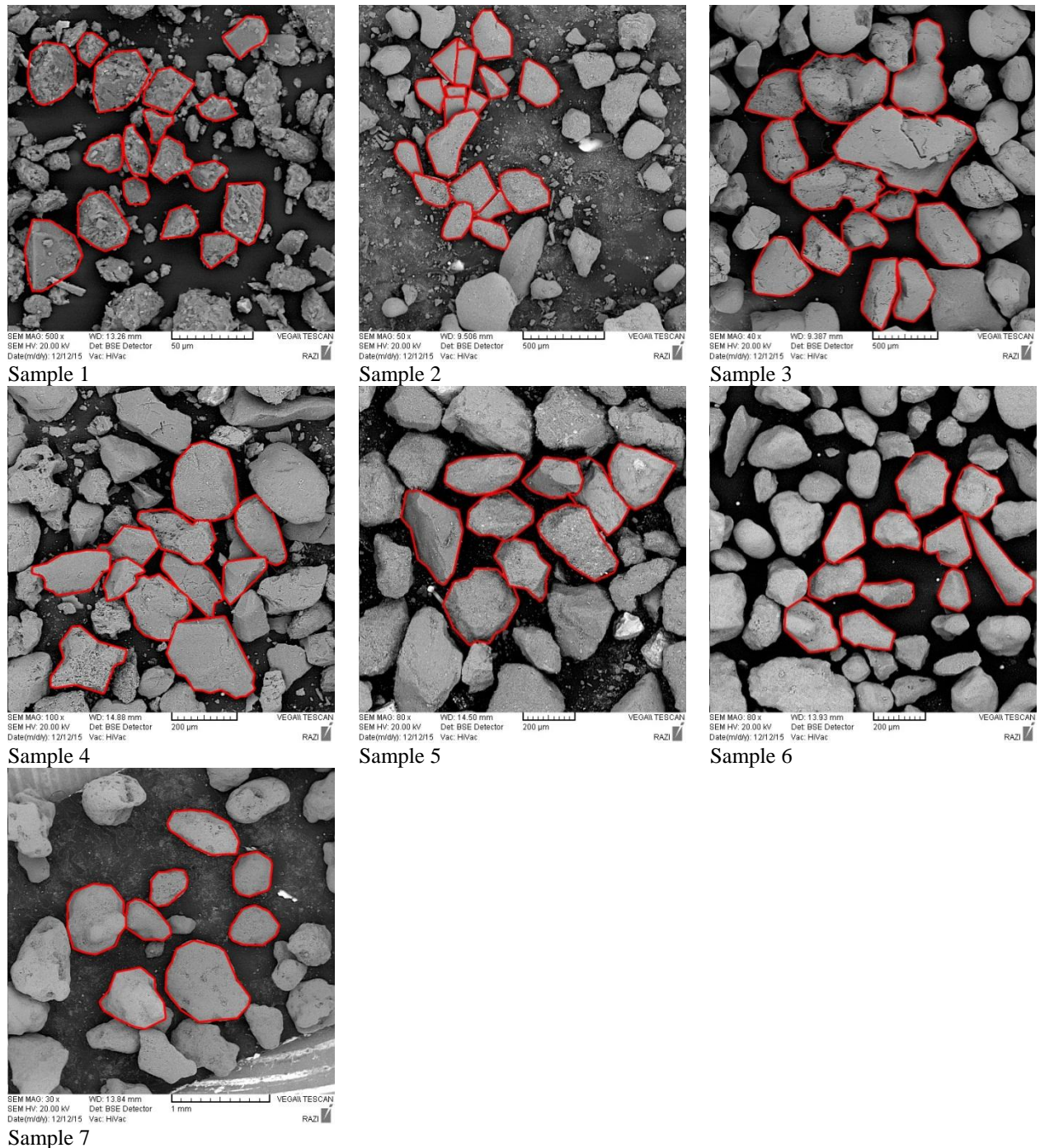
Sample 3

Sample 4

Sample 5

Sample 6

Sample 7

Figure 6. *Microscopic images of samples*

The roundness test is related to the degree of angularity of the particles. The output of this test is the roundness coefficient, which ranges from 0.0 to 1.0. Roundness can be quantified as the average radius of curvature of surface features relative to the radius of the maximum sphere that can be inscribed in the particle. Roughness describes the surface texture relative to the radius of the particle (10). The results of the roundness test on sand samples are presented in Table 6.

Sphericity indicates whether one, two, or three of the particle dimensions are of the same order of magnitude; it is defined as the diameter

of the largest inscribed sphere relative to the diameter of the smallest circumscribed sphere (10). The results of the sphericity test are presented in Table 7.

Table 6. The results of roundness test

	Roundness
Sample 1	0.2
Sample 2	0.2
Sample 3	0.1
Sample 4	0.3
Sample 5	0.4
Sample 6	0.4
Sample 7	0.6

Table 7. The results of sphericity test

	Sphericity
Sample 1	0.8
Sample 2	0.7
Sample 3	0.7
Sample 4	0.8
Sample 5	0.8
Sample 6	0.8
Sample 7	0.9

A clear relationship is not observed between the results of the roundness and sphericity tests and the quality of sand samples used as beach soccer ground coverage, but particle shape parameters is used indirectly in the following steps for the purpose of sand ranking. The quality of sand on the beach soccer grounds mainly appears to be a function of the particle-size distribution (gradation).

Air moisture. The air moisture of the regions in which beach soccer grounds are located is another factor that can have an important impact on the behavior of sands. In fact, the moisture causes the sand to show a small degree of cohesiveness, because of linking between particles. It can change the quality of sand slightly. Therefore, the quality of a sand sample depends on not only the sand properties but also regional conditions. The regional moisture levels for seven sand samples are shown in Table 8.

Numerical simulations. To examine the results mentioned in the previous sections, a 2D numerical model of particles is established using Discrete Element Method (DEM). Using the DEM model, a number of simulations are conducted, through which the effect of gradation and particle shapes is studied. A special test is simulated using the numerical model to study the effect of gradation and particle shapes (Figure 7).

Table 8. Regional average air moisture
(weatherspark.com)

	Moisture (%)
Sample 1	0.74
Sample 2	0.49
Sample 3	0.76
Sample 4	0.70
Sample 5	0.29
Sample 6	0.56
Sample 7	0.51

In the past section, it is shown that the most important factor that affects sand quality is the gradation or particle size distribution. The numerical simulations are conducted in two parts. Firstly, the effect of gradation is investigated and then the impact of friction coefficient as a consequence of particle shape is studied.

The numerical tests program is shown in Table 9. The particle assemblages in Simulations 1 to 5 have different gradations, with varying maximum and minimum particle sizes. Therefore, they are expected to show different behaviors. In Simulations 6–10, different friction coefficients are selected to study the effect of particle shape. It should be noted that in all simulations, the particles are circular for the purpose of simplicity, though the friction coefficient is used as a consequence of the particle shape.

The energy used in Tests 1–5 for 20.0 mm of penetration is shown in Figure 8. The presented diagrams are related to Simulation 1–5 with different gradations. It can be seen that the samples with different gradations show different energy-displacement diagrams.

Therefore, gradation can affect the sand behavior.

The energy for 20.0 mm of penetration for Tests 6–10 is presented in Figure 9. The samples have identical gradations with different friction coefficients. It is observed that the samples with different friction coefficients show different energy-displacement responses. It seems that the friction coefficient has an effect on sand quality, but it is not as significant as that of gradation.
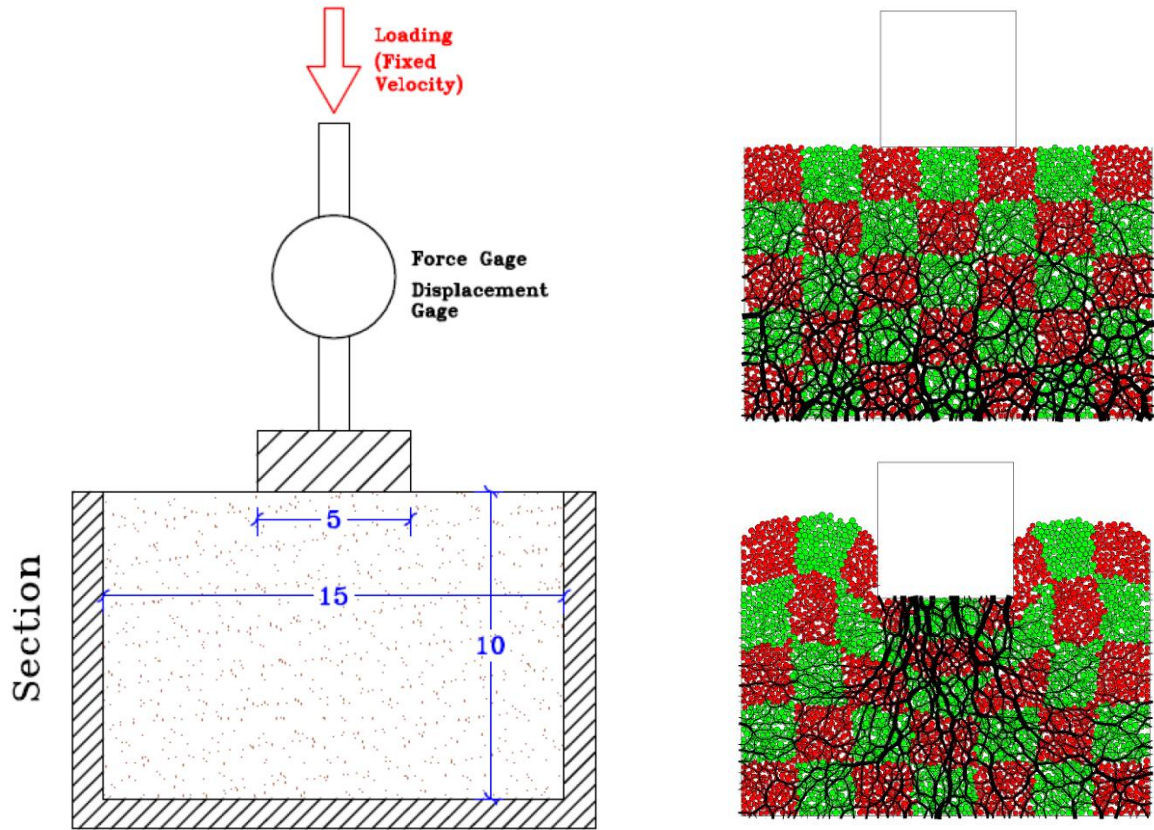

Figure 7. *Numerical model using DEM*

Table 9. Numerical tests program.

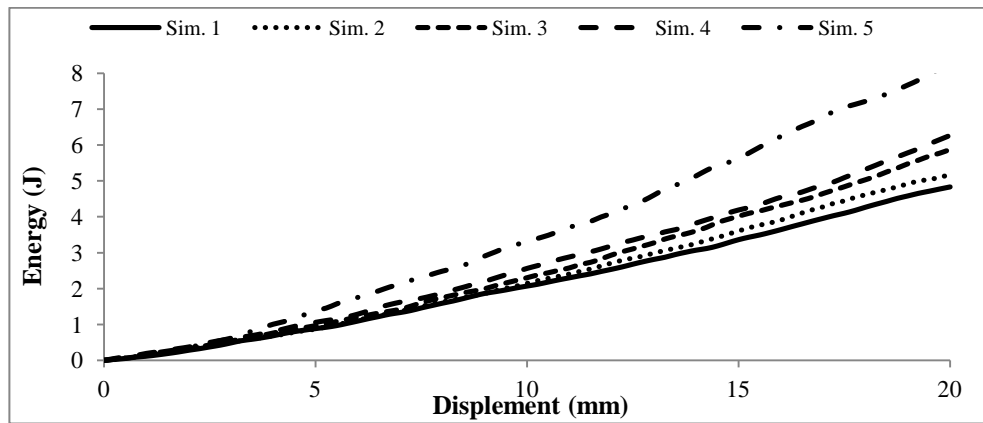| Simulation No.	Average Size (mm)	Min. Size (mm)	Max Size (mm)	Fiction Coeff.
1	2.0	1.8	2.2	0.05
2	2.0	1.6	2.4	0.05
3	2.0	1.4	2.6	0.05
4	2.0	1.2	2.8	0.05
5	2.0	1.0	3.0	0.05
6	2.0	1.8	2.2	0.06
7	2.0	1.8	2.2	0.07
8	2.0	1.8	2.2	0.08
9	2.0	1.8	2.2	0.09
10	2.0	1.8	2.2	0.10

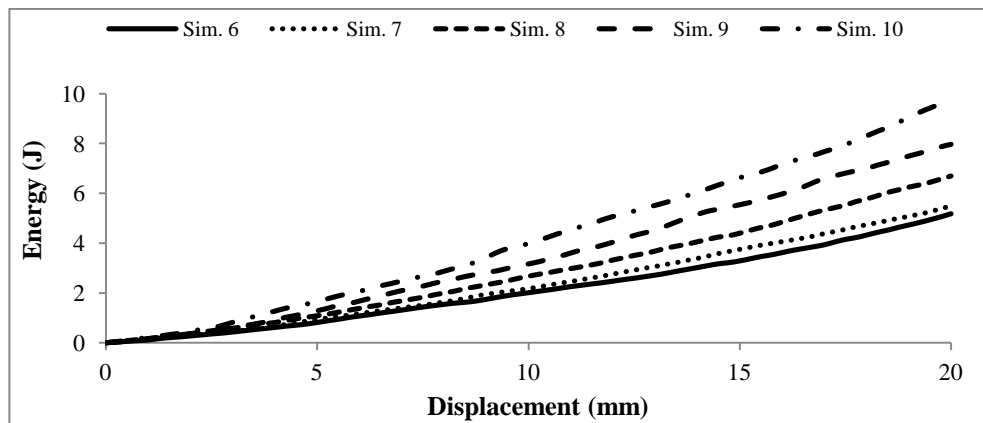**Figure 8.** *Energy vs. displacement (various gradations)*

Figure 9. *Energy vs. displacement (various friction coefficients)*

Proposed ranking method. All tests mentioned in the previous sections are conducted to investigate the effective parameters for the selection of an appropriate sand type to cover a beach soccer ground. The methods presented here can be used to rank different sand samples, to evaluate them in terms of coverage of beach soccer grounds, and to standardize the beach soccer grounds. After analyzing all gathered data of sand samples and regional conditions, it was decided that among all of them, the gradation and roundness test results and the average air moisture can be used to simply and effectively predict the quality of sand to be used for the coverage of beach soccer grounds.

Two parameters (A and B) are calculated from gradation data (Table 5) according to Equations 2 and 3, where Dia(max) is the maximum number in each row in Table 5.

$$A = |0.62Dia(\max) - Dia(20\%)| \qquad (2)$$

$$B = |0.66Dia(\max) - Dia(30\%)| \qquad (3)$$

All selected parameters to be used in the proposed ranking equation are shown in Table 10. The calculated values of these parameters for seven sand samples are shown in Table 11.

Table 10. Selected parameters for sand ranking formula

| Parameter	Definition	Unit
A	Equation 2	mm
B	Equation 3	mm
C	$\dfrac{\text{Dia.}(50\%)}{\text{Roundness}}$, Table 4, Table 6	mm
D	Dia. (90%) , Table 4	mm
E	Average Regional Moisture	-

Table 11. Values of selected parameters

	A	B	C	D	E
Sample 1	0.014	0.009	0.881	0.274	0.74
Sample 2	0.093	0.021	2.118	1.679	0.49
Sample 3	0.083	0.135	6.501	1.641	0.76
Sample 4	0.024	0.131	1.336	1.337	0.70
Sample 5	0.021	0.053	0.510	0.275	0.29
Sample 6	0.129	0.046	0.460	0.545	0.56
Sample 7	0.041	0.057	0.554	0.889	0.51

Equation 6 is the suggested ranking formula resulting from this study. This formula accurately covers the scores of all seven sand samples according to the players' survey. Using this formula, a score can be determined that shows the quality of each sand sample for the purpose of using it to cover the beach soccer ground. The results for the proposed ranking method for seven sand samples are presented in Figure 10. It is obvious from the presented data that Equation 4 can predict the scores of sand samples successfully, with an error close to zero.

$$S = 8.67 - 25.56A - 5.22B - 0.45C + 0.98D + 0.62E \qquad (4)$$
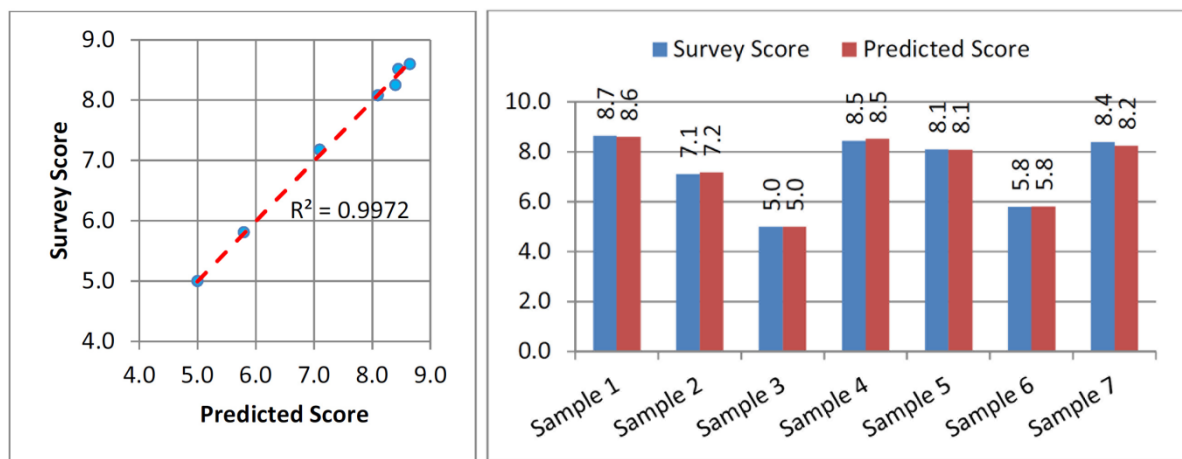
Figure 10. *Predicted score vs. survey score*

DISCUSSION AND CONCLUSION

Beach soccer is one of the most well-known international sports in the world. In this study, an investigation is conducted to identify the effective parameters of beach soccer sand that affect the acceptability and quality of sand. The aim of this study is to determine which type of sand is more in accordance with the expectations of beach soccer players. A method for ranking and standardization of beach soccer grounds is also introduced.

According to the results of this study, the following conclusions can be made.

o The gradation diagrams of high-, medium-, or low-quality sand samples have some substantial differences.

o A high-quality sand sample has a bell-shaped gradation diagram (scaled), with its maximum point in the middle region of the diagram.

o The gradation diagram of low-quality sands is not bell-shaped or smooth enough, or its maximum point is not in the middle area of the diagram.

o According to the numerical simulations, it can be said that gradation and particle shape are two effective factors that determine the sand quality.

o In this study, after conducting several tests, surveys, and regional data collection, a simple and reliable method for ranking the sand types used for beach soccer ground coverage is presented. The method can accurately predict the score of each sand sample using the input data of gradation test and roundness test, as well as regional data (average air moisture).

o According to the level of the match, a score for sand can be specified. In this manner, the beach soccer grounds can be standardized

using the presented ranking method. The authors suggest a score according to the presented ranking method for each level of the beach soccer match (Table 12).

Table 12. Suggested sand quality vs. match level

Level of match	Suggested sand quality
World cup	$S \geq 8$
Continental	$S \geq 7$
National	$S \geq 6$
Regional	$S \geq 5$
Training	$S \geq 3$
Inacceptable	$S < 3$

PATENT

After conducting a comprehensive investigation of the different properties of beach sand, gathering regional data, and doing a survey, a number of parameters are selected, which have the most effect on sand quality. These parameters are extracted from sand gradation diagrams, particle shape, and average regional moisture. Using these parameters, a procedure is introduced to determine sand quality and to standardize beach soccer grounds according to the level of beach soccer matches.

The suggested procedure of determining sand quality is patented with the title "**Sand ranking procedure to evaluate beach soccer ground coverage**" under patent registration No. 90559, Date 2016-12-03 in Real Estate Registration Organization of Iran. In the following paragraphs, the main parts of this patent registration certificate are explained in brief.

Title of the invention. Sand ranking procedure to evaluate beach soccer ground coverage

Technical field. Science (Geotechnics), Sport

Definition of the problem to be solved and aims of the invention. In this section, the existing problems related to sand quality determination and standardization of beach soccer grounds are explained.

The situation of existing knowledge related to the subject of the invention. In this section,

the existing criteria for the selection of an appropriate sand type according to FIFA guidelines are mentioned.

Suggestion of the solution to the technical problem with a detailed explanation. In this section, the concept of sand quality, or "S" parameter (Equation 4), is explained. The bases and steps through which this parameter is developed are mentioned. After that, according to the level of beach soccer matches, a minimum sand quality is suggested (Table 12) on the basis of the personal experiences of the inventor in his role as an international beach soccer referee.

Explanation of figures, drawings and diagrams. In this part, the steps to calculate the needed parameters needed to determine sand quality (S) formula (Parameters A, B, C, D, and E in Table 10) are first explained in detail and then the sand quality formula is introduced (Equation 4).

$$S = 8.67 - 25.56A - 5.22B - 0.45C + 0.98D + 0.62E$$
(4)

APPLICABLE REMARKS

- It presents an accurate and quantitative method for the determination of sand quality used in beach soccer grounds.

- It suggests a method for the improvement the sand quality.

- It suggests the minimum acceptable sand quality according to the level of beach soccer matches.

- It enables classification and standardization of beach soccer grounds in terms of sand quality, for the purpose of organizing beach soccer matches.

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