



THERMAL EFFECT ON PERMEABILITY AND STRENGTH OF SAND-WAX MIXTURES USED IN LINING LANDFILLS

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ABSTRACT

Background: Generated temperature within waste mass is one of the most important factors affecting the performance of insulation systems in landfills. This is due to temperature effect on properties of the material used in lining and particularly permeability and strength. Sand-wax mixtures possess good impermeability, enable it to isolate wastes in landfills and prevent soil and groundwater from contamination caused by landfill's leachate. **Objectives:** This study aims to investigate the thermal effect on permeability and compressive strength of compacted sand-wax mixtures, to evaluate the feasibility of using it as a construction material yielding the required impermeability and strength for bottom barriers in landfills during its lifetime. **Methods:** A series of compaction, permeability and unconfined compression strength tests was carried out at different water temperatures similar to that observed near the bottom barrier in landfill. Samples were prepared by mixing poorly graded sand with various ratios of wax by weight, and compacted at four compaction efforts (reduced, standard, intermediate and modified). **Results:** Results of this study indicated that, increasing of temperature causes decrease in both permeability and strength for all samples of wax-coated sands. The minimum ratios of wax which achieving the required permeability at considered temperatures were: 9% for modified and intermediate efforts, 11% for standard and 13% for the reduced. Furthermore, at the temperature of 40°C, samples with all wax contents showed an acceptable permeability, whereas samples with the optimum wax content became impermeable. On the other hand, all tested samples showed higher compressive strength than the required strength in lining landfills. **Conclusions:** The study reveals that, sandy soil improved by wax possess the required impermeability and strength in lining landfill with consideration of the thermal effect. Thus it can be used effectively as an alternative landfill barrier material.

Keywords: wax, sand, temperature, permeability, unconfined compressive strength, barriers.

1. INTRODUCTION

Landfills are important engineering constructions, which isolate waste's contamination from the surrounding. Several conventional lining systems were used in landfills to prevent the soil and groundwater from pollutions caused by wastes leachates. Although liners have been successfully utilized, those systems may not provide a feasible solution due to some defects occurring in the materials used in them [1,2,3]. As well as, these systems might not be suitable to use in a case of high permeable soil such as sandy soils. Since wax is a good water repellent material, possesses high chemical resistance, is not affected by waste leachate and capable to reduce the permeability of soil to the point of complete impermeability [4,5]. Thus, wax has been suggested in our research as an effective improving material for sandy soil suitable to use in lining landfills rather than the difficult and costly replacement of soil.

Wax-coated sands have been used as alternative construction materials, for several purposes in different engineering applications such as sport surfaces [6], waterproofing layer of highways and recently in Landfills [7]. The lack of research on improving sandy soils with wax [8] makes it useful to expand on this topic. This research presents a new lining system composed of sandy soil coated with wax, fulfils the required terms of impermeability and strength in lining system, and secures soil and groundwater protection from pollution resulting from waste leachates. Even though temperature generated within the waste mass has significant effects on properties and behaviour of liner material in landfills [9, 10], limited information exists on impact of temperatures on the liner behaviour.

This study investigates the thermal effect on barriers of wax-coated sand, and assess the efficiency of using it for lining landfills at sandy soil site. In our study temperatures of (10 - 20 - 30 - 40 - 50) °C were selected as range of observed temperatures near the bottom barrier in landfill. This range of temperature was selected because landfill liner temperatures tended to be rang from 35 to 45°C [9-11,12,13]. Consequently, to achieve the objective of the research, variation of permeability and strength of wax-coated sands with temperature were investigated through a series of compaction, permeability and unconfined compression tests. Sand-wax mixtures were prepared by mixing poorly graded sand with 7, 9, 11, 13 and 15% in weight of wax, and the samples were compacted at four compaction efforts: (Modified proctor

2700KN.m/m³, intermediate proctor 1650KN.m/m³, Standard proctor 600KN.m/m³ and Reduced proctor 360KN.m/m³). Hence, the optimum ratio of wax for each compaction effort was determined. Results showed a decrease of the permeability coefficient in all samples with increasing of temperature. In addition, samples of all wax ratios showed acceptable permeability at the temperature of 40°C, and became impermeable with the optimum ratios of wax. Strength also decreased with increasing of temperature in all tested samples but remained higher than the required strength in lining landfills.

The study revealed that sand improved by wax depending on the specific criteria mentioned in this research possess the required permeability and strength within temperatures generated in landfill.

2. MATERIALS AND METHODS

2.1 Soil:

The sandy soil used in this study has been obtained from three locations: B1, B2 and B3 at depths of between 0.5 and 2.5 m from Al Bassa waste's contamination site at Latakia city in Syria, which is located directly on the seashore (Figure1). The soil consists of fine sand to coarse. The properties of this soil are given in table 3.



Figure 1: The figure presents the sampling sites of natural soil in the research area.

2.2 Wax: The wax used in this study is Paraffin Wax FA 569, which is a petroleum product. This kind of wax was chosen because of its effective performance as well as it is available with low cost compared with other wax types. Properties of the wax presented in table 1.

Table 1: The table presents the properties of properties of Paraffin Wax FA 569.

Testing Methods	Specification		ASTM Method
	Minimum	Maximum	
Physical State (25°C)	Solid		
Melting Point (°C)	60	62	D 938
Needle penetration (mm, at 25°C)	15	20	D 1321
Oil (%)		0.5	FL- 01

2.3 Sampling of sand-wax mixture: Based on the reference studies [7] with some modifications and the preliminary laboratory tests, the following ratios of wax were selected (7, 9, 11, 13, 15) %. Sand-wax mixtures were prepared by mixing sand with various quantities of wax in a laboratory drum mixer at rate of 60 rpm. An external heat sources heated the drum, sand and wax heated to temperature of approximately 65°C (i.e. temperature above the melting point of wax), when the mixture became homogeneous the heat source was turned off. The mixer continued mixing for more minutes while the contained partially cooled to below wax's melting point. Thus, the resulting mixture component of grains of wax-coated sand.

Specimens for Proctor tests were compacted at four compaction efforts to simulate the range of compaction efforts expected in the field: Reduced Proctor (RP): 360 KN.m/m³, Standard Proctor (SP): 600 KN.m/m³, Modified Proctor (MP): 2700 KN.m/m³ and intermediate proctor (AP): 1650 KN.m/m³. All specimens were compacted at standard Mold—4-in. (101.6-mm) diameter in three layers for SP & RP and five layers for AP & MP efforts with modifying the blows number per layer in order to achieve the desired effort.

Specimens for permeability tests were compacted in a special plastic mold (110-mm diameter and 120 mm height) at the same four efforts up to achieve the dry unit weight for each content of wax in proctor curves.

As for unconfined compression tests, sample specimens were compacted at standard Mold-4-in. at the same four efforts to achieve the dry unit weight for each content of wax in proctor curves. Other specimens compacted up to maximum dry unit weight with the optimum ratios of wax for each compaction effort.

2.4 Laboratory model for measuring permeability coefficient with temperature control: To study the impact of temperature on permeability of wax-coated sands samples, a set of permeability measurement devices put inside sealed glass tub filled with water (Figure 2). For the temperature control, electric heater with thermostat was placed in the tub. A compressor, which is connected to a tank filled with water generates compressed air, and thus the air pressure converts to water pressure with the possibility of adjusting the pressure during the test. Pressurized water is distributed on three cells containing the tested samples. The cells were placed within a glass tub where temperature adjusted by heater with thermostat. Water was used instead of waste leachates as water shows higher permeability than leaches [14].

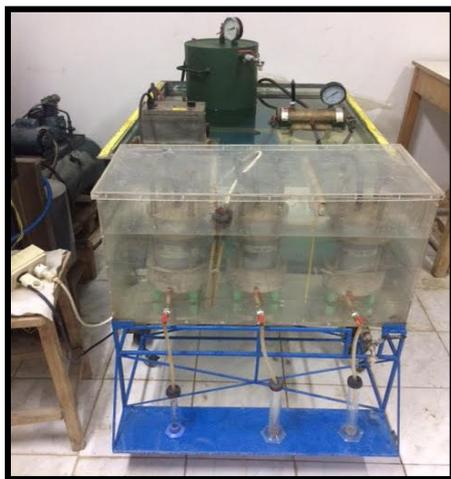


Figure 2: The figure presents the Set of permeability test with temperature control.

3. RESULTS

3.1 Laboratory tests on natural soil:

The particle size distribution curves of the natural soil samples are shown in Figure 3, and the basic properties of samples, which obtained from various laboratory tests according to ASTM are summarized in Table 3.

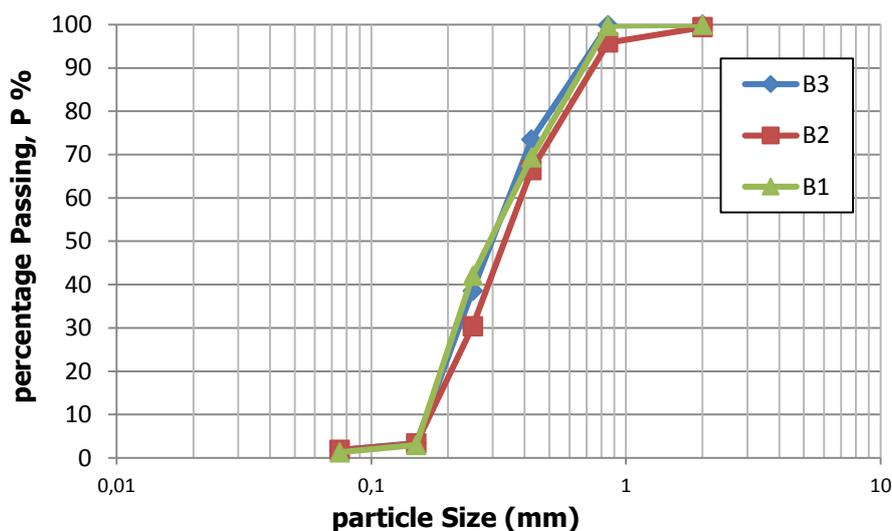


Table 2: The table presents the grain size distribution.

Particle Size mm	Percentage Passing (%)		
	B ₁	B ₂	B ₃
2	99.93	99.37	100
0.85	99.71	95.83	99.83
0.425	69.3	66.42	73.44
0.25	42	30.35	38.56
0.15	2.96	3.31	3.4
0.075	1.28	1.81	1.77

Figure 3: The figure presents the grain size distribution curves.

Table 3: The table presents the properties of the soil samples.

Property	Quantity
Natural moisture content, (%)	5.8 - 6

Specific gravity, G _s	2.69 – 2.7
Natural unit weight (KN/m ³)	17.2 - 17.3
Natural dry unit weight (KN/m ³)	16.2 -16.3
Maximum dry unit weight (KN/m ³)	17.2 -17.3
Minimum dry unit weight (KN/m ³)	15 – 15.1
Density Index, ID	0.61- 0.59
Sand Equivalent (%)	98.4-97.74
Void ratio, n	0.39 – 0.40
Uniformity coefficient, C _u	2.1 - 2.3
Curvature coefficient, C _c	0.74 - 0.94
Percent Passing through #200 sieve,(%)	1.28 – 1.81
USCS classification	SP, Poorly graded sand &Medium dense

Proctor tests were conducted by using the four-compaction efforts mentioned previously. Results of the tests on natural soil are given in the table 4:

Table 4: The table presents the results of Proctor tests on natural soil

Compaction effort	MP	AP	SP	RP
Maximum dry unit weight, $\gamma_{d\max}$ (KN/m ³)	17.3	16.8	16.2	15.9
Optimum water content, W_{opt} (%)	10.3	11.2	12.2	12.8

Reduced Proctor (RP): 360 KN.m/m³, Standard Proctor (SP): 600 KN.m/m³, Modified Proctor (MP): 2700 KN.m/m³ and intermediate proctor (AP): 1650 KN.m/m³.

Permeability and drained direct shear tests were performed on samples prepared by the maximum dry unit weight and optimum water content. The results are listed in table (5).

Table 5: The table presents the results of permeability and direct shear tests on natural soil

Compaction effort (KN.m/m ³)	γ (KN/m ³)	K(cm/s)	ϕ (°)	C` (KN/m ²)
MP-2700	19.08	1.1×10^{-5}	43.11	7.6
AP-1650	18.68	2.8×10^{-5}	40.64	5.2
SP- 600	18.18	4.2×10^{-5}	39.30	4.7
RP-360	17.94	4.7×10^{-5}	33.87	3.1

Reduced Proctor (RP): 360 KN.m/m³, Standard Proctor (SP): 600 KN.m/m³, Modified Proctor (MP): 2700 KN.m/m³ and intermediate proctor (AP): 1650 KN.m/m³.

Note from table (5) that, increasing of compaction effort causes decreasing in permeability, and increasing of the internal friction angle whereas, cohesion was negligible.

3.2. Laboratory tests on wax-coated sandy soil

3.2.1 Compaction: Specimens were compacted at four compaction efforts (2700, 1650, 600,360) KN.m/m³ with wax contents between 7% and 16%. Results of these tests are listed in table (6) and shown in Figure (4) and table (7).

Table 6: The table presents the results of Proctor tests (γ_d KN/m³) of wax-coated sand at compaction efforts

Wax content (%)	7	9	11	13	15	16
MP(2700kN.m/m ³)	16.27	16.52	16.65	16.58	16.38	-
AP(1650kN.m/m ³)	15.92	16.18	16.34	16.3	16.12	-
SP(600kN.m/m ³)	15.56	15.68	15.84	15.9	15.81	-
RP(360kN.m/m ³)	15.36	15.49	15.62	15.68	15.64	15.58

Reduced Proctor (RP): 360 KN.m/m³, Standard Proctor (SP): 600 KN.m/m³, Modified Proctor (MP): 2700 KN.m/m³ and intermediate proctor (AP): 1650 KN.m/m³.

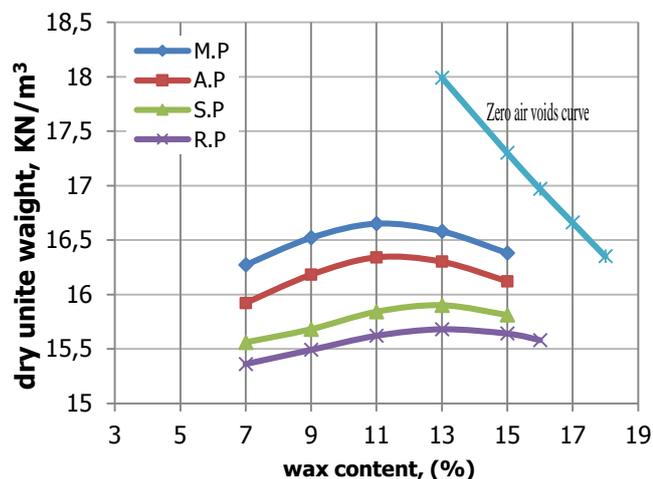


Figure 4: The figure presents Proctor curves of wax-coated sand at four compaction efforts.

Table 7: The table presents maximum dry unit weight & optimum wax content for all compaction efforts

Compaction effort KN.m/m ³	$\gamma_{d\max}$ KN/m ³	Optimum wax content P_{opt} (%)
MP-2700	16.7	11.4
AP-1650	16.3	11.8
SP- 600	15.9	13
RP-360	15.7	13.5

Reduced Proctor (RP): 360 KN.m/m³, Standard Proctor (SP): 600 KN.m/m³, Modified Proctor (MP): 2700 KN.m/m³ and intermediate proctor (AP): 1650 KN.m/m³.

By comparing the results presented in Figure 4 and table(7) with the results of the Proctor tests on natural sand outlined in table (4), it is observed a slight decrease in maximum dry unit weight, and slight increase in optimum content of wax compared with compacted natural soil.

3.2.2 Permeability test: Specimens were compacted to dry unit weight for each percentage of wax shown in table (6). Samples were left for 24 hours to wax harden, and then the permeability tests were carried out at temperature of (10-20-30-40-50) °C by using the laboratory model to control temperature during the test (Figure 2). Water pressure of 50 kpa is applied to the specimens. Water is used instead of waste leaches as water shows higher permeability than leaches [14]. Based on previous studies [15,16] as well as the experimental observations in the lab, seven days was chosen as a standard time for each test, where permeability coefficient tend to be constant in the third test day. The sample considered impermeable if there is no leakage of water during the test. Results of the permeability tests on samples of wax-coated sand at the mentioned temperature are shown in table 8 and figure 5.

Table 8: The table presents the values of permeability coefficient k (cm/s) with temperature and compaction effort.

Compaction effort	T(°C)					
	Wax (%)	10	20	30	40	50
MP	7	1.40E-07	1.20E-07	1.10E-07	1.50E-08	1.20E-08
	9	5.40E-09	4.80E-09	2.50E-09	2.70E-10	0.00E+00
	11	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	13	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	15	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
AP	7	1.70E-07	1.50E-07	1.30E-07	3.40E-08	2.60E-08
	9	1.40E-08	1.20E-08	1.10E-08	2.90E-09	1.80E-09
	11	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	13	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
SP	15	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	9	1.70E-07	1.60E-07	1.40E-07	2.20E-08	1.20E-08
	11	4.60E-08	4.20E-08	3.80E-08	2.10E-09	0.00E+00
	13	1.20E-09	1.20E-09	1.10E-09	0.00E+00	0.00E+00
RP	15	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	9	5.40E-07	4.80E-07	4.20E-07	3.60E-08	2.50E-08
	11	1.90E-07	1.50E-07	1.20E-07	2.20E-08	1.30E-08
	13	2.70E-09	2.40E-09	1.80E-09	0.00E+00	0.00E+00
	15	3.50E-10	0.00E+00	0.00E+00	0.00E+00	0.00E+00

Reduced Proctor (RP): 360 KN.m/m³, Standard Proctor (SP): 600 KN.m/m³, Modified Proctor (MP): 2700 KN.m/m³ and intermediate proctor (AP): 1650 KN.m/m³.

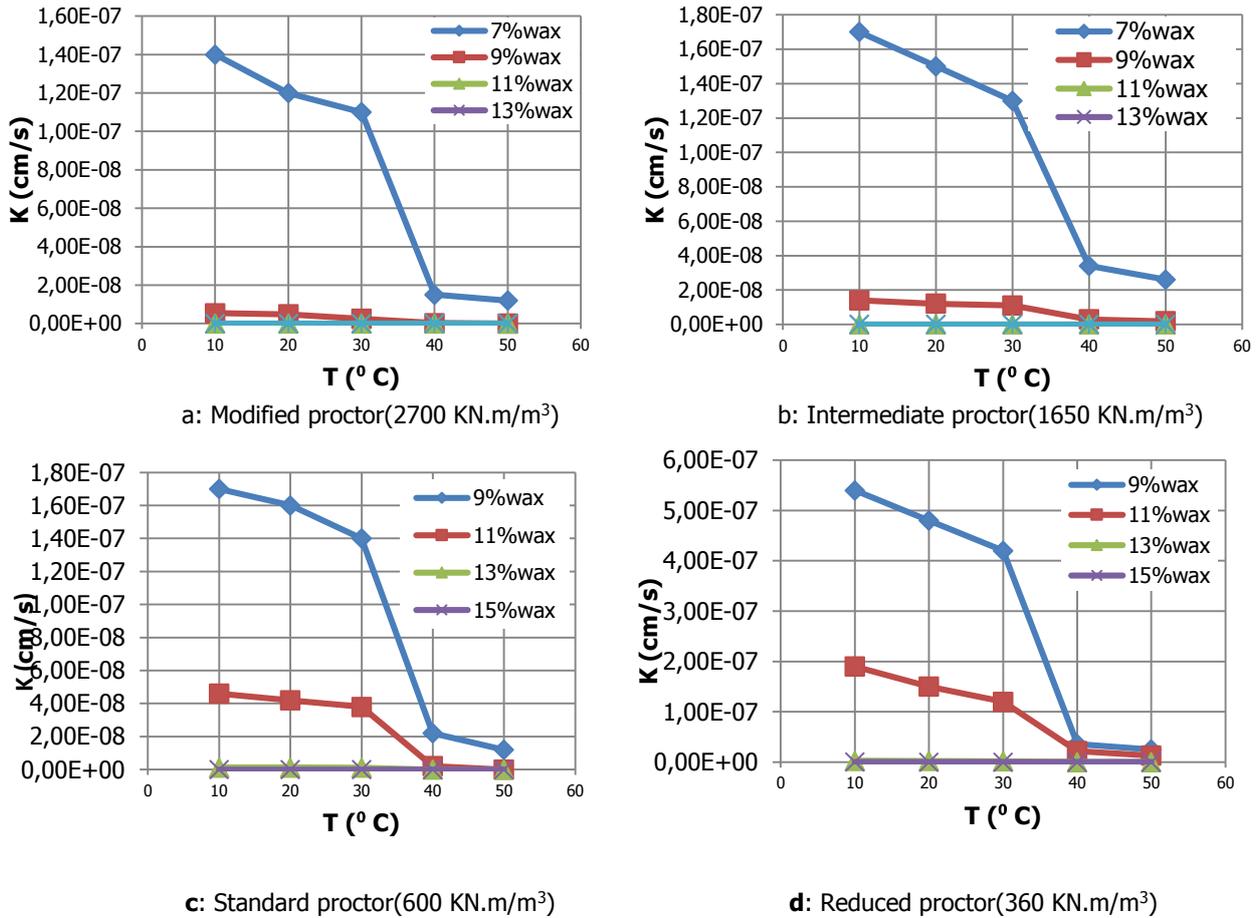


Figure 5: The figure presents changing of permeability coefficient with variation of temperatures at the four compaction efforts.

It can be seen from the table (8) and figure 5 that when the temperature increase the permeability decrease, and the rate of reduction became more obvious within temperatures of (30-40)^oC.

3.2.3 Unconfined compressive strength: Samples were prepared as mentioned in 2-3, and were left for 24 hours to wax harden (Figure 6). Three samples for each wax content were tested, and the average result of the three tests was adopted. Axial compressive strain was applied on the sample with constant velocity of 1.25 mm/min until the sample failed (Figure 7). Temperature was controlled and maintained constant during the test.

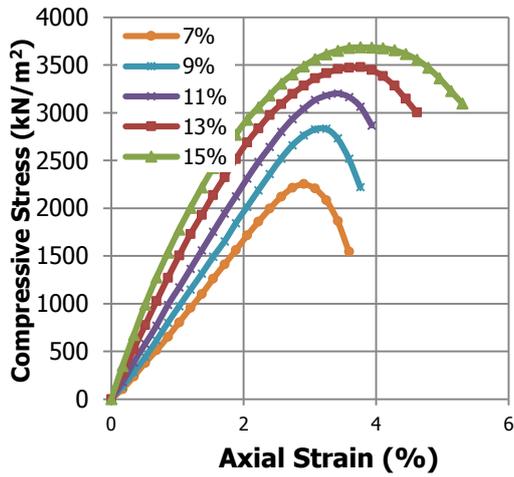


Figure 6: The figure presents numbers of samples for UCS tests.

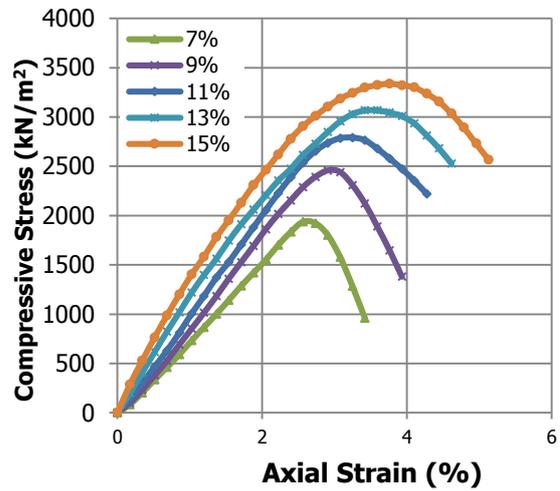


Figure 7: The figure presents apparatus of UCS test.

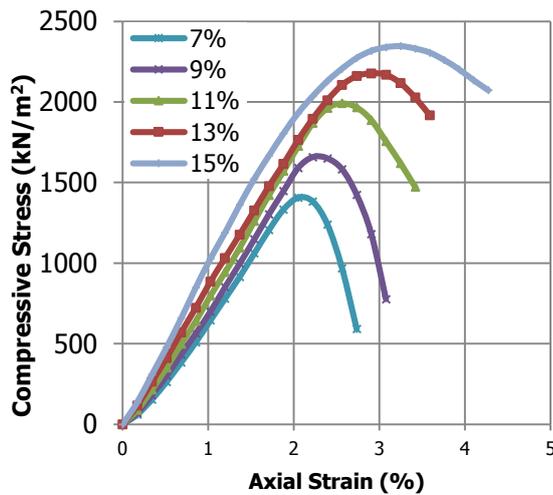
Figure 8, showed (stress-strain) curves for samples of sand coated with various ratios of wax within the temperatures of 40°C.



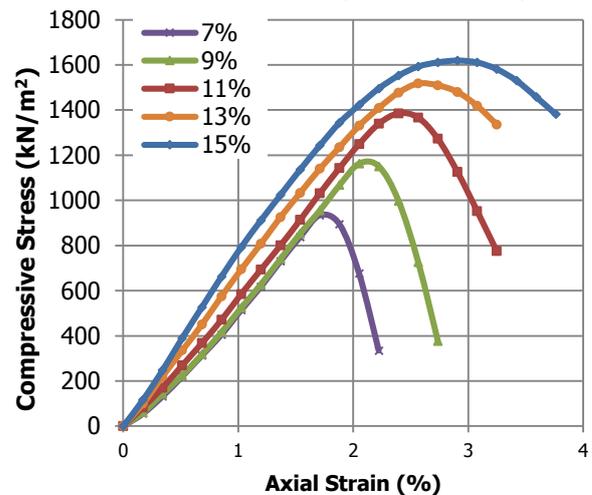
a: Modified proctor(2700 KN.m/m³).



b: Intermediate proctor(1650 KN.m/m³).



c: Standard proctor(600 KN.m/m³)



d: Reduced proctor(360 KN.m/m³)

Figure 8: The figure presents curves of compressive stress versus axial strain for sand coated with different wax ratios and compaction effort.

Stress-strain curves showed that increasing of wax content caused rapid decrease of maximum stress after the peak, and the peak convexity became less obvious.

According to the previous curves, we could determine the unconfined compressive strength, axial strain at maximum strength and the initial young's modulus for the all wax-coated sand samples. Figures 9 to 11 illustrates the results for all wax percentage compacted at the four compaction efforts mentioned previously.

Figure 9 shows unconfined compressive strength with wax percentage and compaction effort. It was noticed that, unconfined compressive strength increased almost linearly with increased wax content up to 15% wax. However, strength was greater with the higher effort.

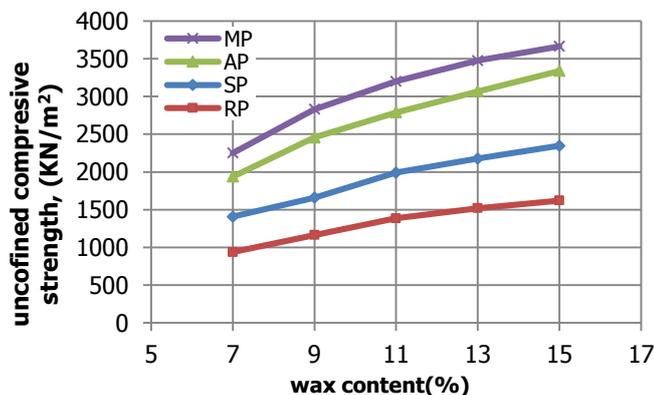


Figure 9: The figure presents unconfined compressive strength versus wax content for all compaction efforts.

Table 9: The table presents the unconfined compressive strength of the tested samples

Wax content (%)	Unconfined Compressive strength,(KN/m ²)			
	MP	AP	SP	RP
7	2252	1937	1407	938
9	2832	2456	1658	1163
11	3201	2789	1991	1385
13	3476	3067	2177	1518
15	3665	3338	2346	1620

Reduced Proctor (RP): 360 KN.m/m³, Standard Proctor (SP): 600 KN.m/m³, Modified Proctor (MP): 2700 KN.m/m³ and intermediate proctor (AP): 1650 KN.m/m³.

Figure 10 shows changes of axial strain at maximum stress versus wax percentages of sand wax mixtures at the four compaction efforts. It was noticed that, strain increased almost linearly with the increase of wax percentage, and the strain at each wax percentage was greater with the higher effort.

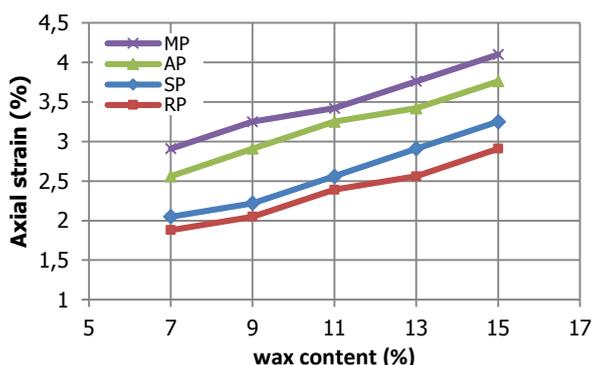


Table 10: The table presents the axial strain of maximum strength for the tested samples

Wax contend (%)	Axial Strain of maximum strength, (%)			
	MP	AP	SP	RP
7	2.91	2.56	2.05	1.88
9	3.25	2.91	2.22	2.05
11	3.42	3.25	2.56	2.39
13	3.76	3.42	2.91	2.56
15	4.1	3.76	3.25	2.91

Figure 10: The figure presents axial strain at the maximum stress versus wax content for all compaction efforts.

As shown in figure (11) initial young's modulus increased almost linearly with the increase of wax percentage for each compaction effort, and the value of young's modulus was greater with the higher effort.

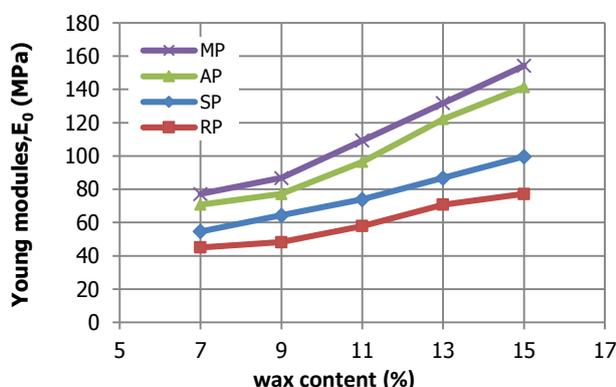


Table 11: The table presents the young's modulus E₀, for the tested samples.

Wax contend (%)	Young's modulus, E ₀ (Mpa)			
	MP	AP	SP	RP
7	77	71	55	45
9	87	77	64	48
11	109	97	74	58
13	132	122	87	71
15	154	141	100	77

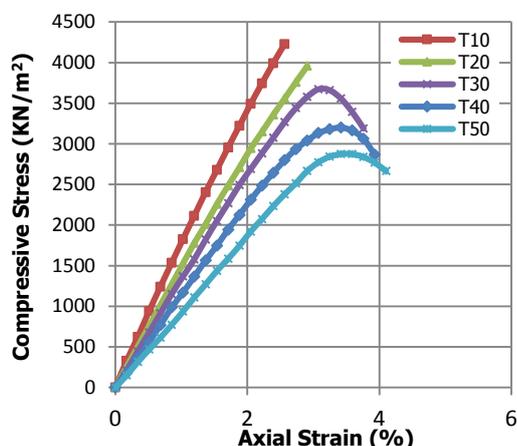
Figure 11: The figure presents young's modulus E₀ versus wax content for all compaction efforts.

Reduced Proctor (RP): 360 KN.m/m³, Standard Proctor (SP): 600 KN.m/m³, Modified Proctor (MP): 2700 KN.m/m³ and intermediate proctor (AP): 1650 KN.m/m³.

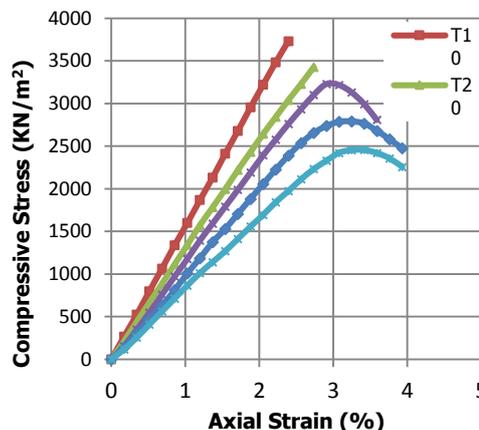
Previous results of unconfined compression strength tests demonstrate that compacted wax-coated sands as mentioned in the research possess the required strength (200 KN/m²) for bottom lining in landfills [17].

To study the thermal effect on strength of sand coated with wax, samples were prepared as mentioned in 2-3 with the optimum ratios of wax for each compaction effort. Then UCS tests were carried out on these samples at temperatures of (10-20-30-40-50) °C respectively.

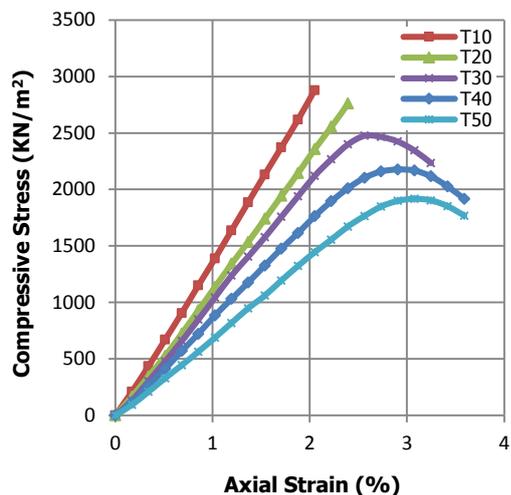
Figure 12 showed curves of compressive stress versus axial strain for all tested samples within the temperatures variation.



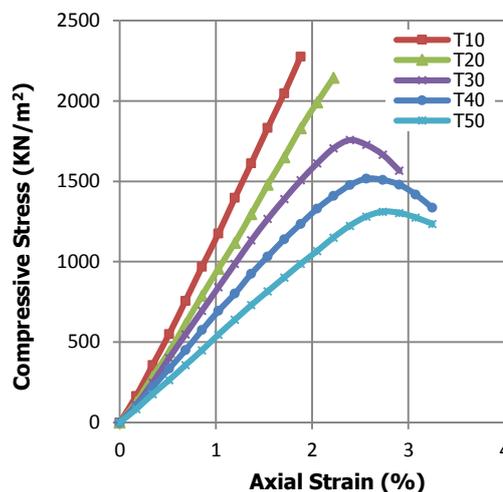
a: Modified proctor (2700 KN.m/m³)



b: Intermediate proctor (1650 KN.m/m³)



c: Standard proctor(600 KN.m/m³)



d: Reduced proctor(360 KN.m/m³)

Figure 12: The figure presents (stress-strain) curves of sand coated with optimum wax content for the compaction effort with temperatures.

It can be seen from figure 12 that when the temperature increase, maximum compressive stress decreased, and the collapse of soil became plastic at 30 °C and above, as well as the curvature becomes less prominent peak with high temperature. Based on the figure 12, unconfined compressive strength, axial strain at the maximum strength and the initial young’s modulus with variation of temperature could be determined. Figure 13 shows unconfined compressive strength with temperature and compaction efforts. It was noticed that, unconfined compressive strength decreased almost linearly with temperature rise. However, strength was greater with higher effort.

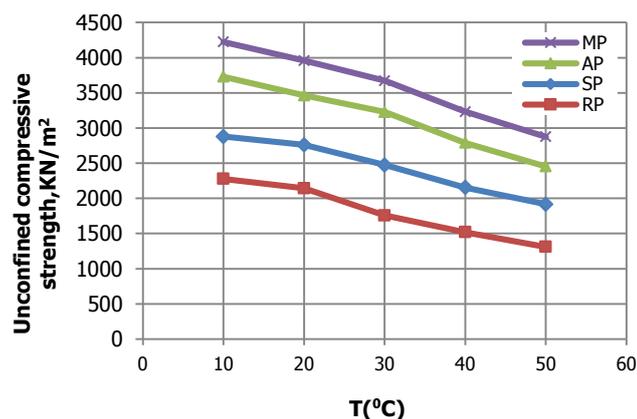


Figure 13: The figure presents unconfined compressive strength versus temperatures for all compaction efforts.

Table 12: The table presents the unconfined compressive strength of the tested samples.

T(°C)	Unconfined Compressive strength,(KN/m ²)			
	MP	AP	SP	RP
10	4224	3730	2878	2276
20	3958	3463	2761	2144
30	3672	3228	2475	1757
40	3233	2789	2154	1518
50	2875	2454	1916	1311

Reduced Proctor (RP): 360 KN.m/m³, Standard Proctor (SP): 600 KN.m/m³, Modified Proctor (MP): 2700 KN.m/m³ and intermediate proctor (AP): 1650 KN.m/m³.

Figure 14 shows changes of axial strain at the maximum stress versus temperature for all tested samples. It was noticed that, strain increased almost linearly with the temperature rise for each compaction effort, and the strain was greater with higher effort.

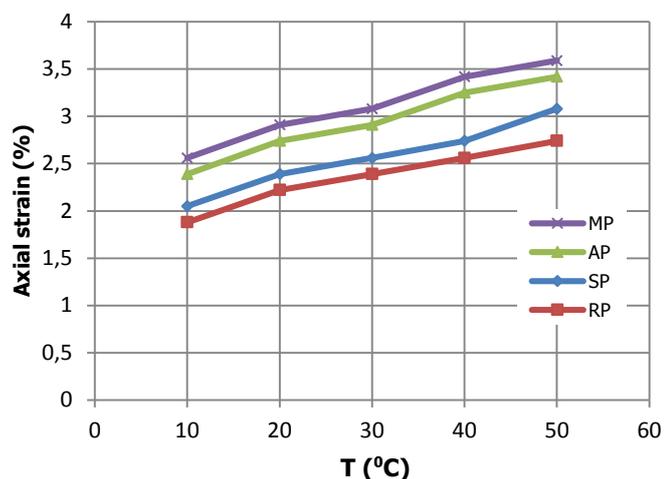


Figure 14: The figure presents axial strain at the maximum stress versus temperatures for all compaction efforts.

Table 13: The table presents the axial strain of maximum strength for the tested samples.

T(°C)	Axial strain of maximum strength, (%)			
	MP	AP	SP	RP
10	2.56	2.39	2.05	1.88
20	2.91	2.74	2.39	2.22
30	3.08	2.91	2.56	2.39
40	3.42	3.25	2.74	2.56
50	3.59	3.42	3.08	2.74

Reduced Proctor (RP): 360 KN.m/m³, Standard Proctor (SP): 600 KN.m/m³, Modified Proctor (MP): 2700 KN.m/m³ and intermediate proctor (AP): 1650 KN.m/m³.

It was noticed from Figure 15, the initial young's modulus decreased almost linearly with the temperature rise for all compaction efforts, and the values of young's modulus was greater with higher effort.

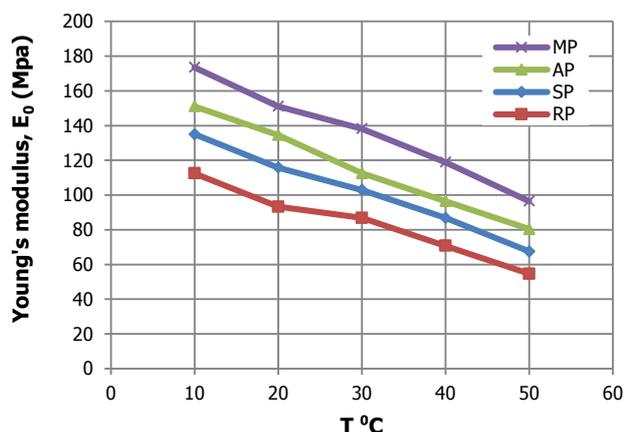


Figure 15: The figure presents young's modulus E₀ versus temperatures for all tested samples.

Table 14: The table presents the Young's modulus E₀, for the tested samples

T(°C)	Young's modulus, E ₀ (Mpa)			
	MP	AP	SP	RP
10	174	151	135	113
20	151	135	116	93
30	138	113	103	87
40	119	97	87	71
50	96	80	68	55

Reduced Proctor (RP): 360 KN.m/m³, Standard Proctor (SP): 600 KN.m/m³, Modified Proctor (MP): 2700 KN.m/m³ and intermediate proctor (AP): 1650 KN.m/m³.

The results of unconfined compression strength tests with temperature reveals that, sand coated with optimum ratios of wax for the four compaction efforts possess the required strength in lining landfills.

4. DISCUSSION

In this study, the thermal effects were determined on permeability and strength of compacted sand-wax mixtures through a series of compaction, permeability and unconfined compression strength tests. The results of the permeability tests indicate reduction of permeability for all samples with increasing of temperature, and this reduction is a significant decline within the range of temperature of (30-40) °C. This phenomenon could be related to the expansion of wax coated sand with temperature rise which caused modification of the pore's shape between particles up to reduce or close those pores. And since sand becomes almost impermeable with high content of wax or with temperature exceeding 40 °C, the influence of temperature is not obvious on permeability.

Moreover, results of unconfined compression strength tests showed reduction of strength with temperature rise for all tested samples. This can be explained by the influence of temperature on wax coated particles of sand, which weakens cohesion between those particles and causing low strength. However, their values remain higher than the desired strength in lining landfills.

The previous results of the thermal effects on permeability and strength of sand wax mixtures demonstrate that permeability is the most influential condition in designing liners of landfills while strength has been accepted for all studied mixtures.

5. CONCLUSION

This paper presents the effects of temperature on permeability and strength characteristics of compacted wax-coated sands, in order to determine the effectiveness of using it in lining landfills. A series of compaction, permeability and unconfined compression test were carried out on samples of sand coated with various ratios of wax (7,9,11,13,15)% by weight, and compacted with four compaction efforts (reduced, standard, intermediate and modified). The results of the tests used for estimating the required compaction criteria of dry unit weight and wax additive, and determining the values of the maximum dry unit weight and optimum wax content for each compaction effort. Samples were prepared based on the previous results and subjected through a series of permeability and unconfined compression tests on temperatures of (10 - 20 - 30 - 40 - 50)^oC similar to temperatures occurring near the bottom barrier in landfills and thus achieving the objective of the research. The effects of temperature on permeability and strength characteristics of sand coated with wax were determined. The following conclusions can be made.

- The coefficient of permeability decreased with temperature rise, and all tested samples possessed the required values of permeability in landfills at temperature of 40 ^oC, whereas the samples with optimum ratios of wax became impermeable. Furthermore, increasing compaction effort caused decrease in wax content required to fill in the voids and achieve the desired impermeability.
- Unconfined compressive strength for all samples decreased with temperature increase. However, all samples met the required strength for the hydraulic barrier in landfills.
- Axial strain at the maximum strength increased with temperature increase for each compaction effort, and the strain was greater with higher efforts.
- Initial young's modulus decreased with the temperature increase, and the values of young's modulus were greater with higher efforts.

This study concludes that the temperature of the waste's leachate reduces the permeability of the bottom barrier in landfill, so that if the wax content was less than the optimum, sand turns into a semi-permeable material and provides the required condition in hydraulic barrier in landfills. Thus, considering the temperature of leachate in designing the bottom barrier in landfills contributes to reduce the cost of its construction in sandy sites. Therefore, wax-coated sands can be adopted as a new effective option for landfills barrier materials.

The following recommendations for future work can be presented as:

- Investigating the permeability and strength characteristics of the barrier exposed to repeated cooling and heating cycles
- Investigating the possibility of applying the results of the research on sandy soils with different classifications

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