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Fine Sand Stabilization Using Metakaolin and Bentonite

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ABSTRACT
Soil improvement techniques by adding different materials, such as bitumen, bentonite, lime, etc. are considered to be effective methods to improve soil properties. Soil stabilization methods are now being utilized to overcome the problems of the soil erosion that causes failures at soil structure. Metakaolin is considered to be a promising supplementary construction material which can be used to improve soil properties. The aim of this study is to investigate the effect of mixing Gamasa sand with Metakaolin and Bentonite, Separately. Different mass percentages of materials (0%, 1%, 2%, 5%, 10%, 15%, and 20%) by dry weight of soil were mixed with Gamasa sand to assess their erodibility with time. A simplified low cost Pocket Erodometer Test (PET), direct shear test and the permeability test were implemented in this research. The experimental results indicated that soil erodibility decreased significantly at optimum percentage of 10% Metakaolin or 10.0% Bentonite by weight compared to untreated soil for each mixed soil sample over time. It was also noted that mixing 10% of Metakaolin or 10.0% Bentonite by dry soil weight with Gamsa Sand increases shear strength and decreases hydraulic conductivity compared to untreated soil.

***Keywords**: Soil stabilization, Soil improvement, Soil Erosion, Fine sand, Sand dunes, Metakaolin, Bentonite*

1- Introduction

The erosion of soil causes failures at soil structure. Consequently, many methods have been used to decrease soil erosion and increase its resistance, including soil stabilization methods. Soil mixture with specific additive can enhance the soil parameters, and this technique has been used earlier for soil stabilization (Shahin et al. 2015). There is a need to investigate the effect of adding different materials on soil properties. Metakaolin and Bentonite are new additives that can modify the mechanical properties of soils, such as shear strength, hydraulic conductivity, etc. The aim of the research was to investigate the effect of mixing fine sand (Gamasa Sand) with different materials as Metakaolin, and Bentonite on soil properties. To achieve this purpose, laboratory tests were operated. Pocket Erodometer, direct shear and permeability tests were performed on the mixed soils subjected to different types of materials. The effects of water erosion resistance, shear strength and hydraulic conductivity were studied. Some of the results shown in this paper are reproduced from the work published by the same authors in (Foda et al. 2018).

2- MATERIALS

2.1 Sand

The used sand in this research is classified as Fine clean sand according to ASTM D2487 - 17. It was obtained from 15 May district near Gamasa city, Dakahlia Governorate (off the international coastal road). The grain size distribution curve is shown in Figure 1. The physical and chemical properties of the used sand are shown in Tables 1 and 2, respectively. This sand will be referred to as Gamasa sand hereafter in the paper.

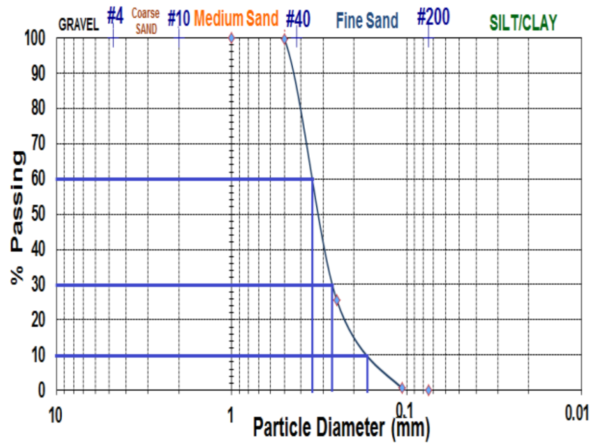

Figure 1 Particle size distribution of Gamasa sand

Table 1 Physical properties of Gamasa sand

Physical properties	Index properties	Gamasa sand
Grain size analysis	% sand (0.06-2) mm	99.912%
	% silt (0.002-0.06) mm	0.088%
	%clay(<0.002)mm	
USCS*		SP
Coefficient of uniformly(C_u)		2.2
Coefficient of curvature(C_c)		1.584
D_{10}		0.15
D_{30}		0.28
D_{60}		0.33

Table 2 Chemical properties of Gamasa sand

Chemical properties	Gamasa sand
PH	8.41
TDS (ds/m)	1.242
Density(gm/cm^3)	1.57
Ca (meq/l)	2.03
Mg(meq /l)	1.16
Na(meq /l)	4.47
K(meq /l)	0.41
So_4(meq /l)	1.12
HCO_3(meq /l)	0.87

2.2. Metakaolin

Metakaolin is a pozzolanic material made originally from kaolin. When kaolin is heated to 700-900◦C, it loses hydroxyl water forming Metakaolin (Ahmed, and Hamza 2015). In their research work, Vikas revealed that adding Metakaolin to concrete improved its strength and durability (Srivastava et al. 2012). Metakaolin was also found to improve the concrete permeability (Srinivasu et al. 2014). Metakaolin can also be used as cementing material when mixed with other materials (Rashad 2015).The used Metakaolin was obtained from *Ahmed Othman* mining factory-Egypt. The percentages of Metakaolin used in this research and shown hereafter are weight percentages of Gamasa sand specimen. The chemical and physical properties of Metakaolin used in this research are shown in Table (3).

Table 3 The chemical and physical properties of Metakaolin used (based on *Ahmed Othman mining factory-Egypt*)

Percentage composition (w/w)	Chemical properties
47.40	SIO_2
1.10	Fe_2O_3
35.40	AL_2O_3
0.06	MgO
0.11	CaO
0.05	K_2O
0.04	Na_2O
2.14	TiO_2
0.01	MnO_2
0.16	P_2O_5

2.3. Bentonite

Bentonite is a clay generated frequently from the alteration of volcanic ash, consisting predominantly of smectite minerals, usually montmorillonite. Smectites are clay minerals, i.e. they consist of individual crystallites the majority of which are < 2µm in largest dimension (Solanki, Dave & Maheshwari 2017). The engineering properties of Bentonite (swelling, water absorption, viscosity, hydration), leads to make Bentonite a very important engineering material for a wide applications and uses (Daud 2018).

2.4 Mixing Water

Tap water was used to get a suspended solution of Metakaolin and Bentonite both separately with different ratios for mixing with Gamasa sand specimens.

Different materials were mixed with minimum quantity of water that ensures the solution workability (Benahmed and Bonelli 2012). The initial water content was about 30.0% from the mixed soil which decreased quickly with time due to drainage and evaporation.

3- Experimental Program

Table 4 showed the details of the Experimental program including the tests on each type of admixtures, the name of admixtures and the content (%) by dry weight of soil etc.

Table 4 Experimental program

Mixed soil	Experiment performed
Untreated Sand	-PET(after25, 50&75 days) -Direct shear test -Permeability test
Sand+ (1.0, 2.0, 5.0, 10.0, 15.0 &20.0%) Metakaolin	
Sand+1.0%Metakaolin	-PET(after25, 50&75 days)
Sand+2.0%Metakaolin	-PET(after25, 50&75 days)
Sand+5.0%Metakaolin	-PET(after25, 50&75 days)
Sand+10.0%Metakaolin	PET(after25, 50&75 days) -Direct shear test -Permeability test
Sand+15.0%Metakaolin	-PET(after25, 50&75 days)
Sand+20.0%Metakaolin	-PET(after25, 50&75 days)
Sand+ (1.0, 2.0, 5.0, 10.0, 15.0 &20.0%) Bentonite	
Sand+1.0%Bentonite	-PET(after25, 50&75 days)
Sand+2.0%Bentonite	-PET(after 25, 50&75 days)
Sand+5.0%Bentonite	-PET(after 25, 50&75 days)
Sand+10.0% Bentonite	-PET(after 25, 50&75 days) -Direct shear test -Permeability test
Sand+15.0% Bentonite	-PET(after 25, 50&75 days)
Sand+20.0% Bentonite	-PET(after 25, 50&75 days)

4- METHODS

4.1 Sample Preparation

In order to assess the effect of Metakaolin or Bentonite on the engineering properties of Gamasa sand, Many samples were prepared in this research:

1. Untreated Gamasa sand with only tap water, (Untreated Gamasa sand is a soil with no additives but only with water, while Treated soil is a soil with additives.).
2. Gamasa sand mixed with (1%, 2%, 5%, 10%, 15%, and 20%) of Metakaolin.
3. Gamasa sand mixed with (1%, 2%, 5%, 10%, 15%, and 20%) of Bentonite.

4.2 Mixing Methods

Mechanical mixing method was used for mixing the soil with different materials with solutions of different percentages. The soil mixed with different additives up to 5.0 cm depth of the surface. Researchers found that the mechanical mixture is the best to get more homogenous soil sample (Uromeihy, Sofian, and Nikudel 2015).

The sand mixture for different samples was assessed for erodibility using a modern simple low cost Pocket Erodometer Test (PET) method. The shear strength and permeability of the mixture was also assessed for some selected samples using conventional direct shear and falling head permeability devices, respectively.

The following subsections explain the tests performed on the different sand- mixtures:

4.3 Pocket Erodometer Test (PET)

Over the past few decades, many devices were used to measure the potential of the soil erodibility, such as Hole Erosion Test, Slurry Jet Erosion Tester, Contact Erosion Test (Briaud, Chen, and Chang 2002). While they provide good results, they are relatively expensive and need long time for set up. (Briaud et al. 2012) developed a new technique called Pocket Erodometer Test (PET) which is simple, cheap and provide an indication on the erodibility of soils. It is a mini jet impulse generating device, with a nozzle velocity of 8±0.5 m/s, and aperture of approximately 0.5 mm (Briaud et al. 2002), as shown in Figure 2.

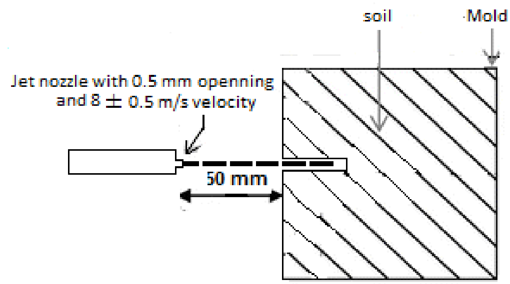

Figure 2 Schematic of the PET

The procedure of the PET is as follows (Briaud et al. 2012):

a. A soil sample approximately 10 cm in diameter is placed horizontally
b. The surface of the soil sample is smoothed to take out any irregular soil.
c. The jet nozzle is placed 50 mm away from the face.
d. 20 water impulses are directed towards the soil surface at a rate of 1 impulse per second.
e. A hole is formed in the soil sample and the depth of the hole is measured.
f. The test is repeated three times and the average hole depth is measured.
g. The erosion chart in Figure 3 is used to determine the erodibility category of the soil sample based on the depth of the hole.

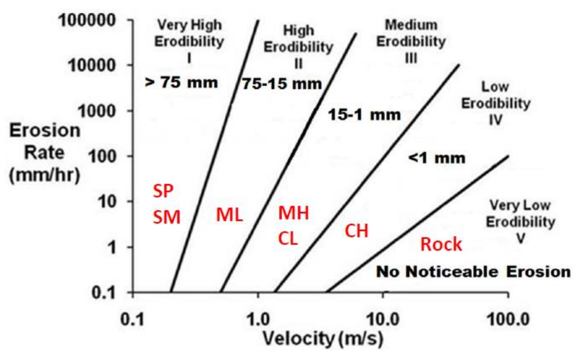

Figure 3 PET calibrated erosion (Briaud et al. 2002)

It must be noted that the PET is considered as index test, as the calibration of the test with other more complicated, well established tests is still in the early stages by the developers (Briaud et al. 2012). The test was used in this research to determine the change in erodibility due to mixing Gamasa sand with different ratios of Metakaolin and Bentonite (1%, 2%, 5%, 10%, 15%, and 20%) by the total dry weight of Gamasa sand.

4.4 Direct Shear Test

The direct shear test was carried out in accordance with the ASTM D3080 on untreated Gamasa sand and on some selected samples of the sand-Metakaolin mixtures and sand-Bentonite mixtures. Specifically, the optimum percentage of Metakaolin and Bentonite was determined using the PET and the direct shear test was only performed on the optimum sand- mixture.

4.5 Permeability Test

Falling head test was carried out in accordance with the ASTM D5084 to determine the hydraulic conductivity. The test, as shown in Figure 4, was performed on untreated Gamasa sand and on the optimum sand-Metakaolin mixture and sand-Bentonite mixture, as indicated before.

Figure 4 Falling head test

5- RESULTS AND DISCUSSION

5.1 Erosion

The test was performed on untreated Gamasa sand. The erosion hole depth was found to be about 8 cm (80 mm) indicating very high erodibility, as shown in Figure 4. This is expected, as fine sand is known to be one of the most erodible soils, as it has no cohesion and very small grains.

The same test was repeated on different sand-Metakaolin mixtures and different sand-Bentonite mixtures. Different mixtures were tested after 25 day as well as 50 & 75 days to test the durability of the treated mixture. It was observed that the resistance to erosion increased significantly when Gamasa sand was treated with 5-10% of Metakaolin. The enhancement was found to be less significant as the percentage of Metakaolin increases. The results also showed that the best ratio of mixing different ratio of Bentonite with Gamasa sand was 10.0% Bentonite, where it was noted that this ratio was stable compared to the rest of the different ratios over time. Figures 5, 6 and Table 5 indicate the optimum ratio of Metakaolin and Bentonite, Separately.

Table 5 The result of PET after 25, 50&75 days for mixing different ratio of Metakaolin & Bentonite

Material	Concentration ratio of Metakaolin	Erosion depth after 25 day(cm)	Erosion depth after 50 day(cm)	Erosion depth after 75 day cm
untreated soil (Fine sand)	0.0%	8.00	8.00	8.00
Metakaolin Sand mixture	1.0%	3.19	2.85	2.5
	2.0%	3.067	2.25	1.6
	5.0%	2.20	1.80	1.7
	10.0%	2.08	1.60	1.3
	15.0%	4.87	3.80	3.35
	20.0%	6.00	5.50	3.4
Bentonite Sand mixure	1.0%	3.43	3.3	3
	2.0%	4.1	3.1	2.7
	5.0%	3.367	4.1	4.55
	10.0%	2	2.3	2.4
	15.0%	1.9	3.75	3.5
	20.0%	2.36	4.8	3

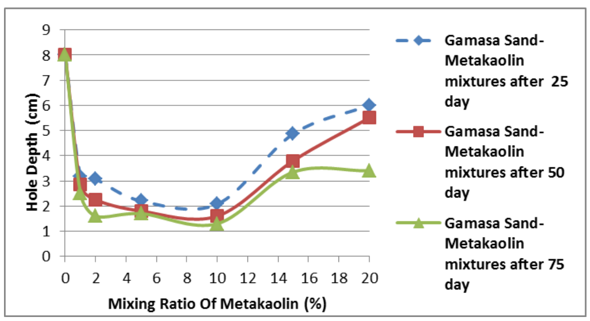

Figure 5 PET results for different ratios of mixing (Metakaoiln) using vs. times

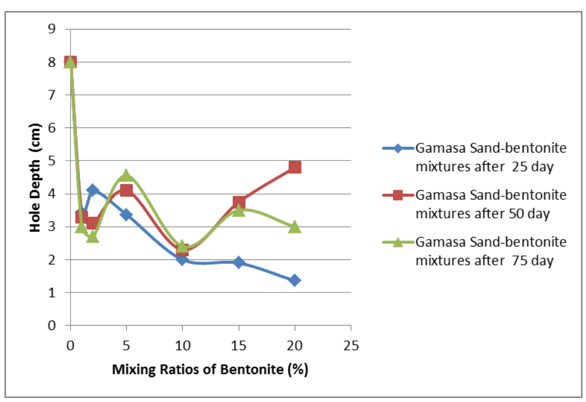

Figure 6 PET results for different ratios of mixing (Bentonite) vs. times

5.2 Shear Strength

As indicated before, the direct shear test was only performed on the optimum sand-Metakaolin mixture and the optimum sand-Bentonite mixture according to the PET, which was found to be 10%, either way. The direct shear test was also performed on untreated Gamasa sand. The results of the direct shear test for untreated Gamasa sand, 10% sand- Metakaolin mixture and 10% sand-Bentonite mixture are shown in Figures 7,8 and 9, respectively.

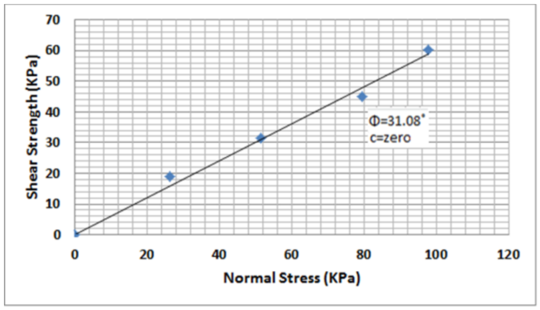

Figure 7 Results of direct shear test for Untreated Gamasa sand

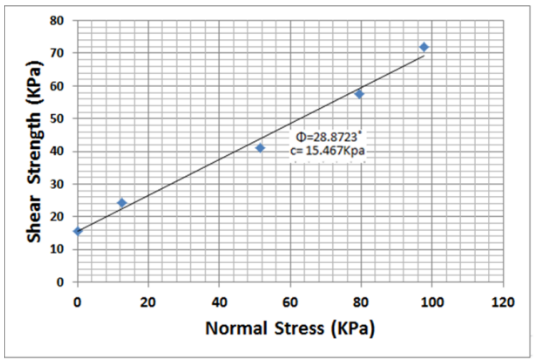

Figure 8 Results of direct shear test for 10% Sand- Metakaolin mixture.

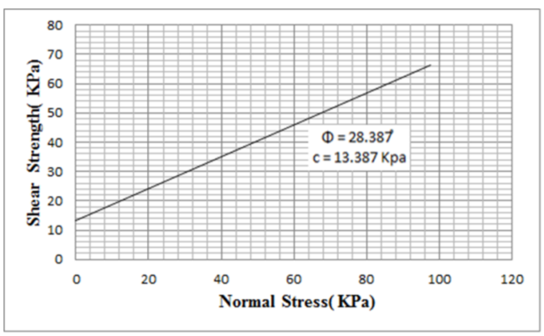

Figure 9 Results of direct shear test for Sand 10.0% Bentonite mixture

The experimental results showed that the cohesion in case of mixing 10% Metakaolin with Gamasa sand increases from zero to 15.467 KPa, while the cohesion of Gamasa sand mixed with 10% Bentonite increased from zero to 13.387KPa. This increase in cohesion is probably the reason to increase the erosion resistance of the mixed soil. The results are summarized in Table 6**.**

Table 6 Summary of the direct shear test results

Sample type	Friction angle	Cohesion KPa
Gamasa sand	31.08	0.0
Gamasa sand+10% Metakaolin	28.8723	15.467
Gamasa sand+10% Bentonite	28.387°	13.387

5.3 Permeability

The untreated Gamasa sand was found to have a permeability of 0.03 cm/sec. The permeability of the soil mixed with 10 % Metakaolin was 0.004 cm/sec, while for Gamasa sand mixed with 10.0 % bentonite was 0.00035 cm/sec. This decrease in permeability is expected due to the increase in the percentage of Metakaolin or Bentonite that blocks the pore of the sand.

6- CONCLUSIONS

Based on the experimental results using the PET simplified erosion test, it was found that:

- The resistance to erosion increased significantly when Gamasa sand was treated with 5-10% or less of Metakaolin.
- The enhancement was found to be less significant as the percentage of Metakaolin increases.
- Due to different ratio of sand-Metakaolin mixtures, the optimum percentage of Metakaolin was determined as 10%.
- The results of the direct shear test also showed that the cohesion in case of mixing 10% Metakaolin to the fine sand increases from zero to 15.467 KN/m^2.
- Hydraulic conductivity test results showed that the coefficient of permeability for Gamasa sand mixed with 10.0% Metakaolin and 10.0% Bentonite decreased comparing with untreated soil due to the increase in the percentage of fines that blocked the pore of the sand.
- The results of the direct shear test also showed that the cohesion in case of mixing 10.0% Bentonite to the fine sand increased from zero to 13.387 KPa where the angle of internal friction didn’t reveal a real effect by increasing of Bentonite.
- After testing different ratio of Sand-Bentonite mixtures, the best percentage of Bentonite was determined as 10.0% over time where it was observed to be stable with time from the rest of the ratios.

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