Section A-Research paper
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Geotechnical Properties of Omani Sabkha-Cement-marble Mixture

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Abstract— Sabkha is used to define salt-encrusted flats is composed of sand, silt or clay soil. It is found all over the world especially in areas with arid and hot and where the evaporation rate substantially exceeds the precipitation rate. Sabkha covers about 10% of earth surface. However, sabkha soil has a low shear strength and low compressibility. Soil improvement techniques are extremely required to enhance physical and mechanical properties of sabkha. On the other hand, marble waste is a challenge that need sufficient and urgent attention. The production of marble worldwide is roughly about 500 million tons. During process of marble cutting, grinding, and polishing, approximately 20-30 % of the marble blocks becomes a waste. This research is aimed to get rid of this waste material by utilizing it for stabilization of sabkha soils. Sabkha samples were collected from Al-Auzayba, Oman. The soil was treated by two binders: cement and cement-marble waste in dosages of 0, 2.5, 5, 7.5 and 10% of dry mass of sabkha. The percentages of marble powder in the cement-marble were 0, 10, 20, 30 and 100%. Physical properties and chemical properties of the mixture were determined.

Key words: Marble powder, sabkha, salt-encrusted flats**,** soil stabilization,

I. INTRODUCTION

Sabkha soil is a problematic soil c which is unstable, compressible and has low shear strength. It has a rapid reduction strength owing to water addition and primary and secondary settlement. Because of these features, sabkha is no more suitable for any infrastructure. Oman has a topography primarily of desert with an arid climate. It is one of the countries with vast areas of sabkha soils such as Umm Samim and Barr Al-Hikman where the sabkha covered areas of 2400 km^2 and 1400 Km^2, respectively (Barth and Boer, 2002).

The engineering properties of sabkha were enhanced by various soil stabilization methods. These stabilizations techniques are able to render a weak soil to be more stable (Afrin, 2017). Improved properties can include soil strength, durability, stiffness and other desirable characteristics. Additives likes cement, lime and other traditional stabilizers were successfully to treat soils. However, addition of waste material is a possible for stabilization of problematic soils (Sivrikaya, 2014). Marble powder is an example of waste material and is obtained from marble quarries. Accordance to Thakur *et al.* (2018), the production of marble worldwide is roughly about 500 million tons. In addition, the processing operations from raw marble stone produced about 20-30% of fine-grained powder. Production of marble created several environmental problems. El-Sayed (2019) reported that marble waste disposal my cause a tangible damage and biological effects of the ecosystem.

There are extensive research in using waste material for soil stabilization. Using of such materials keeps the materials from being dumped, consuming landfill space and avoid its negative impact to environment and economy. Ram and Pareek (2018) studied the effects of using marble dust as an additive material to enhance the properties of clayey soil. Plasticity index, dry density and CBR values are improved by adding a marble dust with various replacement ratios. Zumrawi and Eman

(2018) investigated the behavior of using marble waste powder to enhance the properties of expansive soil. The plasticity index and liquid limit decreased with the increase in MP proportion. Also, it is observed a slight reduction of free swell index and increase in dry density. UCS witnessed growth estimated to be about 3.7 times that of untreated soil. Sabat and Nanda (2011) reported that the use of marble powder and husk ash in stabilization of expansive soil resulted in increase in CBR value and UCS.

The focus of this research was to study the properties of sabkha soil enhanced by using marble powder as an additive to partially replace cement for soil stabilization.

2. Materials and methods

2.1 Materials

2.1.1 Sabkha Soil

Sabkha was obtained from Al-Auzayba, Oman. The soil sample was collected from a depth of 0.5m to 1m below the ground surface. At natural state, surface layers seem weak with some visible salt crusts. In Figure 1, a photograph of the ground surface condition. Average moisture content of collected samples was about 17.3%. The grain size distribution of the soil is shown in Figure 2. The soil is classified as low-medium plasticity sandy clay (CL) based on USCS system. The physical properties of the sabkha soil are listed in Table 1. Chemical compositions were determined using X-Ray Fluorescence (XRF) as well as other tests such as sulfate content, chloride content and total salt content tests. Table2 presents the chemical composition of the soil.

Figure 1. Photograph of surface condition of sabkha soil

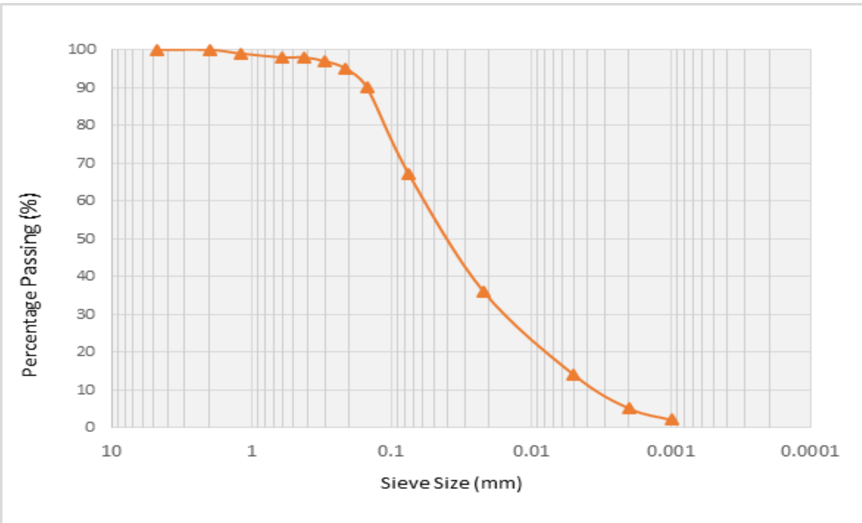

Figure 2. Particle size distribution of the sabkha

Table 1. Basic properties of sabkha

Liquid Limit (%)	Plastic Limit (%)	Plasticity Index (%)	Uniformity coefficient C_u	Curvature coefficient C_c	Specific Gravity
34	21	13	15	0.938	2.67

Table 2. Chemical composition of soil

Mineral Compositi	Percentage %
SiO_2	41.5
CaO	21.9
MgO	11.4
Na_2O	7.0
Fe_2O_3	6.4
K_2O	1.4
TiO_2	0.7
P_2O_5	0.1
MnO	0.1
LOI	24

2.1.2 Marble Powder

MP was obtained from marble-stone cutting factory in Al Seeb, Oman. Tested samples were collected from the surface of marble dump. The average water content of the sample was about 21%. Table 3 presents the basic (physical) properties of marble powder. The oxides composition of marble powder is listed in Table 4.

Table 3, Physical properties of marble powder

LL (%)	PL (%)	PI	C_u	C_c	G_s
35	19.15	16	53.3	0.133	2.71

Table 4. Chemical composition of marble powder

Oxides (%)	**(%)**	**Oxides (%)**	**(%)**
SiO_2	46.69	**CaO**	10.83
TiO_2	0.36	**Na_2O**	1.64
Al_2O_3	19.08	**K_2O**	0.08
Fe_2O_3	8.29	**P_2O_5**	0.08
MnO	0.15	**loss on Ignition**	9
MgO	12.84		

2.1.3 Ordinary Portland Cement (OPC)

OPC is ordinary is manufactured by Oman Cement Company. The chemical composition of OPC are listed in Table 5.

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Table 5. Chemical composition of OPC

Compound	%	Compound	%
SiO_2	21.24	C_2S	20.58
IR	0.45	C_3A	4.88
AL_2O_3	4.63	C_4AF	-
Fe_2O_3	4.37	LSF	91.62
CaO	63.37	$C_3A \leq 8\%$	2.02
Mn_2O_3	-	$C_3A \geq 8\%$	-
CL^-	-	K_2O	-
MgO	1.56	C_3S	53.47
SO_3	-	Na_2O	-
LOI	1.7	TiO_2	-
Na_2O + 0.658 K_2O	0.47		

2.2 Sample Preparation, Mix Design and Tests

For all tests, the soil was oven dried for 24 hours and crushed a day before test. Marble powder was oven dried, crushed, sieved in 2.36 mm sieve size and kept at sealed plastic bags.

2.2.1 Mix Design

The selected binder for stabilization of sabkha consisted of cement and marble powder in the ratios of 100/0; 80/20 and 60/40. The following dosage of binders (i..e. 2.5, 5, 7.5 and 10%) were added to the soil. of the dry mass of the soil. Thus, there were a total of 12 soil-binder mixtures with different binder contents and different cement/marble powder ratios (Table 6).

2.2.2 Maximum Dry Density (MDD) and Optimum Water Content (OWC)

Modified compaction proctor test is carried out for samples of sabkha as per ASTM D1557-15. OWC and the corresponding MDDfor sabkha soil were 16% and 1.74 gm/cm^3, respectively. Moreover, for marble powder, the maximum dry density was 1.55 gm/cm^3 at optimum water content of 26.5%.

2.2.3 Unconfined Compressive Strength Test (UCS)

The prepared samples for UCS test were 10 cm in diameter and 20 cm on height. Specimens prepared by predetermined OWC and MDD. Dried materials were mixed by manual dry mix for 30 sec to ensure a homogenous mixture and water was added gradually later. After remolding, sample is kept

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sealed for 6 days and air cured for 1 days before testing time. The unconfined compressive strength (UCS) test was performed as per ASTM D1633-17using compressive device with a capacity of a 300 KN and 1.3mm/min rate . A total of 24 specimens were tested with various mix percentages.

Table 6. Mix design

Mixture No.	Binder Content (%)	Designation
1	2.5	MS0C100
2		MS20C80
3		MS40C60
4	5	MS0C100
5		MS20C80
6		MS40C60
7	7.5	MS0C100
8		MS20C80
9		MS40C60
10	10	MS0C100
11		MS20C80
12		MS40C60

3. Test Results and Discussion

3.1. Compaction Test

Both treated and treated samples were compacted according to the Modified compaction test. The results are presented in Figures 3. Also, the relation between the MDD and OWC and the percentage of binder is shown in Figures 4 and Table 7. From Figure 5 shows that the vale of MDD of sabkha soil with both binders (OPC binder and OPC-Marble binder) increases as the binder content increases. This is expected because the binder is very fine compared to the soil grains, thus, the voids are filled by the binder. The optimum binder % is 7.5 which gives the maximum dry density.

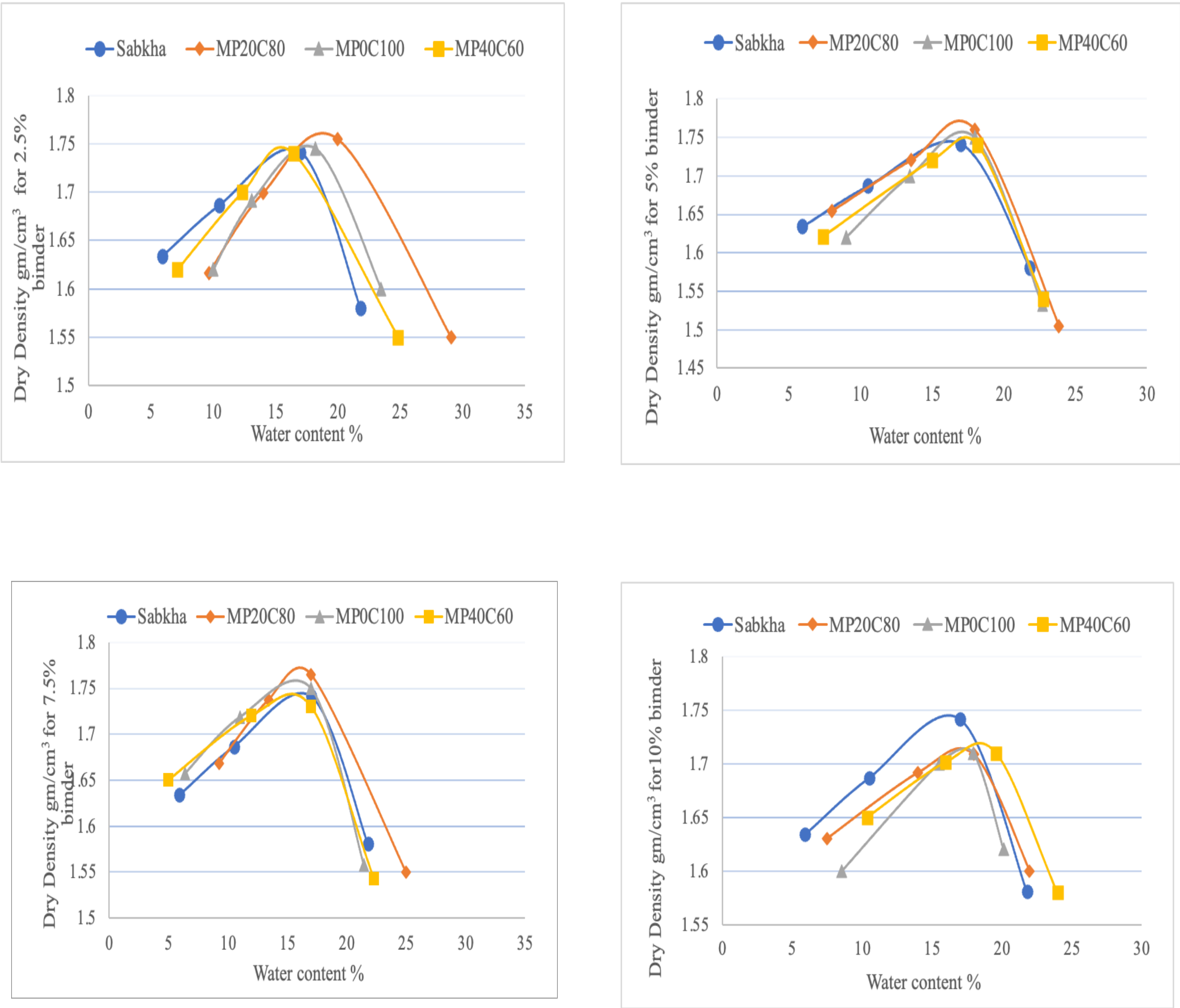

Figure 3 Dry density versus water content for sabkha soil treated with OPC/MP binder

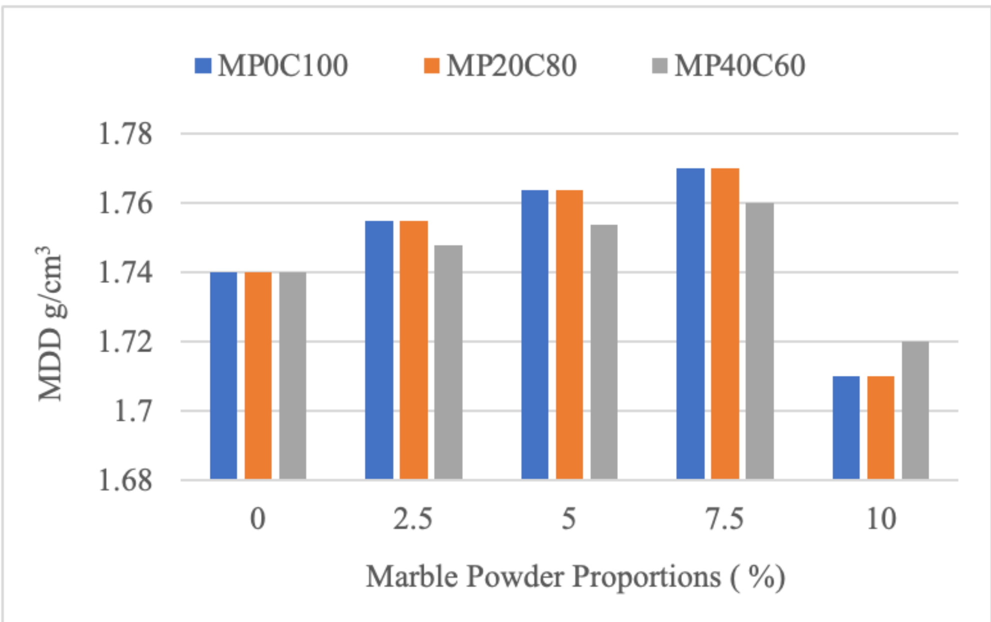

Figure 4. Maximum dry density versus % of binder for sabkha soil with different Cement/Marble ratio

Table 7. Optimum Water Content MDD for various soil-marble powder-cement mixtures

Binder Content (%)	Designation	MDD (gm/cm^3)	OWC (%)
2.5	MS0C100	1.7	16
	MS20C80	1.69	14
	MS40C60	1.73	15.5
5	MS0C100	1.75	15.5
	MS20C80	1.71	17
	MS40C60	1.69	18
7.5	MS0C100	1.74	14
	MS20C80	1.83	10
	MS40C60	1.78	11
10	MS0C100	1.72	17
	MS20C80	1.77	15.5
	MS40C60	1.7	18

3. 2 Unconfined compressive strength

Figure 5 shows the compressive strength for soils stabilized with OPC and OPC-Marble binders. Overall, the compressive strength increases with the increase in binder content for all mixes. The results indicated that the UCS of sabkha treated with cement is slightly larger than UCS for OPC-Marble binder.

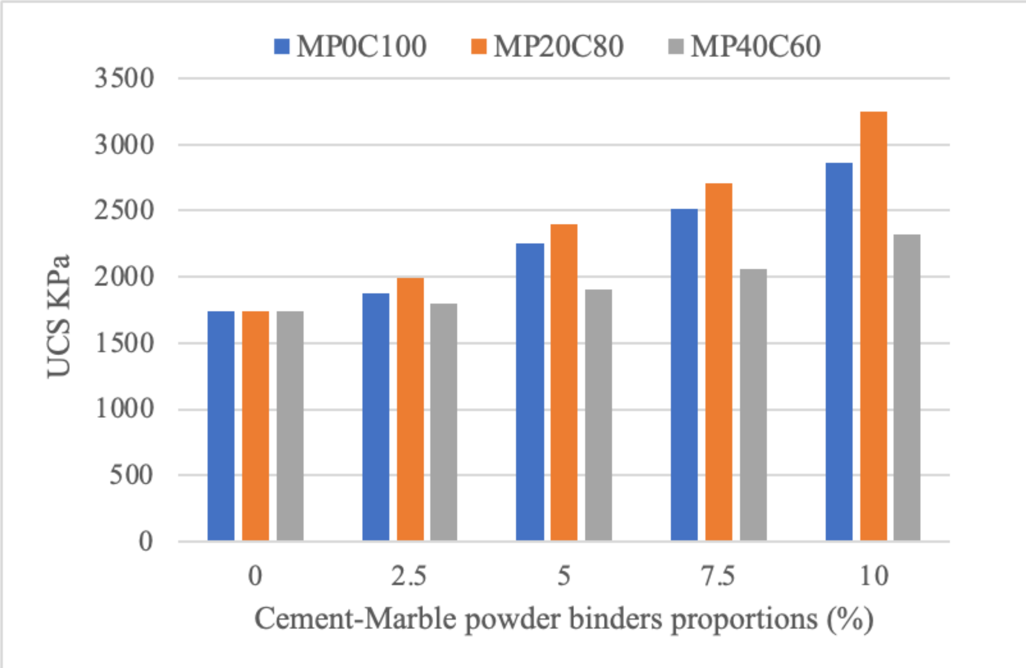

Figure 5. UCS of sabkha treated with OPC and OPC-Marble binders

4. Practical Applications

The UCS of the stabilized sabkha are compared in Table 8 with the minimum required UCS by different organization for possible use in pavements construction. The table indicates that the treated sabkha can be used as subgrade and sub-base with binder percentage of 2.5% and more.

5. Conclusions

The conclusions from this study are:

1. The maximum dry density of sabkha soil increases as the cement –marble dosage increases.
2. Treated sabkha soil using binders of OPC-Marble showed a large improvement in UCS.
3. Partially replacement of cement with Marble provides a suitable stabilizer comparable with cement stabilizer alone. Thus, the cement can be replaced with Marble slurry.
4. The product can used to support different pavement layers such as subgrade and sub-base as well as foundation soil for support of different infrastructures.

Table 8. Comparison of USC of treated sabkha with minimum UCS values recommended by different standards

References	UCS (KPa), based on standard at 7d	UCS (kPa) results for this study at 7d	Binder % for use based on the UCS Results of this study	Application
Unified Facilities Criteria (Department of Defense USA, 2004)	1723	1850 1900	2.5% (MS40C60) 2.5% (MS20C80)	Subgrade course
Texas Department of Transportation (2019)	2070	2050 2150	5% (MS40C60) 5 % (MS20C80)	Cement treated sub-base
Portland Cement Association (1992)	2068	2050 2150	5% (MS40C60) 5 % (MS20C80	Sub-base
Federal Highway Administration (FHWA) (2013)	1400	1850 1900	2.5% (MS40C60) 2.5% (MS20C80)	Subgrade cement/soil, cement
Mechanistic-Empirical Pavement Design Guide (MEPDG, 2004)	1720	1850 1900	2.5% (MS40C60) 2.5% (MS20C80	Sub-base layer for medium- to high- volume roads
Indian Road Congress, New Delhi (IRC 37, 2012)	1500	1850 1900	2.5% (MS40C60) 2.5% (MS20C80	Sub-base layer for medium- to high-volume roads

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