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Efficacy of Red Mud and GGBS in Improving the Engineering Properties of Black Cotton Soil

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Abstract. Red mud (RM), a byproduct of bauxite refining, has been the prime matter of concern for the Alumina Industries in the country. Due to the enormous quantity and high alkalinity (ph>11) of red mud, industries are clueless on how to reuse or dispose it off. Off late, geoenvironmental researchers and practitioners have initiated research on utilization of Red Mud in various ways in line with the theme of "sustainable practices". In this context, the Red Mud along with Ground Granulated Blast Furnace Slag (GGBS) which is also a by-product obtained from steel plant, have been taken up in the present study and mixed with Black Cotton Soil in multiple proportions to find out the efficacy of Red Mud and GGBS in stabilizing highly expansive black cotton soil. Moreover, this study investigates the alteration of index properties and engineering properties from laboratory experimentations on individual material as well as for mixed samples, where percentage of Red Mud are 10%, 20%, 30%, 40% and percentage of GGBS is 20% of dry sample. The analysis of result reveals substantial decrease in Plasticity index which implies a decline in expansiveness of Black Cotton Soil. Subsequently, an increase in California bearing ratio was observed, which further demonstrates the feasibility of utilization of Red Mud and GGBS as composite engineering material.

Keywords: Red Mud, GGBS, Black Cotton Soil, Plasticity Index, CBR

1 Introduction

In recent years, due to population growth, progressive living standards, and industrial progress, two major unavoidable problems are arising continuously. The first one is the degradation of good quality soil or lack of good land for engineering construction. To counteract this problem our approach is continuously going towards stabilizing unused soft soil or expansive soil which is suffering from lack of engineering properties. Subsequently, the second one is storing and disposal of hazardous industrial waste material. Now a days one of the most growing industrialization is aluminium industry as aluminium is cheap and can be use as an alternate of steel and timber. And during production of alumina (Al_2O_3) from bauxite refining by bayer's process, a highly alkaline bauxite residue, named as Red Mud, is obtained in a large scale. Al-

most 35 to 40% of bauxite ends up as Red Mud during production of alumina. About 4.71 million tonnes per annum Red Mud is generated in India only [1]. This enormous quantity of Red Mud has become a serious threat to environment because of its high alkalinity and heavy toxic metal content such as aluminum, silica, calcium, iron, titanium. Red Mud also consists of some minor constituents such as K, Na, Cr, Ba, Ni, Mn, Cu, Zn, Pb [2]. Generally, Fe_2O_3, Al_2O_3, SiO_2, Na_2O, CaO are the major constituents in Red Mud. The main drawbacks of Red Mud are low compactibility, dispersion, leaching, alkalinity [3]. This hostile nature of Red Mud ceaselessly degrades the fertility of cultivated area. Red Mud with small percentage of cement mixed with clay can be use as clay liner because of its high compressive strength and low hydraulic conductivity [4]. Compression behavior of Red Mud was found to be similar as clayey soil and frictional behavior was same as sandy soil [5]. Moreover, most of the industries are clueless about storing or disposal of this abundant quantity of highly alkaline Red Mud, due to lack of resources and technology. So, purpose of this study is to use Red Mud in bulk quantity which can be done by using it in ground improvement technique i.e stabilization.

2 Experimental Study

2.1 Materials used

Black cotton soil

In India, expansive soils are generally known as Black Cotton Soil because of its dark colour and suitability of cotton farming. Black cotton soils are mainly originated from lava basaltic rocks and covered almost 20% of Indian geographical region.
For this particular study, Black Cotton Soil was carried out from Nagpur, Maharashtra. The properties of this soil were examined by standard procedure and provision as given by Indian Standard code. Table 1 is representing the properties of the soil.

Table 1. Properties of Black Cotton Soil

Property	Values
Specific gravity	2.61
IS Classification	MH
% of Sand, Silt and Clay	19, 73.6, 6
D_{10} (mm)	0.0045
D_{30} (mm)	0.0126
D_{60} (mm)	0.0591
Coefficient of Uniformity (Cu)	13.13
Coefficient of Curveture(Cc)	0.596
Maximum Dry Density(kN/m^3)	17.02
Optimum Moisture Content (%)	18
Liquid Limit (%)	63.35

Plastic Limit(%)	34.52
Plasticity Index(%)	28.83

Red mud

Highly alkaline Red Mud was collected from Hindalco industries limited situated in Muri, Jharkhand. In this study use of Red Mud is the prime concern. Fig 1 shows the Red Mud used in this research work and Table 2 represent its properties.

Fig. 1. Red Mud

Table 2. Properties of Red Mud

Property	Values
Specific gravity	2.9
% of Sand, Silt and Clay	1.6, 98.4, 0
D_{10} (mm)	0.011
D_{30} (mm)	0.012
D_{60} (mm)	0.053
Coefficient of Uniformity (cu)	4.82
Coefficient of Curveture(cc)	0.246
Maximum Dry Density(kn/m^3)	17.2
Optimum Moisture Content (%)	26.2
Liquid Limit (%)	33.33
Plastic Limit(%)	30
Plasticity Index(%)	3.33

Ground granulated blast furnace slag

GGBS is obtained by quenching molten iron slag (a by-product of iron and steel making). A glassy granular product obtained which further dried and ground into a finer powder. GGBS was carried out from Tata steel plant in Jharkhand. Table 3 represents the properties of GGBS.

Table 3. Properties of GGBS

Property	Values
Specific gravity	2.88
Fineness (%)	12
Compressive Strength (MPa)	5

3 Results and Discussion

3.1 Particle size distribution

The particle size distribution of red mud and black cotton soil was conducted as per IS: 2720 (Part-IV)-1985. The particle size distribution was done by wet sieve analysis and hydrometer test. Fig 2 represent the particle size distribution curve for Black Cotton Soil and Fig 3 represent the particle size distribution curve for Red Mud.

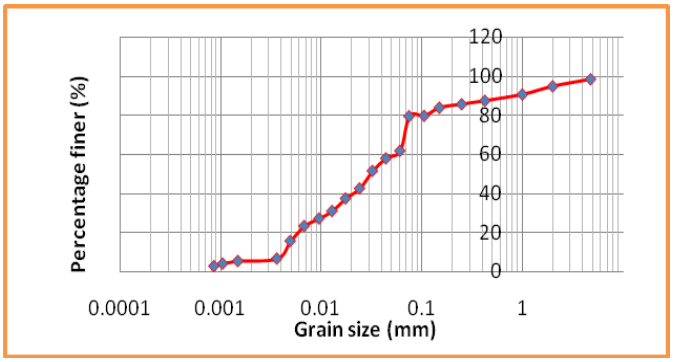

Fig. 2. Particle size distribution of Black Cotton Soil

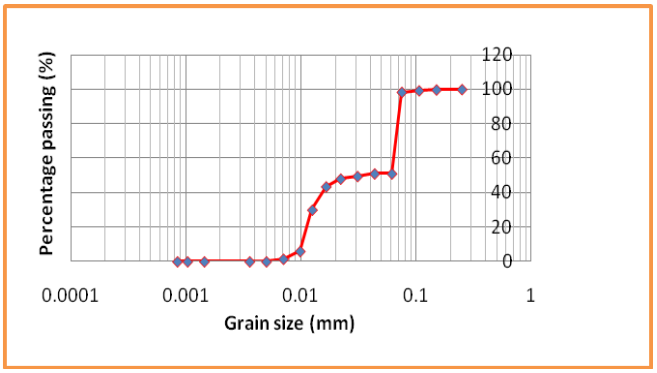

Fig. 3. Particle size distribution of Red Mud

3.2 Modified proctor test

Compaction test for virgin Black Cotton Soil and for Red Mud-GGBS mixed black cotton soil were done in laboratory with standard procedure and provision as per IS: 2720 (Part-8)-1980. The test results were plotted in graph as shown in Fig 4 and in Fig 5 for Black Cotton Soil and Red Mud respectively, to find out the OMC and MDD.

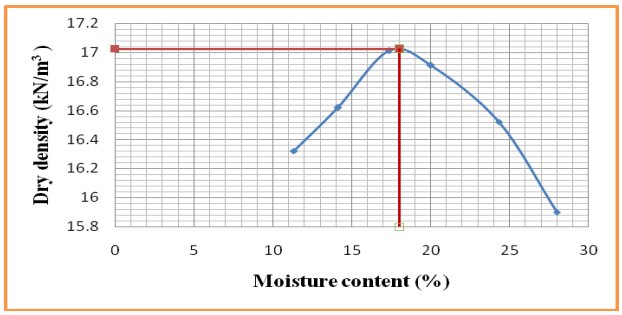

Fig. 4. Compaction curve of Black Cotton Soil

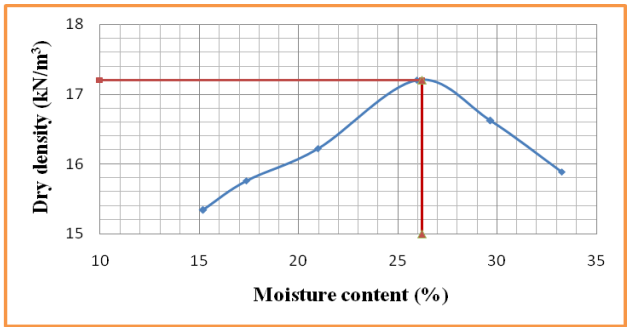

Fig. 5. Compaction curve of Red Mud

3.3 Atterberg's limit

In this context, liquid limit and plastic limit was determined as per IS 2720 (Part-V)-1985. The aim of this test in RM - GGBS mixed black cotton soil is to reduce plasticity index and make it suitable for engineering purpose. Liquid limit was determined by Casagrande apparatus and after that the result was plotted in semi log graph. The flow curve obtained from liquid limit test, for Black Cotton Soil and for Red Mud has been shown in Table 1 and Table 2 respectively.

3.4 Effect of RM and GGBS on liquid limit of black cotton soil

The liquid limit of soil gets effected largely by specific surface area as both are proportional [Young and Warkent in 1975]. Due to addition of RM and GGBS in Black Cotton Soil, the specific surface area of the soil gets changed and water absorption

capacity also gets changed. Fig 6 shows the effect of RM and GGBS in liquid limit of Black Cotton Soil.

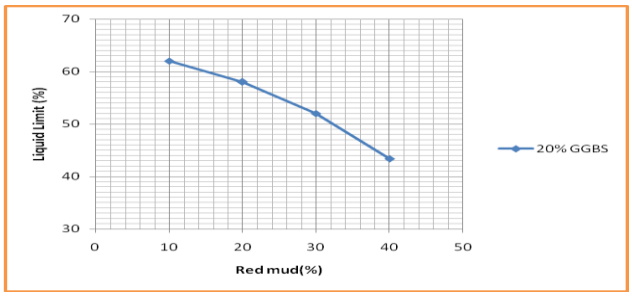

Fig. 6. Variation in liquid limit with Red Mud content

Fig 6 shows a remarkable decrease in liquid limit which is lighting towards a positive result. Reduction of liquid limit leads to reduction of compressibility which further helps to make the Black Cotton Soil suitable for engineering purpose, though other factors also should be considered. From the Fig 6 it can be ensure that increase in RM in Black Cotton Soil rapidly decrease the liquid limit. The most effective composite sample in terms of liquid limit is "40% Black Cotton Soil+40% Red Mud+20% GGBS" as this sample helps to decrease the liquid limit from 63.35% to 43.41.Other variations of liquid limit for different composite samples were tabulated in Table 4.

3.5 Effect of RM and GGBS on plasticity characteristics of black cotton soil

Plasticity is one of the most important parameter of a soil for engineering consideration. If a soil suffering from high plasticity then it is impossible to construct any structure over it. Black cotton soil is also of this category. Plasticity is represented by plasticity index (Ip) and plasticity index can be defined as range between liquid limit and plastic limit.

$$Ip = w_l - w_p$$

Plasticity has a high influence on swelling and shrinkage property. In this study plasticity of black cotton soil was tried to minimize to a acceptable limit. Fig 7 shows the variations of plastic limit of Black Cotton Soil, stabilized by RM and GGBS.

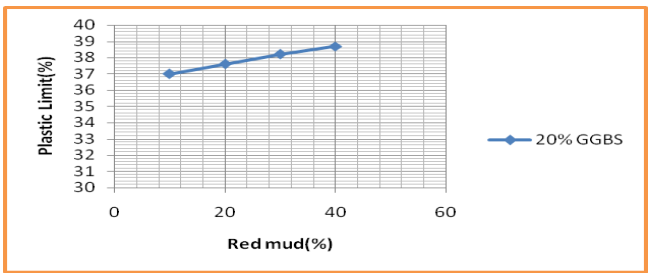

Fig. 7. Variations of plastic limit with Red Mud content

The graph evaluted that increase in Red Mud leads to increase in plastic limit. In other side high percentage of GGBS also have participated in increasing plastic limit. It can be ensure that 40% Black Cotton Soil with 40% Red Mud and 20% GGBS have increased the plastic limit from 34.52% to 38.7%. In addition, a graph showing the variation of plasticity index with change in proportion of RM and GGBS was also represented in Fig 8.

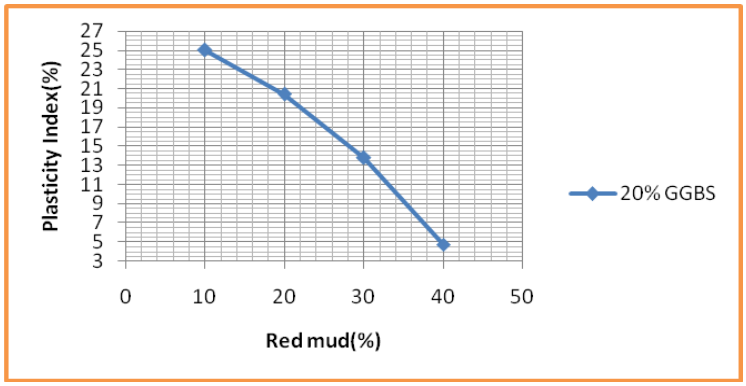

Fig. 8. Variation in plasticity index with red mud

It can be clearly observed that by using Red Mud and GGBS in Black Cotton Soil, plasticity can be decreased tremendously. Using of 40% Red Mud 20% GGBS is giving a promising result as it decreases plasticity index from 28.83% to 4.71%. Other variations of liquid limit, plastic limit and plasticity index have been displayed in Table 4.

Table 4. Variation in liquid limit, plastic limit and plasticity index due to RM and GGBS

Samples	Liquid Limit(%)	Plastic limit (%)	Plasticiy index (%)	Remarks
100%BCS	63.35	34.52	29.28	Highly plastic
70%BCS+10%RM+20% GGBS	62	37	25	Highly plastic
60%BCS+20%RM+20% GGBS	58	37.6	20.4	Highly plastic
50%BCS+30%RM+20% GGBS	52	38.2	13.8	Medium plastic
40%BCS+40%RM+20% GGBS	43.41	38.7	4.71	Low plastic

3.6 Effect of RM and GGBS on maximum dry density and optimum moisture content of black cotton soil

Modified proctor test has been carried out to find out OMC and MDD for each sample. The results of composite samples were compared with virgin soil to investigate the efficacy of RM and GGBS in increasing dry density. Further, OMC obtained from the test was used to compact samples for CBR test. The test samples were compacted in five layers and 25 blows in each layer by a hammer of weight 4.9 kg. Dry density corresponding to given water content was plotted in graph and formed a bell-shaped curve. The curve is known as compaction curve and the peak point is known as Maximum Dry Density (MDD). The moisture content corresponding to MDD is known as optimum moisture content. Fig 9 shows the compaction curve for raw black cotton soil as well as for composite samples.

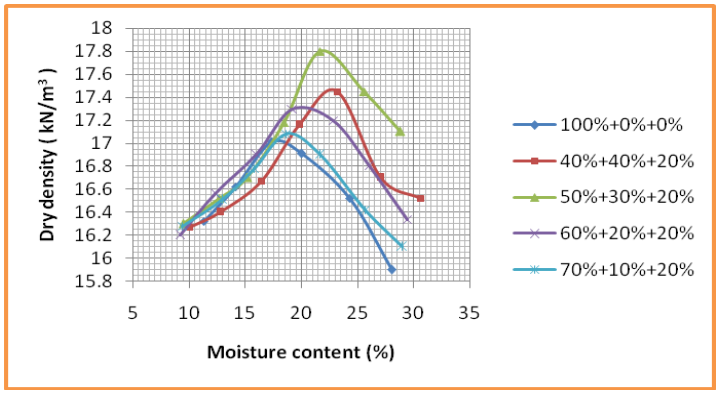

Fig. 9. Compaction curve of different sample with 20% GGBS

Fig 9 shows the compaction curves for raw soil and for 20% GGBS mixed black cotton soil with varying percentage of Red Mud. MDD obtained from the graphs illustrate that maximum dry density is increasing with increase in Red Mud up to 30%. Beyond 30% of Red Mud, MDD is again in decreasing mode. By using 30% RM and 20% GGBS, MDD can be increased from 17.02 kN/m^3 to 17.8 kN/m^3. In other side, instead of decreasing, OMC was also increased on increasing red mud percentage. The OMC was increased up to 23.2% when 40% RM with 20% GGBS was mixed with black cotton soil. Table 5 shows the effect of RM and 20% GGBS on maximum dry density and optimum moisture content in tabulated form.

Table 5. Variation in MDD and OMC due to RM and GGBS

SAMPLES	MDD(kN/m^2)	OMC(%)
100%BCS	17.02	18
70%BCS+10%RM+20%GGBS	17.09	19
60%BCS+20%RM+20%GGBS	17.33	20

50%BCS+30%RM+20%GGBS	17.8	21.6
40%BCS+40%RM+20%GGBS	17.45	23.2

3.7 Effect of RM AND GGBS on CBR value of black cotton soil

CBR test is mainly conducted to find out the resistance against penetration or to find out strength characteristics. In this study, CBR test was conducted to investigate the load bearing characteristics of virgin black cotton soil and of different composite sample. The test was conducted as per the provision of IS: 2720 (Part-16)-1961.

Unsoaked condition

CBR value should be determined for both unsoaked and soaked condition to simulate the field conditions during dry and rainy season. For conducting CBR in unsoaked condition, the raw black cotton soil and composite samples were compacted at OMC, obtained by modified proctor test. The fresh compacted samples were than immediately tested. The result of the test have been plotted in graph as shown in Fig 10 for different RM and GGBS content. Table 6 is representing the test results for different samples.

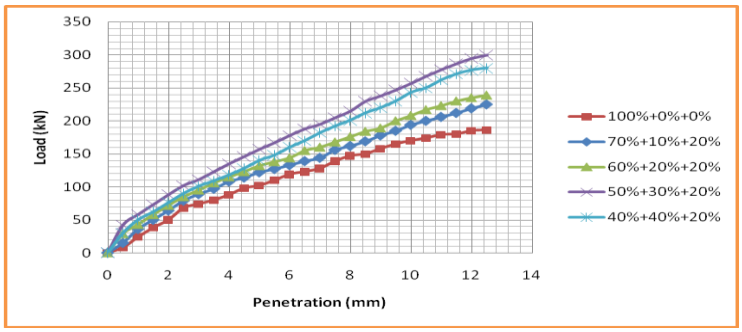

Fig. 10. Effect of different proportion of RM and 20% GGBS on CBR test result of BCS

From the Fig 10, it was concluded that use of 30% RM and 20% GGBS gives the best suited result for CBR. This composition increased CBR value up to 7.6. Moreover, the CBR value increased up to 55% by using 30%RM and 20% GGBS. The other variation in CBR value for different composition of RM and GGBS were illustrate in Table 6.

Table 6. CBR value of BCS for different RM value and 20% GGBS

SAMPLES	CBR VALUE (%)
100%BCS	4.9
70%BCS+10%RM+20%GGBS	5.9
60%BCS+20%RM+20%GGBS	6.4
50%BCS+30%RM+20%GGBS	7.6
40%BCS+40%RM+20%GGBS	6.8

Soaked Condition

After compacting the sample with OMC, it is soaked for 96 hrs. The process of soaking is adopted in laboratory to simulate in situ condition of monsoon season. As black cotton soil has high swelling tendency, so it posses very less CBR value in soaked condition. For finding out the load bearing characteristics in soaked condition, the samples were subjected to 25 N surcharge load. Fig 11 and Table 7 shows the test result of CBR test for the sample with different RM content and 20% GGBS. From the Fig 11 it was concluded that 30% RM and 20% GGBS have given the maximum CBR value i.e. 2.15%. This value is 38% more than CBR value of raw soil.

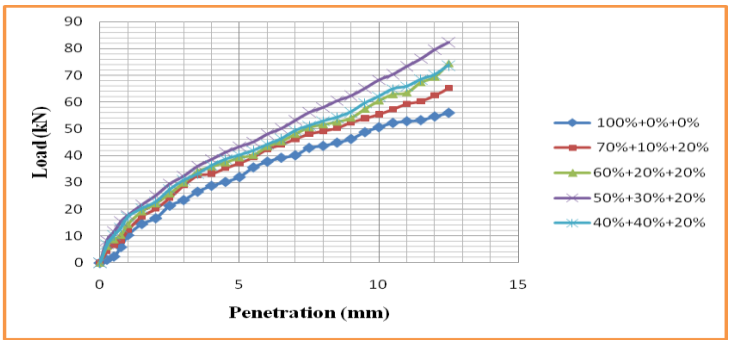

Fig. 11. Effect of different proportion of RM and 20% GGBS on CBR test result of BCS

Table 7. CBR value of BCS for different RM value and 20% GGBS

SAMPLES	CBR VALUE (%)
100%BCS	1.55
70%BCS+10%RM+20%GGBS	1.81
60%BCS+20%RM+20%GGBS	1.88
50%BCS+30%RM+20%GGBS	2.15
40%BCS+40%RM+20%GGBS	2

4 Conclusions

Based on the obtained results from the experimental investigation and analyzing the data, following conclusions can be drawn.

1. From the test results of liquid limit, it was concluded that low plasticity of red mud i.e. 3.33% and cementing property of GGBS helped in decreasing liquid limit abundantly. Moreover, mixing of 40% RM and 20% GGBS with black cotton soil gives the best result in terms of liquid limit as liquid limit decrease from 63.35% to 43.41%.

2. Similarly, due to use of 40% RM and 20% GGBS increases plastic limit from 34.52% to 38.7%. Increment of plastic limit further helped in decreasing plasticity index. The plasticity index gets decreased to a value of 4.71% when 40% RM and 20 % GGBS was mixed with black cotton soil. Moreover, high plasticity of black cotton soil was converted to low plasticity by using RM and GGBS.
3. The MDD and OMC of the composite sample get increased in comparison to raw soil after mixing these additives. The MDD was increased up to a RM content of 30%. Further increase in RM lead to decrease MDD. The increase in MDD is due to change in particle size distribution and specific surface area.
4. The value of CBR was also increased with increase in red mud up to 30% as voids of composite sample get packed densely by finer particles of additives. It is noteworthy that CBR value in soaked condition is not satisfied as it is less than minimum permissible value as per IRC.

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