

Effect of Lime on the Index Properties of Black Cotton Soil and Mine tailings mixtures

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Abstract : Index properties are extensively used in geotechnical engineering practice. Among them, liquid limit is an important physical property used in classification and correlations with engineering properties of soils. Liquid limit, plastic limit and shrinkage limit of Black cotton soil (BCS) and mine tailings (MT) mixtures treated with lime are investigated and are presented in this paper. In the present investigation an attempt has been made to utilize the mine tailings in geotechnical applications and to evaluate the index properties of black cotton soil and mine tailings mixture treated with lime. The test results indicate that the progressive decrease in liquid limit, decrease in plastic limit and increase in shrinkage limit with curing time. The liquid limit in particular is used in many correlations with engineering properties and it is significant to know the stress history and general properties of the soil met with constructions. Liquid limit is used for the estimation of compression index and compression index is useful for the settlement analysis of soils. The Physico-chemical mechanism which alter the index properties of black cotton soil and mine tailings mixture treated with lime and the mechanisms have been explained based on thickness of diffused double layer and alteration of the reaction products of soil-lime reaction .for various curing periods.

Keywords: *Mine tailings, Curing period, diffused double layer, particle aggregation, cation exchange.*

I. INTRODUCTION

The engineering behaviour of fine-grained soils depends on their water content. Liquid limit (W_L) and plastic limit (W_P) are important water contents as well as two important parameters of plasticity index (P_I), which is the main index parameter of the classification of fine-grained soils. Plasticity index has also been used in correlation with many other engineering properties like internal friction angle, undrained shear strength, lateral earth pressure over consolidation ratio etc. Shrinkage limit (S_L) is also an important parameter in which soils tend to shrink when they loose moisture. In particular, fine grained soils are susceptible to shrinkage and the resulting volume change. Shrinkage can cause cracking of soils that can adversely influence the behaviour of the soils. It is widely accepted that the liquid limit test is essentially a measure of the shear strength of soil that is so soft it approaches the liquid stage (Sowers et al 1959) [1]. Generally the plasticity, workability and strength properties of fine grained soils are improved by the addition of small quantities of lime (Bell, 1988a and 1988b, Diamond and Kinter, 1965) [2][3][4]. Most of the soils decreases the plasticity index by addition of lime and thereby increasing the workability (Thompson 1966)[5]. When liquid limit increases with lime addition, the plasticity index usually decreases because of the increase in the plastic limit. Mine tailings is the by-product obtained from mining industries and finely ground material which is discharged in to tailings impoundments after the extraction of minerals from underground mined ores. As a result of the crushing and grinding (milling) process, the large quantity of tailing particles are disposed in the form of slurry in to the tailings impoundments and later in the form of dumping which creates environmental problems. Mine tailings can be effectively utilized for civil engineering constructions which will minimize the disposal problems and reduce the environmental hazards (Pebble Project, 2005) [6]. Lime is an additive which has been recognized to bring several beneficial changes in the engineering properties of fine grained soils. Treatment with lime is observed to decrease the plasticity and shrink-swell potential and improve the strength characteristics of the soil (Sridharan et al 1986, Katti et al 1966) [7],[8]. According to Worth (1979) [9], a sustainable part of strength variation at the liquid limit obtained by using the Casagrande apparatus can be attributed to the fact that soil deformation in it is self weight-induced. Addition of lime or any other salts which decreases the thickness of diffused double layer because of increased valency of the exchangeable ion or in the increase in the electrolyte concentration (Sridharan and Jayadeva 1982) [10]. Udayashankar and Puranik (2012)[11], investigated the effect of Dandily fly ash treatment to the black cotton soils of Hubballi-Dharwad on their index properties in an effort to improve the geotechnical characteristics and it was observed that the liquid limit and plastic limits decrease while the shrinkage limit increases with the addition of fly ash. In the similar way, mine tailings can be used for the assessment of index properties of black cotton soil in presence of lime.

II. MATERIALS AND METHODS

2.1 Materials

2.1.1. Black Cotton Sol

In the present investigation the black cotton soil was obtained from Davanagere, Karnataka state, India. This is a residual soil and was collected from an open excavation, at a depth of two meter below the natural ground surface. The black cotton soil was air dried, pulverized and passed through 425micron BIS sieve was used for the present investigation.

2.1.2. Mine tailings

Mine tailings was collected from an open dump from Kolar Gold Fields (KGF), Kolar, Karnataka, India. After removing the vegetations from the mine tailings, it was air dried, pulverized and passing through 425 micron BIS sieve was used in the present investigation.

2.1.2. Lime

Lime used in the present investigation was obtained from Fisher Scientific Chemicals private limited, Mumbai, India.

The physical properties of black cotton soil and mine tailings are presented in Table 1 and the chemical analysis of black cotton soil and mine tailings were carried out by adopting the standard procedures by P.R.Hesse, Soil Chemical Analysis published by Chemical Pub. Co. (1972) [12]. University of Michigan, and are presented in Table 2 and 3 respectively.

Table 1. Physical properties of Black Cotton Soil and Mine tailings (Ramesh et al 2012) [13].

Properties	Values	
	BCS	MT
Colour	Black	Pale gray
Specific Gravity	2.70	2.78
Liquid limit (%)	82.0	34.0
Plastic limit (%)	47.2	Non plastic
Plasticity Index (%)	34.8	Non plastic
Shrinkage limit (%)	8.4	24.6
Fine sand fraction (%)	10.0	17.0
Silt fraction (%)	21.2	70.4
Clay fraction (%)	68.8	12.6
Maximum dry density (kN/m ³)	14.3	15.7
Optimum moisture content (%)	29.9	21.54

Table 2. Chemical properties of Black Cotton Soil.

Chemical composition	Percentage
Silicon dioxide	52.85
Alumina	12.24
Iron oxide	8.04
Titanium dioxide	0.24
Calcium oxide	6.01
Magnesium oxide	2.94
Potassium oxide	0.48
Loss on ignition	16.18
Sodium oxide	0.26

Table 3. Chemical properties of Mine tailings.

Material	pH	SiO ₂ (%)	Al ₂ O ₃ (%)	P ₂ O ₅ (%)	K ₂ O (%)	Cu (%)	Pb (%)	As (%)	CN ⁻ (%)	SO ₃ (%)	SO ₄ (%)	CaO (%)	MgO (%)
MT	8.44	40.5	0.5	0.09	16.1	2.55 ppm	0.04	< 0.01	Nil	0.05	0.5	14.96	6.97

2.2 Methods adopted:

2.2.1. Liquid limit: The liquid limit was conducted by using cone penetration method as per BIS: 2720 (Part V)-1985[14]. The liquid limit tests were carried out to secure a minimum of five points for plotting the flow curve.

2.2.2. Plastic limit: The plastic limit was conducted as per BIS: 2720 (Part VI) - 1985[15].The plastic limit reported as an average of two determinations.

2.2.3. Shrinkage limit: The shrinkage limit was conducted as per BIS: 2720 (Part VI)-1972[16]. The shrinkage limit reported as an average of three determinations

III. RESULTS AND DISCUSSIONS

Liquid limit, plastic limit and shrinkage limit tests are carried out on black cotton soil and mine tailings respectively. Further, same tests were also carried out on black cotton soil and mine tailings mixtures treated with lime. 30% of mine tailings for black cotton soil was found to be optimum percentage (Ramesh et al 2012) [13], and 3% of lime for black cotton soil and mine tailings mixture was found to be optimum lime content (Ramesh et al 2013) [17]. The tests were conducted for 0, 7, 14 and 30 days curing periods and the results are presented.

3.1. Effect of lime on the Liquid limit of black cotton soil and mine tailings mixture

The liquid limit of black cotton soil and mine tailing are found to be 82% and 34% respectively. Addition of various percentages of mine tailings to black cotton soil, liquid limit decreases for immediate testing due to reduction in the specific surface area of the soil, the consequent decrease in the diffuse double layer thickness possibly accounts for the lower liquid limit of the treated soil during initial stages. Addition of mine tailings, decreases the liquid limit of black cotton soil and mine tailings mixture immediately due to replacement of exchangeable ions particularly monovalent ions by calcium ions and decrease the thickness of the diffused double layer leading to decrease in the water holding capacity (Sherwood 1958, Taylor et al 1960)[18],[19]. Liquid limit of black cotton soil and mine tailings mixture treated with lime is 61.3 % on immediate testing and it was observed that liquid limit increases with increase in curing period to 71.92% for 30 days of curing as shown in Fig.1 and Table4.

Table 4. Liquid limit of black cotton soil treated with d percentages of mine tailings and lime for different curing periods

Mixtures	Liquid Limit (%)			
	Curing period in days			
	0	7	14	30
BCS Alone	82	82	82	82
MT Alone	34	35.1	35.7	35.5
BCS +1 0% MT	60.8	67.5	70.2	69.4
BCS +2 0% MT	59.2	65.2	68.4	65.1
BCS +3 0% MT	57.9	61.1	65.7	62.7
BCS +4 0% MT	54.5	57.9	59.8	56.3
BCS +5 0% MT	48.4	52.3	55.3	54.9
BCS +6 0% MT	43.7	47.6	50.2	48.2
BCS +7 0% MT	40.2	39.7	42.1	42.3
BCS + 80% MT	36.7	35.6	35.2	34.9
BCS + 90% MT	34.2	34	35.3	35.8
BCS +30% MT+3%Lime	61.3	69.5	70	71.9

Addition of lime initially leads to a decrease in liquid limit of black cotton soil and mine tailings mixture compare to untreated black cotton soil. This is due to depression in the diffused double layer thickness associated with the clay particles. Subsequent curing with lime addition leads to an increase in the liquid limit of the soil this is due to prolonged equilibrium of the lime–soil-mine tailings mixture results in formation of coarser aggregates and a more flocculated particle arrangement. Possibly, the water entrapped in the large void spaces of the flocculated structure of the soil fabric, thereby increase in liquid limit (prakash et al 1989) [20].

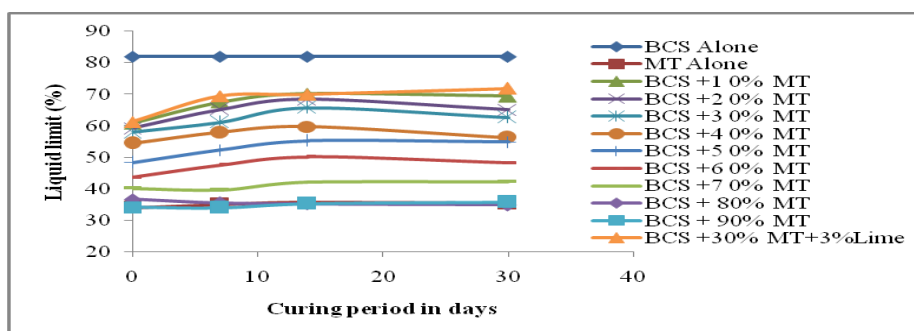


Fig. 1 Variation of liquid limit of black cotton soil treated with various percentages of mine tailings and lime for different curing periods

3.2. Effect of lime on the plastic limit of black cotton soil and mine tailings mixture

The plastic limit of black cotton soil is found to be 47.2% and mine tailings is non plastic in nature. Addition of various percentages of mine tailings to black cotton soil, the plastic limit decreased immediately after the addition of mine tailings to black cotton soil and increases continuously with increase in curing period. The increase in plastic limit is due to decrease in diffused double layer thickened of clay particles leads to increase in shearing resistance, the soil fabric varies with changes in exchangeable cation and mine tailings concentration. Depending upon the particles arrangement size and shape of the pores vary. Thus the flocculated structure will have higher plastic limit (Sivapullaiah et al 1995) [21]. Immediately on addition of optimum 3% lime, the plastic limit of black cotton soil and mine tailings mixture increases from 25.8% to 36.6%. After curing for 30 days with 3% lime, the plastic limit further increases to about 42.2% as shown in Fig 2 and Table 5.

Table 5. Plastic limit of black cotton soil treated with various percentages of mine tailings and lime for different curing periods

Mixtures	Plastic Limit (%)			
	Curing period in days			
	0	7	14	30
BCS Alone	47.2	47.2	47.2	47.2
MT Alone	Non plastic	Non plastic	Non plastic	Non plastic
BCS +1 0% MT	38.6	39.2	39.4	39.6
BCS +2 0% MT	31	31.4	32.1	32.8
BCS +3 0% MT	25.8	26.1	29.4	31
BCS +4 0% MT	23.2	23.6	24.1	24.9
BCS +5 0% MT	20.2	20.5	21.4	21.8
BCS +6 0% MT	19.3	19.8	20	21
BCS +7 0% MT	18.2	18.5	18.7	19
BCS + 80% MT	16.2	16.5	16.8	17.2
BCS + 90% MT	Non plastic	Non plastic	Non plastic	Non plastic
BCS +30% MT+3%Lime	36.6	41.6	41.9	42.2

The initial increase is due to decrease in the diffused double layer thickness of clay particles leads to increase in the shearing resistance at particles level and also flocculation of clay particles which leads to increased plastic limit with curing period (Sivapullaiah et al 1995)[21].

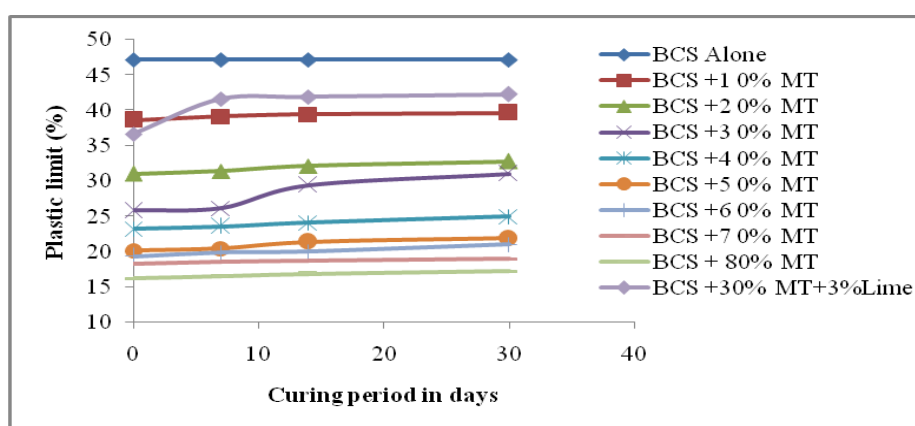


Fig. 2 Variation of plastic limit of black cotton soil treated with various percentages of mine tailings and lime for different curing periods

3.3. Effect of lime on the shrinkage limit of black cotton soil and mine tailings mixture

The shrinkage limit is extremely useful parameter in the areas where soils undergo large volume changes due to wet and dry cycles. It was observed that the shrinkage limit of black cotton soil and mine tailings are 8.2 % and 26.6% respectively. Addition of various percentages of mine tailings to black cotton soil the shrinkage limit increases with increase in curing period. Addition of optimum 3% of lime to black cotton soil and mine tailings mixture, the shrinkage limit is found to be 21.7% at immediate testing and further it increases to 32.6% for 30 days of curing as shown in Fig.3 and Table 6. The shrinkage limit of black cotton soil and mine tailings mixtures progressively increases with lime addition on immediate testing and exhibits

significant increase with increase in curing period. The instantaneous increase in shrinkage limit is attributed to flocculation brought about by cation exchange and particle agglomeration reactions with curing period. (Prakash et al 1989)[20]. The shrinkage limit of black cotton soil and mine tailings mixture increased immediately on lime treatment due to flocculation of clay particles. However, with curing time shrinkage limit increases. This indicate that the flocculation of clay particles improved immediately and for curing period on the addition of lime (Sivapullaiah et al 1995)[21].

Table 6. Shrinkage limit of black cotton soil treated with various percentages of mine tailings and lime for different curing periods

Mixtures	Shrinkage Limit (%)			
	Curing period in days			
	0	7	14	30
BCS Alone	8.4	8.4	8.4	8.4
MT Alone	24.6	26.72	26.8	27.1
BCS +1 0% MT	8.87	9.26	10.8	11.2
BCS +2 0% MT	9.24	10.58	11	12
BCS +3 0% MT	9.58	11.6	12.2	13.5
BCS +4 0% MT	10	12.2	13.4	16.5
BCS +5 0% MT	11.1	14.8	16.2	19.9
BCS +6 0% MT	17.9	18.5	20.5	22.8
BCS +7 0% MT	19.6	20.1	21.5	25.4
BCS + 80% MT	20.1	23.9	25.7	32.2
BCS + 90% MT	22	25.1	31.2	37.1
BCS +30% MT+3%Lime	21.7	24.6	27.5	32.6

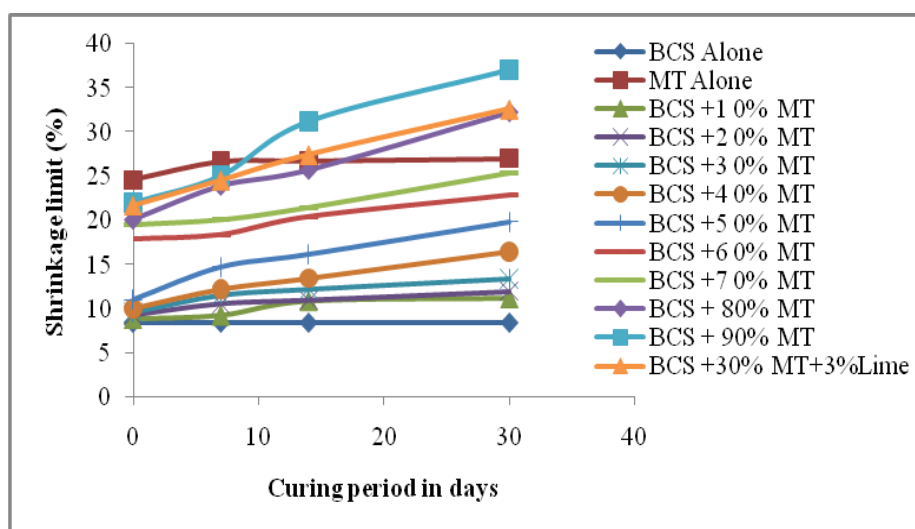


Fig. 3 Variation of shrinkage limit of black cotton soil treated with various percentages of mine tailings and lime for different curing periods

3.4. Effect of lime on the plasticity index of black cotton soil and mine tailings mixture:

Plasticity index is one of the important criteria for selection of soil as construction material. Generally, reduction in plasticity index is desirable as it increases the workability. Plasticity index of black cotton soil is 34.8% the untreated black cotton soil can be classified using casagrande classification chart which is on the border line between silt and clay of medium compressibility. Plasticity index of black cotton soil reduces with increase in mine tailings proportions, black cotton soil changes its classification to CI (sandy and silty clay having medium plasticity with medium compressibility) when treated with mine tailings in the range of 50 to 80% as shown in Fig. 4. Plasticity index reduces from 34.8% to 29.7% when black cotton soil treated with optimum percentages of mine tailings and lime. It indicate that there is slight variation in plasticity index which lies below the A-line having high compressible material. Plasticity index of black cotton soil and mine tailings mixture treated with lime reduced to 17% compared to untreated black cotton soil after 30 days of curing. The reduction in plasticity indices are indication for soil improvement (Amu et al 2011).

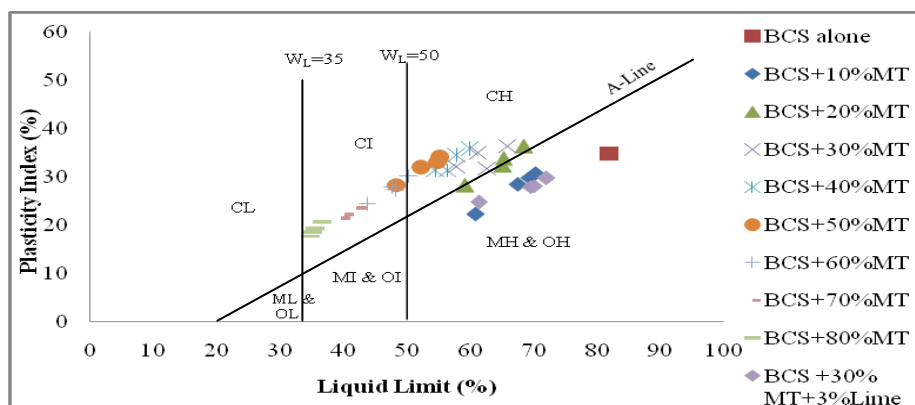


Fig. 4 Classification of lime treated black cotton soil in presence of mine tailings with curing

IV. CONCLUSIONS

From the present investigation the effect of lime on the index properties of black cotton soil and mine tailings mixture treated with lime, the following conclusions are drawn

- Liquid limit of black cotton soil and mine tailings mixtures decreases for all the curing periods due to depression in the diffused double layer thickness associated with the clay particles and it increases with increase in curing period for black cotton soil and mine tailings mixture treated with lime due to prolonged equilibrium of the soil-lime-mine tailings mixture resulted in formation of coarser particles and more flocculated particle arrangement.
- Plastic limit of black cotton soil and mine tailings mixtures decreases for all the curing periods and it increases with increase in curing period for black cotton soil and mine tailings mixture treated with lime due to decrease in the diffused double layer thickness of clay particles leads to increase in the shearing resistance at particle level and also flocculation of clay particles which leads to increase in plastic limit with curing periods.
- Shrinkage limit of black cotton soil and mine tailings mixtures increases for all the curing period and the same trend has been observed for black cotton soil and mine tailings mixture treated with lime, the increase in shrinkage limit is attributed to flocculation brought about by cation exchange and particle agglomeration reactions with curing period.
- Plasticity index of black cotton soil and mine tailing mixture treated with lime reduces compare to untreated black cotton soil after 30 days of curing, the reduction in plasticity index is the indication of improvement of properties of soil with the addition of lime and mine tailings.

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