

# Influence of Cyclic Temperature on Black Cotton Soil

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**ABSTRACT:** Thermal treatment alters the physical and mechanical properties of clayey soils. The changes undergone by clayey soil when it is exposed to cyclic temperature variation (i.e., heating-cooling cycles) are also important to understand. These situations are commonly observed during summer season or situation where soil is exposed to heat due to industrial manufacturing process. This paper illustrates the effect of cycling temperature on geotechnical properties of black cotton soil which was heated at elevated temperatures of 50°C and 100°C separately for different cycles. All properties were determined at different heating-cooling cycles (i.e. 1, 2, 4, 8, 12 cycles). The geotechnical properties of black cotton soil studied include liquid limit, plastic limit, specific gravity, optimum moisture content, maximum dry density, unconfined compressive strength, swelling pressure, differential free swell, California bearing ratio (Soaked) etc. All tests were performed three times for each cycle. It was observed that as the temperature and number of heating – cooling cycles increase, the sp. gravity, plastic limit, maximum dry density, differential free swell, swelling pressure, UCS and CBR increase while liquid limit and optimum moisture content decrease. The heating-cooling cycles affect the geotechnical properties of black cotton soil.

**KEYWORDS:** black cotton soil; raised temperature; cyclic temperature; geotechnical properties

## I. INTRODUCTION

Black cotton soil is expansive in nature due to the presence of montmorillonite and illite clay minerals. Many times these clays are subjected to heating-cooling cycles instead of heating only. The heating-cooling cycle means the temperature to which soil is subjected increases and then cools down. The soil may be subjected to a number of cycles. In such situations, properties of clay may change. The soil exposed to cyclic temperature due to various activities on ground. The geotechnical properties of heated black cotton soil in laboratory have been conducted since 1950. The present work carried out the study of the effect of the change of cyclic temperatures on geotechnical properties of black cotton soil.

Geotechnical properties such as liquid limit, plastic limit, specific gravity, optimum moisture content (OMC), maximum dry density (MDD), unconfined compressive strength (UCS), swelling pressure, differential free swell (DFS), and California bearing ratio (CBR) value were determined for 5 numbers of cycles (i.e., 1, 2, 4, 8, 12 cycles) at two different temperatures of 50°C and 100°C.

## II. RELATED WORK

The effective stress and water pressure in saturated clays due to heating-cooling cycles was investigated [1]. A heating-cooling-reheating cycle 22.5-60-22.5-100°C and 21-35-21-34°C was performed. An increase in axial strain up to 5.4% was observed starting from 64°C, followed by stabilization and then by a slight drop in the pore-water pressure. It may be concluded that the progressive compression by heating was not affected by the cooling-reheating cycles.

An experiment on soft Bangkok clay was carried out conducted on different temperature levels (25, 70, 90°C) [2]. The modified triaxial apparatus was used to test shear strength of heating-cooling cycles. Three ring heaters were placed

on the outer wall of the cell and the required temperature was controlled by a K-type thermocouple placed inside the triaxial cell. Test was began at room temperature followed by increasing the temperature by steps of 10°C up to 90°C, thereafter temperature was decreased to 25°C. Three Heating / cooling cycles were conducted. The results indicated that the total changes during heating and cooling are approximately equal. The stiffness, undrained and drained shear strength increases as temperature increases.

The study on the volume change behaviour of saturated clays under drained heating conditions was carried out using a modified odometer apparatus subjected to cyclic temperature (22 to 90 to 22°C) [3]. The volumetric change (strain) increases as temperature increases.

An experimental study on thermal conductivity of soft Bangkok clay using different temperatures gradient (30 to 50°C, 30 to 70°C and 30 to 90°C) was carried out using modified consolidometer [4]. The results shows that the thermal conductivity values increases as the temperature increases and soil porosity decreases as thermal conductivity increases.

The temperature effects on geotechnical properties of kaolin clay were studied for temperature range of 5°C and 40°C [5]. The temperature was maintained by circulating hot water from the circulating type of low temperature thermostatic water bath. The results show that shear stiffness of kaolin clay increases as temperature increases and pre-consolidation pressure increases as temperature increases to 40°C.

The literature review shows the cycling temperature variation, its methodology and nature of test conducted affects the geotechnical properties. The black cotton soil, which prominently observed in the central India, also subjected to various cyclic temperatures variations. The present work aims to study the effect of cyclic temperature on geotechnical properties of the black cotton soil.

### III. MATERIAL AND METHODOLOGY

The black cotton soil heated in an oven was used in this investigation. The specimens were placed in the oven at room temperature and then the temperature was increased until the desired temperature was reached. The same temperature was maintained for 24 hours for 1 cycle then the oven was turned off and soil allowed to cool down. Each cycle considered was of 24 hours. The tests were conducted at selected temperatures (i.e., 50°C and 100°C) with different cycles. The number of cycles selected were 1, 2, 4, 8, and 12. All tests for geotechnical properties of black cotton soil were performed three times for all cycles and average was taken.

#### BLACK COTTON SOIL

The soil used in experimental investigation was a locally available black cotton soil selected by conducting DFS test on oven dried soils from three locations. After analysis, black cotton soil of Sammati Colony, Amravati having 80% DFS was selected for the present study.

The geotechnical properties of black cotton soil collected from the field are given in Table 1. These properties are calculated on soil collected from the field before subjected to any raise of temperature.

**Table 1: Properties of Black Cotton Soil**

Sr. No.	Properties of Clay	Value
1	Liquid Limit (%)	71
	Plastic Limit (%)	25
	Plasticity Index (%)	46
2	IS-Classification (Clay of High Compressibility)	CH

3	Maximum Dry Density (MDD) ( $\text{kN/m}^3$ )	14.45
4	Optimum Moisture Content (OMC) (%)	31
5	Differential Free Swell Index (DFS) (%)	35.55
6	Specific gravity	2.5
7	Unconfined Compressive Strength (UCS) ( $\text{kN/m}^2$ )	120
8	Swelling pressure ( $\text{kN/m}^2$ )	58.56
9	California Bearing Ratio (CBR) (%) Soaked CBR	1.75

#### IV. EXPERIMENTAL INVESTIGATIONS

Table 2 present the experimental program developed for studying the effect of cyclic temperature increases on black cotton soil. The geotechnical properties of black cotton soil were determined for each cycle separately.

**Table 2** Program for experimental investigation

Group	Heating methods	Tests	Various Temperatures
Group A	Heating-cooling cycles	DFS, Liquid limit, plastic limit, specific gravity, Proctor test, UCS test, swelling pressure, Soaked CBR test.	1 cycle 2 cycles, 4 cycles, 6 cycles, 8 cycles. at 50°C and 100°C temperature separately.

#### RESULTS AND DISCUSSIONS

The results of geotechnical engineering properties tests carried out on black cotton soil subjected to cyclic temperature variation were calculated and compared and discussed below.

##### Atterberg's Limits

The liquid limit and plastic limit of black cotton soil for various temperatures and number of cycles were determined. The liquid limit test conducted on black cotton soil for temperature of 100°C and 50°C flow curves are shown in Fig. 1 and Fig. 2 respectively. It is clearly observed that as the cycle's of temperature increases, the liquid limit decreases in both cases. However, the change in geotechnical properties for 50°C temperature cycle are small.

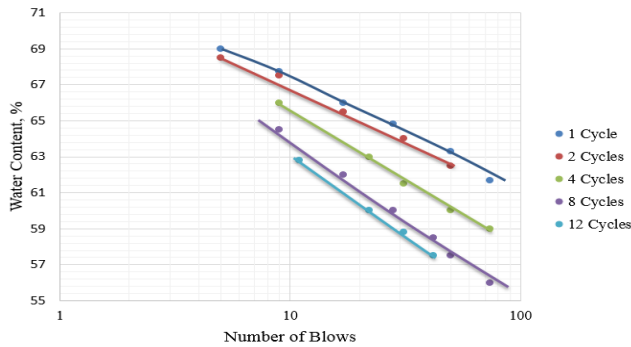


Fig. 1: Liquid Limit values with different cycles at 100°C

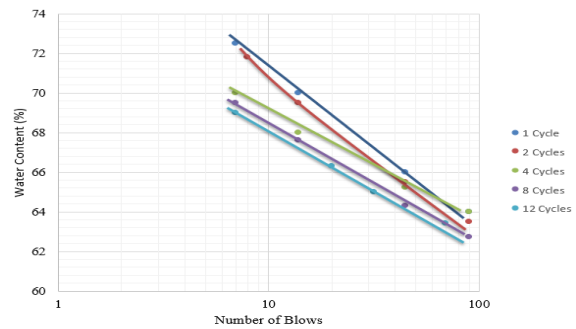


Fig. 2: Liquid Limit Values with different Cycles at 50°C.

Fig.3 and Fig.4 shows results of specific gravity and plastic limit for various cycles at 50°C and 100°C respectively. It was observed that as the cycle's increases; the plastic limit and specific gravity of black cotton soil increases. The increase in temperature shows increase in specific gravity and plastic limits.

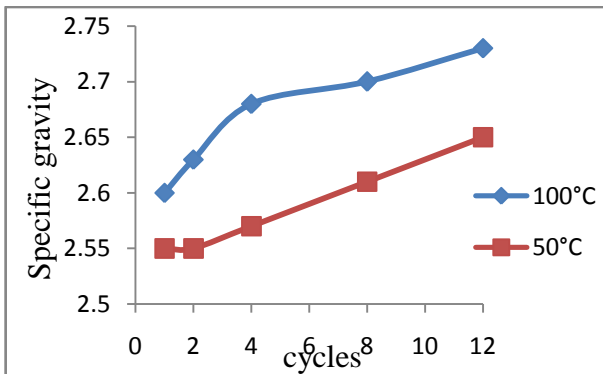


Fig. 3: Specific gravity values for different cycles and Temperature

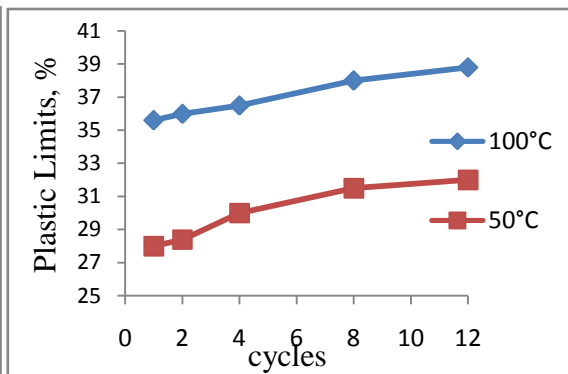


Fig. 4: Plastic Limit Values for different cycles and Temperature

**MDD and OMC**

OMC and MDD were determined by standard Proctor test method. Fig. 5 and Fig. 6 show the dry unit weight and water content variation for different heating-cooling cycles at 100°C and 50°C respectively. It shows that as number of cycle of heating and cooling increases MDD decreases and OMC increases. Also higher temperature shows that if the soil heated at higher temperature, MDD increases and OMC decreases.

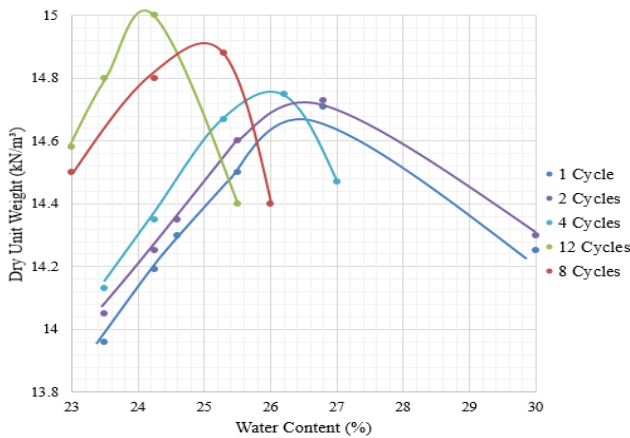


Fig. 5: Proctor Results for Cycles at 100°C

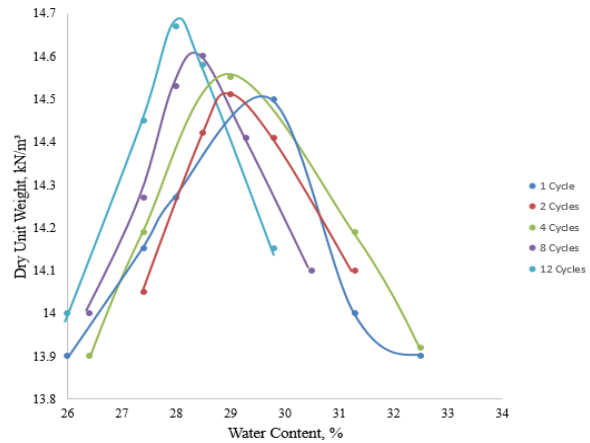


Fig. 6: Proctor Results for Cycles at 50°C.

### Unconfined Compressive Strength

For determination of unconfined compressive strength, black cotton soil was passed from 4.75mm sieve. The required amount of water equal to OMC was added in the sample. Then test sample was prepared and tests were performed. The undrained shear strength of a cohesive soil is equal to one-half the unconfined compressive strength. Fig. 7 and Fig.8 shows the variation of unconfined compressive strength of soil subjected to different cycles at temperatures of 100°C and 50°C respectively. It was observed that as the heating-cooling cycle's increases; unconfined compressive strength increases i.e. undrained shear strength is also increases.

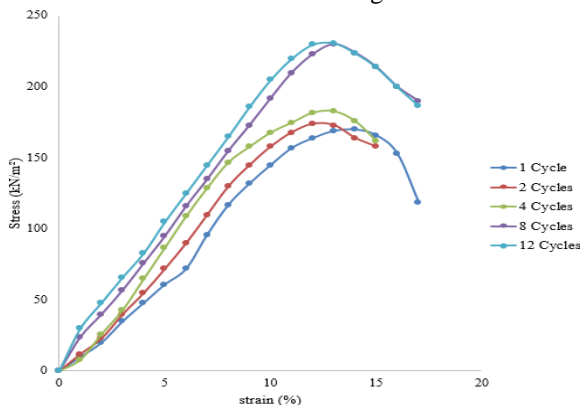


Fig. 7: Unconfined Compressive Strength for various Cycles at 100°C

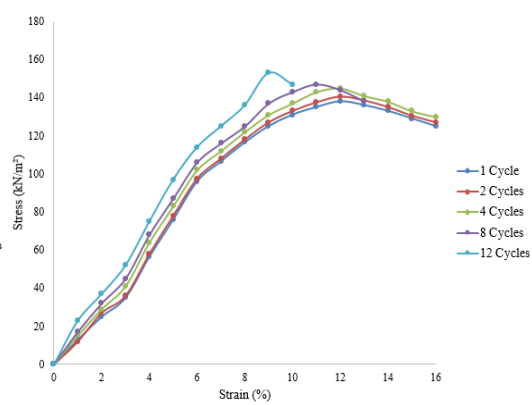


Fig. 8: Unconfined Compressive Strength for various Cycles at 50°C.

### Swelling Pressure and Differential Free Swell Index

For the determination of swelling pressure and Differential free swell of black cotton soil, the heated soil to respective heating-cooling cycles was used. The soil was compacted at respective OMC. Fig 9 and Fig 10 shows changes in differential free swell index and swelling pressure with different cycles of heating at 50°C and 100°C. It was observed that swelling pressure as well as differential free swell index increases as cycles increases and heating temperature increases.

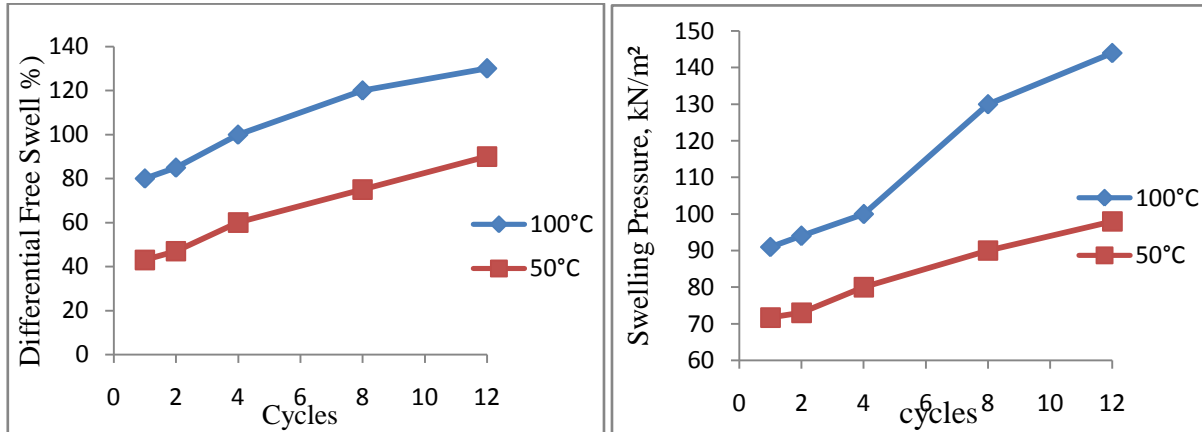


Fig. 9: Differential Free Swell for various Cycles Fig. 10: Swelling Pressure Results for various Cycles

### CBR

The CBR mould was prepared at moisture content equal to OMC and maximum dry density obtained by standard Proctor test. The soaked CBR was determined for all tests. Fig.11 shows CBR results of CBR test at cycles of 50°C and Fig. 13 shows the variation of CBR value with different cycles of heating at 50°C and 100°C. It shows that the CBR increases when cycle's of heating increases. The heating of black cotton soil at higher heating cycles results in improvement CBR.

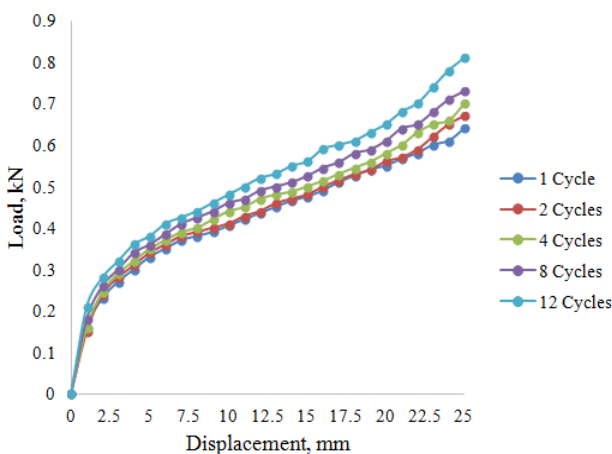


Figure 11: CBR for Different Cycles at 50°C

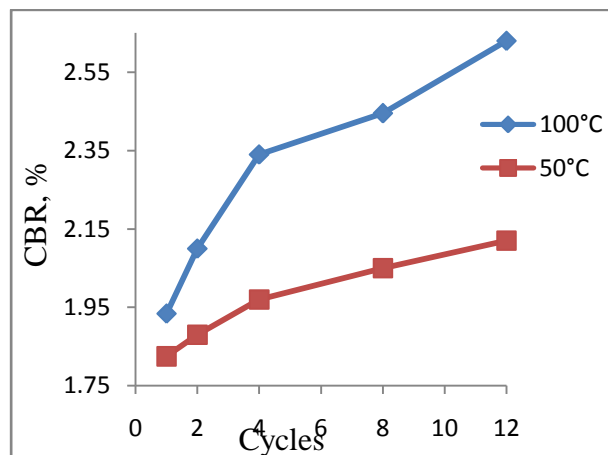


Figure 12: Variation of CBR Values for Different Cycles

### Discussion

Table 3 shows % variation in geotechnical properties of black cotton soil subjected to different heating- cooling cycles at 50°C and 100°C. When black cotton soil was heated and cooled to higher number of cycles the % decrease in liquid limit was varied from 1.23 % to 9.23 % while % decrease in OMC was of the range of 1.13% to 9.43%. Similarly, when black cotton soil was heated and cooled to higher number of cycles the % increase in plastic limit range between 1.29 % to 11.3%, MDD 0.14% to 3.6%, DFS 9.1% to 106%, swelling pressure 3.2% to 57.6%, UCS 5% to 36.37% and

CBR 3% to 35.99%. Thus heating and cooling cycle of even 50°C and 100°C, affect the geotechnical properties of black cotton soil.

## V. CONCLUSION

The present work aims for understanding the effect of heating-cooling cycles of different temperature on geotechnical properties of black cotton soil. The effect was studied for different heating-cooling cycles and heating temperature. The experimental investigation was also carried out on black cotton soil for 1-12 heating-cooling cycles at temperature 50°C and 100°C. Based upon the results of experimental investigation, following conclusions were drawn

- The heating cooling cycle of BC soil shows that liquid limit decrease and plastic limit increase with increase of number of cycles.
- The heating cooling cycle also shows increase in specific gravity with increase of number of cycles.
- The increase in MDD and decrease in OMC was also observed with increase in number of heating-cooling cycles.
- Swelling pressure and Differential free swell index increases as heating-cooling cycle's increases.
- The increase in shear strength was observed when black cotton soil was subjected to increase heating-cooling cycles.

**Table 3:** % Variation in Geotechnical Properties due to number of Heating Cooling Cycles  
(- sign decrease % and + sign increase % over one cycle of heating-cooling)

S No	Geotechnical Properties	Temperature °C	Number of Heating Cooling Cycles			
			2	4	8	12
1	Liquid limit	50	-1.6	-2.48	-3.79	-4.52
		100	-1.23	-4.61	-7.69	-9.23
2	Plastic limit	50	1.39	3.57	7.14	11.3
		100	1.29	2	6.145	10.3
3	MDD	50	0.14	0.42	0.76	1.31
		100	0.15	0.41	1.496	3.6
4	OMC	50	-1.67	-3.33	-5.66	-6.67
		100	-1.13	-2.26	-5.6	-9.43
5	DFS	50	12.3	27.3	72.3	106
		100	9.1	23.3	50.3	61.2
6	Swelling pressure	50	3.2	10.4	24.4	32.2
		100	4.4	8.8	43.3	57.6
7	UCS	50	7	10.77	13.85	18.46
		100	5	8.24	35.29	36.47
8	CBR	50	3	7.95	12.33	16.16
		100	8.58	21	26.42	35.99

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