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STABILIZATION OF FINE SAND USING METAKAOLIN

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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. Metakaolin is considered to be a promising supplementary construction material which can be used to improve soil properties, especially fine sand. Fine sand in sand dunes that spread by the wind may lead to several damages to agricultural crops, buildings and roads. The purpose of this study is to investigate the effect of mixing fine sand with Metakaolin. Different mass percentages of Metakaolin (0%, 1%, 2%, 5%, 10%, 15%, and 20%) by dry weight of soil were mixed with fine sand to assess their erodibility with time. A simplified low cost Pocket Erodometer Test (PET) was implemented in this research. The experimental results indicated that soil erodibility decreased significantly at optimum percentage of 10% Metakaolin by weight compared to untreated soil. It was also noted that mixing 10% of Metakaolin increases shear strength of soil and decreases hydraulic conductivity compared to untreated soil.

الملخص:

تعتبر تقنيات تحسين خواص التربة عن طريق اضافة بعض المواد المختلفة مثل البيتومين، البنتونيت، الجير من الطرق الفعالة لتحسين خواص التربة. و تعتبر مادة الميتاكاولين من المواد الواعدة للبناء التى يمكن استخدمها في تحسين خواص التربة وخاصة التربة الرملية الناعمة. فقد تتسبب التربة الرملية الناعمة (في الكثبان الرملية) التى تنتشر بواسطة الرياح في العديد من الأضرار التى قد تصيب المحاصيل الزراعية والمنشآت والطرق. ويعد الهدف الرئيسي من هذا البحث هو دراسة تأثير خلط الميتاكاولين مع الرمل الناعم ولذلك تم خلط نسب مختلفة من الميتاكاولين (0.0%,1%,2%,5%,10%,15%,20%) من وزن التربة الجافة لقياس مقاومتها للتآكل مع الزمن. و أشارت النتائج التجريبية إلى أن تآكل التربة انخفض بشكل ملحوظ عند النسبة المثلى 10٪ من الميتاكولين مقارنة بالتربة الغير المعالجة. وقد اوضحت نفس النتائج مع الزمن. كما لوحظ أن خلط 10٪ من الميتاكولين يزيد من قوة القص في التربة ويقلل التوصيل الهيدروليكي مقارنة بالتربة غير المعالجة.

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

1. INTRODUCTION

Fine sand (such as that found in sand dunes) encroachment problems on roads, villages, farms, and other construction establishments are associated with sand storms. Soil stabilization by adding different materials, such as bitumen, bentonite, lime, etc. is considered to be effective methods to improve soil properties. In this research, Metakaolin was used for fine sand stabilization. Metakaolin material is available in different places with low cost [1]. Metakaolin is a pozzolanic material made originally from kaolin. When kaolin is heated to 700-900◦C, it loses hydroxyl water forming Metakaolin [2], as shown in Equation (1) [2]. In their research work, Vikas revealed that adding Metakaolin to concrete improved its strength and durability [3]. Metakaolin was also found to improve the concrete permeability [4]. Metakaolin has recently been used in improving the properties of expansive soils to reduce its expansion capabilities [2]. Metakaolin can also be used as cementing material when mixed with other materials [5]. The aim of this research is to investigate the effect of mixing different percentages of Metakaolin with fine sand in order to improve its engineering properties such as erodibility, shear strength, and permeability.

$$Al_2Si_2O_5OH_4 \xrightarrow{(700-900)^\circ C} Al_2O_32SiO_2 + 2H_2O \quad (1)$$

2. MATERIALS

2.1 Sand

The used sand in this research is classified as Fine clean sand with fines content =10% 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.

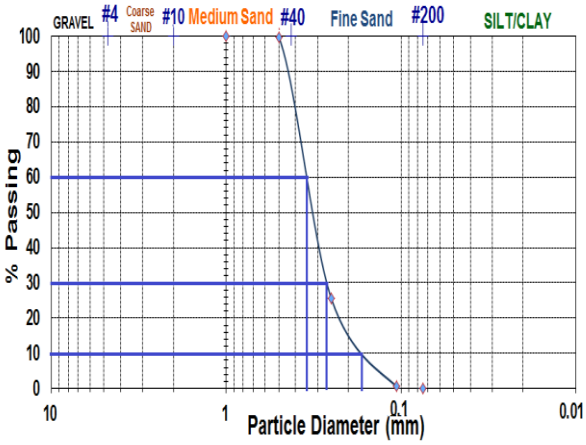

Figure 1 Particle size distribution of Gamasa sand

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

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 Water

Tap water was used for providing solutions of Metakaolin with different ratios for mixing with Gamasa sand specimens.

The literature shows that the increase of water content improves significantly the soil properties against erosion due to increased workability of the water-Metakaolin mixture when mixed with the dry soil [6].

3. METHODS

3.1 Sample Preparation

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

1. Untreated Gamasa sand with only tap water (0.0% Metakaolin).
   (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.

Metakaolin was mechanically mixed with minimum quantity of water that ensures the solution workability. The initial water content was about 30% from the mixed soil which quickly decreased with time due to drainage and evaporation. The dry Gamasa sand was then mechanically mixed with solutions of different Metakaolin percentages. Researchers found that the mechanical mixture is the best to get more homogenous soil sample [7].

The sand-Metakaolin mixture 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 sand-Metakaolin mixtures.

3.2 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 [8]. While they provide good results, they are relatively expensive and need long time for set up. Briaud et al. [8] 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 [8], as shown in Figure 3.

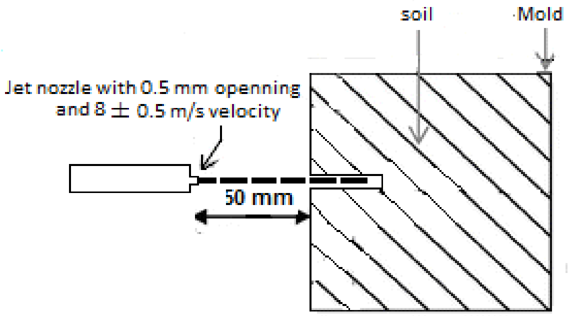

Figure 3 Schematic of the PET

The procedure of the PET is as follows [8]:

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 4 is used to determine the erodibility category of the soil sample based on the depth of the hole.

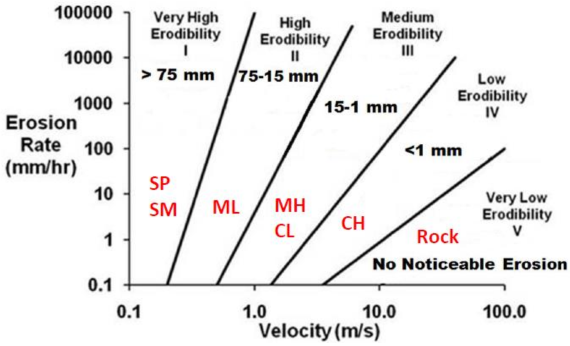

Figure 4 PET calibrated erosion [8]

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 [8]. The test was used in this research to determine the change in erodibility due to mixing Gamasa sand with different ratios of Metakaolin (1%, 2%, 5%, 10%, 15%, and 20%) by the total dry weight of Gamasa sand.

3.3 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. Specifically, the optimum percentage of Metakaolin was determined using the PET and the direct shear test was only performed on the optimum sand-Metakaolin mixture.

3.4 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 5, was performed on untreated Gamasa sand and on the optimum sand-Metakaolin mixture, as indicated before.

Figure 5 Falling head test

4. RESULTS AND DISCUSSION

4.1 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 that were tested after 25 day as well as 50 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. Figure 6 and Table 4 indicate that the optimum ratio of Metakaolin was about 10%.

Table 4. The result of erosion test after 25&50 days for mixing different ratio of Metakaolin

Material	Concentration ratio of Metakaolin	Erosion depth after 25 day(cm)	Erosion depth after 50 day(cm)
untreated soil (Fine sand)	0.0%	8.00	8.00
Metakaolin Sand mixture	1.0%	3.19	2.85
	2.0%	3.067	2.25
	5.0%	2.20	1.80
	10.0%	2.08	1.60
	15.0%	4.87	3.80
	20.0%	6.00	5.50

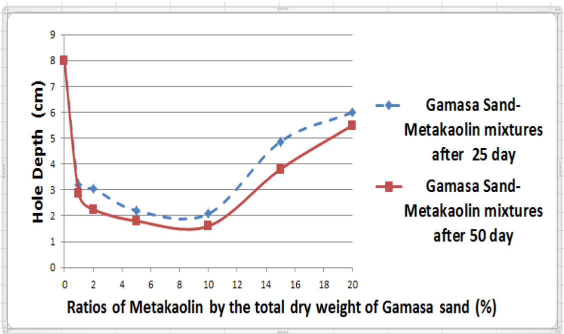

Figure 6 Comparison between the result of erosion test after 25 and 50 days for different ratios of sand-Metakaolin mixtures

4.2 Shear Strength

As indicated before, the direct shear test was only performed on the optimum sand-Metakaolin mixture according to the PET, which was found to be 10%. The direct shear test was also performed on untreated Gamasa sand. The results of the direct shear test for untreated Gamasa sand and 10% sand-Metakaolin mixture are shown in Figures 7 and 8, respectively. The results are summarized in Table 5**.**

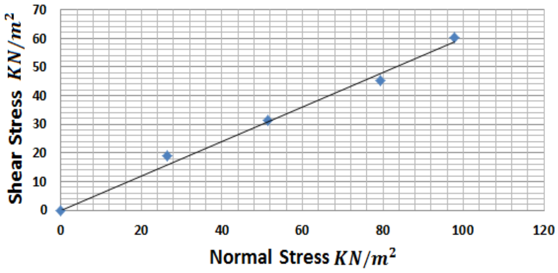

Figure 7 Results of direct shear test for Untreated Gamasa sand

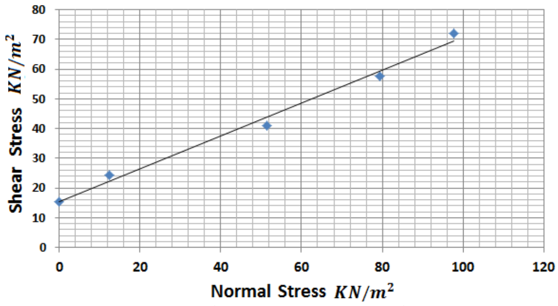

Figure 8 Results of direct shear test for 10% Sand-Metakaolin mixture.

The experimental results show that the cohesion in case of mixing 10% Metakaolin with Gamasa sand increases from zero to 15.467 KN/m^2. This increase in cohesion is probably the reason to increase the erosion resistance of the mixed soil.

Table 5 Summary of the direct shear test results

Sample type	Friction angle	Cohesion KN/m^2
Gamasa sand	31.08	0.0
Gamasa sand+10% Metakaolin	28.8723	15.467

4.3 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. This decrease in permeability is expected due to the increase in the percentage of Metakaolin that blocks the pore of the sand.

5. 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 permeability of the soil mixed with 10 % Metakaolin decreased comparing with untreated soil due to the increase in the percentage of fines that blocks the pore of the sand.

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