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Evaluation on effect of alkaline activator on compaction properties of red mud stabilised by ground granulated blast slag

Sarath Chandra[1], Sankranthi Krishnaiah[2]

[1] *Department of Civil Engineering, Jawaharlal Nehru Technological University Anantapur, Anantapur, India and Department of Civil Engineering, Christ (Deemed to be University), Bangalore, Karnataka-560029, India*
[2] *Department of Civil Engineering, Jawaharlal Nehru Technological University Anantapur, Anantapur, Andhra Pradesh-515002, India*

ABSTRACT
Any industrial waste has a potential to be used as a civil engineering material with an effective and appropriate waste management system. Like many industrial wastes, red mud (RM) and Ground granulated blast slag (GGBS) are some of the industrial wastes produced from aluminium and steel industries respectively. Utilization of only waste materials will not be effective without a suitable stabilizer, which forced to use an alkaline activator to satisfy the needs of a building materials. This paper evaluates measurements to assess the effect of alkaline activator on the compaction properties of GGBS stabilized RM. Different ratios of NaOH to Na_2SiO_3 was used as an alkaline activator with 10, 20 and 30 percentage replacement of GGBS to RM and measured the compaction properties by using a mini compaction apparatus. Upon conducting standard and modified proctor compaction tests for various combinations of RM and GGBS, the compaction curves depicted that huge variation in maximum dry density and optimum moisture content with the change of GGBS percentage and different ratios of NaOH to Na_2SiO_3 are measured and analysed. Further the influence of compaction energy on the density characteristics of these trails were assessed for better understanding.

Section: RESEARCH PAPER

Keywords: Red mud; ground granulated blast slag; alkaline activator; evaluating compaction properties; assessing compaction energy

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Corresponding author: Sarath Chandra, e-mail: chandrasarath011@gmail.com

1. INTRODUCTION

It's very important to develop new methods rather than traditional methods of civil engineering construction to control the utilization of virgin resources. On the other hand, handling the industrial waste materials which are generated with the new methods of construction and the unpredictable growth of industries around the globe is also essential. The best method to balance both sides of this worldwide issue is by utilizing industrial waste materials in construction industries with suitable and environmentally friendly methods. With the revolution of sustainable construction technique, in the last two decades, enormous research was carried out in utilization of various industry materials like fly ash, ground granulated blast slag, pond ash, red mud, iron ore tailings, foundry sand, etc. in various verticals or areas of civil engineering constructions like manufacture of bricks and paver blocks [1], [2], as a subgrade and sub base material in road construction [3], [4], as an embankments and backfill materials [5], [6], as a soil stabilisation technique [7], [8] and vegetation [9]. Along with the industries, construction activities also increased tremendously with the advancement in technologies were utilization of raw materials increased exponentially. It directly results on another important waste material called construction and demolished waste [10]. It is important to induce the latest technologies like optical metrology which involves digital, vision and video systems in order to understand the exact behaviour of various materials. The usage of advance technologies will help to reduce the pollution and gives new solutions with an accuracy in measuring and assessing the problems in civil engineering [11].

Like many industry waste materials Red mud (RM) is also a type of highly alkaline (pH ranging from 10.5 to 13) industrial residue which is produced during the process of extraction of aluminium from the bauxite ore [12]. RM is generally produced in the form of slurry which contains up to 40 % of water into the collection ponds situated next to aluminium industries [13]. The high alkaline nature and very fine particle size of RM along with the aluminium traces result in a threat to the environment. It is also difficult to store RM for longer periods which may create air pollution with open exposure to air and also groundwater pollution with the leachate without proper liners. Annually more than 4 million tons of red mud is producing in India. On the other side, it requires huge land to dispose of and involves a good amount of money for proper waste management. The lack of appropriate waste management and storage system of RM will show adverse effects on the environment which may end up taking both many lives and huge property which was resulted in the past [14]. These negative shades of RM emphasizing to use it in civil engineering constructions where a bulk material can be used with minimal cost. On the other side, RM also shows the similar properties of clayey and sandy soils, which is a good indication to use in civil engineering applications like the construction of embankments, landfills, and different layers of road construction. However, the application of these waste materials always depends on the density characteristics. This implies the measurement and compaction characteristics of finding optimum moisture content and maximum dry density of the material. Measurement of compaction characteristics is a very important parameter for any foreign material in the geotechnical application at various stages upon satisfying the standard specifications of relevant codes, this manner measurement technology plays an important role in such real time applications.

For any soil or waste material upon the application of loads, there will be a change in the volume because of the expelling of air form the voids. The change in the volume of the material depends on the number of voids developed in the material, the amount of air filled in the voids and the amount of load or pressure applied. The standard and modified compaction tests show the differences in dry densities with the change of load applied for any type of material. The maximum dry density and optimum moisture content values obtained from the compaction tests form the basis to determine many strength parameters of the waste material at various construction stages. Various geotechnical parameters depend on the amount of water added to the material as we know the moisture largely controls the behaviour of soils, particularly fine-grained soils. Hence, it is important to understand the in-depth information on compaction characteristics of RM for the benefit of various applications as a geo-material.

As very limited work was carried out in the past focusing on measurement of compaction characteristics of RM along with other waste material stabilisation in India. So, an attempt was made to determine the compaction characteristics of RM along with GGBS and alkaline activators by using mini compaction apparatus. The prototype gives a better study of the load and the material behaviour with the control of the loads applied in the study [15]. RM was replaced with 10 %, 20 % and 30 % of GGBS to its dry weight, which is commonly used as stabilising material in many civil engineering applications because of its capability in increasing the strength and bearing capacity and also good in compaction [16]. NaOH and Na_2SiO_3 are used as alkaline activators which are effectively proved as good stabilisers for GGBS mixed materials in the past [17]. The alkaline activators in various proportions are used in different industry waste materials to increase the strength properties of the waste materials exponentially and to use them effectively in the field of construction [18]-[20]. To understand the effect of alkaline activators on compaction characteristics of RM, series of standard and modified proctor compaction tests were performed on various combinations made of RM, GGBS, NaOH and Na_2SiO_3.

2. EXPERIMENTAL INVESTIGATIONS

RM for this study was collected from waste disposal pond of Hindustan Aluminum Corporation (Hindalco), Belgaum, Karnataka, situated in the southern part of India. GGBS was procured from the JSW cement limited. GGBS is produced as a by-product or waste from the blast furnaces during the process of making iron. Figure 1a shows the original images of over dried red mud and GGBS and Figure 1(c) and Figure 1(d) presents the Scanning electron microscopy (SEM) images of red mud and GGBS respectively to understand the microstructure of these materials to use as a geo material in this study. The SEM images showing red mud present the particles of scattered behaviour whereas the SEM images of GGBS show the smooth sharp ends which indicate that a better compaction can be attained by using both the materials with the appropriate amount of water and energy. The microstructure of these two materials supports the current study on finding the compaction characteristics of RM with GGBS and an addition of water, experiments were also performed by using alkaline activator to achieve a better density of the material upon drying. Sodium hydroxide (NaOH) pellets, which were put into use for this study was purchased from The Prince Chemical Bangalore, Karnataka, India, which sells pellets with 98 % purity. Based on many research findings, prioritizing the economical and strength aspects, the molarity of the sodium hydroxide solution was chosen to be 8 M throughout the research. Hence, molarity calculations to prepare a sodium hydroxide solution of 8 M were, 320 g of sodium hydroxide pellets have to be dissolved in 1 l of water [8 mol/l x 40 g/mol = 320 g, where 40 g/mol is the approximate molecular weight of NaOH]. The sodium silicate (Na_2SiO_3) solution was purchased from the Para Fine Chemical Industries, Bangalore, Karnataka, India, which contains Na_2O = 14.78 %, SiO_2 = 29.46 % and water = 55.97 % by mass.

Before finding the compaction characteristics of alkaline activated, GGBS stabilised RM, the physical and geotechnical properties of RM and GGBS were determined to understand and classify the materials for better justification on the compaction properties. According to ASTM D854, the specific gravity of RM and GGBS were determined by using pycnometer and the results are presented in Table 1. Average of three trails was considered for all the tests to maintain accuracy in the results. Compaction is considered as a very important geotechnical property to obtain the maximum dry density and to know the optimum moisture content. So, it is also important to understand both physical and geotechnical properties of the waste material used in this research work as a pre-requisite. The properties prove that the RM can be effectively used in the subgrades in place of virgin soil. According to ASTM D4318, D422, D1140 and D2487, the liquid limit, plastic limit and particle size distribution and soil classification was determined for both RM and GGBS and the same were presented in Table 2 [21]-[25]. The RM was classified into silt of low plasticity and GGBS as silt with low compressibility according to Unified Soil Classification System.

In this study [26], [27] the compaction characteristics of all the combinations were determined by using mini compaction apparatus which is presented in Figure 2. This method of

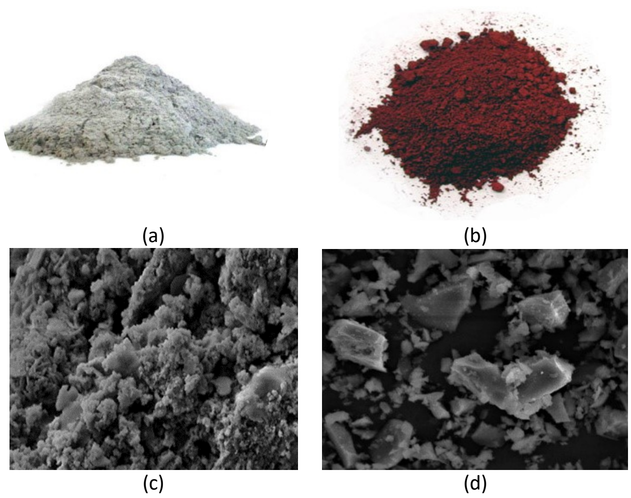

Figure 1. a) Original image of Red mud b) Original image of GGBS c) SEM image of Red mud d) SEM image of GGBS.

compaction is only suitable for the materials which have particle size less than 2 mm and this method is opted as both RM and GGBS particle sizes are less than 2 mm. The unique advantage of this apparatus is the low amount of material used for testing, i.e. up to 300 g instead of 3 kg of soil, which is generally used for the standard proctor compaction test. The amount of energy given by the number of blows can be easily calculated by using mini compaction apparatus. It is difficult to determine the amount of energy applied with respect to number of blows accurately by using of standard or modified proctor compaction apparatus, but this can be easily done by using the mini compaction apparatus. It is also observed better results accuracy because less material is used and not much energy is applied. This method of compaction saves both time and energy of a researcher compared to the traditional method of compaction and the characteristics can be observed with the change of number of blows in a better way. The same compacted samples after trimming can be used for the purpose finding strength parameters of the material directly. Both standard and modified compaction tests can be performed by using of this mini compaction apparatus. The dimensions of this apparatus are very small as the internal diameter of the cylinder is equal to 3.81 cm, the height of the cylinder is 8 cm and it was used by many researchers in the past for the easy conduction of compaction test with less material usage and less labour and time. [28]

Table 1. Physical and Geotechnical Properties of RM and GGBS.

SNo.	Property	RM	GGBS
1	Specific Gravity	2.95	2.81
2	Consistency Limits:		
	Liquid limit (%)	43	32
	Plastic limit (%)	38	NP
	Plasticity Index	5	NP
3	Percentage Fractions:		
	Sand	3	75
	Silt	75	24
	Clay	22	1.0
4	USCS	ML	ML

3. RESULTS AND DISCUSSION

Table 3 shows the optimum moisture content (OMC) and maximum dry density (MDD) obtained for various combinations upon conducting an average of three trails of SP and MP tests of each. The OMC and MDD of RM are 34.39 % and 1.59 g/cc, respectively, whereas in the case of GGBS it is 25.63 % and 1.62 g/cc with distilled water. RM shows more similar reproducible values with the MP tests compared to SP tests and the values of OMC and MDD are noted as 28.65 % and MDD was 1.64 g/cc. This shows an initial idea about the material behaviour with the change of application of load and accuracy in OMC and MDD. The results confirm that with the increase of compaction energy in RM, the dry density increases, and the water content requirement decreases in appreciable way which coincides with the past research results also [12]. It is observed that an increase up to a maximum of 5 % in MDD and up to 31 % in the OMC with the standard and modified proctor compaction tests. It is because of increase in the rammer weight for the modified compaction. Standard indicates the lightweight compaction light tampers and rammers and modified compactions indicates the rollers and other compactors. The OMC and MDD presented in Table 3 for various combinations shows the influence of alkaline activators on the GGBS stabilised RM. The GGBS replacement in first three combinations shows that the decrease in OMC and increase in MDD in both SP and MP tests which indicates the sensitivity of GGBS stabilised RM

Table 2. Combinations and Nomenclature used in the research work.

Sl No.	Combinations	Mixing Agent	Nomenclature
1	90 % RM + 10 % GGBS	100 % Distilled Water	RGD1
2	80 % RM+ 20 % GGBS	100 % Distilled Water	RGD2
3	70 % RM+ 30 % GGBS	100 % Distilled Water	RGD3
4	90 % RM + 10 % GGBS	100 % NaOH	RGA1
5	80 % RM + 20 % GGBS	100 % NaOH	RGA2
6	70 % RM + 30 % GGBS	100 % NaOH	RGA3
7	90 % RM + 10 % GGBS	90 %NaOH + 10 % Na_2SiO_3	RGA4
8	80 % RM + 20 % GGBS	90 % NaOH + 10 % Na_2SiO_3	RGA5
9	70 % RM + 30 % GGBS	90 % NaOH + 10 % Na_2SiO_3	RGA6
10	90 % RM + 10 % GGBS	80 % NaOH + 20 % Na_2SiO_3	RGA7
11	80 % RM + 20 % GGBS	80 % NaOH + 20 % Na_2SiO_3	RGA8
12	70 % RM + 30 % GGBS	80 % NaOH + 20 % Na_2SiO_3	RGA9
13	90 % RM + 10 % GGBS	50 % NaOH + 50 % Na_2SiO_3	RGA10
14	80 % RM + 20 % GGBS	50 % NaOH + 50 % Na_2SiO_3	RGA11
15	70 % RM + 30 % GGBS	50 % NaOH + 50 % Na_2SiO_3	RGA12

Figure 2. Mini compaction test apparatus.

to water. The addition of GGBS beyond 30 % will not show any significance in the compaction characteristics of RM which was confirmed in the past studies and so limited to 30 % replacement only [29] and also the OMC and MDD values of RGD2 and RGD3 are almost similar which confirms that the further increment in GGBS will not be beneficial regards to stabilisation and cost. The increase in MDD with the addition of GGBS to RM may be due to the reduction of clay fraction in RM which reduces the particle movement resistance during compaction.

The addition of NaOH and Na_2SiO_3 shows the decrease in OMC and increase in MDD for all the cases of GGBS stabilised RM. The highest value of MDD was observed in combination RGA12 with a value of 1.91 g/cc which is an exponential increase up to 20 % compared to the virgin RM with respect to SP test and the same percentage of increment in MDD was observed in the case of MP test also. OMC was reduced up to 50 % in combination RGA12 with respect to virgin RM both in SP and MP tests. Almost similar pattern of change of OMC and MDD percentages of all the combinations were observed both in SP and MP tests. OMC was retained same and MDD was decreased with the addition of NaOH alone compared to water which proves that the only NaOH will not affect on the dry density on the GGBS stabilised RM and shows to add silicates to have more effective dry density in all the combinations. The increase in MDD and decrease in OMC trend was observed with the addition of silicates to NaOH in different ratios. Both SP and MP tests confirms that the effect of alkaline activator depends on the percentage addition of GGBS to RM.

The change in OMC and MDD with the change of ratio of NaOH/ Na_2SiO_3 was observed very minimum for a particular

Table 3. OMC a nd MDD of Alkaline activated GGBS stabilised red mud for both SP and MP.

SlNo	Combination	SP Test		MP Test	
		OMC (%)	MDD (g/cc)	OMC (%)	MDD (g/cc)
1	RGD1	30.65	1.60	25.14	1.65
2	RGD2	29.64	1.61	24.22	1.67
3	RGD3	27.88	1.62	22.10	1.68
4	RGA1	30.68	1.53	25.15	1.58
5	RGA2	27.38	1.51	22.55	1.59
6	RGA3	26.05	1.57	21.10	1.62
7	RGA4	28.04	1.65	21.11	1.71
8	RGA5	26.54	1.68	20.24	1.72
9	RGA6	25.91	1.71	19.34	1.72
10	RGA7	27.90	1.57	20.90	1.64
11	RGA8	26.40	1.68	18.60	1.73
12	RGA9	25.68	1.72	17.61	1.77
13	RGA10	26.56	1.78	19.36	1.82
14	RGA11	24.80	1.88	17.90	1.92
15	RGA12	21.62	1.91	15.01	1.99

GGBS replacement to RM. Combinations RGA 10,11,12 shows very good increase in MDD values supporting that the same 50:50 ratios of NaOH to Na_2SiO_3 for 10 %, 20 %, 30 % replacement by GGBS gives more effective results. In all the combinations the effect of alkaline activators largely depends on the addition of GGBS to RM, which may be due to the reaction of minerals present in the GGBS with the NaOH and Na_2SiO_3. According to IRC SP:20-2002, the minimum MDD of 1.46 g/cc is required to use any material as an embankment fill or in any road construction [30]. In this research work all the trails exceeds the minimum MDD required as per the specifications of IRC which shows that alkaline activated GGBS stabilised RM satisfies the requirements to use in embankments with further evaluation of strength properties.

The effect of compaction energy on the moisture content and dry density of untreated RM in the form of number of blows was studied by the research fraternity in the past. It is confirmed that the increase in the compaction energy has resulted to the decrease in moisture content and increase in dry density. In this study an attempt was made to evaluate the effect of compaction energy on the GGBS stabilised RM by replacing 10 %, 20 and 30 of RM with GGBS by using distilled water. Based on the previous study, the number of blows used for this research work are 12, 15, 18, 22, 25, 28, 33, 45, 56 and the tests have been conducted by using a mini compaction apparatus. Table 4 depicts the effect of compaction energy which was converted by using the number of blows on the GGBS stabilised RM. It shows that

Table 4. Effect of Compaction energy on density -water relationship of GGBS stabilised RM.

Number of Blows	Compaction energy (kJ/m³)	RGD1		RGD2		RGD3	
		MC (%)	DD (g/cc)	MC (%)	DD (g/cc)	MC (%)	DD (g/cc)
12	285	31.66	1.59	31.01	1.60	29.10	1.60
15	356	31.30	1.59	29.90	1.61	28.22	1.61
18	427	30.59	1.59	30.11	1.60	28.45	1.61
22	522	30.41	1.60	29.90	1.61	27.58	1.62
25	594	30.65	1.60	29.64	1.61	27.88	1.62
29	689	29.11	1.61	28.45	1.62	26.66	1.62
33	783	28.34	1.63	27.44	1.64	24.59	1.64
45	1068	26.40	1.64	25.81	1.66	23.56	1.66
56	2595	25.14	1.65	24.22	1.67	22.10	1.68

the increase in GGBS indicates the increase in the dry density with the increase of the compaction energy. This confirms that the compaction energy has a significant impact on moisture content (MC) and dry density (DD) in all the GGBS stabilised RM which also proves that the effective compaction results on attaining the better dry density of any stabilised waste material.

4. CONCLUSIONS

In the current study, detailed compaction tests were performed on virgin RM, GGBS stabilised RM and alkaline activated GGBS stabilised RM samples. From the results it is concluded that the MP tests show better compaction characteristics compared to SP test which highlights the effect of compaction energy on increasing the density of samples with the close package of fine particles present in RM and GGBS stabilised RM. GGBS acts as a good stabiliser for RM with the satisfying density as per the IRC specifications for the construction of embankments and other filling layers. The increase in MDD and decrease in OMC was observed with the increase of GGBS percentage to RM in all the trails. The results conclude that there is a minimum amount of influence on the density of RM with alkaline activator, but the influence of alkaline activator was more on the amount of GGBS added to the RM in both SP and MP tests. The outcome of this research work emphasizes that the waste materials can be effectively utilized upon stabilising with suitable other industry by products or waste materials and the available alkaline activators. Further, strength properties and leachate characteristics can be studied of these combinations in future to improve the utilization in various civil engineering applications.

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