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Effects of Steel Mill Scale on the strength characteristics of Expansive Clay Soils(Black Cotton Clay soil)

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Abstract: The results of laboratory investigations on the influence of Steel Mill Scale on the strength characteristics of tropical black cotton clay soils are presented. Tropical Black Cotton clay soils were mixed with Steel Mill Scale at 0%, 5%, 10%, 15%, 20% and 30% Steel Mill Scale content (by dry weight of soil) in order to establish the soil stabilizing potentials. Steel Mill Scale increased the Maximum Dry Density, MDD, of the soil by about 19% and reduced the Optimum Moisture Content, OMC, by about 28%. Soaked CBR increased with increase in Steel Mill Scale while Un-Soaked CBR decreased with increase in Steel Mill Scale content. Steel Mill scale increased the Un-soaked CBR by about 19% and reduced the Soaked CBR by about 75%. Swelling potential reduced by about 60% with the addition of Steel Mill Scale. Steel Mill Scale increased the unconfined compressive strength of black cotton soils by about 53% at 5% Steel Mill Scale content. The results indicate that there is a potential in the use of Steel Mill Scale to strengthen Black cotton soils.

Keywords: Expansive soils, Black cotton clay soil, Steel Mill Scale, Strength Characteristics

1. Introduction

Black Cotton Soils (BCS) are dark colored expansive clays found between 50° N and 45° S of the equator. Major areas of occurrence include Eastern Australia, India, Sudan, Cameroon, Ghana, Ethiopia, Kenya, and Chad. BCS are also found in USA (Southern Texas, California, Montana, Hawaii, and Mississippi): South America (Mexico, Uruguay and East Argentina): Eastern China, Russia and Ukraine. Black cotton soils (BCS) are found predominantly in the North-Eastern part of Nigeria, lying within the Chad Basin and partly within the Benue trough (Ola, 1981; NIBBRI, 1983; Osinubi et al, 2009).

Black Cotton Soils have been identified as very problematic engineering soils for structural foundations and earthworks (ASCE 2012; Sabat 2012; Osinubi 2009). When dry, BCS appear very hard with high bearing capacity to sustain imposed loads from building foundations and road pavements. But when wet, BCS absorb large volumes of water, rapidly swell, soften and loosen their high bearing capacity thereby leading to excessive settlement, differential settlement, failure of building structures, road pavements and destruction of structures built on them. These geotechnical characteristics make BCS highly problematic as foundation for buildings and road pavements.

Various efforts are being made to stabilize Black cotton soils with cement, lime, admixtures and waste products to make the soils meet the requirements for construction works (Ali and Korranne 2011; Osinubi 2009; Ola 1983; Balogun 1991a, b). However, these have achieved limited success. Cement has been useful in stabilizing expansive clays but is expensive and requires huge foreign exchange which is scarce in developing countries. In addition, there is a tendency for the formation of cracks in the soil-cement mixture. Hence researches have focused on potentially cost effective materials, admixtures and waste products like fly ash, rice husk ash and marble dust that can improve the properties of black cotton soil, (Osinubi 2006; Sabat 2012; Sabat and Nanda 2011; Patil et al 2011).

Steel Mill Scale is a metal industry waste which is produced in large tons. It is mainly iron oxide formed in the surface of steel during casting, hot rolling and reheating of steel. Mill scale poses grave disposal problems; therefore the dumping of mill scale in landfills may create serious environmental issues. Murthy (2012) reported that mill scale increases the CBR and permeability of black cotton soil while lowering the plasticity, but did not investigate the effect on other strength properties. The Steel Mill Scale contains oxides of Aluminium and Iron which can be available for cation exchange with clay soils. The possible use of Steel Mill Scale will reduce the importation of cement and associated foreign exchange difficulties. The use of Steel Mill Scale in soil stabilization is therefore of much economic and environmental benefit. The Steel Mill Scale was ground into powder and mixed with black cotton soil in various proportions.

1.1 Location and Geology of the study area

Disturbed soil samples used for this investigation were collected along the Dikwa-Gamboru Road, Borno State, North-East Nigeria. It is part of the area extensively covered by the Black Cotton Soil of North-Eastern Nigeria. The study area falls within the Chad Basin which is part of the lacustrine and fluviatile clays and sands of the Pleistocene age laid down during the late Tertiary and Quaternary periods (Ola 1983). Black Cotton Soils are expansive clay soils.

2. Materials and Methods

2.1 Tropical Black Cotton Clay Soil

Tropical black cotton clay soils were collected along the Dikwa-Gamboru Rd, Borno State, Nigeria. The soils used in the study are dark grey clay soils classified as A-7-6 in the AASHTO Soil Classification System (AASHTO 1986) and CL in the United Soil Classification System (ASTM 1992)

2.2 Steel Mill Scale (SMS)

The steel mill scale used in this investigation was sourced from a major steel rolling mill in Ikeja Area of Lagos State, Nigeria. The chemical analysis was done at the Chemistry Department, University of Lagos. Chemical composition is shown on Tables 1 and 2.

2.3 Methodology

Tests involving moisture-density relationship, CBR and Unconfined compression were carried out using air dried samples ground into powder. The samples were then mixed with Steel mill scale in various proportions before each test.

2.4 Soil Index Properties

Fresh soil samples collected and tested within 3 months were used in order to prevent alteration of the properties of the residual soil. All the samples were air-dried for 1-day before testing in order to simulate field conditions as suggested by Peck (1971). X-ray diffraction (XRD) analysis was carried out on the soil samples to aid the identification of the clay mineral present. The predominant clay mineral present in the soil samples was found to be montmorillonite. The results are in agreement with those obtained by Ola (1983) and Osinubi (2006) for soils from the study area. A summary of the oxide and metallic composition of the clay soil and Steel Mill Scale (SMS) is presented in Tables 1 and 2. A summary of the soil index properties is presented in Table 3.

Laboratory tests were performed on the samples in accordance with British Standard, BS 1377 (1990) for the natural soil and BS 1924 (1990) for the treated soil. California Bearing ratio (CBR) tests were done in accordance with the Nigerian General Specifications (1997) which stipulates that specimens are to be cured in the dry for 6 days and then soaked for 24 hours before testing. The soil was characterized and classified by the following tests: Atterberg limits, compaction, California bearing ratio (CBR) and unconfined compressive strength (UCS).

2.5 Compaction Tests

Tests involving the compaction tests and strength tests of CBR and Unconfined compressive strength were carried out using the West African Standard (WAS) energy levels. If the BS (Proctor) compaction mould is used, the compactive effort for the WAS consists of the energy derived from a 4.5kg rammer falling through 45cm onto five layers, each receiving 10 blows. When the CBR mould is used, the WAS compactive effort is also derived from a 4.5kg receiving 25 blows (Osinubi 1998a, b). WAS compaction is commonly used in West Africa region.

2.6 California Bearing Ratio (CBR) Tests

Two tests of CBR tests were conducted on each soil sample, one at the Optimum Moisture content, compacted to the Maximum Dry Density (as per the West African Standard of Compaction) and the other test on a similarly compacted under soaked conditions. A four-day soaking period was adopted. During soaking of the sample, the amount of swelling was also measured. The test was repeated using the Standard Proctor Compaction for the natural soil.

However, Nigeria Building and Road Research Institute (NIBRI 1983) reported that from observations on subgrade data collected from old roads, subgrade moisture tends to attain equilibrium conditions after undergoing significant changes with seasonal variations from year to year. After these equilibrium conditions are attained, the subgrade moisture does not undergo any significant change. Hence, the practice of soaking for 4-days before determining the CBR value may only be appropriate only in a few cases where the ground water table is high or areas with high rainfall and other soil drainage conditions. These areas may warrant 4-days soaking of sample.

2.7 Admixture Stabilization Mechanism

Stabilization mechanisms usually depend on the chemical reaction between the admixture and soil particles and compaction. Test results of the oxide composition of the steel mill scale show a high percentage of Aluminium Oxide (21.2%). Hence, the mechanism of stabilization expected is a cation exchange reaction between the soil particles and the Aluminium Oxide.

3. Results and Discussion

3.1 Mineral Composition

The result of the chemical analysis is presented in Tables 1 and 2. The main oxides present in the soil sample are Silicon Oxide (S_IO_2) and Aluminium Oxide (Al_2O_3). The main oxide present in the Ground Polyvinyl Waste is Calcium Oxide; hence the mechanism of stabilization will be similar to that of lime which depends on a cation exchange with Calcium Oxide. The main metals present in the soil sample are Copper, Manganese and Iron, Table 2.

3.2 Mineralogical Characterization of Soil samples

The mineralogical characterization was carried out by X-ray diffraction techniques. The XRD spectrum is shown in Fig.1. Seven (7) peaks were identified in the XRD spectrum. The main minerals found are identified in Table 3 below with corresponding International Centre for Diffraction Data (ICDD), Joint Committee on Power Diffraction Standards (JCPDS) Card No:

3.3 Index Property of Soils

The Index properties of the soil sample are summarised in Table 4. Classification test indicates that the underlying soil lies above the A-line (Fig.2) and can be classified as A-7-6 soil under the AASHTO Soil Classification System (1986) or CH in the United Soil Classification System. The soil is clayey.

3.4 Effect of Steel Mill Scale on the Compaction Characteristics

The effect of steel mill scale content on the maximum dry density (MDD) and the optimum moisture content (OMC) of the soil for the West Africa Standard compactive efforts, WAS, are shown in Fig.3. The MDD of the stabilized soil increased with increase in steel mill scale content, Fig.4, while the OMC decreased with increase in steel mill scale content, Fig.5. The results show that steel mill scale increased the compaction and strength of the BCS while reducing the optimum moisture content, OMC. This trend is opposite that obtained with the effect of lime on clayey soils. Lime usually reduces the MDD and increases the OMC of clayey soils at a given compactive effort, Osinubi (2006). The result may be due to the presence of high quantity of Aluminium oxide and low Calcium oxide in the Steel Mill Scale, Table 1. The steel mill scale increased the MDD of the soil samples by about 19%. The MDD obtained at 10% steel mill scale content and above is within the range of 1720 to 1920kg/m3 which is considered satisfactory to excellent. The OMC of the natural soil was reduced by about 28%.

3.5 Effect on the Strength Characteristics

3.5.1 Effect on California Bearing Ratio

The CBR test was carried out using the results of the West African Standard (WAS) compaction test. It should be noted that the Soaked CBR of the natural soil appear higher than other expansive clays, two significant factors greatly affect CBR values. These are the density to which the soil is compacted and the moisture content of the sample at the time of testing (NIBRI 1993). The moisture content is also affected by the amount of water contained in the natural soil samples. Natural black cotton soil of CBR value of 11% using the WAS compaction has been reported (Osinubi 2006).

The test results shown in Figs.6 and 7 indicate that there is appreciable increase in strength with the addition of steel mill scale to stabilize the tropical black cotton clay soil. Fig.6 shows that the Unsoaked CBR of the natural soil increased with increase in steel mill scale content. Fig.7 shows that the Soaked CBR of the natural soil reduced with the addition of steel mill scale. The Soaked CBR initially decreased from 24% to about 2% at 5% steel mill scale content, further increase in steel mill scale content led to a gradual increase in soaked CBR. The Soaked CBR increased with increase in steel mill content up to a value of 6% at a steel mill scale content of 30%, with no tendency to come down. The Un-soaked CBR increased by about 16% while the Soaked CBR decreased by about 75%. The soaked CBR at 30% fell below the minimum CBR requirement of 40% for sub-base. The Soaked CBR of the natural soil was greatly reduced by the steel mill scale thereby indicating a significant disintegration of the stabilized mixture in the presence of water. However, based on the results, there is evidence that the Un-soaked CBR increased with the addition of steel mill scale. Therefore, if the mixture is protected from water, the CBR will be within the requirement. The swelling potential decreased with increase in steel mill scale content. The swelling potential reduced by about 60% with the addition of steel mill scale, Fig.8.

3.5.2 Effect on the Unconfined Compressive Strength

The variation of UCS with Steel Mill Scale content for the stabilized soil mixture is shown in Fig.9. The variation of the Cohesion with Steel Mill Scale content for the stabilized soil mixture is shown in Fig.10. The Unconfined compressive strength of the Black cotton soil increased from 31.8% to 48.6% at 5% Steel Mill Scale content. Further addition of Steel Mill Scale above 5% led to a decrease in the unconfined compressive strength. The reduction in the unconfined compressive strength may be attributed to non-alignment of the filler particle interface with the matrix of the soil particles thereby creating a line of weakness and subsequent loss of strength. This is also reflected in the loss of cohesion as indicated in Fig. 10. Composite strength and toughness are strongly affected by particle/matrix adhesion as strength depends on effective stress transfer between filler and matrix while toughness/brittleness is controlled by adhesion

(Fu et al, 2008). The better the mixing, the better the dispersion and diffusion and consequently the stabilization process (Locat et al, 1990).

4. Conclusion

From the results of the investigations conducted, the following conclusions can be made:

i. Steel Mill Scale (SMS) increased the MDD of black cotton soils by about 19%. The increase is within the range of 1720 to 1920kg/m3 which is considered satisfactory to excellent.

ii. Steel Mill Scale reduced the OMC of black cotton soils by about 28%.

iii. The strength characteristics of the soil-steel mill scale mixtures improved as the swelling potential was reduced by about 60%. Steel mill scale also increased the Un-soaked CBR of black cotton soils by about 16%. The increase in strength shows a potential for future usage. The addition of steel mill scale reduced the Soaked CBR of black cotton soils by about 75%.

iv. Steel Mill Scale increased the unconfined compressive strength of black cotton soils by about 53% at 5% Steel Mill Scale content.

v. Suggested future works include investigating the influence of lime on Steel mill scale-soil mixture.

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Table 1: Oxide Composition of Samples

Mineral (%)	Soil sample	Steel Mill Scale
S_IO_2	39.61	62.5
Al_2O_3	30.87	21.20
Fe_2O_3	0.43	4.30
CaO	0.39	0.20
MgO	0.36	0.14
Na_2O	0.09	0.15
K_2O	0.52	0.52
SO_3	0.13	0.12

Table 2: Metallic Composition of Samples (mg/kg)

Mineral (%)	Soil sample	Steel Mill Scale
Cadmium	Not detected	Not Detected
Copper	0.00000313	0.00000248
Manganese	0.00000135	0.00000496
Nickel, Nl	0.00000004	Not detected
Lead, Pb	Not detected	0.00000004
Iron, Fe	0.00000234	0.0002644
Zinc, Zn	0.0000007	0.00000045

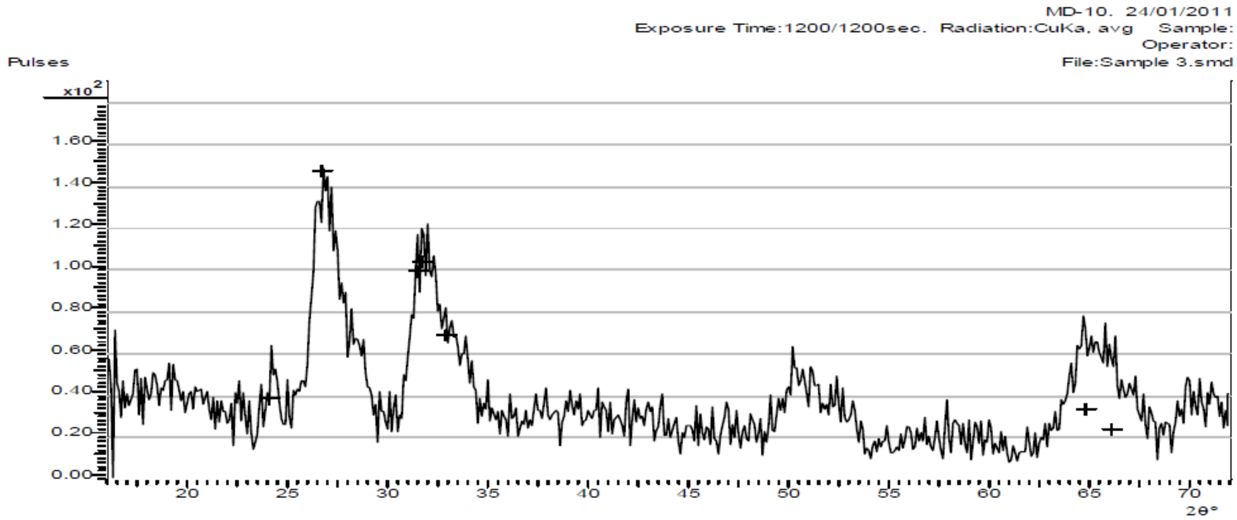
Table 3: Mineralogical Characterization of Soil samples

Peak	**2**	**Corresponding to**	**JCPDS Card No**	**(h, k, l)**	**Structure**	**Colour**
Peak 1	24.03	Hydrogen Aluminium Silicate	42-0024	5, 2, 0	Monoclinic	Not given
Peak 2	26.64	Aluminium Oxide	46-1131	0, 1, 5	Tetragonal	Not given
Peak 4	31.61	Silicon Oxide	40-1498	3, 2, 1	Tetragonal	Not given
Peak 5	32.85	Hydrogen Aluminium Silicate	42-0024	3, 6, 2	Monoclinic	Not given
Peak 6	64.74	Silicon Oxide	40-1498	0, 5, 17	Tetragonal	Not given
Peak 7	66.02	Aluminium Silicate	11-0046	-5, 1, 1	Triclinic	Blue

Other minerals present are Calcium Silicate Hydroxide, Iron oxide

Table 4: Index properties of Natural soil sample

Property	Soil sample (Standard Proctor)	Soil sample (West Africa Standard)
Liquid limit, %	66.0	66.0
Plastic limit, %	24.5	24.5
Plasticity Index, %	41.5	41.5
Shrinkage limit, %	9.4	9.4
Free Swell, %	70	70
Optimum moisture content, %	20.45	20.48
Maximum Dry Density, MDD (Mg/m^3)	1.484	1.639
Unsoaked CBR (%)	24	31
Soaked CBR (%)	15	24
UCS	32.7	32.7
Swell potential	High	High
Free Swell	High	High
Compressibility	High	High



2θ°	d	I int	I max	I rel	I corr	FWHM
24.03	3.70264	558	26.7	19.7	20.6	0.27975
26.64	3.34581	2837	135.8	100.0	100.0	0.28893
31.44	2.84534	1828	87.5	64.4	60.6	0.28885
31.61	2.83014	1929	92.4	68.0	63.8	0.28882
32.85	2.72598	1194	57.2	42.1	39.0	0.28855
64.74	1.43995	447	21.4	15.8	12.8	0.27913
66.02	1.41495	249	11.9	8.8	7.1	0.28023

Fig.1: XRD Spectrum for Soil sample

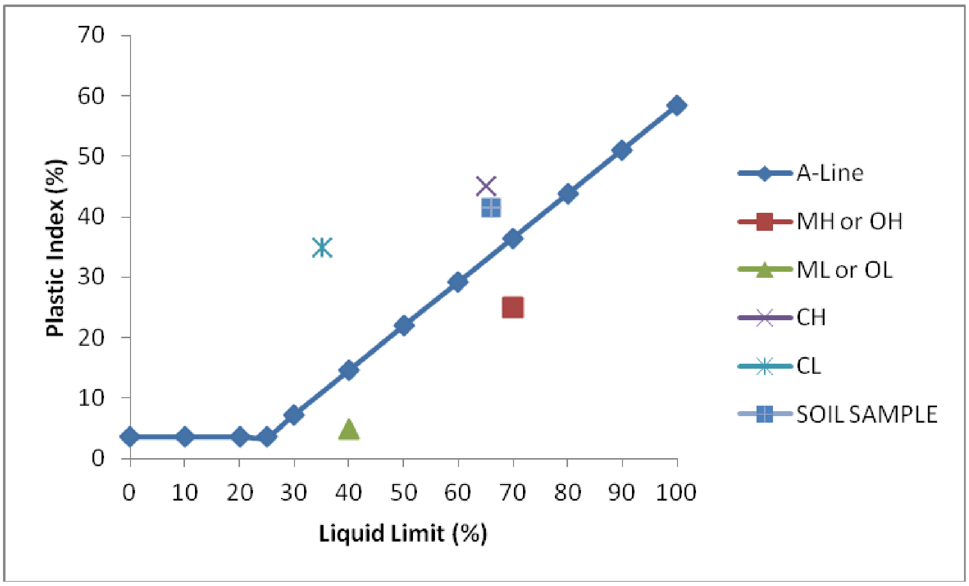


Fig.2: Plasticity Chart for soil classification

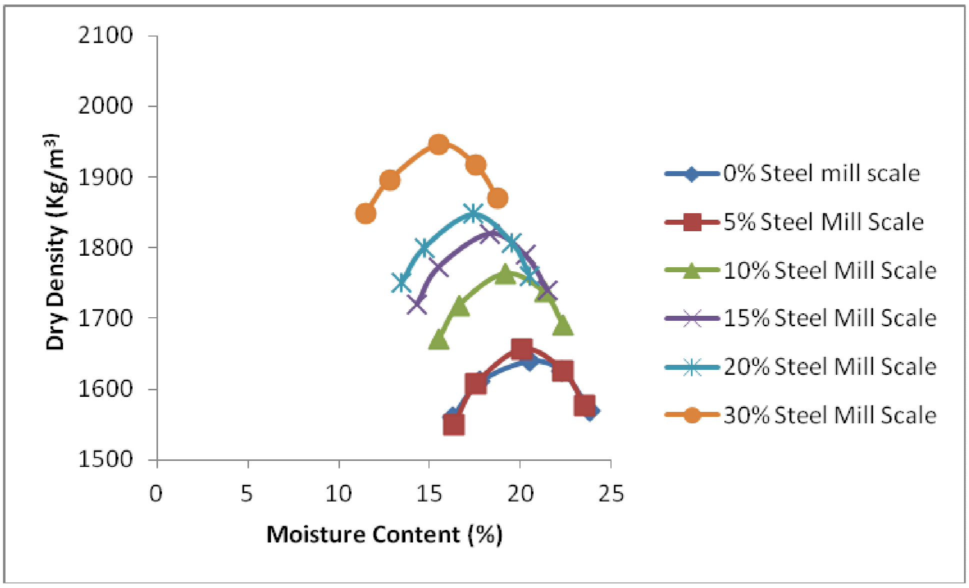


Fig.3: Moisture-Dry density relationship for the soil sample with varying Steel Mill Scale content

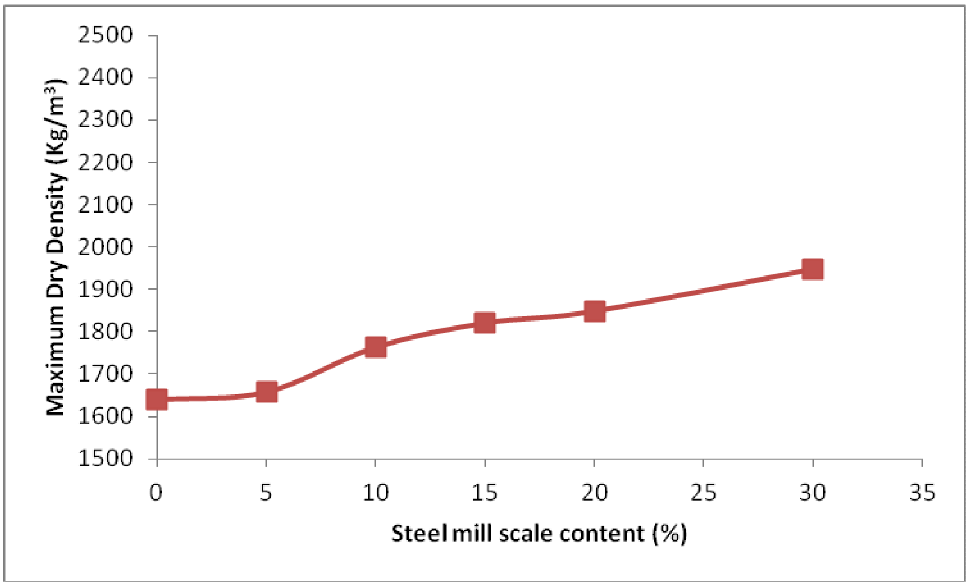


Fig.4: Variation of Maximum Dry Density with Steel Mill Scale content for the soil samples

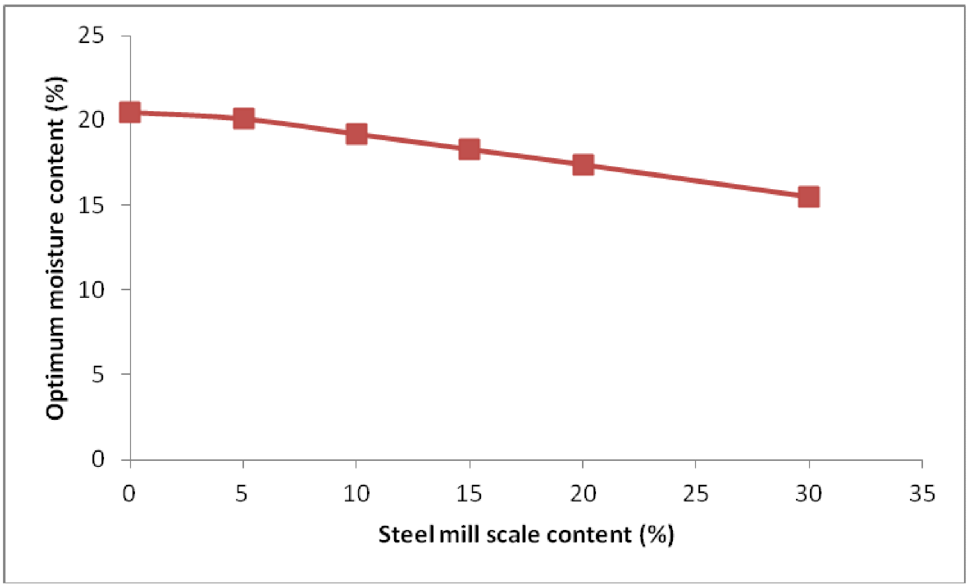


Fig.5: Variation of Optimum Moisture Content with Steel Mill Scale content for the soil samples

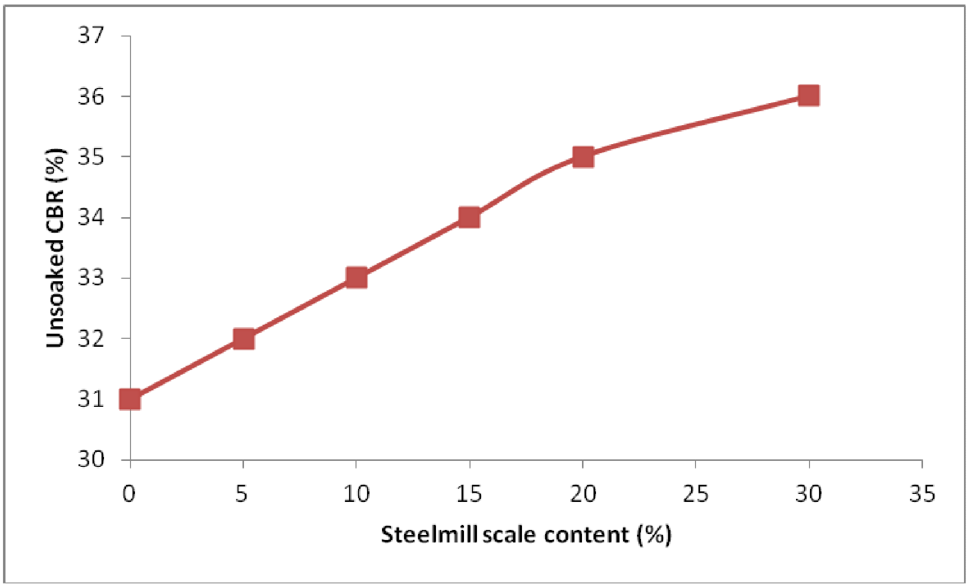


Fig.6: Variation of Un-soaked CBR with Steel Mill Scale content for the soil samples

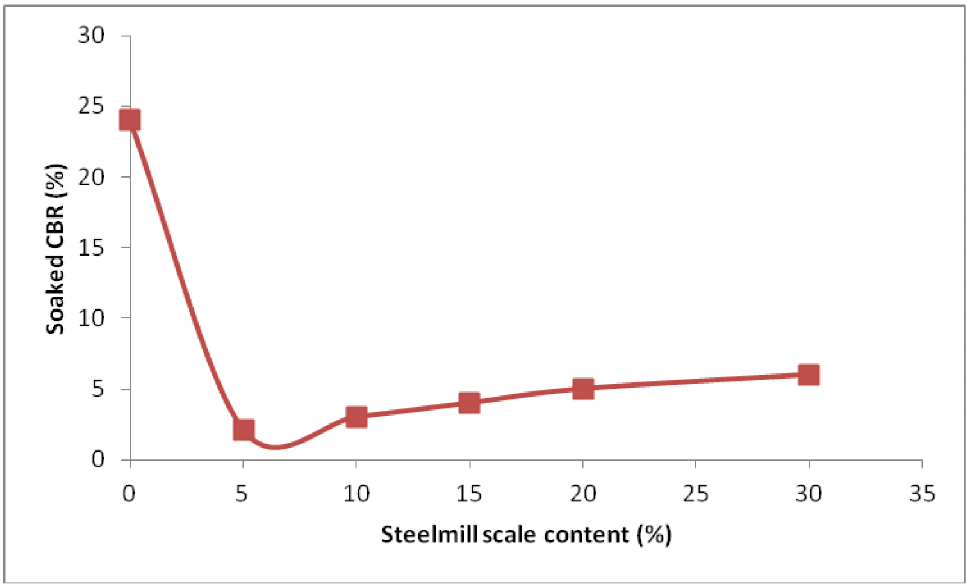


Fig.7: Variation of Soaked CBR with Steel Mill Scale content for the soil samples

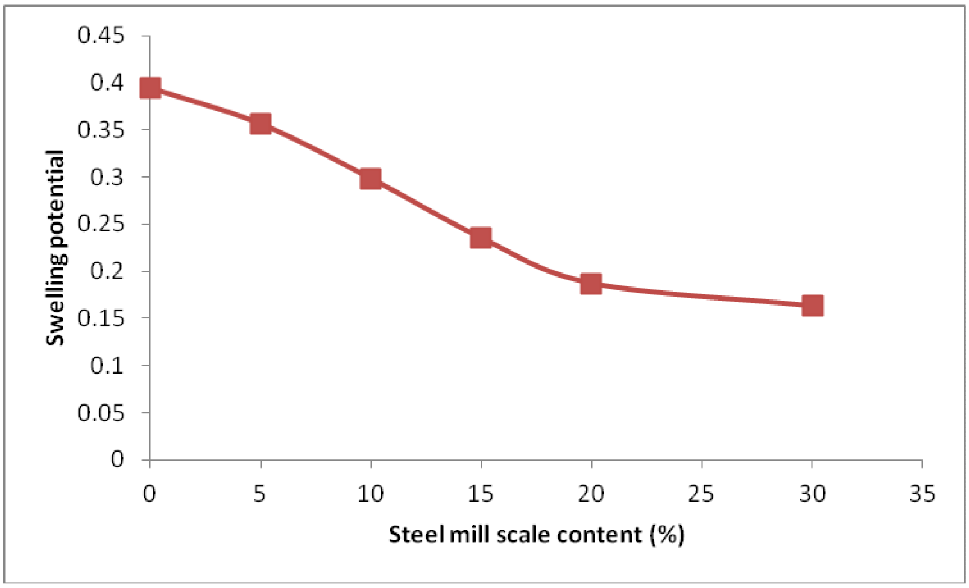


Fig.8: Variation of swelling potential with Ground Polyvinyl waste content for the soil samples

Fig.9: Variation of Unconfined Compressive Strength with Steel Mill Scale content for the soil samples

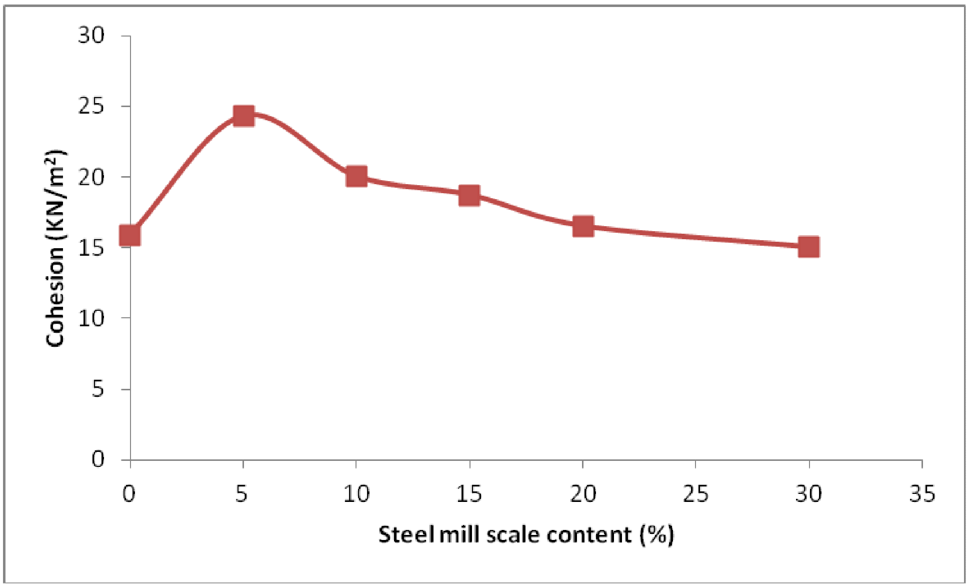


Fig.10: Variation of Cohesion with Steel Mill Scale content for the soil samples

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