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EFFECT OF BURNING CYCLES ON THE PHYSICAL PROPERTIES OF CLAY

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Abstract: Natural soil is exposed, like other elements of the construction, to significant changes in temperatures are sources of forest fires or volcanic eruptions or natural bulky. Usually, accompanied by significant changes in temperatures of up to more than 300 degrees centigrade. Therefore, the need arises to study the effect of burning clayey soils, on the grain distribution and distribution of particleboard intricacies and atterbering limit and soil classification, in addition to the direct impact on the variables for the design of foundations such as the cohesion of the soil. The soil used was naturally clayey soil brought from Diyala province with (Liquid limit=56%, Plastic limit=51%, Specific gravity=2.59, the soil is classified as OH (Organic clays of medium to high plasticity). The soil was burned at different temperatures (75- 150- 300- 600 ° C) using special oven for burning at high temperature, the study was directed to investigate the effect of repeat arson for each grade and study changes in soil properties and distribution particleboard and suitability of the construction. The study showed basic change in the particle distribution and Atterbering limits which means changing the engineering properties for the design of foundations construction which indicates the importance of this types of research and potential development to expand in this area and develop ways to put construction solutions for such cases. A reduction percent in plastic limit was 20% and 26% at the end of the fourth cycle at 300°C and 150°C respectively. Author Discoverd that the soil type changed from OH to MH after the first burning cycle at 75°C. With the repetitive burning cycle, more changes on soil properties and type accrue. The soil is Ml after the fourth burning cycle at 75°C.

Keywords: *Clay, Burning, Atterberg limits, grain size distribution.*

تاثير دورات الحرق على الخواص الفيزيائيه للترب الطينية

الخلاصه: تتعرض التربة الطبيعيه، حالها حال بقية باقي العناصر الانشائيه لتغيرات كبيره في درجات الحراره تكون مصادرها حرائق الغابات او البراكين الطبيعيه او الانفجارات الضخمه. وعادة ما تصاحبها تغيرات كبيره في درجات الحراره تصل لاكثر من 300 درجة مئويه. لذلك دعت الحاجة لدراسة تاثير حرق الترب الطينيه على خصائصها الهندسيه والتوزيع الحبيبي لدقائقها وحدود اتربرك، التي يتم على ضوئها تصنيف التربه، اضافة لتاثيرها المباشر على المتغيرات الخاصة لتصميم الاسس مثل تماسك التربه. حيث تم استخدام تربه طينيه طبيعيه من محافظة ديالى وتم اجراء تصنيف فيزيائي شامل (حد السيولة =56%، حد اللدونه =51%، الوزن النوعي =2.59 وتم تصنيف التربه من نوع OH). ثم تم حرقها بدرجات حراره عاليه مختلفه 75-150-300-600 درجه مئويه باستخدام فرن خاص للحرق بدرجات عاليه ودراسة تاثير تكرار الحرق لكل درجة على تغيير خواص التربه وتوزيعها الحبيبى ومدى ملائمتها من الناحيه الانشائيه. اظهرت الدراسه تغير كبير في التوزيع الحبيبي و حدود اتربرك مما يعني تغير الخواص الهندسيه لتصميم الاسس الانشائيه مما يؤشر اهمية هذا المسار البحثي وامكانية تطويره للتوسع في هذا المجال واعداد السبل لوضع الحلول الانشائيه لمثل هذه الحالات. اظهرت النتائج نسبة تقليل في حد اللدونه وصل الى 20% و 26% بعد الدوره الرابعة للحرق بدرجة 300 درجة مئويه و 150 درجة مئوية على التوالي.

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اكتشف الباحثون ان نوع التربة يتغير من OH الى MH بعد اول دورة حرق لنموذج التربه بدرجة حرارة 75 درجة مئويه. ومع الاستمرار بدورات الحرق، تحدث تغيرات اكبر على نوع وخصائص التربه. تتحول التربه الى النوع ML بعد رابع دوره للحرق لنفس الدرجة.

1. Introduction

Clay is one of soil deposits, it becomes plastic when subjected to water, and hardened when fired or dried [1, 3, 4] .The term plasticity refer to the containing of some menials inside soil skeleton. It always spread out at a wide land surface, and forming sedimentary rocks. The plasticity, swelling and low permeability of such soil type are attributed to small particle size and the crystal structures [2, 5, 7].

There are many types of clay like Kaolinite, Ball clay, Stoneware, Fireclay, Earthenware and Bentonite. All of these types depend on the deposit formation. But all shares with the same formation, the particle size is less than 2µm in size [10, 12].

Temperature has unknown behavior on the behavior and characteristics of clayey soil, and a lake of information are available on such condition [3, 8].

Soil physical properties (for example, soil structure, pore space, aggregation) are all affected by heating during a fire. Other soil physical properties, such as clay content, are not readily affected, except on the immediate soil surface during a very intense fire. An important physical property affected by fire, one that regulates the hydrology of a soil, is water repellency [6, 7]. During fires, OM in the litter and upper mineral soil layers is volatilized Fig. 1. Most of the volatilized OM is lost upward in the smoke, but a small amount moves downward along steep temperature gradients in the upper 5 cm of the soil and condenses to form a water-repellent layer that impedes infiltration Fig. 1.

The degree of water repellency formed depends on the steepness of temperature gradients near the soil surface, soil water content, and soil physical properties. For example, coarse-textured soils are more susceptible to heat- induced water repellency than fine-textured clay soils. The formation of this water-repellent layer, along with the loss of protective plant cover, increases surface runoff and erosion during the first rains following burning. A reduction in infiltration by a water-repellent layer can lead to extensive rill erosion on burned watersheds [7,9].

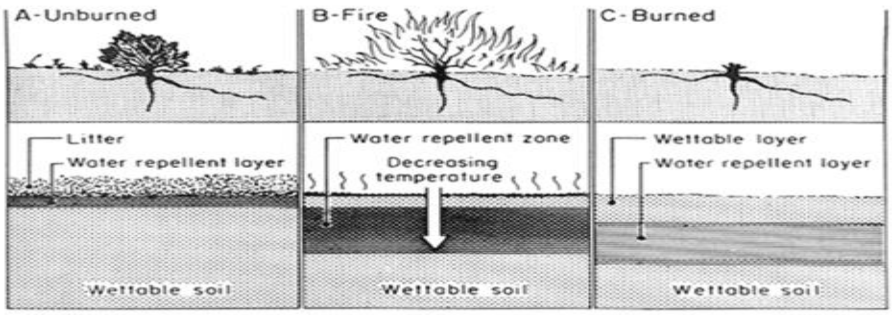


Figure1. Soil-water repellency as altered by fire: (A) before fire, hydrophobic substances accumulate in the litter layer and mineral soil immediately beneath; (B) fire burns the vegetation and litter layer, causing hydrophobic substances to move downward along temperature gradients; (C) after fire, a water-repellent layer is present below and parallel to the soil surface on the burned area [6].

The purpose of this study is to investigate the effect of various repetitive burning cycles on soil properties like Atterberg limits, grain size distribution and specific gravity of clay by applying various levels of temperature ranged from (75^{o}C to 600^{o}C).

3. Experimental work

3.1 Soil used

The soil used in this study was brought from Diyala province. Full classification tests were carried on ,at the soil mechanic laboratory in the College of Engineering / Diyala University.

The results of classification tests includes liquid limit , plastic limit, specific gravity and grain size distribution curve for this soil are shown in Table. 1 to Table. 4 and Fig. 2 to Fig. 4.

Table 1. Liquid limit test for soil before burning.

No.of Con.	3U	1D	2D	1-U-	3D	4
Container weight + moist soil	36.6	41	33.4	35.6	34.8	32.8
Contener weigt+dry soil	30.4	33.8	25.9	30.4	30	26
Weight of containerl	20.6	20.6	21.2	20.6	20.8	20.6
Weight of dry soil	9.8	13.2	4.7	9.8	9.2	5.4
Weight of wet soil	16	20.4	12.2	15	14	12.2
Water content%	63.3	54.5	55.9	53	52	65
No. Of blows	17	21	22	30	16	50

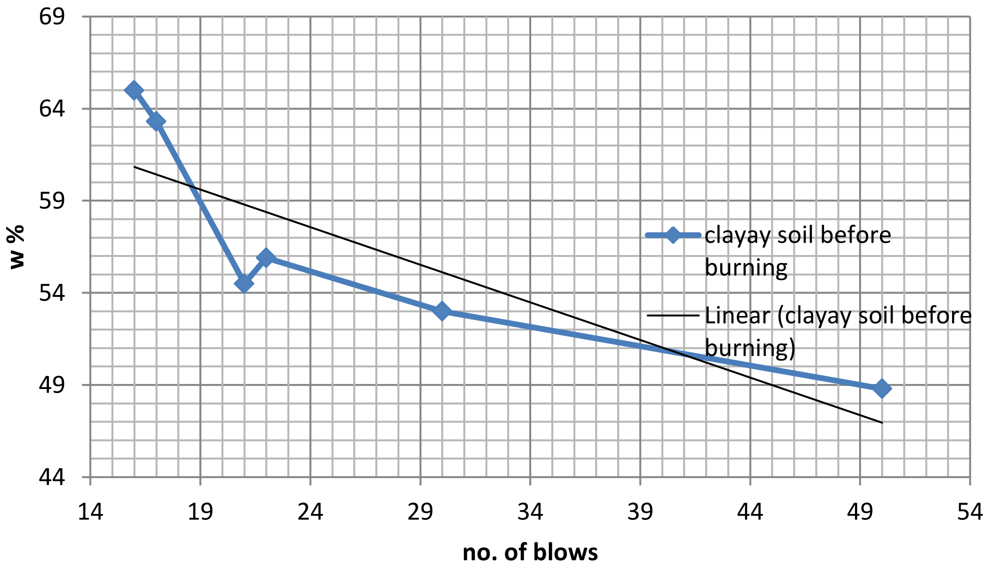


Figure 2. Liquid limit test for soil before burning LL=56

Table 2. plastic limit test for soil before burning.

No. vessel	2	3D	Z-1-	CD
Container weight + moist soil	25.6	25	28	24.2
Contener weigt+dry soil	24.2	23.4	25.6	23
Weight of container	20.8	20.8	20.6	20.8
Weight of dry soil	3.4	2.6	5	2.2
Weight of wet soil	4.8	4.2	7.4	3.4
Water content%	41	61	48	54.5

Pl=51.125

The specific gravity was determined for the natural soil using the equation:

$$Gs = \frac{\text{M1}}{\text{M3r} - (\text{M2} - \text{M1})}$$

Where:

M1=weight of dry soil.

M3=weight of water.

M2=weight of dry soil +weight of water.

m1 =15.3gm

m2 =108.5gm

m3 =99.1 gm

$\text{Gs} = \frac{15.3}{99.1-(108.5-15.3)}$ Gs=2.59

Table 3. Grain size results for soil before burning.

U.S. sieve	Dia.	Weight of sieve	Remaining +weight of sieve	remaining	Cumulative mass retained	Percent finer	Percent passing
10	2	503.6	504.8	1.2	1.2	99.3	0.7
20	0.85	454.4	455	0.6	1.8	99	1
30	0.60	447	449.8	2.8	4.6	97.5	2.5
50	0.30	407	413.8	6.8	11.4	93.8	6.2
200	0.07	376.6	530.4	153.8	165.2	10.3	89.7
PAN	-	518.4	601.4	83	-	-	

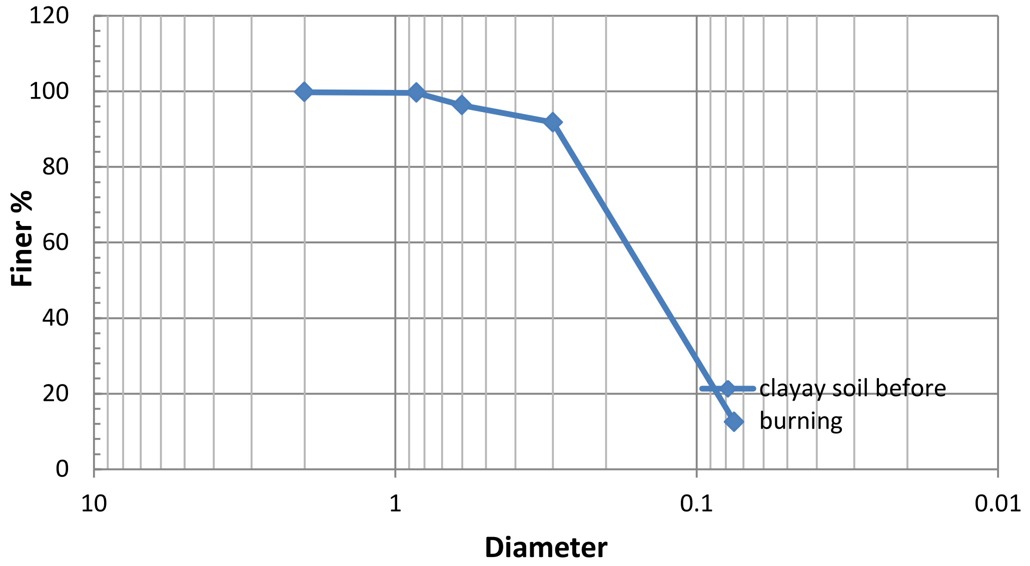


Figure 3. Grain size distribution curve for natural soil before burning.

Table 4. Hydrometer test results for soil before burning.

FINER %	D Diameter	K Constant	L/T Velocity	L Calculate	Hyd. Reading	Zero Reading	True Reading	Temperate C	Time Min
94.84	0.017	0.0143	1.4652	7.326	48.01	47.9	48	20	5
88.90	0.009	0.0143	0.488	7.326	45.01	44.9	45	20	15
71.28	0.006	0.0151	0.214	6.426	37.01	36	37	16	30
48.31	0.004	0.0148	0.113	6.826	25.01	24.4	25	18	60
8.31	0.001	0.0149	0.004	6.626	5.01	4.2	5	17	1440

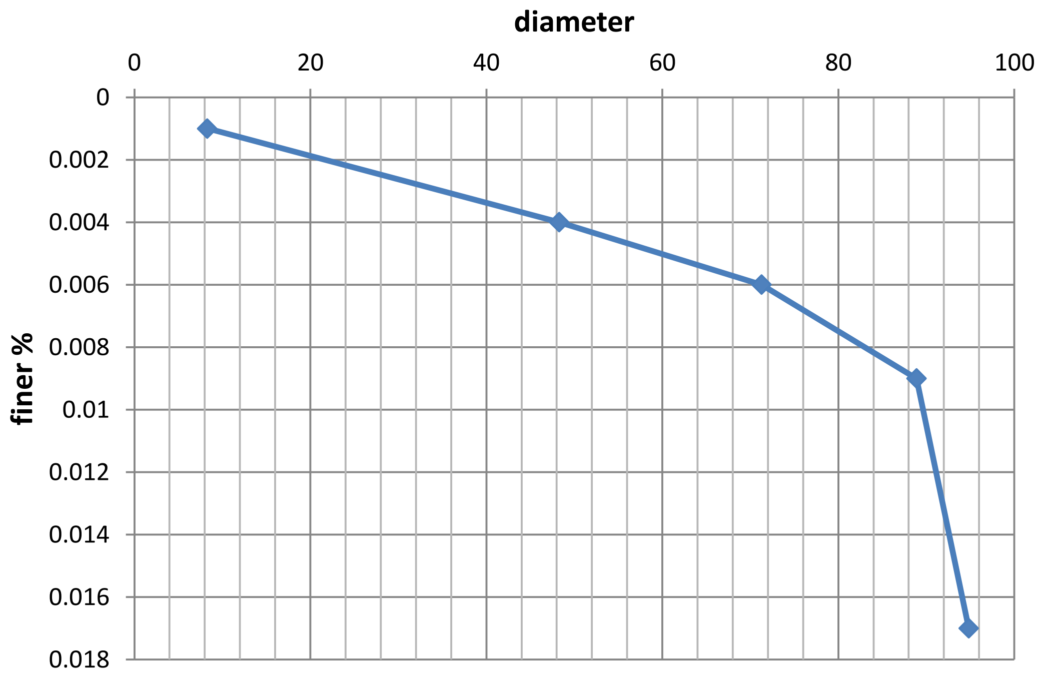


Figure 4. hydrometer test for soil before burning

A classification for the natural soil are given in Table 5.

Table 5. Soil classification for soil before burning.

LL	PL	GS	AASHTO	UNIFIED
54	51.125	2.59	A-6	OH

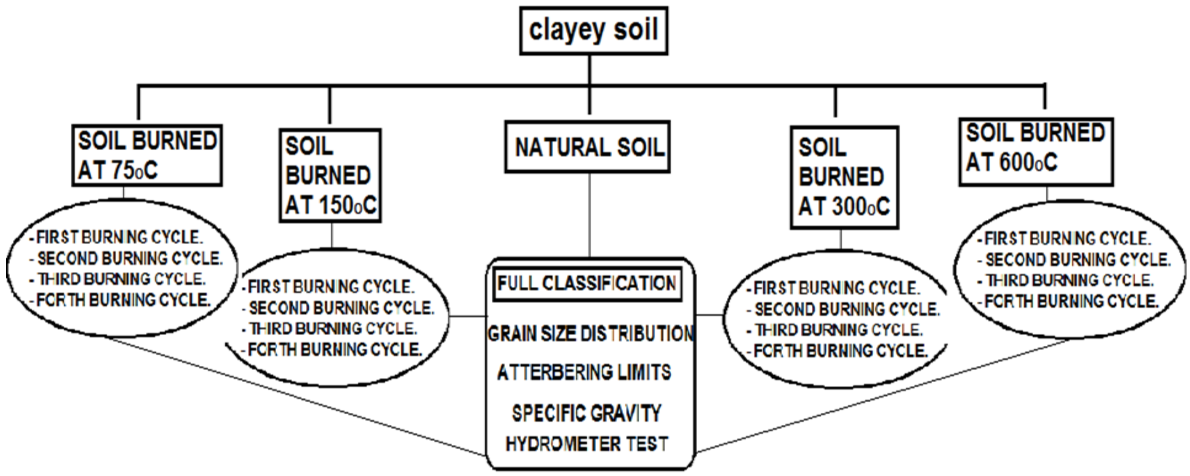
3.2 *Testing and Burning Methodology*

Burning of clayey soil at different temperatures (75-150-300 and 600^{o}C) are briefly studied and its effects on the soil parameters and weather the soil change its properties like liquid limit, plastic limit, specific gravity and particle distribution. The oven used for burning was bought from market and placed in the civil department laboratories in Diyala University. This oven was designed to carry high temperature levels.

The oven basically used for pottery. Fig. 5 shows a photo for the special oven used for burning soil samples different stress levels .

Figure 5. Special oven used for burning soil samples at high temperature, used in this study In Diyala University-collage of Engineering-Civil Engineering Department laboratories

The flow chart program is shown in Fig. 6. The oven used in this study specialized for burning samples at temperature ranges from 75^{o}C to 600^{o}C. A cycles of burning with each temperature was carried, with the following steps:



.Figure 6. Flow chart program of the experimental work carried out on this study

1. The soil was prepared and pulverized , sieved throw sieve No. 4 sieve (4.75mm).
2. The soil is oven dried and tested at the same water content.
3. A special oven for soil burning at which temperature level varies between 75^{o}C to 600 ^{o}C, used during this study.
4. After first burning cycle which continue about 10 hours. The sample was cooling and a series of classification test includes (liquid limit, plastic limit, specific gravity, sieve analysis and hydrometer test) were carried out.
5. The burned soil were retained to the oven and fired at the same temperature and prepared to burning for the second burning cycle.
6. The burned soil sample was extruded from the oven and the same procedure for full classification test was carried on it after the second burning cycle.
7. And so on, the same procedure was carried out for the soil for the third and fourth burning cycle at the same burning conditions and temperature.
8. The test procedure was repeated from step 4 to 7 for the soil burning temperature at (75-150-300 and 600^{o}C) for the same soil and full classification, which carried for each burning cycle.
9. The classification of the burned soil was carried out after each burned cycle. The classification was done according to the Unified and AASHTO classification chart.

4. Results and Discussion

The clayey soil burning at different temperature degrees: (75-150-150-300 and 600^{o}C). Each temperature included four repetitive burning cycles. The study was objective to study the behavior of clayey soils at each session of burning. All the results are described below in detail:

4.1. Effect of burning cycles with different temperatures on the specific gravity of soil:

Fig. 7. shows the relation between specific gravity of clayey soil, and the number of burning cycles, using different burning levels (75-150-300 and 600^{o}C). The specific gravity

for the natural soil before burning was recorded as reference. After first burning cycle the soil. The particle conditions changes for 300°C burning temperature more clearly than that for the soil burned at 75°C. This may attributed to the loss of weight of organic material inside soil skeleton at that temperature. When the soil burned, at second cycle, no changes was recorded for particle weights, it may refer to unchanging of weight at that stage of test.

on the other hand, at the third burning cycle great drop of specific gravity value recognized for soil sample burned at 300°C, while there are no changes for sample burned at 75°C. That behavior may attribute to the continuous burning of organic materials for soil sample at 300°C temperature level. While the organics still not completely burned at 75°C temperature.

A strange and confusing behavior appeared for soil sample burned at 150°C. The specific gravity values still unchanged during the fourth burning cycles, unlike that for other burning levels. This may reflect to a less changes in the particles properties and physical structure, unchanging of particle weight and condition. And it may became a pottery so, no changes in Gs was recorded.

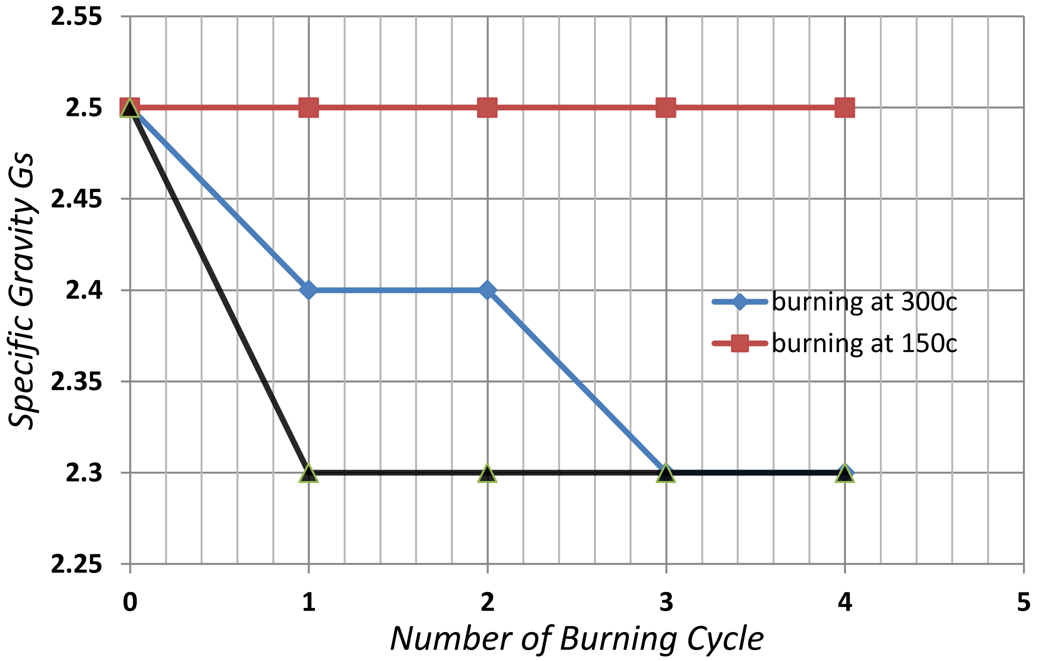


Figure 7. Relation between number of cycle and specific gravity using different burning levels (75-150-300°C).

4.2. Effect of burning cycles at different temperature on the liquid limit of soil

Fig. 8 shows the relation between liquid limit and number of burning cycles, using three burring grades (75-150 and 300°C). In this relation we study the effect of burning cycles on the liquidity of the soil, which is good parameter for determining many soil parameters.

It can be recognize from "Fig. 8" that the liquid limit increase at the first burning cycle reaches about 30% for soil sample burned at 75°C and the sample burned at 150°C compared with that of unburned soil sample. After that, the liquid limit decrease with the increase of burning cycle. This may refers to the change in soil nature and condition because of heating and its physical properties with repetitive burning cycles, causing big changes and translation of soil type from cohesive clayey to silty soil. It can be observe also A high drop of liquid limit curve at the fourth burning cycle for clayey soil sample at 75^{o}C, reaches 1/4 the liquid limit value for unburned sample. This behavior may cause high changes in soil cohesion and so reflect on the engineering properties and behavior, like bearing capacity. On the other hand the liquid limit for soil sample burned one cycle at 300^{o}C reduced 10% compared with that of unburned sample. This may attributed to the sudden subjecting of high temperature which was affecting greatly on the organic material inside soil, causing a reduction of liquid limit and this may greatly cause changes soil properties.

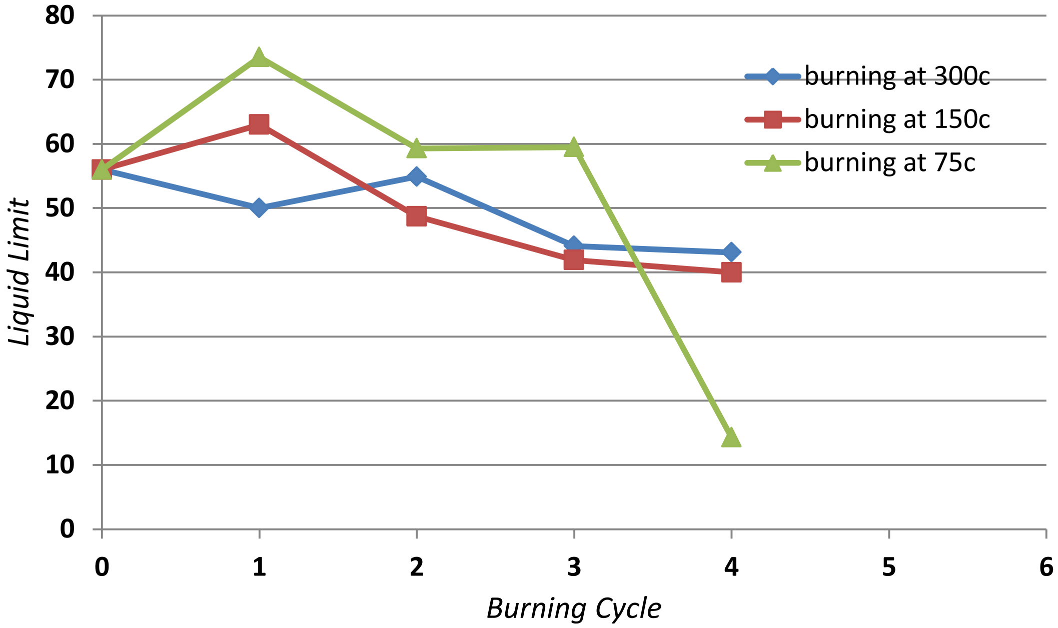


Figure 8. Relation between number of burning cycle and liquid limit for a burned soil with 3 burning levels (75-150-300oC).

4.3 Effect of burning cycles with different temperatures on the plastic limit of soil

Fig. 9. shows the relationship between the plastic limit and number of burning cycles for the soil use with three levels of burning at (75-150-300^{o}C). It can be recognize that the plastic limit after first and second burning cycles, that a sharp reduction in the curve. This behavior may attributed to particle structure changes for the soil sample at this stage condition. After that the curve was fractured for samples burned at 75^{o}C and 150^{o}C. While the curve for sample burned at 300^{o}C was inclined slightly. The oscillation in the plastic limit curve at the third burning cycle for the two burning levels 75^{o}C and 150^{o}C may attributed to incompleteness of burning organic materials inside clayey soil for soil sample subjected to 75^{o}C or 150^{o}C temperature. While Most organic materials were completed after the second burning cycle for soil sample burned at 300oC. After the fourth burning cycle the soil properties depending on each burning temperature and this is evident from the values of plastic limit, specially for the soil sample burned at 75^{o}C, where the plastic limit reduced 80%, if it was compared with unburned soil. This represents a big change in the soil nature and behavior, and therefore a change in type and engineering properties.

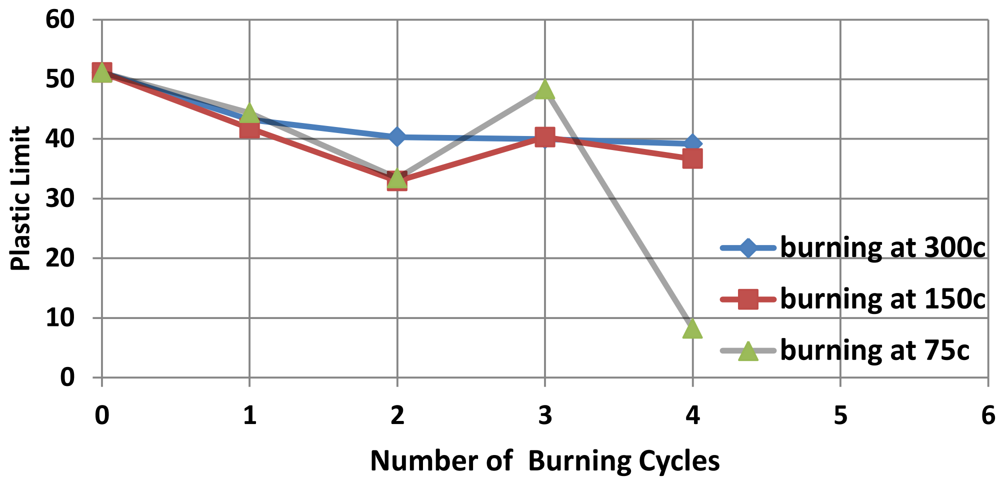


Figure 9. Relation between no. Of cycle and plastic limit for a burner soil with 3 burning levels (75-150-300°C).

4.4 Effect of burning cycles with various burning temperatures on the grain size

Fig.10. to "Fig. 13" shows the relation of particle diameter (mm) with percent finer. It represents the soil distribution curve for the soil before and after burning it with different burning cycles and temperature levels.

4.4.1 Grain size distribution curve for burned soil at 600°C:

Fig. 10. shows the relation between particle diameter and percent finer for burned clayey soil one cycle at 600°C. it can be observe that no changes was appeared for the curve with the burning cycles at 600°C. This behavior may attributed to pottery process for soil particles and unchanged on particle size and distribution with the continuous burning cycles during one burning cycle at that grade. The reason behind taking one burning cycle was the damaging of the oven customized for burning, which prevented the examination from being completed. Otherwise it was scheduled complete the tests for other three burning cycles at that grade.

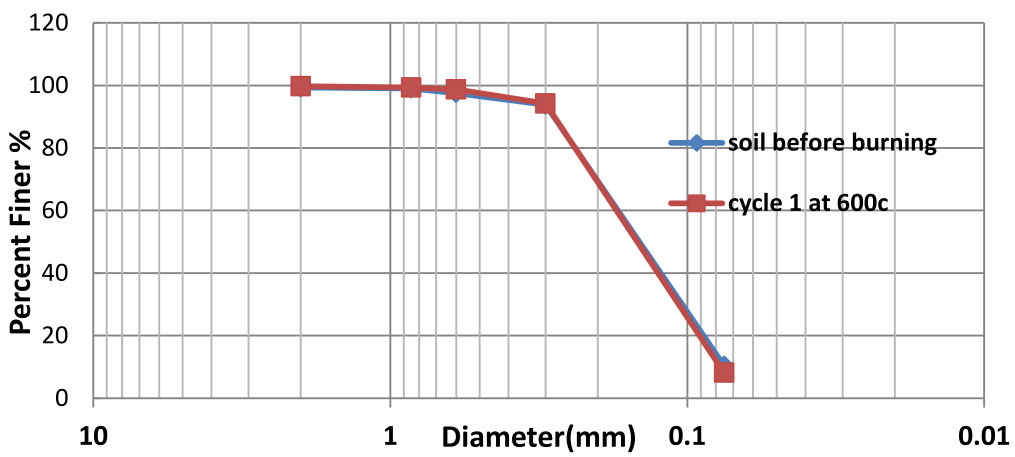


Figure 10. grain size distribution curve for burned and unburned soil at 600°C

4.4.2 Grain size distribution curve for burned soil at 300°C

The grain size distribution curve is a good indication to specify soil type and physical properties and so to dedicate engineering parameters required for the design of the footing constructed on that soil. "Fig. 11" shows the effect of burning temperature at 300°C using a special burning oven. It can be seen that, the curve shape was close for the first three burning cycles, this behavior may belong to unchanged in particle size at these states. On the other hand the distribution curve became more smooth at the fourth burning cycle. This may attributed to high changes in particle diameter at that state of test and so this lead to high changes for soil type and properties. The partials became finer as the burning cycles increases. The percent finer increase from about 7% to 57% at curve end when burning the soil four repetitive cycles, compared with first burning cycles..

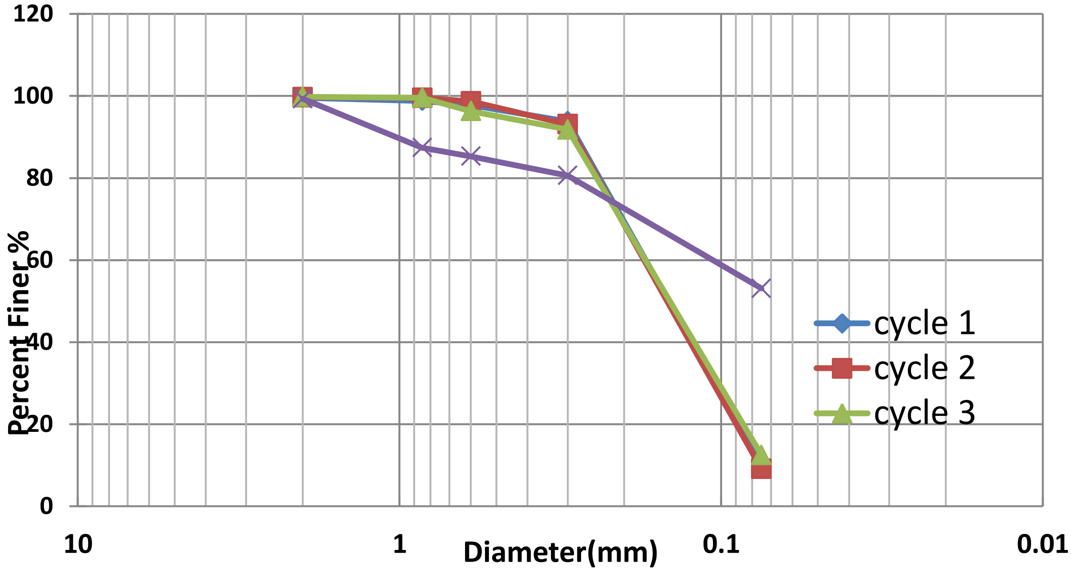


Figure 11. Grain size curve for buried soil at 300°C with 4 burning cycles.

4.4.3 Grain size distribution curve for burning soil at 150°C

Fig. 12. shows the grain size distribution curve for soil sample burned at 150°C. It can be seen that the distribution curve at first and second burning cycles are very close. This behavior may appear because the organic materials was burned earlier from the first cycle of burning at 150°C. At the second cycle the presence of organic materials was little. So no changes on the distribution curve was observed.

The influence of burning cycles at 150°C was more pronounce after the second burning cycles. The percent finer increase about 40% at the end of curve, if it compared with the curve at first cycle so this may reflect big changes on soil properties and type. This behavior maybelongs to the changes in particle size diameter starting after the second burning cycle at 150°C temperature. This behavior remains vague and need microscopic study to show the changes on particle size at that state of test at that temperature.

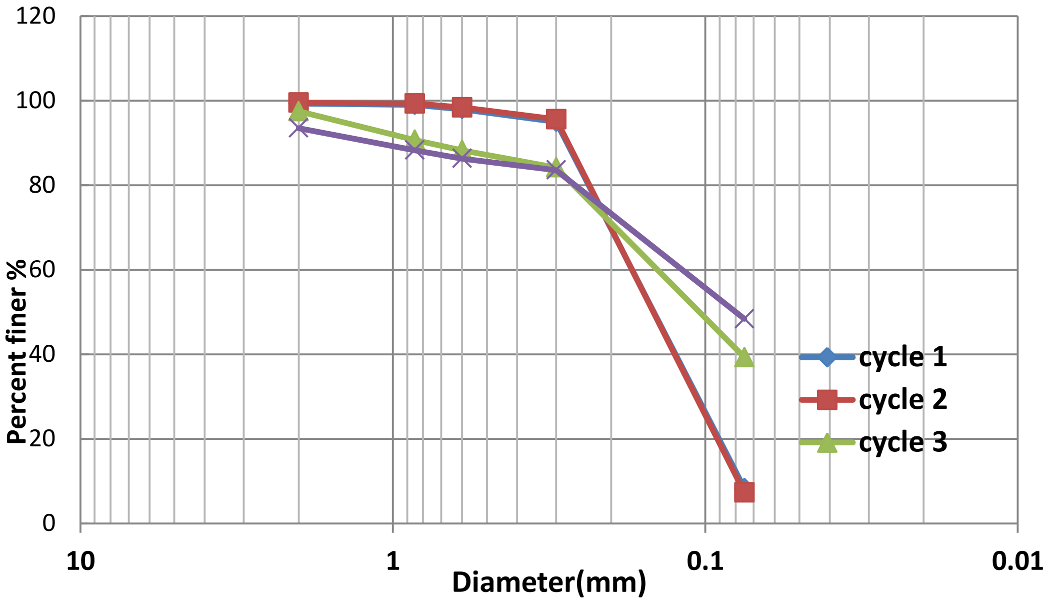


Figure 12. Grain size curve for buried soil at 150°C with 4 burning cycles.

4.4.4 Grain size distribution curve for burned soil at 75°C

Fig.13. shows the effect of burning cycles for the used soil at 75°C.it can be seen that, the soil partials became more finer as we proceed to cycling the burning and the percent finer in the distribution curve for first burning cycle increase from about 5% to 38% and it is increase about 64% for cycle 3.so the soil skeleton and particles effect widely with cycling of burning.

This temperature level is very close to the weather of many regions in the middle east and Arab golf, and its soil are subjected to same testing conditions (cycles of heating). So it is subjected to changes its properties and type with time and became more finer.

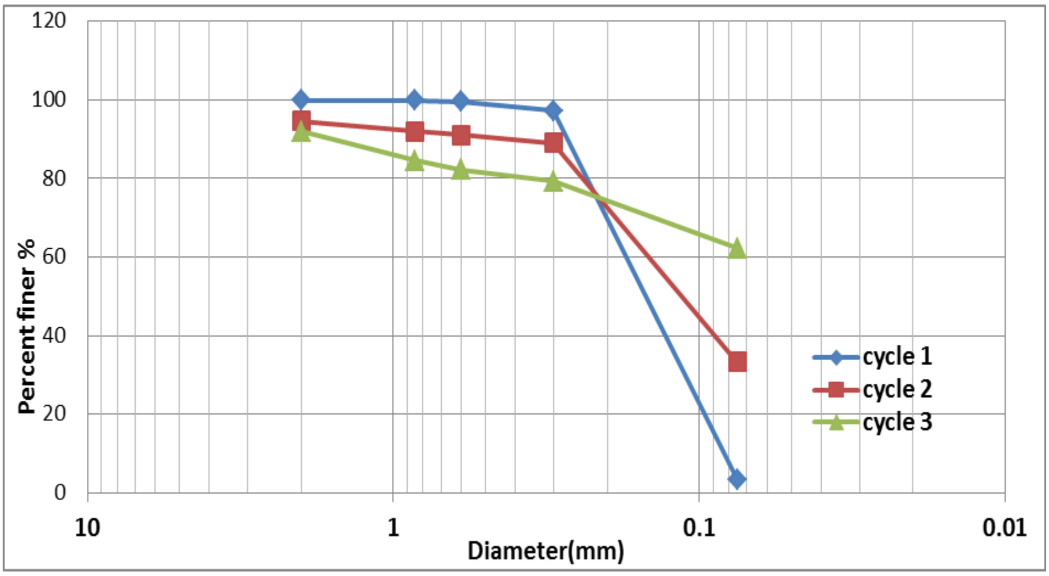


Figure 13 .Grain size distribution curves for buried soil at 75°C with 4 burning cycles.

Results for the Atterberg limits and other physical properties for unburied and burned soil with repetitive cycles are shown in Table. 6.

Table 6. Results of the effect of burning cycles at 75^{o}C on clayey soil, at which close to the natural weather temperature in summer for many regions in the world (especially in Arab world).

Soil Condition (subjecting to 75^{o}C)	LL	PL	PI	Gs	AASHT Classification	Unified Classification
Soil before burning	56	51.1	5	2.5	A-5	OH
Cycle 1of burning	73.5	44.35	29.15	2.3	A-7	MH
Cycle 2 of burning	59.3	33.4	25.9	2.3	A-7	MH
Cycle 3of burning	59.5	48.3	11.2	2.3	A-7	MH
Cycle 4 of burning	14.3	8.19	6.11	2.3	A-4	CL-ML

5. Conclusions

Atterberg limits, specific gravity and grain size distribution curve are well known indication for the geotechnical engineer to determine soil type, and so to determine other parameters necessary like soil settlement, bearing capacity, shear strength, soil modulus of elasticity, poisons ratio or coefficient of consolidation. Once we determine soil type we can propose parameters of such soil. Authors believe that the soil condition and consistency would change with burning, and so the soil will change its properties. And concluded the following:

1. The specific gravity of the soil tested in this study affected in general with burning. At 75^{o}C temperature, great changes were observed at the end of fourth burning cycle. And the Ds value decreases 8%for burned soil sample compared with unburned one. While the Gs are not affected during burning cycles at 300^{o}C.
2. The liquid limit at the end of fourth burning cycle at 75^{o}Ctemperature reduced 80% from the liquid limit value for unburned soil. While the reduction in liquid limit is 24%, 27% at the fourth cycle at 300^{o}C and 150^{o}C respectively.
3. Temperature has different effect on the plastic limit of clayey soils with various burning levels. Little changes were observed at the fourth cycle at 150^{o}C and 300^{o}C temperature. A reduction percent in plastic limit was 20% and 26% at the end of the fourth cycle at 300^{o}C and 150^{o}C respectively. On the other hand, great change was observed at the fourth burning cycle at 75^{o}C. The reduction in plastic limit reaches 84%. at 600^{o}C burning temperature clayey soil had lost its plasticity at the first round.
4. The grain size distribution curve for all tests with different temperature levels are widely affected after the second burning cycle, Soil particles became more finer as the burning cycles increases, the percent finer increases 4-8 times for the 4th burning cycle at 300^{o}C compared with first burning cycle at 300^{o}C.
5. The effect of burning cycles was more pronounse especially for sample burned at 75^{o}C. Author shows that the soil type changed from OH to MH after the first burning cycle at 75^{o}C. With the repetitive burning cycle more changes on soil properties and type accrue. The soil is Ml after the fourth burning cycle at 75^{o}C.

6. Recommendations

•After conducting several tests and experiments on clayey soil and study the effect of burning on its properties. authors recommends expanding laboratory and field tests on other soils and analyze their properties and learn more about thermal effect on it, in order to facilitate its use in construction work and burning effects on other properties.

•Future studies may require more information and deep study with microscopic study, to investigate soil particles changes and distribution after and before burning. And studying the effect of burning on other parameters, shear strength, permeability, soil angle of friction and cohesion.

6. References

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