

# Ucs Regression Analysis for Cement Stabilized Red Mud Mixes

Dr. Venkata Hanumantha Rao Chittam<sup>1</sup>, Dr. P V V Satyanarayana<sup>2</sup>, B V Suresh Kumar<sup>3</sup>

<sup>1</sup>Lecturer in Civil Engineering, Government Polytechnic, Nani Daman – 396210.

<sup>2</sup>Professor in Civil Engineering, Andhra University College of Engineering – Visakhapatnam – 530003, Andhra Pradesh

<sup>3</sup>Assistant Professor in Civil Engineering, Miracle Education Society, Bhogapuram – 535216, Andhra Pradesh

**Abstract**—Red Mud is an Aluminium plant waste disposed into the Red Mud ponds along with water. The use of this material in various civil Engineering applications such as brick manufacturing, concrete preparation, tiles making and others. The present study made an attempt to check the possible use of this material in the construction of roads as one of the component layer i.e. as sub base or base course. The substance has been collected from the NALCO (National Aluminium Company) which is located at Damanjodi in the state of Odisha. The collected material has been brought to the laboratory and tested for all basic Geotechnical properties. The research journey continued with the determination of engineering properties like OMC, MDD and UCS. This remoulded waste mixed with cement in various proportions such as 2, 4, 6, 8, 10, 12, 14, 16, 18 and 20 percentages by dry weight. The same experimental investigation was carried out on these modified substances for the identification of Engineering properties. The strength test UCS was performed for different aged samples respectively 3, 7 and 28 days for all combination mixes. A linear Regression Analysis has been exercised on the obtained experimental findings to predict the trend of the UCS values. It is evident from the whole research program that attained results are satisfactory to recommend for the road construction especially Flexible Pavements.

**Index Terms**—Red Mud, Cement, Stabilization, Omc, Mdd, Ucs, Regerssion Analysis

## I. INTRODUCTION

Red mud is a waste product disposed from Aluminium Industry. It can also be called as Bayer's process residue, which is obtained during the refining

process of bauxite. For every 1 ton of Aluminium production 2.5 tons of Red Mud is produced. So, it requires ample space for its disposal and storage. Generally Red mud is red in colour, pungent in odour and mud in appearance. It is Iron Oxide dominated material which is rich in Gibbsite and Goethite minerals. It is disposed in wet state and stored in an open space called red mud pond which consists hectares of land. The storage of red mud for a longer period result in creating soil, air and ground water pollutions. It also leads to various health hazards to living organisms. In order to overcome these difficulties red mud should be treated to get rid of health hazards and must be used in other works to minimize the problem of land scarcity also. This can be accomplished when Red Mud is widely used in other areas such as chemical industries, plastic industries especially civil engineering activities. The engineers especially civil understood this situation and started checking its feasibility in various civil engineering activities such as bricks preparation, cement manufacture, concrete formation and soil modification. Red Mud is produced in major quantities in some parts of the globe such as Australia, Jamaica, guinea and china with annual growth rate of 120 million tons, whereas in India there are four major Aluminium plants that are disposing Red Mud regularly. The Aluminium manufacturing units are located in various parts of the country such as Hindustan Aluminium Company (HINDALCO) Renukoot, in Uttar Pradesh, National Aluminium Company (NALCO) Damanjodi, in Orissa, Madras Aluminium Company (MALCO)

Chennai, in Tamil Nadu, and Bharat Aluminium Company (BALCO) in Delhi. Huge quantities of Red mud are produced annually (35 million tons from western countries and India) and disposal of this waste is a major problem facing by Aluminium industries. Red Mud has adverse environmental effects when it is disposed in the form of slurry into the red mud ponds, This is due to the caustic nature of it and ground water pollution. In addition to that disposal/storage requires huge quantities of valuable land. There are soils which are unconsolidated in nature have minimum shear strengths under effective stress conditions, such soils used as foundation materials or fill materials subjected to deformations and encounters high maintenance cost. In such locations industrial waste like Red mud can be an alternative which obtains from Aluminium industries in large quantities. Efforts have been putting by the engineers since last decade to utilize the Red mud to the maximum possible extent. Some of the researchers have been contributed for the use of red mud as construction material that are mentioned in the present research work. In recent times several attempts have been made to use red mud in various civil engineering applications in the form of bricks, ceramic products, partial replacement to cement and partial substitute to clay. All these utilized small quantities of its production and some of them proven to be economically unsatisfactory. Researchers have been making efforts to identify Geotechnical characteristics of Red mud. Li L. Y. (1998) identified Red mud as high alkaline, with pH 11-13. Vogt. M. F (1974) observed that it has high frictional angle varying from  $38^{\circ}$ - $42^{\circ}$ . Somogyi and Grey (1977) and Newson (2002) identified that Red mud has compression index (Cc) in the range of 0.27-0.39 and coefficient of permeability from 2 to  $20 \times 10^{-7}$  cm/s and coefficient of consolidation (Cv) as 3 to  $50 \times 10^{-3}$  cm<sup>2</sup>/sec. Subrat K. Rout (2013) identified that Red mud has a specific gravity of 3.34 and ML in nature. Yang, A.P (1996) utilized Red mud and Fly ash in production of light weight bricks. Yang (1996) studied Red mud, Flyash, lime as grout material in filling up of mines. Qi (2005) studied Red mud in highways as construction material. Jitsangian, P&Nikraz, H.R (2013) investigated Red mud with Fly ash and lime as base course material. He identified the optimum mix as 75% Red mud + 25% Fly ash + 5% Lime. Obtained

UCS in between 0.6 and 1MPa. Kahagia (2014) constructed roads with 97% RM and 3% of Fly ash. This pilot project is free from rutting, surface deformations and any erosion traces. Lima M.S.S (2015) used Red mud and Crusher dust as filler material.

## II. MATERIALS USED

### Red Mud

It is a waste product obtained from Aluminium plant during refining process of bauxite (ore of Aluminium  $Al_2O_3 \cdot 2H_2O$ ). It is also called as Bayer's process residue. It contains high number of compounds among those more frequent are Hematite, goethite, gibbsite, boehmite, calcite, calcium Aluminium hydrate, sodalite, Aluminium silicates and kaolinite. Red Mud highly complex material that differs due to the different bauxites used and the different parameters. Therefore, Red Mud should be regarded as a group of materials. It has characteristics like water suspension, alkalinity, high specific surface and fine particle size distribution.

### Cement

The cement used in this project work is OPC43 grade (Priya cement) which is collected from the local construction site.

### Red Mud + Cement

The collected Red mud and Cement are subjected to experimental program individually and in the later stage both of them blended in different proportions such as Red Mud with

### Curing

Four identical samples were prepared for their maximum density at optimum water content based on compaction curves obtained. The samples for various curing periods of testing, i.e.3, 7, 14 and 28 days are prepared. All the samples prepared were labelled according to the trial combination chosen. Samples were cured in desiccators and covered with moist cloth to maintain 100% humidity and prevent loss of any moisture from the samples. All the samples intended for immediate testing were tested after 2 hours.

### Unconfined Compressive Strength (UCS):

The samples modified with cement were examined for the strength in terms of Unconfined Compressive

Strength at different days curing such as 3,7,14 and 28. All samples prepared to their maximum dry densities at optimum water content presence. The prepared samples tested as per IS2720. A l/d (Length/ Diameter) ratio of 2 has been maintained while manufacturing the soil cylinders of red mud with cement.

### III. EXPERIMENTAL EXECUTION

Physical properties of Red mud Initial tests are carried out for the Characterization of Red mud and the results are shown in the following table

Table 1 Physical characteristics of red mud

S. No.	Property	Value
1	Appearance	Mud
2	Colour	Dark Red
3	Odour	Pungent
4	Texture	Fine
5	Specific Gravity	3.05
6	Specific Surface (m <sup>2</sup> /gm)	18
7	pH	10.3

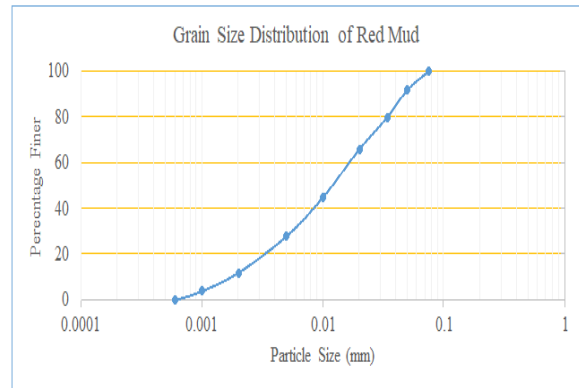
Table 2 Geotechnical Parameters of Red Mud

Sr. No.	Property	Value
01	Liquid Limit (w <sub>L</sub> ) (%)	32
02	Plastic Limit (W <sub>p</sub> ) %	24
03	Shrinkage Limit W <sub>s</sub> %	20
04	Plasticity Index I <sub>p</sub>	8
05	Optimum Moisture Content (%)	22
06	Maximum Dry Density (g/cc)	1.65
07	Coefficient of Permeability (cm/sec)	6.2*10 <sup>-7</sup>
08	Unconfined Compressive Strength (MPa)	0.15
09	Soaked California Bearing Ratio (%)	4

### IV. GRAIN SIZE DISTRIBUTION

The particle sizes that are present in the red mud are identified by performing the hydrometer analysis experiment. The obtained results manifested in the form of graph

Figure 1 Grain Size Distribution of Red Mud



Based on the test data it is identified that Red mud is a silt dominating industrial waste exhibited low compressibility, low plasticity characteristics. Considering the above test data, based on IS 1498-1970 it is classified under ML group as Silt particles of low Compressive nature.

From the grain size distribution of red mud it is identified that red mud contains 100% particles less than 75 μm (fines) out of which 88% is silt size particles (75 μm to 2 μm) and 12% is clay size particles (<2 μm). It is also identified that it has 20% of 75 μm - 34 μm range, 35% of 34 μm - 10 μm range, and 33% of 10 μm - 2 μm is 33% and 4% is less than 1 μm sizes majority of the particles are in the range of 50 μm to 5 μm.

### Cement

The Cement used in the present research work was collected from local Commercial market. The Brand of Cement used is RAMCO and Type of Cement is OPC43 Grade. The required Engineering Parameters such as specific gravity, normal consistency, compressive strength, Initial and final setting time were determined. The obtained values are shown below in Table

Table 3 Basic Properties of Cement

Sr. No.	Property	Value
01	Colour	Dark Grey
02	Texture	Fine
03	Specific Gravity	3.1
04	Normal Consistency (%)	31
05	Initial Setting Time (Minutes)	89

06	Final Setting Time (Minutes)		359
07	Compressive Strength MPa	3Days	26
		7 Days	37
		28 Days	48

V. INTERACTION OF RED MUD WITH CEMENT

Red mud is abundantly available in huge quantities and it requires large areas for disposal. So it is necessary to use this in various purposes especially in geotechnical engineering applications to minimize its adverse effects on environment but it is not suitable to use as upper layers of road pavements and foundation platforms for high intensity loadings because of low unconfined compressive strength and CBR values. In this aspect an attempt has been made to improve the characteristics of red mud in terms of unconfined compressive strength and CBR by stabilizing with various percentages of cement such as 2, 4, 6, 8,..... Up to 20% by dry weight of red mud as per IS 2720, PART – VII.

Compaction:

To know the compaction characteristics of Red mud with Cement, Modified proctor test was adopted and it's OMC, MDD values were determined as per IS 2720 part- VII. The experimental results are shown below in table 4 and figures 2 & 3.

Table 4 variation of compaction characteristics of red mud with cement content

Cement (%)	OMC (%)	MDD (g/cc)
0	22.000	1.650
2	22.500	1.660
4	23.200	1.680
6	24.000	1.700
8	25.000	1.710
10	26.200	1.720
12	27.200	1.730
14	28.000	1.740
16	28.800	1.750
18	29.500	1.760
20	30.000	1.770

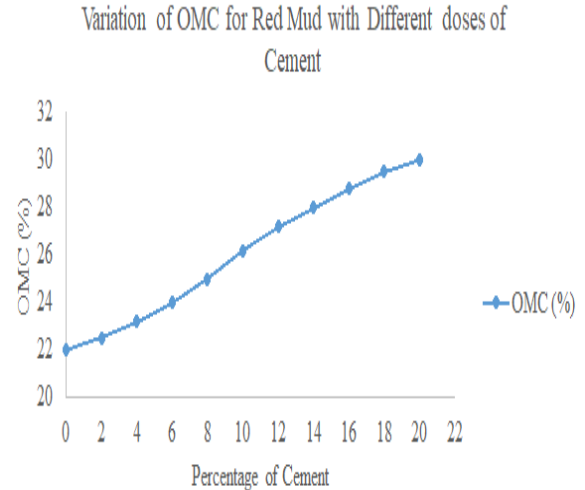


Figure 2 Variation of OMC for Red Mud with Different doses of cement

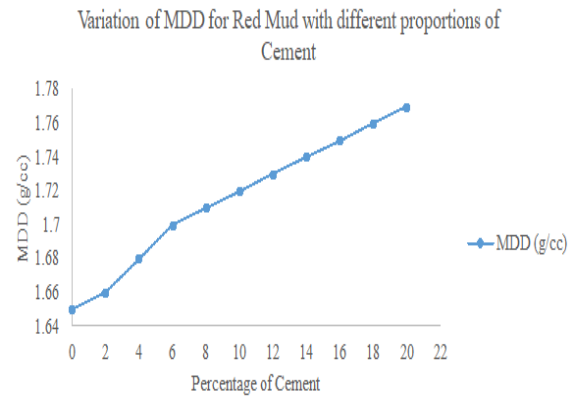


Figure 3 Variation of MDD for Red Mud with different proportions of Cement

From the test results the following observations are made. When the percentage of cement is increasing OMC values are steadily increasing from 22% to 30% and MDD values are also follows the same trend i.e. from 1.65g/cc to 1.77g/cc. Increase in OMC values are due to the requirement of more water is needed to coat the red mud and cement particles, because these are finer particles which have more specific surface and more water is required for hydration process. This phenomenon is continued when the percentage of cement is increased. Increase in MDD values is due to filling up of voids of red mud with cement mortar and further, cement motor binds these red mud particles effectively and make the red mud – cement matrix more cohesive and compacted under the given compaction energy.

Unconfined Compressive Strength (MPa) of Cement stabilized Red mud Mixes:

To know the strength of red mud stabilized with cement samples of 3.8cm diameter and 7.6cm length were prepared at various percentages of cement i.e 2,4,6,8,20 % and their maximum dry densities respectively and these samples were cured for 3, 7, 28 days in a Desiccator. After completion of their respective curing periods these samples were tested for unconfined compressive strengths as per IS2720, Part-10 for Unsoaked and soaked conditions and the results are shown in Tables and figures

Table 5 Variation of UCS values in MPa for red mud with cement mixes at different curing periods under moist curing (un-soaked)

Cement (%)	Curing period in days		
	3	7	28
2	0.340	0.648	1.085
4	0.682	1.414	2.082
6	1.000	2.137	3.004
8	1.320	2.743	3.824
10	1.582	3.064	4.528
12	1.765	3.434	5.132
14	1.886	3.846	5.836
16	2.040	4.528	6.542
18	2.162	4.924	7.035
20	2.286	5.218	7.582

Table 6 Variation of UCS Values for red mud with cement at different curing periods under moist curing (soaked)

Cement (%)	UCS (MPa)		
	3 Days	7 Days	28 Days
2	0.290	0.536	0.926
4	0.590	1.316	1.826
6	0.828	1.965	2.818
8	1.146	2.560	3.594
10	1.406	2.874	4.236
12	1.542	3.126	4.829
14	1.672	3.596	5.564
16	1.846	4.268	6.208
18	2.015	4.703	6.807
20	2.128	5.032	7.316

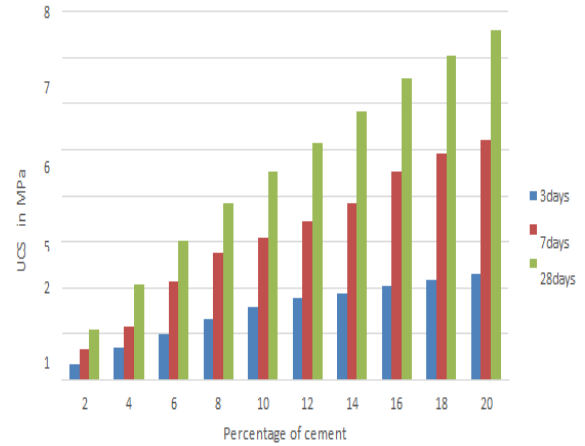


Figure 4 variation of UCS for red mud with cement mixes at different curing periods under moist curing (Unsoaked)

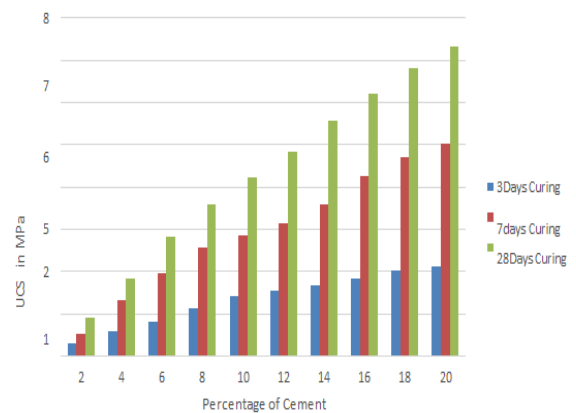


Figure 5 Variation of UCS for red mud with cement mixes at different curing periods under moist curing (soaked)

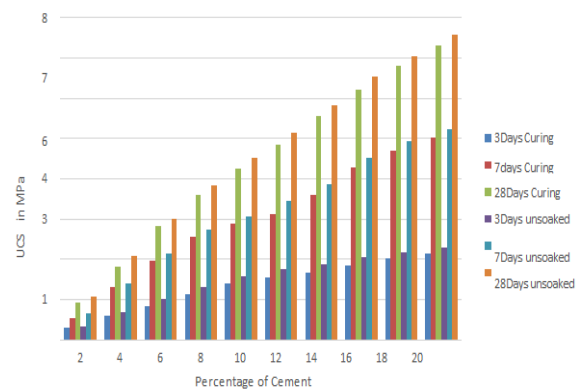


Figure 6 Comparison of UCS in MPa for Unsoaked and soaked samples at various curing periods From the test results it is identified that increasing the percentage of cement increase UCS values for all

curing days. High rate of increase of strengths are observed at early days of curing i.e. 3 and 7 days comparatively at 28 days, and high values are observed at 28 days as usual in the case of cement modified soil or soil - cements. The same trend was continued even after 10-12% addition of cement. Considering the UCS values of Red mud with cement in soaked condition are also following the same trend but these values are slightly less than Unsoaked values.

According to IRC-37,2012 the 7day strength of cement modified soil (material) with an UCS value of 3MPa can be considered as desirable dosage.

From the test results it is also seen that at 12% dosage the red mud – cement mixes in Unsoaked and soaked conditions achieved UCS values of 3.434MPa, 3.126MPa respectively for 7 days. Requirement of 12% of cement is needed to achieve high compressive strengths greater than 3MPa. Initially Red mud requires some amount of cement to reduce the negative charges due to the presence of particles of fine particles i.e., less than 2µm and adsorption of calcium cations (Ca<sup>+2</sup>) released from cement which adheres on to the particle surfaces of red mud. In addition to that development of initial and secondary reactions in formation of cementitious compounds such as C-S-H, C-F-H and C-A-H gels made the red mud particles to bind together in the form of flocculation structure and eventually leads to agglomeration also need more amount of cement. These modifications continuous with age and became hardened (crystalline form) which helps in enhancement of strengths. Hence Red mud –cement mixes need high quantities of cement to attain received strengths.

VI. REGRESSION ANALYSIS FOR CEMENT MODIFIED RED MUD UCS VALUES

A linear regression analysis has been performed between the Dosage of cement and UCS values for both soaked and Unsoaked conditions. The equations developed for each curing separately then a combined equation was formed for dependent Variable Unconfined Compressive Strength by considering percentage of cement and curing period as independent variables.

The equations developed are shown in tables 4.4.2a), 4.4.2b)

Table 7 UCS Equations of Regression Analysis for Red Mud with Cement mixes at different curing periods

S. No.	Curing Period in Days	Regression Equation	Co-efficient of regression (R <sup>2</sup> ) value
01	03	UCS=0.105924242C+0.341133333	0.956662356
02	07	UCS=0.246466667C+0.484466667	0.98556245
03	28	UCS=0.355981818C+0.7492	0.990692114
04	For all curing periods	UCS=0.236124C+0.107747CP-0.83986	0.833998

Table 8 UCS Equations of Regression Analysis for Red Mud with Cement mixes at different curing periods (Soaked condition)

S. No.	Curing Period in Days	Regression Equation	Co-efficient of regression (R <sup>2</sup> ) value
01	03	UCS=0.100972727C+0.2356	0.974550873
02	07	UCS=0.239539394C+0.362666667	0.986412005
03	28	UCS=0.351C+0.5514	0.99218949
04	For all curing periods	UCS=0.23050C+0.104407CP-0.93927	0.83015

C= Cement in percentage, FA= Fly Ash in percentage, P= curing period in days

The above tables manifested the equations of Regression to predict the Unconfined Compressive Strength Values. The developed equations are in accordance with the attained strengths to the samples from the laboratory. This is evident in the form of Co-efficient of Regression (R<sup>2</sup>) values.

## VII. CONCLUSIONS

- The Red Mud can be treated as the Silt with low plastic soil ML as per the Grain Size Distribution.
- Red mud obtained high maximum dry density as 1.65g/cc, high angle of shearing resistance as  $36^{\circ}$  and soaked CBR as 4
- The values of both OMC and MDD were increased upon increase in cement addition.
- Optimum Characteristics were attained at 7- and 28-Days curing period for all combination of samples
- Addition of cement to Red mud increases UCS values with curing time. At 4% of cement 1.5 MPa and 2.08 MPa for 7 days and 28 days respectively, at 10% of cement 3.06MPa and 4.53 for 7 days and 28 days respectively. At higher percentages of cement i.e 12% these values are 3.4 MPa and 5.1 MPa for 7 and 28 days respectively.
- Cured cement mixed red mud samples ventilated the better results than
- Red Mud can be used in the Flexible Pavement Constructions as one of the component layer such as Sub base or base course. This has been proved in terms of the CBR values obtained to 7 and 28 Days Cured samples.
- The trend followed by the cement modified mixes as a result of Unconfined Compressive Strength has been manifested in terms of Regression Analysis equations and these indicated that the obtained results are satisfactory.
- The prediction analysis of the Regression Equations was close to the acquired experimental findings.

Evaluation of Characteristic properties of red mud for possible use as A Geotechnical Material in Civil Construction. International Journal of Advances in Engineering & Technology, ISSN:22311963. July, Vol.7, Issue 3, pp 1053- 1059.

- [4] Saxena, A. K., Jain, P. K., & Jain, R. (2013). Application of machine learning techniques to predict soaked CBR of remoulded soils. International Journal of Pavement Engineering, June 2013.
- [5] Bhatt, S., & Jain, P. K. (2014). Prediction of California Bearing Ratio of soils using artificial neural network. International Journal of Engineering Research and Technology, 3(6).
- [6] Shirur, N. B., & Hiremath, S. G. (2014). Establishing relationship between CBR value and physical properties of soil. IOSR Journal of Mechanical and Civil Engineering, 11(5), 26–30.
- [7] Srinivasa, R. H., Naagesh, S., & Gangadhara, S. (2016). Development of regression equations to predict C.B.R of black cotton soils of Karnataka, India. International Journal of Geotechnical Engineering.
- [8] IS2720 Testing of Soil Samples in the Laboratory

## REFERENCES

- [1] Amritphale, S.S and Patel, M. (1987).” Utilization of red mud, Fly ash for manufacturing Bricks with pyrophyllite. ” Silicates industrials, Vol.52, Nos.3-4, pp.31-35
- [2] Chaddha MJ, Rai SB, Goyal RN (2007)., ENVICON 2007, national seminar on environmental concern and remedies in Aluminium industry at NALCO, Damanjodi, India, 27-28<sup>th</sup> Jan., 2007. characteristics of red mud of Indian alumina plants and their possible utilization:41-44
- [3] Deelwal K Dharavath K.,Kulshreshtha M., (2014).