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ORIGINAL PAPER

Effect of Drying on the Index Properties of Lateritic Soils

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Abstract Due to significant variation in geological and climatic conditions the characteristics of lateritic soils vary from place to place. Because of the prevailing climatic conditions, the laterites and lateritic soils of a particular region may be different from those found in other parts of the world. Some investigators report that the pretest drying has significant effect on the properties of soils. In such studies the authors associate the effect of drying on the properties of soils due to the mineralogy of soil. From this context there is a need to investigate the effect of sample preparation on lateritic soils prior to testing. In the present study lateritic soils from different sources in west coast region of India were studied to investigate the effect of drying on their index properties. Due to pretest drying it is observed from the results that there is a significant change in Atterberg limits and other properties of soils tested. These changes are attributed due to aggregation of particles. The observed changes are found to be permanent.

Keywords Lateritic soil · Air dried · Oven dried · Index properties · Chemical properties

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1 Introduction

Laterities and lateritic soils are highly weathered and altered residual soils formed by the in situ weathering and decomposition of rocks in the tropical and subtropical regions with hot, humid climatic conditions. In these regions, these soil deposits are often used as civil engineering construction material. The coastal districts of Karnataka State, India, (Fig. 1) situated between Arabian Sea on the west and Western ghats in the east having high average annual rainfall of more than 3,000 mm and humid temperature, where naturally occurring engineering materials are mainly lateritic soils. The importance of lateritic soils in the region is evident due to successful use of these soils in the construction of highways, earthen dams, airfields, foundations and slopes. The properties of lateritic soil deposits vary from place to place because of the differences in the geological setups, prevailing climatic conditions and the type of mineral present. In fact the mineralogical content plays an important role. Adnan et al. (1994) report that the method of sample preparation techniques can have significant effects on the index and engineering characteristics of soils. Based on their study the authors conclude that drying at 110 °C removed all of the free water and most of the clay attached water while 60 °C removed part of this latter water. On the other hand, air drying caused a minimal loss of attached water. Loss of this type of water (which is considered an integrated part of the soil) resulted in a destruction of the soil structure and

Fig. 1 Soil map of the study area with sample locations (shown in enlarged view)

consequently affecting the soil properties. Additionally, it was noted that drying at 110 and 60 °C caused soil aggregation and thus resulted in a marked reduction in liquid limit, plasticity index, and clay content. According to Rao et al. (1989), in the case of China clays, presence of calcium and magnesium ions in pore fluid together with a high pore salt concentration of 9.4 g/l is an important factor contributing to the close spacing of particles, leading to the development of capillary stresses of significant magnitude. These capillary stresses lead to particle aggregation and reduce the available surface for interaction with water, which is reflected in the reduction in plasticity characteristics. Mitchell (2009) relates the unusual properties of soils are due to the type of mineral present. Due to the above reasons there is a need to study effect of drying on lateritic soils. In view of this the present paper reports a systematic study aimed to find out the effects of pretest drying on the index properties of selected lateritic soil samples.

2 Experimental Methodology

The study area chosen for the present work along with approximate soil samples locations is shown in Fig. 1 (Karnataka state, India). All the soil samples were collected from open trial pits of depth about 1.5 m to 2 m from natural ground level. The dry density of in-place soil was determined using core-cutter method. A small area in the trial pit was leveled and cleaned. The core cutter is then rammed down vertically into the soil layer. The cutter is then dug out of the surrounding soil and placed in plastic wrap. Dry density and natural moisture content were determined in the laboratory. Disturbed soil samples were collected to perform index properties of soil. Disturbed samples obtained from each site were placed in airtight containers. Soil samples stored were labeled properly with data as soil type, location of site where sample was taken, sample depth and sample number. Some typical characteristics of these soils are presented in Table 1.

Table 1 Moisture content and unit weight of typical lateritic soil

Parameter	Result
NMC (%)	14
Field bulk density (γ_b) (kN/m^3)	19.10
Field dry density (γ_d) (kN/m^3)	16.75
Specific gravity (G_s)	2.71

NMC natural moisture content

2.1 Sample Preparation

For testing purposes all soil samples were prepared in the laboratory under the following two conditions:

1. Air dried (AD)—soil samples air dried under normal ambient temperature in shade, between 25 to 30 °C and
2. Oven dried (OD)—soil samples dried in a thermostatically controlled oven to constant weight at 110 ± 5 °C.

2.2 Testing Procedure

All the soil samples were first prepared and tested at natural moisture content and then in oven dried condition. The flow chart in Figs. 2 and 3 shows the schematic diagram of various tests conducted on soils which include index properties for soil passing 20 mm sieve/425 μm (No. 40) sieve. A detailed testing procedure is explained below:

2.3 Index Properties

Index, and other geotechnical tests were performed on the soils using relevant Indian standards. The Table 10 ("Appendix") summarizes the references in determining different parameters and analogue of ASTM standards. In determining the Atterberg limits, the samples were mixed with water to an appropriate consistency. They were then covered with plastic wrap and left to stand for 24 h so that the paste became uniformly saturated before testing. The grooving tool

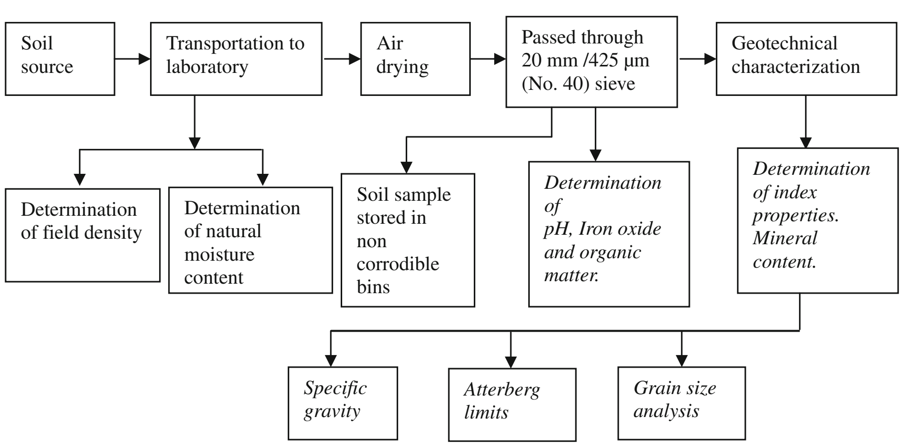

Fig. 2 Schematic diagram of various tests conducted on soils

Fig. 3 Liquid limit test in the laboratory

was used for the liquid limit tests to make a clean groove in lateritic soils.

Combined wet sieve analysis was performed on all the soil samples as per relevant standards. The same soil sample was used to determine the particle size distribution at both the natural moisture content and oven dried conditions. Sieves are used for the portion of soil greater than 75 μm (No. 200 sieve) in particle size. The specimen fraction that is finer than the No. 200 sieve is analyzed using sedimentation. Sedimentation test was performed using a hydrometer. Prior to hydrometer analysis the soil sample was pretreated in order to deflocculate the clay particles. Sodium hexametaphosphate is used as the dispersing agent at a concentration of 5 g/l in the final slurry volume. The distilled water is then added to the soil and dispersant to a volume of about 400 ml, covering soil. The soil and the dispersant was thoroughly mixed for about 15 min to break up flocs and cemented particles. The deflocculated mixture is transferred to the cylinder and filled to 1,000 ml with distilled water. The suspension is then mixed by inverting the cylinder several times by hand. After mixing, the cylinder is placed in the upright position and a timer is started at the same instant. A hydrometer is quickly inserted into the suspension and readings taken with time for the first 2 min. This process is repeated for different time intervals.

2.4 Chemical Properties

2.4.1 pH

The pH values of soilwater solutions is measured electrometrically by means of an electrode assembly. 30 g of the representative soil from the sample passing No. 40 sieve is taken in a beaker. 75 ml of demineralized water is added to the beaker. The suspension is then stirred for few seconds and allowed to stand for 1 h with occasional stirring. After 1 h pH of soilwater solution is measured.

2.4.2 Organic Matter

Organic matter influences many of the physical, chemical and biological properties of soils. Some of the properties influenced by organic matter include soil structure, soil compressibility and shear strength. In addition, it also affects the water holding capacity. Organic matter was estimated by chemical oxidation method using standard method (potassium dichromate as oxidizing agent and ferrous sulphate as titrant). A representative soil sample passing 425 μm sieve was used and the test conducted as per relevant standard Indian standard [SP 36 Part 1, (1989)].

2.4.3 Iron Oxide Content

Iron content in soil is frequently in the form of oxides. These oxides may exist as discrete particles, as coatings on soil minerals, and as cement between mineral particles. The vales of iron oxide presented in Table 8 were obtained on a representative soil portion passing No. 200 sieve using calorimetric method.

2.5 Mineralogy of Lateritic Soil

The mineralogical composition of lateritic soils is determined by X-ray diffraction technique (XRD). In X-ray diffraction analysis of minerals by the powder method, the powdered mineral sample is placed in a beam of X-rays, which is diffracted through a limited number of angles by the crystal lattice of the sample. The X-ray patters were obtained using Cu-K_α radiation scanned from $2\theta = 2$ to about 90° at a rate of 2°/min. The results of the X-ray diffraction analyses showed that the lateritic soil was essentially composed of kaolinite, gibbsite and goethite minerals. The effect of drying on soil structure was studied using scanning electron microscope. Scanning electron micrographs of air dried and oven dried soil samples were taken at same magnification to study the effect of sample preparation on soil. The analyses was carried out on the JEOL scanning electron microscope (model

JSM-6380LA), which provided fabric appraisal and gave an elemental description using an energy-dispersive X-ray analyzer (EDXA). Each sample was held in an aluminium sample holder and sputter-coated with a fine platinum film.

3 Results and Discussion

The results of the experimental investigation are discussed in the following sections:

3.1 Effect of Method of Sample Preparation on Index Properties

3.1.1 Specific Gravity

The effect of sample preparation on the specific gravity of soil is shown in Table 2. From the results in Table 2 it is observed that the specific gravity of air dried soil samples varied from 2.88 to 2.55 and the for oven dried samples the specific gravity values vary from 2.75 to 2.44. There is a slight decrease in the values of specific gravity of oven dried soils. However the decrease is not significant when compared to the air dried soil. Maximum difference observed for oven drying versus air drying (sample no. 8) was only about 0.09. The higher specific gravity of natural lateritic soil may be attributed due to high iron content. In order to have a better visualisation of the comparison appropriate graphs columns were added in various Tables. Figure 4 in Table 2 shows the variation of specific gravity of air dried and oven dried soils.

3.1.2 Grain Size Distribution

The same soil sample was used to determine the grain size distribution at both the air dried and oven dried conditions. Results of grain size analyses are presented in Table 3. It is observed from Table 3 that due to oven drying of soil there has been increase in silt content and decrease in clay content of soil. This effect may be due to the aggregation of particles. Clay content in some cases (sample 2, 4, 6, 7, 9 and 11) decreased and the decrease is greater than 2 percent. In others no significant changes were observed. From Table 3 it is found that oven drying decreases the clay content of soils. However changes in clay content of soil samples less than one percent are not significant by considering the accuracies of experimental techniques. Figure 5 shows the variation of silt and clay content of air dried and oven dried soils.

3.1.3 Atterberg Limits

While conducting Atterberg limit tests, soil samples were first mixed thoroughly with distilled water. To ensure uniform moisture distribution the soil in the mixed state is left for sufficient time. Figure 3 shows a liquid limit test on soil sample in the laboratory.

Table 4 shows the test results of Atterberg limits. It is observed from Table 4 that the liquid limit of all soils decreased when compared with air dried soils.

Table 2 Effect of sample preparation on specific gravity of soil

Sample No.	Sample preparation method	
	Air dried	Oven dried
1	2.80	2.76
2	2.82	2.78
3	2.76	2.73
4	2.58	2.56
5	2.59	2.55
6	2.59	2.57
7	2.64	2.63
8	2.53	2.44
9	2.55	2.54
10	2.58	2.57
11	2.63	2.55

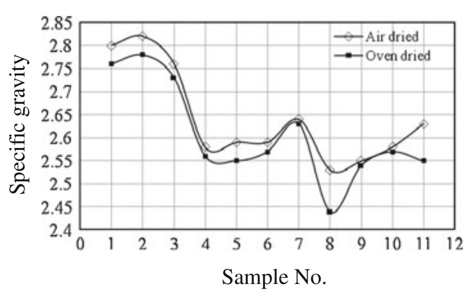

Fig. 4 Variation of specific gravity of air dried and oven dried soils

Table 3 Effect of method of sample preparation on grain size distribution

Sample no.	Sample preparation method	Grain size distribution (%)			
		Gravel (>4.75 mm)	Sand (2.00–0.075 mm)	Silt (0.075–0.002 mm)	Clay (<0.002 mm)
1	AD	30.0	48.3	19.5	6.8
	OD	29.2	47.9	21.3	6.1
2	AD	33.0	31.5	28.5	7.5
	OD	32.5	30.4	33.4	5.8
3	AD	22.3	65.5	11.0	7.8
	OD	21.1	64.9	13.4	6.2
4	AD	11.0	69.0	14.5	8.5
	OD	10.3	67.6	19.6	6.9
5	AD	9.5	60.8	25.5	9.8
	OD	8.6	58.7	30.1	9.1
6	AD	8.2	63.0	25.5	8.7
	OD	7.3	62.6	29.4	7.8
7	AD	–	71.5	24.2	5.6
	OD	–	70.5	27.4	4.3
8	AD	5.4	58.5	30.5	8.3
	OD	4.3	56.6	34.4	6.5
9	AD	6.0	53.0	37.3	10.5
	OD	5.1	51.8	42.2	8.7
10	AD	4.0	58.0	35.1	8.2
	OD	3.1	57.2	38.9	7.6
11	AD	2.2	52.0	40.2	10.3
	OD	1.8	52.0	44.1	8.3

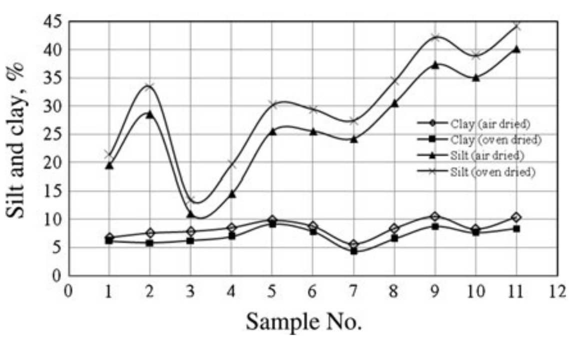

Fig. 5 Variation of silt and clay content of air and oven dried soils

This shows that the sample preparation techniques may have significant effect on the properties of soils. The decrease in liquid limit of soil samples due oven drying may be attributed to decrease in the clay content. Oven drying removes all the free water attached to the clay particles. Since free water is an integral part of the soil and loss of attached water resulted in a destruction of the soil structure and consequently affecting the index properties. However air drying caused a minimal loss of attached water. Additionally, it was noted that oven drying caused soil aggregation (as depicted in Fig. 6) and thus resulted in a marked reduction in liquid limit, plasticity index, and clay content (as shown in Table 3). According to Pandian et al. (1993a, b) changes in plasticity characteristics upon drying are attributed to the grouping of particles into aggregates either due to mineralogy or presence of cementing agents and/or pore fluid characteristics. Some researchers also report that the decrease in clay content of soil after drying may be attributed to the free iron oxide content of soils. Moh and Mazhar (1969) based on their study on lateritic soils they conclude that the coating of free iron oxide on the surface aggregates the particles into clusters. The clusters thus formed would have less specific surface and would absorb less water thus lowers the liquid limit.

Table 4 Effect of method of sample preparation on Atterberg limits

Sample no.	Liquid limit (%)		Plastic limit (%)		Plasticity index (%)		Shrinkage limit (%)	
	AD	OD	AD	OD	AD	OD	AD	OD
1	35.2	33.2	26.7	26.6	8.5	6.6	22.3	20.4
2	41.1	31.2	29.4	24.8	11.7	6.4	23.9	22.9
3	37.4	35.1	22.9	24.1	14.5	11	23.7	22.5
4	43	36.3	31.8	29.2	11.2	7.1	22.1	20.9
5	47.3	45.2	30	29.8	17.3	15.4	25.5	24.5
6	53.2	51.6	32.8	34	20.4	17.6	26.5	24.5
7	30.4	27.2	21	20.6	9.4	6.6	22.4	21.7
8	42.2	38.1	26	28.7	16.2	9.4	24.2	23.7
9	57	55.1	33.9	38.8	23.1	16.3	30.0	28.5
10	39.6	37.9	27.2	27.3	12.4	10.6	23.7	22.6
11	50	45.2	31.7	32.8	18.3	12.4	28.5	27.2

AD air dried, *OD* oven dried

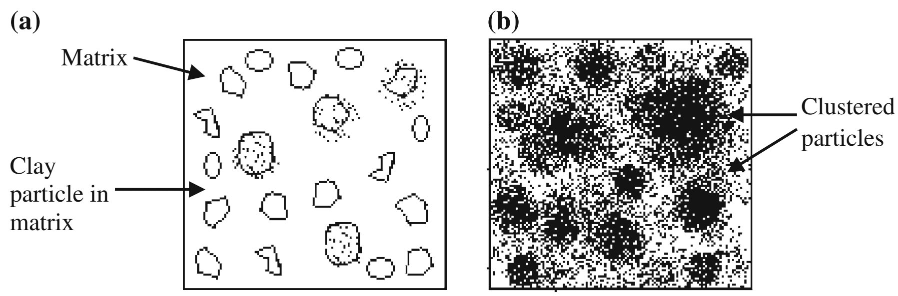

Fig. 6 Example of soil particles in a matrix. **a** Air dried soil **b** oven dried soil

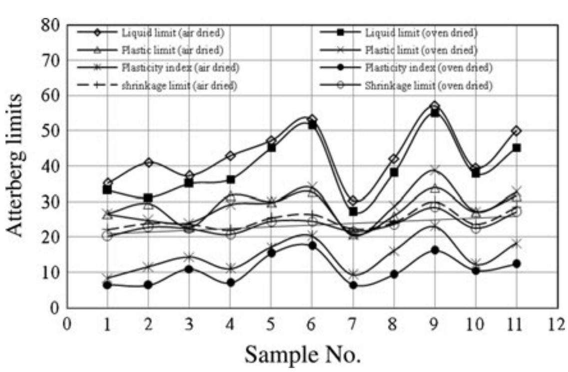

Fig. 7 Variation of liquid limit, plastic limit, plasticity index and shrinkage limit of air and oven dried soils

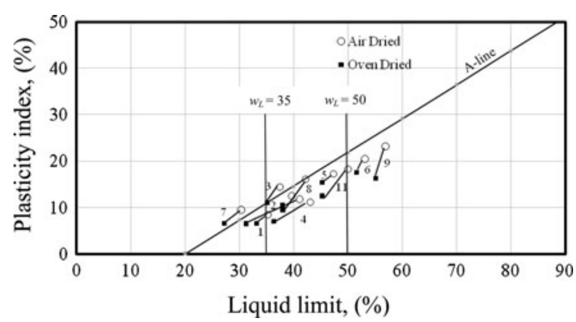

Fig. 8 Plasticity chart

The results of effect of drying on the plastic limit and shrinkage limit of lateritic soils are presented in Table 4. The variation of limits of air dried and oven dried soils is shown in Fig. 7. It is observed that there is very little effect of drying on the plastic limit and shrinkage limit of soils. A larger reduction in liquid limit and small change in plastic limit due to drying resulted in decreases of plasticity index as shown in Fig. 7.

3.2 Plasticity Chart

The plasticity chart for identifying fine grained soils is shown in Fig. 8. On the chart an empirical boundary

Table 5 Effect of drying on activity of soil

Sample No.	Sample preparation method	
	Air dried	Oven dried
1	1.25	1.08
2	1.56	1.10
3	1.86	1.21
4	1.32	1.03
5	1.77	1.69
6	2.34	2.26
7	1.68	1.53
8	1.95	1.45
9	2.20	1.87
10	1.51	1.39
11	1.78	1.49

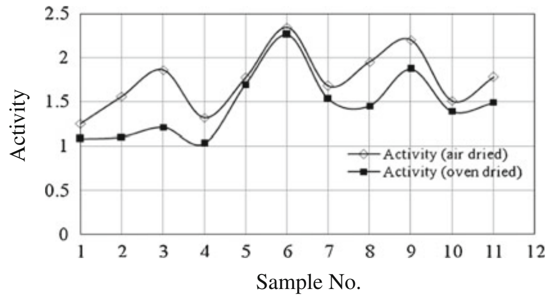

Fig. 9 Activity of air and oven dried

known as A-line separates inorganic soils from organic soils. Above the A-line are inorganic soils whereas below A-line are organic soils. Figure 8 shows the position of the soils tested on the plasticity chart. It is found that plotted points fall very close to A line. In general, soils containing kaolinite as the major mineral usually lie below the A-line, behaving as inorganic silts (such as ML, MI, MH).

3.2.1 *Activity*

From the plot in Fig. 9 (in Table 5) it is observed that the activity of soils decreased due to drying. This reduction may be attributed due to decrease in the plasticity index (I_p) values of soils. From engineering point of view it means that the soil becomes more workable upon oven drying. Although the soil samples contained kaolinite as a predominant mineral the activity values appeared to be slightly higher. In this work activity values were calculated using Skempton's equation. Based on the relationship between plasticity index and the clay content Skempton concluded that the approximate values of activity for kaolinite and sodium montmorillonite (for soils containing high proportion of fines) are 0.38 and 7.2. In the present work, the soils tested contained relatively small amount of clay fraction but were plastic due to the combined effect of clay and silt. This may have lead to increase in plasticity index of soils and hence increase in the activity values. Figure 10 shows the relationship between plasticity index and clay content. It is observed from Fig. 10 that the Skempton's definition of activity is restricted to these soils due to the reason that the lateritic soil contains less of clay size fraction.

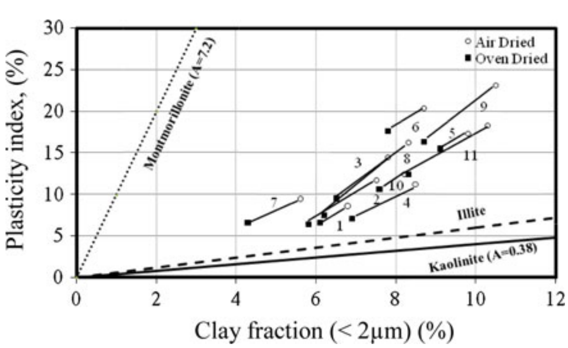

Fig. 10 Relationship between plasticity index and clay content of lateritic soils

3.3 Effect of Drying on Chemical Properties

3.3.1 *pH*

The pH values of air dried and oven dried soils are shown in Table 6 and the variation in Fig. 11. The acidic nature of natural lateritic soil is due to leaching of appreciable amounts of exchangeable bases, from the soils because of high precipitation and decomposition of organic matter which leads to the formation of organic and inorganic acid which render the soil acidic. The reduction in pH value of oven dried soil

Table 6 Effect of drying on pH of soil

Sample No.	Sample preparation method	
	Air dried	Oven dried
1	4.89	3.80
2	5.08	4.20
3	5.80	5.39
4	5.82	5.68
5	5.18	4.99
6	5.96	5.36
7	5.24	5.02
8	5.63	5.54
9	5.79	5.34
10	6.03	5.75
11	5.79	5.49

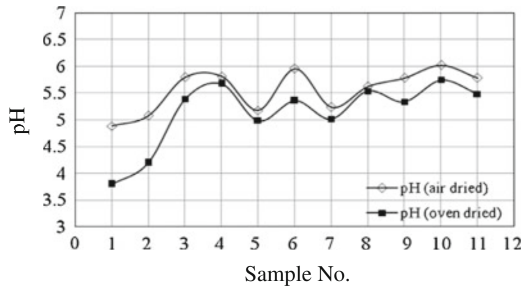

Fig. 11 pH of air dried and oven dried soils

Table 7 Effect of drying on organic matter

Sample No.	Sample preparation method	
	Air dried	Oven dried
1	0.36	0.27
2	0.86	0.65
3	0.46	0.36
4	0.36	0.28
5	0.58	0.46
6	0.52	0.42
7	0.34	0.26
8	0.51	0.40
9	0.23	0.18
10	0.37	0.28
11	0.68	0.56

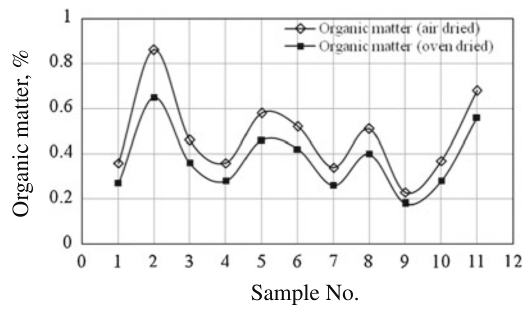

Fig. 12 Variation of organic matter of air dried and oven dried soils

may also be attributed due to decrease in organic matter (see Table 7 and Fig. 12). Reduction in organic matter content might affect the pH of soils.

3.3.2 Iron oxide Content

The mineralogical and chemical compositions of laterites and lateritic soils are dependent on their parent rocks. A large portion of the total iron is frequently in the form of oxides. The iron oxide is responsible for coating and cementation of particles/soil minerals. Some of the soil particles in their natural condition are held together because of the presence of free iron oxide. Generally this aggregation of clay minerals in the natural condition is weak. But upon oven drying and because of the coagulation/aggregation affect the free iron oxide decreases as shown in Table 8. The variation is plotted in Fig. 13.

3.4 Mineralogical Composition

In this work mineralogy of air dried and oven dried soil sample (from source 1) has been studied using X-ray diffraction technique. X-ray diffractograms were

Table 8 Effect of drying on iron oxide

Sample No.	Sample preparation method	
	Air dried	Oven dried
1	3.44	2.66
2	2.28	1.68
3	3.08	2.22
4	3.25	2.11
5	2.71	1.81
6	4.86	3.71
7	1.94	1.4
8	3.43	2.06
9	3.25	2.17
10	3.38	2.45
11	5.54	4.57

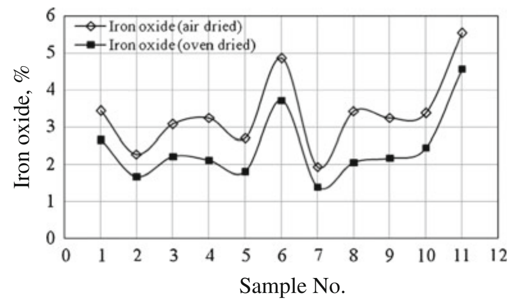

Fig. 13 Variation of iron oxide content of air dried and oven dried soils

Table 9 Effect of drying on mineralogical composition

Sample no.	Sample preparation method	
	Air dried (X-ray diffraction)	Oven dried (X-ray diffraction)
1	Kaolinite, goethite, gibbsite, quartz, small traces of illite	Kaolinite, goethite, gibbsite, quartz

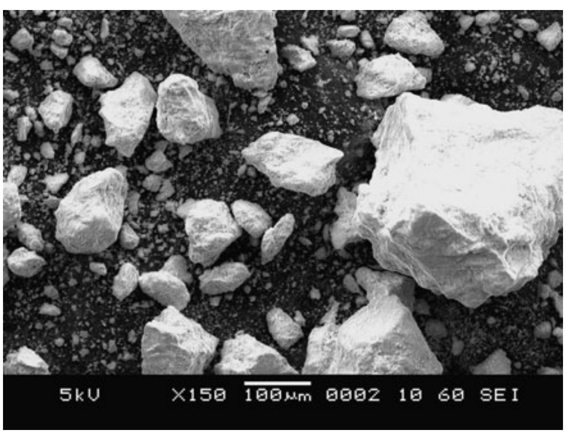

Fig. 14 Scanning electron micrograph of air dried soil sample

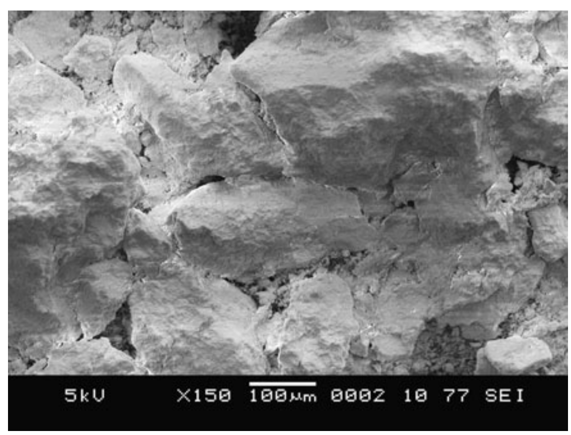

Fig. 15 Scanning electron micrograph of oven dried soil sample (structure appear to be aggregated)

obtained on soil sample passing 0.075 mm sieve. The major minerals present in the clay fraction of the soil sample tested were kaolinite, some gibbsite and goethite minerals, or mixture of these three. Oven drying appeared to have no significant effect on the mineralogy of the soils. The results of the analyses are summarized in Table 9.

3.5 Scanning electron microscope (SEM) studies

SEM studies were carried out on air dried and oven dried soil samples using JEOL scanning electron microscope (model JEOL JSM—6380LA Analytical Scanning Electron Microscope). In order to compare the changes at micro level photo micrographs were taken on air dried and oven dried samples at the same magnification. The SEM micrograph of air dried soil in Fig. 14, shows the random distribution of individual soil particles in the background. The soil structure appear to be somewhat dispersed in Fig. 14. On the other had the SEM micrograph in Fig. 15 reveal that the structure of the oven dried soil sample appeared to be aggregated because of drying. After aggregation the soil particles appeared as lumps in Fig. 15. Decrease in clay content or decrease in Atterberg limits are explained on this basis.

4 Conclusions

The results presented above clearly indicated that the method of sample preparation prior to testing has significant effect on the index properties of lateritic soils. This is attributed due to the mineralogical composition of the soils. Although there is no significant change in the mineralogy of the air dried and oven dried soil, however drying has more effect on the Atterber limits and grain size distribution of lateritic soils. The plasticity index values and clay content of soils tested decreased due to drying. This is due to aggregation of soil particle upon drying, which reduces the water holding capacity and thus liquid limit of soil decreased. From engineering point of view soil becomes more workable after drying. In this study the soils tested were subjected to one cycle drying. However repeated wetting and drying may have significant effect on the structure and affect the soil properties. The chemical properties of lateritic soil such as pH, organic matter and iron content decreased after oven drying. The importance of laboratory testing procedures to simulate the actual field conditions, particularly for lateritic soils cannot be overemphasized.

Appendix

See Table 10.

Table 10 References and Analogue ASTM Standards to determine various geotechnical properties

Sample no.	Parameter	Reference	Analogue ASTM standard
1.	Specific gravity test	IS: 2720 (Part 3/Sec 1)—1980 (Reaffirmed 1987)	ASTM D834
2.	Atterberg limits	IS: 2720 (part 5) 1985 IS: 2720 (part 6) 1972	ASTM D4318- 10
3.	Grain size analysis	IS: 2720 (Part 4)—1985	ASTM D6913-04 ASTM D422

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