GEOTECHNICAL CHARACTERISTICS OF PUMICE FOR REDUCE LIQUEFACTION POTENTIAL

Muhajirah[1], *Ahmad Rifa'i[2], Agus Darmawan Adi[3],
[1,2,3]Department of Civil and Environmental Engineering, Gadjah Mada University, Jl. Grafika No. 2, Yogyakarta, Indonesia
muhajirah_mstf@yahoo.com[1]
*Corresponding Author: ahmad.rifai@tsipil.ugm.ac.id[2]

ABSTRACT

Mataram city is based on volcanic sediment from the eruption of Mount Rinjani. Several earthquake events have occurred and resulted in heavy damage in some areas near from the Mataram city.The objects of research are: 1) determine the physical properties of volcanic deposits in Mataram city, 2) assess the influence of particle size on the shear strength of granular materials and its permeability behavior as factors that affect the liquefaction potential.To determine the geotechnical characteristics of the volcanic sediments, the test series was carried out on soil samples from Kebon Talo of Mataram city. Testing includes gradation test, determination of bulk density and dry density, void ratio, relative density effect to permeability, and grain size effect on increasing frictional angle. Based on the results of gradation test, bulk density, dry density, void ratio, SEM, and EDS test, it is concluded that the soil sample from Kebon Talo ofMataram city is pumice sand. The permeability of Mataram pumice decreases with increasing relative density. They are illustrated by the exponential interpolation function$k = 0.3675e^{-0.071D}r$.The grain size of Mataram pumice can depend on the internal friction angle. Mataram pumice, having large grain size, with short grain size range, will have a large friction angle.

Keywords: pumice; permeability; friction angle

A. INTRODUCTION

Pumice deposits are found in several areas of Mataram city, originated from a series of volcanic eruptions of Mount Rinjani. Muhajirah, et al. (2014) has conducted a soil investigation at Kebon Talo Ampenan Utara using SPT and refraction seismic survey. They found that there wassand mixed with pumice as much as 12 m thick. Hiden, et al. (2017) has conducted a soil investigation near Selaparang airport using the 2D geo-electric survey.They concluded that the area was the largest alluvial with an average altitude of 15 to 16 m a.s.l.

According to Pender, et al. (1996), Marks, et al., (1998), and Orense, et al. (2012),a problem with sands of volcanic origin have been encountered in some large geotechnical projects in New Zealand. The Edgecumbe earthquake of 1987 exhibited widespread liquefaction of these types of sand. Failures in hydro development projects have also occurred due to the high erodability of pumice sands.

Pumice soils are characterized by a number of distinctive properties. They are generally lightweight, highly frictional, and exhibit high water absorption due to their vesicular nature. The coarser grained particles found in pumice sands are also highly degradable, compressible and erodible (Marks, et al., 1998).In 2015, Liu and Orense tested the liquefaction resistance of Waikato Pumice and Toyoura sand with relatively different densities. The resistance of liquefaction of Waikato pumice and Toyoura sand is almost the same at relatively high density. Furthermore, when the Waikato pumice is mixed with Mercer sand using a 1:1 volume ratio, the liquefaction resistance mixture of Waikato pumice and Mercer sand is lower than Waikato Pumice liquefaction resistance.

On June 22, 2013, there was an earthquake with a magnitude of M= 5.4, the epicenter was located about 14 km northwest of West Lombok, and its focal depth was 10 km. This earthquake caused severe damage in three sub-districts in North Lombok Regency.Previously, research on pumice was mostly focused on pumice characteristics as a material for lightweight concrete, and there is not much research in the literature about the mechanical behavior of pumice under seismic loading.The objective of this study is 1)determine the physical characteristics of volcanic deposits in Mataram city, 2) assess the influence of particle size on the shear strength of granular materials and its permeability behavior as factors that affect the liquefaction potential.

B. LITERATURE STUDY

Liquefaction Theory

The liquefaction phenomenon of soil deposits can be described as the reduction of shear strength due to pore pressure buildup in the soil skeleton. The shear strength of cohesionless soil, τ, depends mainly on the angle of internal friction and the effective stress acting on the soil skeleton and can be expressed as (GDP-9, 2015)

$$\tau = \sigma' - \tan\varphi \qquad \text{….. (1)}$$

where,

τ = shear strength

σ' = effective normal stress

φ = angle of internal friction

When saturated loose sands are subjected to earthquake loading, primarily induced by upward propagation of shear waves from bedrock, they tend to settle and density. However, the duration of the cyclic stress application is so short compared to the time required for water to drain, that the soil volume contraction cannot occur immediately and excess pore pressure will progressively build up. When the pore pressure equals the total stress, thereby reducing the effective stress to zero, sands will, at least temporarily, completely lose their stiffness and shear strength. Such a state is referred to as "initial liquefaction". At the onset of initial liquefaction, loose sands will undergo unlimited deformations or flow without mobilizing significant resistance to deformation. As a result, structures supported above or within the liquefied deposit undergo significant settlements and tilting; water flows upward to the surface creating sand boils, and buried pipelines and tanks may become buoyant and float to the surface.

Pumice Materials

According to Wesley (2010),pumice materials are not strictly residual soil. However, they are volcanic and have unusual properties. Pumiceous materials are a product of rhyolitic eruptions, andthey are characterized by the vesicular nature of their particles; each particle contains a dense network of fine holes, some of which are interconnected and open to the surface, while others appear to be entirely isolated inside the particles. The result is that the particles are lightweight, have a very rough surface, and are easily crushed, especially when compared to more hard-grained sands, such as quartz sand. Figure 1 illustrates voids within a pumice clasts.

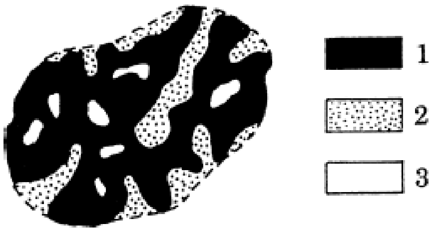

Figure1. Voids within a pumice clast
1. Solid material 2. External voids 3. Internal voids(Pellegrino, 1966)

Somerecent research by the geotechnical group at Auckland University has shown a particularly unusual and important aspect of Pumice sands are found in various parts of New Zealand (Wesley, 2010). Two large bulk samples of sand were used in this research. One was pumice sand and the other was a hard-grained sand consisting predominantly of quartz. The oedometer tests highlight the large difference in compressibility of the two sands type: the pumice sand is about five times more compressible than the quartz sand.

Marks, et al. (1998) investigated dynamic properties of a pumice sand taken from the Puni river in the Waikato. This work found that permeability of the Puni sand falls within the range of 0.08 to 0.4 cm/s, which is higher than the permeability obtained from the well-known Hazen’s equation involving the value of D_{10}. According to Braja (2002),for coarse sands, the value of the coefficient of permeability may vary from 0.01 to 1 cm/s and for fine sand, it may be in the range of 0.001 to 0.01 cm/s.

Yildiz and Soğancı (2012) investigated the geotechnical properties of three pumice soils sourced from the Nevsehir City. The results showed that as the diameter of pumice decrease, the specific gravity, dry unit weight, water absorption value and internal friction angle increase.According to Braja (2002), the angle of friction (φ) is a function of the relative density of compaction of sand, grain size, shape and distribution in a given soil mass. For a given sand, an increase in the void ratio will result in a decrease of the magnitude of φ. However, for a given void ratio, an increase in the angularity of the soil particles will give a higher value of the soil friction angle.

Table 1 illustrates the physical properties of pumice from Nevsehir City and Waikato river.

Table 1. Physical properties of pumice from Nevsehir City and Waikato river

No.	Variabel	Source	
		Nevşehir City, Turkey[1]	Waikato river, New Zealand[2]
1.	Specifi gravity, G_S	1,96*	-
2.	Bulk unit weight, γ kN/m^3	-	21,88
3.	Dry unit weight, γ_{dry} kN/m^3	9,88	17,36
4.	Friction angle, φ ^{o}	34,43	41
5.	Cohesion, c kN/m^2	-	-
6.	Permeability, *k* cm/det	-	0,08 – 0,4
7.	The most mineral composition(%)	SiO_2 (68.5%)	quartz

Source: [1] Yildiz and Soğancı (2012), and [2]Marks, et al. (1998)

In a previous study (Orense et al., 2015), the effect of relative density on the liquefaction resistance of reconstituted pumice sands was examined by performing undrained cyclic triaxial tests on dense (*Dr*= 70%) and loose (*Dr*= 25%) specimens and comparing them with those for Toyoura sand. The results, shown in Figure 5, indicate the effect of relative density on pumice sand's liquefaction resistance. The resistance of liquefaction of Waikato pumice and Toyoura sand is almost the same at a relatively high density (relative density of Toyoura sand = 90%).

It is also noticeable from Figure 2 that under the same test condition, pumice sand would not liquefy as easily as Toyoura sand, even when its density (*Dr*= 25%) only half of that for Toyoura sand (*Dr*= 50%).

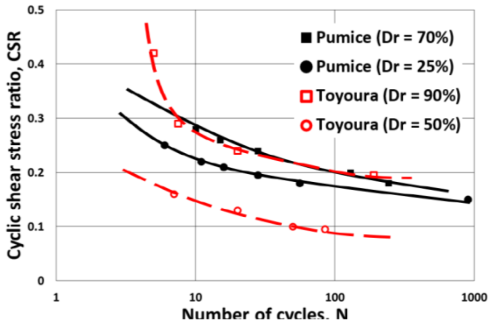

Figure 2.Comparison of CSR values from Waikato Pumice and Toyoura sand with different densities (Liu, et al., 2015)

In order to further investigate the crushing-interlocking interaction, undrained cyclic tests were performed on a mixture of pumice sand and Mercer River sand with a volume ratio of 1:1 under an effective confining pressure of 100 kPa. Attempts were made to form specimens with *Dr*similar to dense pure pumice specimens (*Dr*= 70%) as reported in Figure 3.Based on the cyclic vs. cyclic shear stress ratio (Figure 3) curve, when the pumice is mixed with other materials, the liquefaction resistance value will decrease.

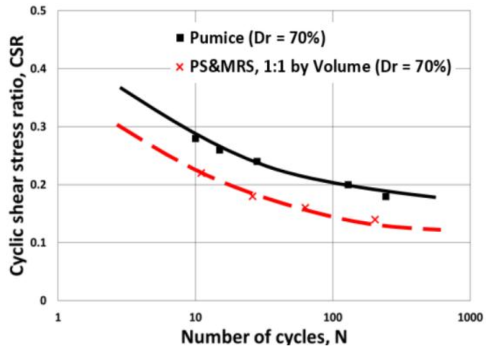

Figure 3.Comparison of CSR values from mixed Waikato pumice with Mercer sand, and Toyoura sand at the same relative density (Liu et al., 2015)

C. METHODOLOGY

For this research, soil samples taken from Kebon Talo of Mataram city were taken up to a depth of 2 m. The series of tests carried out are:

a. The tests of grain size distribution, water content, specific gravity, bulk and dry density, and void ratio.
b. The SEM and EDS analysis.
c. Permeability behavior.
   There are four pumice samples with different relative density (D_r = 40, 50, 60, 80%). This test is conducted to determine the effect of density relative to soil permeability.
d. Shear strength characteristics.
   There are four types of soil with different grain size, tested direct shear. The test was conducted to determine the effect of grain size on soil shear strength.

In the experimental study, the sieve analysis, specific gravity, dry unit weight test was conducted to determine the geotechnical properties of pumice. Geotechnical characteristics were executed in the Laboratory of Soil Mechanics of the Civil Engineering and Environmental Department of Engineering Faculty of Gadjah Mada University. The SEM and EDS analysis were carried out in LPPT of Gadjah Mada University.

D. RESULTS AND DISCUSSION

1. Physical properties of Mataram pumice

For this study, the materials were obtained from Kebon Talo in Mataram city. The original sample was dried in the oven for at least 24 hours before the testing program was initiated thus the moisture content was essentially zero. Figure 4a) shows sieve tests result of pumice sand that obtained from the studied site. As shown in the Figure 4a), particles of sand material are in sub-round to sub-angular shapes,black spots on the pumice grain show the pumice cavity. For comparison, Figure 4b) shows Waikato Pumice from New Zealand, standard pumice sand, often used in research at Auckland University. Figure 4c) shows Toyoura sand, hard-grained sand containing quartz, often used in Japan for liquefaction research.

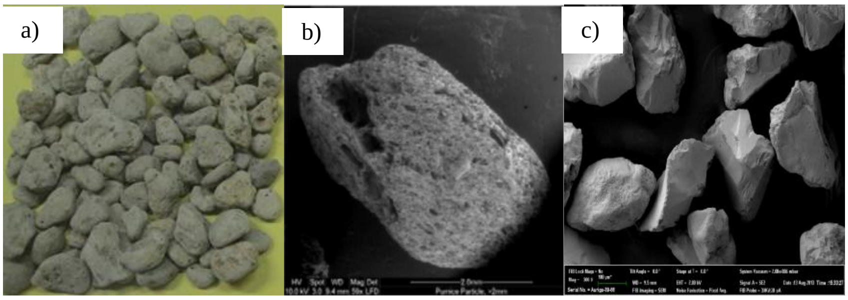

Figure 4. a) Mataram Pumice, retained #10 sieve (grain size 4.75 – 9.52 mm),
b) Waikato Pumice, original saize is ≥ 2.0 mm (Liu, et al., 2015)
c) Toyoura sand (Alshibli, K., 2013)

Particle size analysis of the sample was performed by sieve analysis. The particle size distribution curve for the testing material is shown in Figure5. According to the Unified Soil Classification System (USCS), the testing material is classified as (SW-SM) well-graded sand with silt and gravel. For comparison, in this figure, a curve of grain size distribution of Toyoura sand, Waikato pumice, and sand mercer, three types of sand is used in the research of Liu et al (2015). Sand UMY is sand that had experienced liquefaction at Muhammadiyah University of Yogyakarta, UMY (Kusumawardani, R., 2014). All parts of the Toyoura Sand gradation curve lies in the most liquefiable zone, almost all parts of the Mercer sand and Waikato Pumice gradation curves are in potentially liquefiable zones. While the UMY Sand gradation curve, the half curve is in the potentially liquefiable zone and the other half is in the most liquefiable zone. For Mataram pumice, one-third of curves are in most liquefiable zones, one-third of curves are in potentially and other are outside the zone.

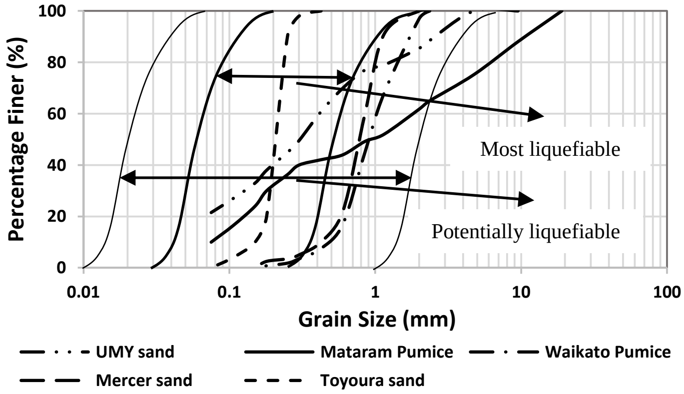

Figure 5. Particle size distribution of soil sample

Table 2summaries the material characteristics, including size distribution, soil classification, specific gravity, water content, bulk and dry density, void ratio, minimum and maximum void ratio, minimum and maximum dry density. To find out the comparison between Mataram Pumice characteristic and material that has experienced liquefaction, the physical characteristics of Mataram Pumice compared with UMY sand, UMY sand had experienced liquefaction during earthquake occurred in Yogyakarta on 26 May 2006 (Kusumawardani, R., 2014).

Tabel 2. Physical characteristics of Mataram pumice and UMY sand

No.	Physical Properties		Value	
			Mataram Pumice	UMY Sand*
1.	Gravel	(%)	24.77	0.00
2.	Sand	(%)	65.26	73.04
3.	Silt and Clay	(%)	9.97	26.96
4.	D_{10}	mm	0.075	0.020
5.	D_{30}	mm	0.190	0.130
6.	D_{50}	mm	0.900	0.300
7.	D_{60}	mm	1.800	0.400
8.	Coefficient of uniformity (C_u)		24.0	20
9.	Coefficient of gradation (C_c)		0.27	2.11
10.	USCS Classification		SW-SM	SW
11.	Specific gravity, G_s		2.51	2.66
12.	Water content, w	(%)	83.88	22.3
13.	Bulk density, ρ_s	gr/cm^3	1.184	1.87
14.	Dry density, ρ_{s-dry}	gr/cm^3	0.644	1.47
15.	Void ratio, e		2.90	0.59
16.	Relative density, Dr	◦	59	64
17.	$e_{\min}$		2.48	0.48
18.	$e_{\max}$		3.50	0.80
19.	$\rho_{dry-\min}$	gr/cm^3	0.566	-
20.	$\rho_{dry-\max}$	gr/cm^3	0.731	-

Source: *Kusumawardani, R., (2014)

According to Haldar (1976), the general ranges of D_{50} which will be critical to the liquefaction problem are between 0.02 mm and 0.60 mm.Liquefaction susceptibility is influenced by grain characteristics (particle size, gradation and particle shape). Particle size in a soil relates to soil composition and its influence on liquefaction susceptibility. Fine sand more susceptible to liquefaction than coarse sand. Field evidence indicates that most liquefaction failures have involved uniformly graded soils (Kramer, 1996).

2. SEM and EDS analysis

Figure 6a) shows the Scanning Electron Microscope (SEM) image of particles that obtained from the studied site. This figuredepicts scanning electron microscope photographs of the particles retained on #10 sieve. As shown in the figure, there is a dense network of fine interconnected holes (white arrow), most of them open to the surface, but others isolated inside the particle. All this result in lightweight, rough surface and easily crushable particles.In Figure 6b), the structure of Toyoura sand shows hard grains, stiff and has no voids.

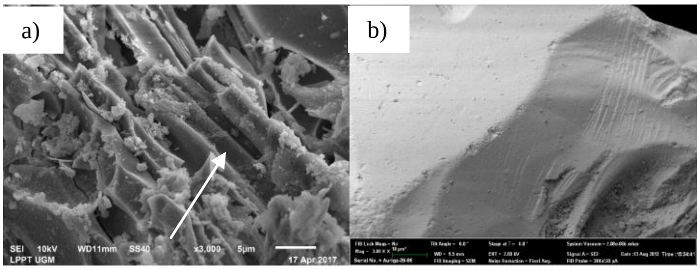

Figure 6. SEM micrograph showing: a) the internal voids in Mataram pumice, b) Toyoura sand (Alshibli K., 2013)

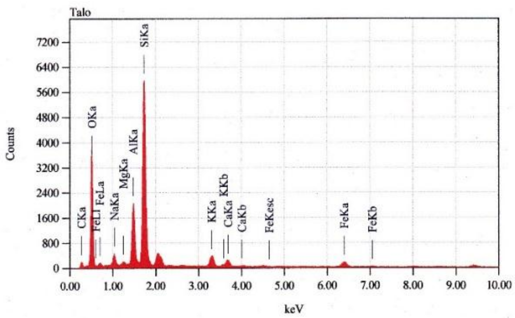

Figure7.Counts vs keV

The Figure 7and Table 3show the EDS test results. From the figure and table, the mineral of silica (SiO_2) and alumina (Al_2O_3) are the dominant compositions with percentages 56.64 and 14.91%.

3. The permeability characteristics

The permeability characteristics pumice was investigated using a constant head test on four samples of varying relative density (*Dr* = 40, 50, 60, and 80%). The test results show that the permeability of the pumice sand falls within the range of 1.3×10^{-3} to 1.9×10^{-2} cm/s. Figure 8 summarises the permeability characteristics of the pumice sand. The figure also shows a best fit exponential interpolation function relating relative density to the coefficient of permeability over the range of relative densities, which is given by the expression:

$$k = 0.3675\,e^{-0.071Dr} \quad \text{.... (2)}$$

Table 3. Mineral composition of Mataram pumice

ZAF Method Standardless Quantitative Analysis(Oxide)
Fitting Coefficient : 0.0707
Total Oxide : 24.0

Element	(keV)	Mass%	Sigma	Mol%	Compound	Mass%	Cation	K
C K	0.277	16.42	0.06	51.79	C	16.42	0.00	5.4560
O		40.12						
Na K	1.041	2.28	0.05	1.88	Na2O	3.07	0.95	4.4545
Mg K	1.253	0.42	0.05	0.66	MgO	0.70	0.17	0.7101
Al K	1.486	7.89	0.10	5.54	Al2O3	14.91	2.80	15.8993
Si K	1.739	26.47	0.21	35.72	SiO2	56.64	9.02	56.9246
K K	3.312	1.75	0.03	0.85	K2O	2.10	0.43	4.3361
Ca K	3.690	1.55	0.04	1.47	CaO	2.17	0.37	4.4698
Fe K	6.398	3.10	0.06	2.10	FeO	3.99	0.53	7.7497
Total		100.00		100.00		100.00	14.27	

where:*k* is the coefficient of permeability (cm/s)
Dr is the relative density (%)

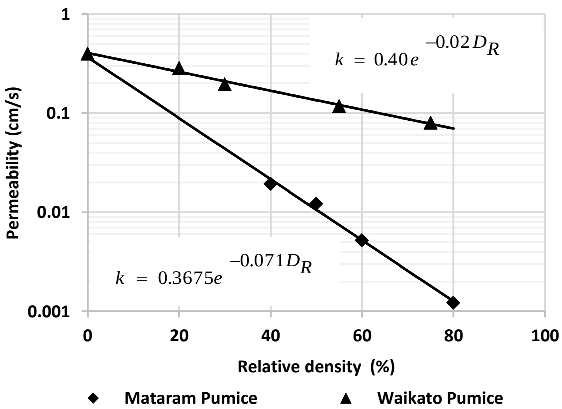

Figure 8. Permeability of Mataram pumice

Figure 8 also shows the result of Mataram Pumice permeability test compared to Waikato pumice permeability. Value of permeability of Waikato Pumice is bigger than Mataram Pumice, but both are still in medium permeability category (k = 10^{-3} to 10^{-1} cm/s). Soil composition and grain characteristics affect soil permeability, which plays an important role in the liquefaction characteristics of a soil deposit. The coarse-grained soils with high permeability are considered to permeable to sustain any generated pore pressure long enough for liquefaction to develop.

4. Shear strength characteristics

The shear box test of pumice was carried out according to the procedures in ASTM D-3080. Due to the formation of different diameter pumice, the height of 2 cm and 31.67 cm^2 cross section ring were used for the shear box test. Direct shear tests were conducted to determine shear strength of four different groupof grain pumice. Type A is typical for a grain size of less 4.75 mm, type B is typical for grain size range of 0.075 to 4.75 mm, type C is typical for grain size range of 0.0106 to 4.75 mm, while type D is typical for grain size range of 0.250 to 4.75 mm.The vertical stresses for each sample were respectively 0.25, 0.50 and 1.00 kg/cm^2, and the sample prepared as 50% water content.

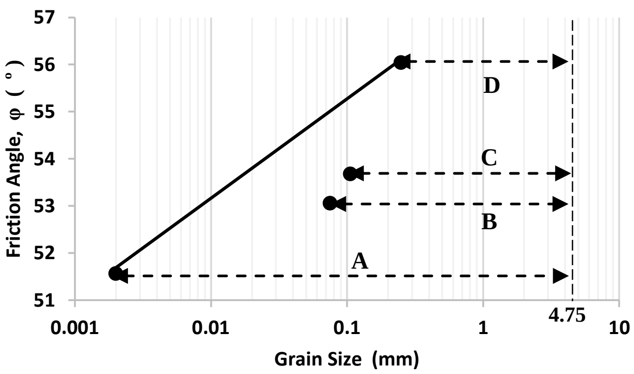

Figure 9.Shear strength behavior of Mataram pumice

Figure 9 shows the effect of soil grain size on increasing the frictional value of ground friction. Type D with a grain size of 0.25 to 4.75 mm has the greatest frictional angle value, while type A has the lowest frictional friction value. This phenomenon shows that the increase of friction angle is greatly influenced by the friction between the soil grains. Tests with larger size particles produced higher internal friction angle and developed high shear strength.

E. CONCLUSION

A series of tests have been performed on Mataram pumice, including determination of physical properties, permeability and shear strength test. The conclusions of the test results are:

1. Based on the results of gradation analysis, bulk density, dry density, void ratio, and SEM test, the soil sample from Kebon Talo is pumice sand.
2. The biggest mineral composition of Mataram pumice is Silica (SiO_2) and Alumina (Al_2O_3) were respectively 56.64 and 14.91%.
3. The relative density is highly influential on the permeability of Mataram pumice, and the permeability type is medium permeability.
4. The grain size of Mataram pumice is very influential on the increase of friction angle values. Pumice that has a large grain size, with a small size range, will have a large friction angle.

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