On improving the performance of silty soil by treating with ferrochrome slag: an experimental study

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Abstract. Establishing synergy between industrial slags and soils to apply as a ground improvement technique, has been one of the prime focuses for Geotechnical engineering researchers. This solves the issue of scarcity of "good soil" for construction of embankments, and aids to maintaining the sustainable practices of the industries producing slags. In this context, this study analyses the performance of ferrochrome slag as additive in silty soil (ML). The ferrochrome slag passed through 4.75mm and retained in 1.0 mm IS sieves, is used and mixed with the silty soil in different ratios by weight (10:90) to (60:40), to find out the most suitable ratio of mixture. Therefore, the present study describes series of triaxial (Unconsolidated Undrained) and CBR tests on soil and slag individually, and mixture of both by different weight ratios as mentioned before. This exercise demonstrates the fact that, the mixture of soil and ferrochrome slag by ratio 50:50 shows maximum overall improvement of strength. Furthermore, it has been observed that the CBR value of the mixture illustrates an increment of about 500% and the result of the triaxial test of the mixture demonstrates an enhancement of shear strength by16.5% of the mixture.

Keywords: Ferrochrome slag; silty soil; experimental investigation.

1 INTRODUCTION

Soil with low CBR and bearing capacity is the most troublesome and challenging to the geotechnical engineers to make it suitable for the construction of durable subgrade courses of pavement. Most of the road failure occurs due to poor characteristics of sub-grade, causing loss of wealth and lives. Thus, there should be some remedy to overcome this crisis.

Traditionally natural materials were used as additives to fill the lacuna of incapable soil (Jones and Jefferson 1998), for Civil engineering purposes, but exponential population growth and its demands in civil engineering field lead to scarcity of natural material and causing its depletion.

Additionally, alarming population and progressive industrialization results in cumulative accumulation of huge amount of by-products which if not utilized may cause several types of socio-environmental and economic problems.

By considering all this factors, a suitable and effective ground improvement technique is required, which will act as a symbiosis and may pave the way toward sustainable development.

So many soil stabilizing methods are there, but stabilizing with industrial by-products is found to be most promising in term of cost feasibility and simplicity. Ferrochrome slag is one such by-product, generated 12-16 million tons across the world and increasing 2.5 to 3 % per year (Kauppi et al., 2007) India contributes 10 % of total production. Being new in the field only limited work is done with it. So there is a vast scope of it being used as additive material for pavement construction on virtue of its high CBR and strength.

Chromium particles in it in small percentages (less than 6), (Lind et al., 2001). There is a threat of using ferrochrome slag in practical field on lest of leaching of "Chromium". On this, showed low leachability of slag except potassium (k^+) under suitable lab. Condition (Lind et. al), yet to confirm by leachate analysis. But the superior physical and chemical properties of ferrochrome slag overpower its draw back and becomes attractive construction material. Researchers showed ferrochrome slag is very stiff, and exhibit all over superior performance in construction field (Kauppi et al., 2007; Nkhola, 2006; Yilmez et al., 2009; Altan et al., 2010; Sahu et al., 2016) compared to natural aggregate (Sangamitra et al., 2016) and very suitable for construction of pavement Sub-grade (Yilmez et al., 2009; Altan et al., 2010; Das, B.B, 2014; Sangamitra et al., 2016) layers material.

The study infer that the mechanical and chemical properties of ferrochrome slag indicates suitability for using in road construction applications, such as base or sub-grade materials. Environmental impact assessment studies proved that ferrochrome is non-hazardous material and not harmful to be used as a green construction material in substitute of natural material to prevent its depletion. Additionally, utilization of ferrochrome slag will lead toward sustainability of industries generating it and reduce the cost of construction.

2 EXPERIMENTAL METHODOLOGY

2.1 Materials

Silty Soil: Local silty soil is collected from Balasore, Odisha and its basic geotechnical properties were determined by standard test procedure as per the provision of IS code of practice. Fig.1 shows the grain size distribution curve table.1 summarize the properties of soil used.

Ferrochrome Slag: The slag was collected from Balasore Ferro. Alloy Ltd, Odisha, passing through 4.25mm and retained in 1mm IS sieve is used. Fig.2 shows the grain size distribution curve and table 2 shows the engineering properties.

2.2 Sample Preparation

Different percentages of ferrochrome slag content adopted in the present study were 10, 20, 30, 40, 50 and 60 by dry weight of the silty soil used. Mixing between soil and slag was done manually and proper care was taken while preparing the sample in order to maintain a homogeneous mix.

2.3 Laboratory Test Program

The test program adopted for this study is described here. The Atterberg's limits (liquid limit & plastic limit) of original soil were found out to determine the consistency of soil. The proctor and modified proctor test were carried out on both soil and different proportion soil-ferrochrome slag composites to determine OMC and MDD. Then, the value achieved in proctor test were used to prepare sample for triaxial test (UU) to determine undrained shear strength of soil for different designated soil and soil-ferrochrome slag composite mixes. And a cylindrical specimen with slender ratio (38 mm diameter and 76 mm height) was extracted from it. OMC value achieved in the modified proctor test were used to prepare the sample of unsoaked and soaked CBR test for different proposed mixes.

3 RESULTS and DISCUSSIONS

For the grain size distribution, wet sieve analysis was conducted as per the provision of IS: 2720 (Part IV)-1985. Since the percentage of fines (<0.075 mm) is 5-12 % so we have to go for hydrometer analysis.

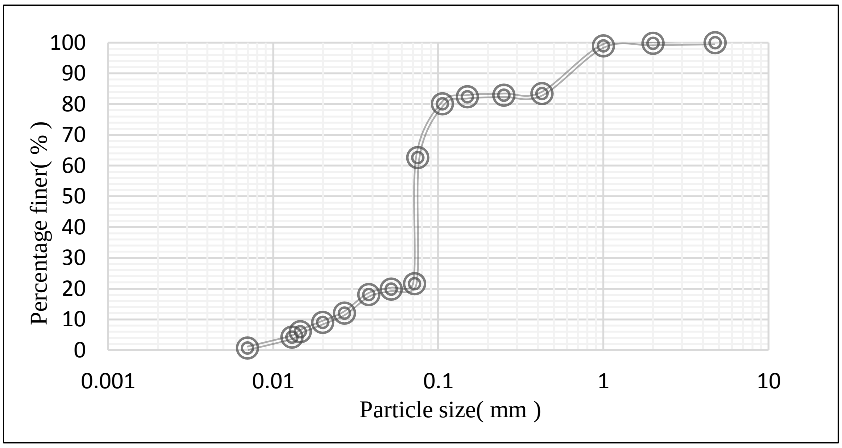

Fig. 1 Grain size distribution curve for local soil

Since, the percentage of fines is greater than 50 % so Atterberg's test as per provision of IS: 2720 (part 5) & IS: 9259-1979, was conducted to classify the soil.

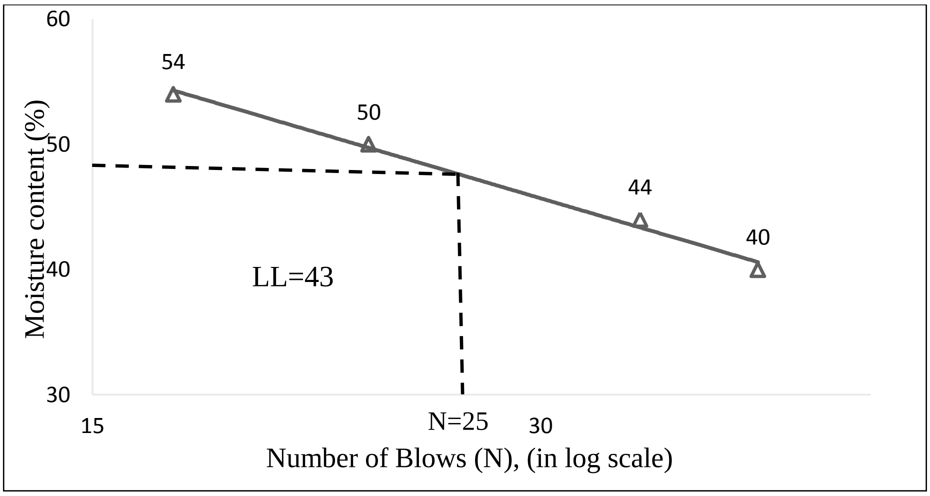

Fig.2 Liquid limit curve

With the help of plasticity chart and A-line of IS code the above soil was classified as ML.

In order to designate the soil and check its suitability or its deficiency for being used as sub-grade soil, basic tests were conducted as per IS code which is tabulated in table 1.

Table.1 Basic Geotechnical engineering properties of Soil

Property	**Value**
Specific gravity	2.65
Natural moisture content (%)	25.00
LL (%)	48.00
PL (%)	28.00
I_P	20.00
Dry density(kN/m^3)	17.80
OMC (%)	16.20
C_{uu} (kPa)	28.42
CBR (unsoaked in %)	4.97
CBR (soaked in %)	2.97

Now, in case of ferrochrome slag only dry sieve analysis was found sufficient in order to classify the soil, as Percentage of fines (<0.075mm) is very less as mentioned above.

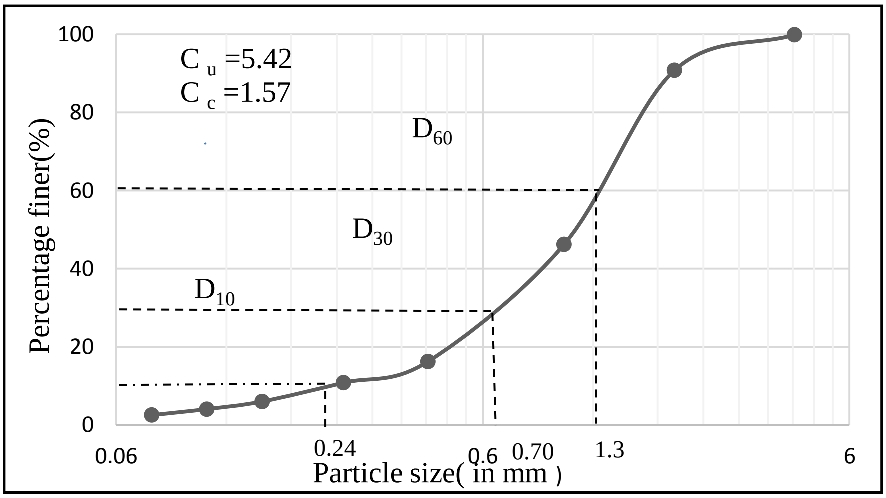

Fig. 3 Grain distribution curve for ferrochrome slag.

The above slag is classified as SP from figure 3 by using C_u & C_c value. And to justify the suitability of ferrochrome slag for being used as additive material for improving the performance of soil, few basic tests were required is delineate in table.2.

Table.2 Basic Geotechnical engineering properties of Ferrochrome Slag

Property	**Value**
Colour	Dark black
Specific gravity	2.92
Percentage finer than 75µ sieve	2.42
C_u	3.74
C_c	3.74
Soil classified as per ISSCS	SP
Maximum Dry unit weight(kN/m^3)	14.60
Minimum dry unit weight(kN/m^3)	11.80
Field dry density (kN/m^3) at 100 cm fall.	13.50
Peak frictional angle at 70% relative density	43.00
Cohesion C (kPa)	0.00

3.1 Effect on Compaction Characteristics

Compaction test were conducted to establish co-relation between moisture content and dry density for both unreinforced and different proportions ferrochrome slag reinforced soil. Two trials were conducted for each mix for more creditable comparative outcomes. We can observe, as the percentage of FS in the mixture increases, with increase in compacting energy MDD value increases and OMC decreases. These changes may be attributed high specific gravity of FS, low water absorption of FS and better interlocking of soil-FS composite, which results in decrease in void ratio. Graph 1 for zero % slag, 2 for 10 % slag and so on up to 60 % inclusion of ferrochrome slag.

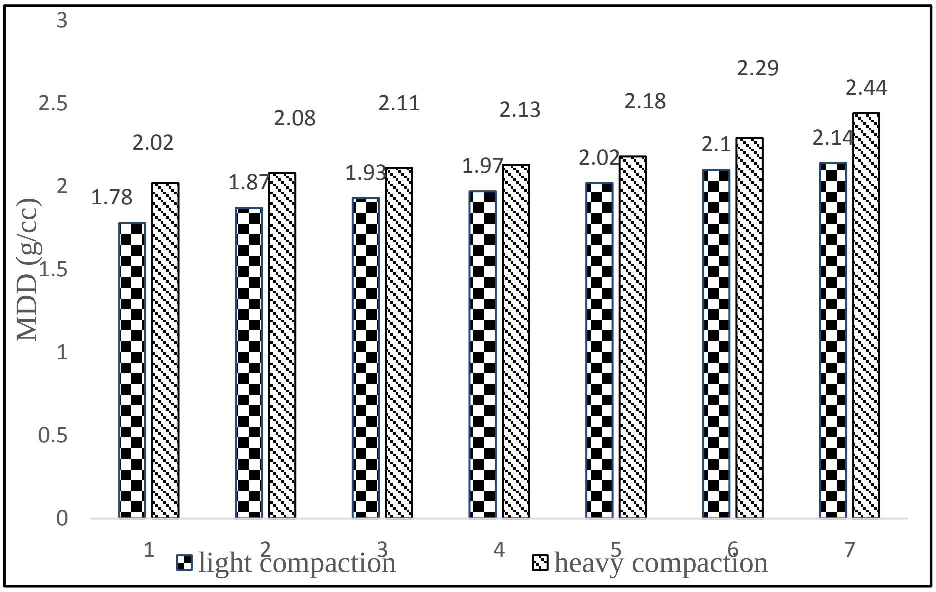

Fig. 4 showing the improvement of MDD value with inclusion of ferrochrome slag and comparing

3.2 Effect on Undrained Shear Strength

The value of undrained shear strength obtained from stress-strain curve of UU test by plotting Mohr’s circle. Increase in the undrained shear strength of soil mixed with ferrochrome slag composites may be attributed due to better interlocking resulting in decrease in void ratio, which provides more stress resistance for a particular strain. However, cohesion decreases after 40 % inclusion, due to too many fiber or poor gradation, but frictional angle keeps on increasing and approaches the value that of ferrochrome slag.

The ratio of the mixture is ratio of silty soil to that of ferrochrome slag by weight. The shear parameters obtained from the UU test, from table 3 are used to evaluate the shear strength for the specific mixture, tested at its respective OMC (%)

Table 3 Shear parameters obtained from UU test for soil slag mixture of different proportions

Mixture	**C (kPa)**	**φ(degree)**
100 % SS	28.40	6
90:10	30.20	14
80:20	34.00	18
70:30	36.00	20
60:40	37.40	22
50:50	34.40	27
40:60	28.00	29

Undrained shear strength of the soil is calculated as per the formula given below

$$q = 2C + \tan(\boldsymbol{\varphi}) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \textbf{(1)}$$

Where q= undrained shear strength of specimen

The value undrained shear strength for different soil and soil-ferrochrome composite mixture are plotted in the bar graph, fig. 5 below. Here also the sequence of curve is same as mentioned above from 1 to 7.

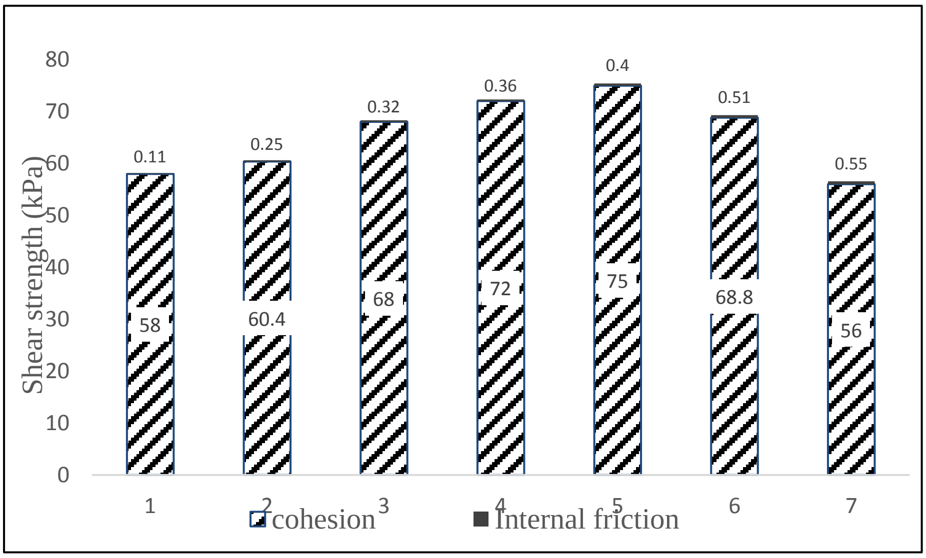

Fig. 5 Change in undrained shear strength with inclusion of ferrochrome slag

3.3 Effect on the CBR Value

The typical load versus settlement behavior of soil and ferrochrome slag mixed soil in different proportions under unoaked and soaked condition of CBR test is plotted in fig. 3 & 4.

It can be observed that with the increase in percentage of ferrochrome slag in composite mixture, the load value increases and deformation value decreases significantly, subsequently shows nearly linearity in its behavior at higher percentage.

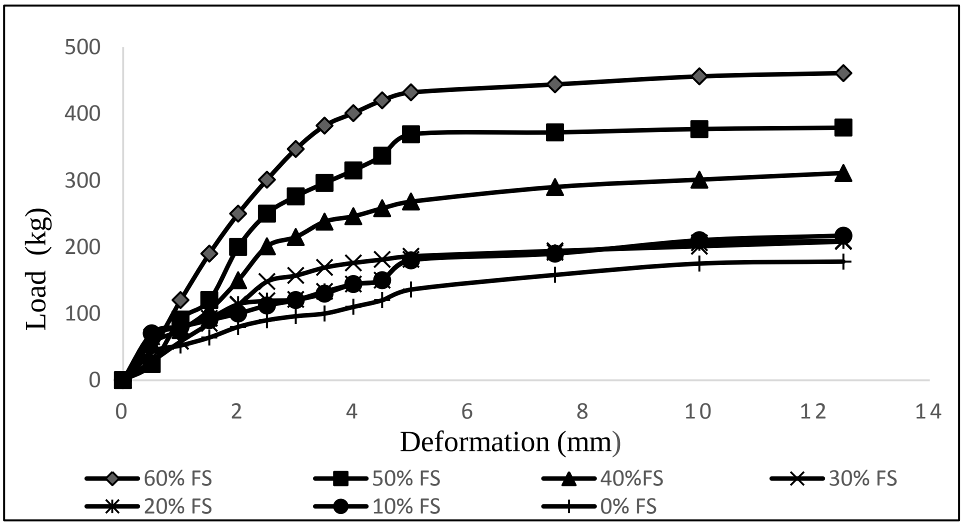

Fig. 6 CBR curve for soil and different Soil-slag composite mixture in unsoaked condition

In case of unsoaked test, from the stress-strain for higher percentage of slag in the composite mixture, showing linearity. The unsoaked CBR value is however finds very limited application in practical field, because in real practical field the sub-grade courses get subjected to moisture due to precipitation or other sources. But in semi-arid and arid condition the unsoaked CBR value may be used to construct pavement courses and will show superior behavior due to its linearity in stress-strain relationship.

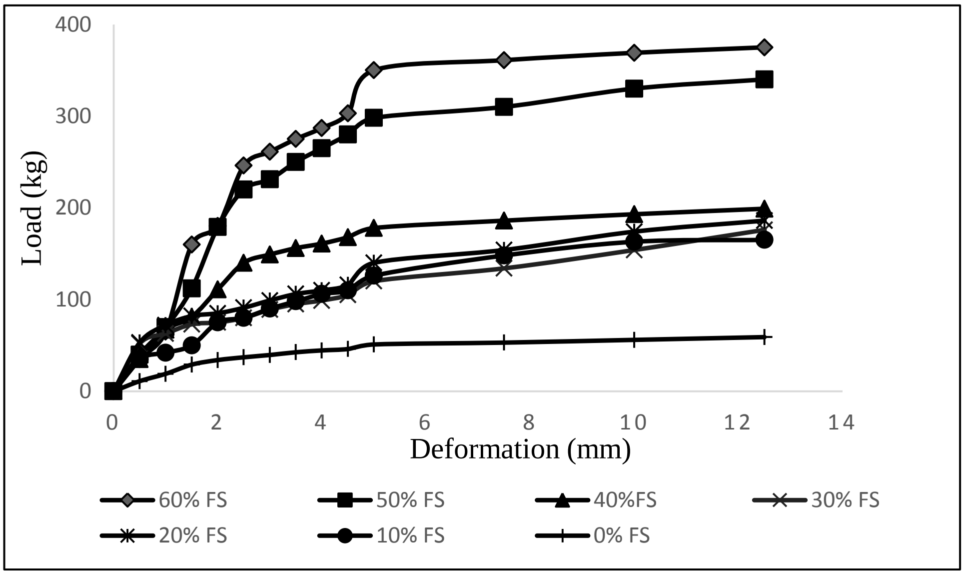

Fig. 7 CBR curve for soil and different Soil-slag composite mixture in soaked condition

Where in case of soaked condition the curve is non-linear even in higher percentage, this may be attributed due to forming of lumps in wet condition, causing uneven settlement. This can be attributed to elasto-plastic behavior of the soil-slag mixture with soaked condition. Although, the improvement in CBR value in wet condition is significant but on account of settlement behavior dry condition may called superior. However, soaked CBR finds large scale applications in practical field. From the CBR curve or result of CBR test, CBR value is calculated and given in table 4.

Table 4 Showing CBR value in unsoaked and soaked condition

Constituents	**Un-soaked CBR (%)**	**Soaked CBR (%)**
100 % SS	5.60	2.97
90 % SS + 10 % FS	7.65	6.34
80 % SS + 20 % FS	8.42	6.50
70 % SS + 30 % FS	10.72	8.47
60 % SS + 40 % FS	15.69	11.94
50 % SS + 50 % FS	18.36	14.96
40 % SS + 60 % FS	21.95	17.94

CBR value is calculated at 2.5 mm settlement with surcharge load of 2.5 kg at OMC. From the table is can be observed that the CBR value increases as the percentage inclusion of ferrochrome slag increases.

4 CONCLUSIONS

With the increase in percentage of ferrochrome slag inclusion in the soil-ferrochrome composite, the following conclusions can be drawn on the basis synthesis of test results. From proctor and modified proctor compaction test, it is observed from Fig. 4 that, inclusion of ferrochrome slag, significantly changes the MDD value of the mixture. MDD goes on increasing and OMC decreases, since water absorption of slag is very low. Therefore, a huge amount of water can be saved and heavy-duty pavement sub-grade courses can be constructed, which will reduce post construction settlement. Undrained shear strength of soil also goes on increasing up to 40 % (Fig. 4) therefore shear failure can be minimized to. However, it starts decreasing after further increase in percentage of slag. CBR value of soil in soaked condition was 2.96 % the value increased to 17.94 % in case of 60 % slag in the soil-slag composite mixture. However, according to our requirement of pavement sub-grade construction to be constructed we can adopt the suitable soil-ferrochrome mixture from Table 3.

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