Experimental Study on Partial Replacement of Cement by Red Mud in Concrete

J. Shankar[1], Dr. N. Victor Babu[2]
[1, 2] Department of Civil Engineering
[1, 2] BITS, VIZAG, Andhra Pradesh, India

Abstract- *The generalized Process for the production of alumina from Bauxite ore is characterized by low energy efficiency and it results in the production of significant amounts of dust-like, high alkalinity bauxite residues known as red mud. Disposal of large quantities of red mud a solid waste generated at the Aluminum plants all over the world possess an increasing problem of storage, land cost and availability and pollution. Because of the complex physical-chemical properties of red mud it is very challenging task for the designers to find out the economical utilization and safe disposal of red mud.*

Presence of soda in the red mud which when used in clinker production neutralizes the sulfur content in the pet coke that is used for burning clinker enrooted cement production and adds to the cement's setting characteristics. Based on economics as well as environmental related issues, enormous efforts have been directed worldwide towards red mud management issues i.e. of utilization, storage and disposal.

Different avenues of red mud utilization are more or less known but none of them have so far proved to be economically viable or commercially feasible. Experiments have been conducted under laboratory condition to assess the strength characteristics of the red mud. The project work focuses on the suitability of red mud obtained for construction. Five test groups were constituted with the replacement percentages 0%, 10%, 15%, 20% and 30% of cement by red mud in concrete. To achieve Pozzolanic property of red mud, hydrated lime was added. This paper points out another promising direction for the proper utilization of red mud.

I. INTRODUCTION

Cement in general the most widely used cementing ingredient present day concrete comprises phases that consisting of compounds of calcium, silicon aluminum, iron and oxygen. Characteristics of concrete depend upon the properties of its ingredients, on the proportion of mix, the method of compaction and other controls during placing, compaction and curing. For constructional purposes the meaning of the term cement is restricted to the bonding materials used with stones, sand, bricks, blocks etc. Cement is the most important material in structural constructions as it is used at different stages of construction in the form of mortar or concrete. Concrete is most popular engineering material in the field of civil engineering. It is an artificial compound generally made by mixing of binding material, fine aggregates, coarse aggregate, water and admixtures in suitable proportions. The matrix is usually 22-34% of total volume. Freshly mixed concrete before set is known as wet or green concrete whereas after setting and hardened concrete. The moulded concrete mix after sufficient curing becomes hard like stone due to chemical actions between the water and binding materials. The increased demand for the usage of the huge quantity of concrete leads to increase in cost of the binding materials (cement) and depletion of natural sources of fine aggregate which i turn increase cost of concrete. This prompted Civil Engineering to use Red Mud, as a partial replacement material for cement.

INDUSTRIAL SOLID WASTE AND ITS PRODUCTS

There have been many industries produce the solid waste which effects on the environment. Generally the major solid waste from the industries are Red mud, fly –Ash, phospho-gypsum and steel and furnace slags, brine mud, copper slag, kiln dust, lime sludge and mica copper waste(Sawant et. Al.,2013) which have more effect on the environment some time the waste can be best alternative for conventional materials used like red mud. Red mud is an industrial waste produced by the Bayer's process of Aluminum extraction.

ALUMINA GENERATION

Production of aluminum metal in the public sector unit namely National Aluminum Company Ltd. (NALCO) and private sector units namely Bharat Aluminum Company Limited (BALCO) {which has 49% Central Govt. equity}, Hindustan Aluminum Company Ltd.(HINDALCO) and Madras Aluminum Company Ltd.(MALCO) in the country during the month of January 2008 was mentioned in table (Sawanth,B.Kumar et.al 2013).National Aluminum Company Limited sold 91,352 tons of alumina/hydrated and exported

6,972 tons of aluminum during the month of January, 2008. The nation's solid wastes are increasing and posing a severe threat to the environment.

PRODUCTION OF ALUMINA IN INDIA

The worldwide alumina production is around 58 million tons in which India counts for 2.7 million tons (Haresh krushna suthar et al., 2014). The Indian aluminum sector is characterized by large integrated players like Hindalco and National Aluminum Company (Nalco, Alumina plant at Damanjodi, Orissa), and the newly started Vedanta Alumina Ltd (Alumina plant at Lanjigarh, Orissa). The other producers of alumina include Indian Aluminum Company (Inda having two plants at Belgaum, Karnataka and Muri, Jharkhand), now merged with Hindustan Aluminum Company (Hindalco, Renukoot, Uttar Pradesh), Bharat Aluminum (Balco) and Madras Aluminum (Malco) the erstwhile PSUs, which have been acquired by Sterlite Industries. Consequently, there are only three main primary metal producers in the sector namely Balco (Vedanta), National Aluminum Company (Nalco) and Hindalco (Aditya Birla Group).

The procedure of alumina generation which produces Red Mud waste

- Aluminum or alumina is produced by BAYER process.
- In the Bayer process, bauxite is digested by leaching it with a hot solution of Sodium hydroxide, NaOH, at 106-240°C and at 1-6 Atm pressure.
- This converts the aluminium minerals into tetrahydroxidoaluminate Al (OH)4, while dissolving in the hydroxide solution.
- The insoluble compounds (Silica) are separated by settling and the decant solution is further clarified by faltering off remaining solid impurities.
- The waste solid is washed and filter pressed to regenerate caustic soda and Red mud presenting a disposal problem.
- The hydroxide solution is then cooled and the dissolved aluminum hydroxide Precipitates as a white, fluffy solid.
- When heated to 1050°C (calcined), the aluminium hydroxide decomposes to alumina giving off water vapour in the process.
- A large amount of the alumina so produced is then subsequently smelted in the Hall Heroult process in order to produce aluminium.

II. OBJECTIVES OF WORK

Basically this paper is based on the dissertation work carried out to overcome the problems created due exhaustion and obsolescence of raw material required for manufacturing of conventional building material and also minimize the thrust of Industrial waste on the environment by utilizing the same in the Construction Industry. Some other objectives are;

- Planned exploitation of waste materials essentially helps to maintain ecological balance. The successful utilization of a waste material depends on its use being economically competitive with the alternate natural material.
- The development of alternate low-cost and ecologically suitable building materials from agricultural and industrial wastes is an economic necessity.
- The use of industrial wastes in place of conventional raw materials will help to decrease the environmental pollution and also conserve our natural resources.
- Conventional building materials such as bricks, cement, lime and their derivatives are becoming increasingly uneconomical because of obsolescence, exhaustion of raw materials, low plant efficiencies and over-whelming costs.

III. EXPERIMENTAL METHODOLOGY

- In order to achieve the above task and to verify the assumptions made general objectives is divided into the following stages. The research studies comprises of following stages:
- **Stage1:** Literature survey of red mud, previous research of concrete based on the Red Mud and effects on the important properties of concrete such as workability and strength will be studied.
- **Stage 2:** In this phase concrete samples will be prepared in laboratory. Specimens will be cast for testing the compressive strength of concrete. After 7, 14 and 28 days the compressive strength of these specimens will be computed. Ratio of mix design is constant as 1:1:2 for M25 Of characteristic compressive strength 25 N/mm2. These results will be used to find the variation in strength of concrete by using different proportion (10%, 15%, 20% and 30%) of red mud with respect to ordinary Portland cement tests will be conducted within estimated time.
- **Stage 3:** Experimental work will be executed, taking into consideration the physical properties of constituent's materials. Laboratory tests and results are reported. Analysis of test results and observations are drawn, all results are completed in the required formats. Based on this comparative study of this experimental work, conclusions and recommendations are presented in order to establish guideline for future.

IV. REVIEW OF LITERATURE

ManjurA.Shendure, MohitUphade and GaganChajjed (2009) They Studied and evaluate the effect on properties of self-compacting concrete using neutralized red mud. The flow

characteristics of self-compacting concrete using neutralized red mud was measured from J-ring test, V-funnel test, U-box test, L- box test, J-Ring test. Also the strength properties of self-compacting concrete using neutralized red mud like compressive strength and these properties are compared with ordinary concrete strength and normal self-compacting concrete and attempt has been made to study the effect of replacement of cement with Neutralized Red Mud and performance of concrete using it. They concluded that up to 15% replacement of red mud, the targeted strength was obtained

Daniel verasribeiro, Joao Antonio labrincha (2010) They Suggests that non-calcinated red mud is an interesting constituent for use in mortars and concretes for non-structural applications, partially replacing the cement in the mixture. Formulations prepared with a fixed amount of mixing water and with increasing amounts of red mud tend to set quickly due to the fineness of the waste material and its composition. The mechanical strength diminishes with increasing proportions of red mud in place of cement, but mortars prepared with a 50% substitution still show suitable strength for non-structural applications. The red mud recycling alternative proposed here appears to be technologically viable.

Ramesh et al., (2010) According to Ramesh and Rathod reports the view of this work was to investigate the possibility of replacing the Portland cement by red mud. Because of storing issues, the waste negatively affects the environment. To solve this problem, Portland cement was replaced up to 30 % Red Mud by wt. of cement. And evaluating its compressive and splitting tensile strength of red mud concrete. This study examines the effects of red mud on the properties of hardened concrete. The test results show that how its compressive strength & splitting tensile strength decreases with increase red mud content, it is concluded that Optimum percentage of the replacement of cement by weight is found to be 25%.By this percentage replacement we can have strength is equal to the strength of controlled investigations on optimum possibility of replacing cement partially by red mud in concrete.

D. Linora Metilda, C. Selvamony, R. Anandakumar (2012) The main objective the of this concept was to investigate the possibility of partially replacing Portland cement in concrete by red mud and evaluating its compressive and splitting tensile strength. This study examines the effect of red mud on the properties of hardened concrete and compares with the conventional concrete. The test results revealed that 15% of cement can be optimally replaced by red mud beyond which compressive strength and flexural strength starts decreasing. Cement replacement by red mud up to 15% yields characteristics strength than the conventional cubes. Further increase in percentage of red mud by 20, 25 and 30% tends to decrease the compressive strength. However the optimum replacement level was observed as 15% without decrease in strength.

V. CHEMICAL AND MINERALOGICAL CHARACTERISTICS OF RED MUD

No matter what the production process is, the chemical composition of red mud contains six major constituents, Chemical analysis shows that red mud contains silicium, aluminium, iron, calcium, titanium, sodium as well as an array of minor elements namely K, Cr, V, Ba, Cu, Mn, Pb, Zn, P, F, S, As and etc. The variation in chemical composition between red muds worldwide is high.

COMPOSITION OF RED MUD

Composition	Weight%
Fe_2o_3	37
Al_2o_3	16
Sio_2	22
Na_2o	4
Cao	6
Tio_2	Trace-25%

The collected red mud was first sun dried, and then it was neutralized using sea water. After that the sample was again dried in hot oven. The moisture was removed from the red mud sample. It was pulverized into powder, the powder was sieved through the 90µ IS Sieve.

PHYSICAL PROPERTIES OF RED MUD

The red mud was replaced in place of cement in concrete in the ratio of 10%, 15%, 20% and 30%.Very fine red mud powder passing from 150 mm was used in this process.

Physical Properties of Red Mud

Sl. No	Property	Remarks
1	Particle Size	less than 44 microns
2	Appearance & Odor	Red, Earthy odor, slight pungent
3	pH	11 to 12

EFFECT OF RED MUD ON ENVIRONMENT

In the last decade, the production of aluminum in spite of some Stagnancy and even set back periods, has shown a steady rise of about 1%.The ecological consequences of aluminum production are well known land devastation by bauxite exploitation usurpation of big land areas by erection of disposal sites for red mud, threatening of surface &underground water & air pollution by waste gases from aluminum electrolysis plant & rolling mills. The degree of damage inflicted to ground water & air during the single production stages from bauxite to aluminum depends on a couple of tact's of which those connected with the alumina winning & red mud disposal

SOURCE OF RED MUD AVAILABILITY

BHUBANESWAR

Vedanta Aluminum Ltd (VAL) has commissioned a red mud powder producing unit at lanjigarh refinery in Odessa describing it as first of its kind in alumina industry tackelingmajor environmental hazards.

The unique project of producing red mud powder has been commissioned in a fully mechanized and automatic plant. The system has been developed in-house after continuous research for more than three years, a senior company official said in a statement today. This will have advantages like savings in caustic consumption by 10-15 kg per ton of alumina, minimizing land requirement by 50 to 60 per cent, and doing away with wet red mud storage thereby eliminating environmental hazards. Red mud is a waste from alumina industry and its disposal and utilization has always been a matter of concern for environmentalists as well as alumina industry.

Although, the alumina technology is more than 100 years old but no solution could be evolved by the industry to avoid storage of red mud slurry As the slurry is alkaline in nature and its generation is nearly one and a half times of alumina, world over millions of tons of red mud is lying in various red mud ponds except in some countries where it is discharged into the sea. In any alumina refinery, a major portion of land is used for handling this waste. Although, red mud is rich in iron and titanium, no use could be made till now mainly due to presence of caustic soda.

Mix Design for M_{25} Graded Concrete

5.4.1 Design – Stipulation

1. Grade Designation :M_{25}
2. Maximum size of aggregate : 20 mm angular
3. Degree of Workability:: 0.8
4. Standard Deviation : 5%

5. Type of Cement :OPC 53 Grade confirming
6. Specific Gravity
   i. Cement :3.21
   ii. Fine Aggregate : 2.67
   iii. Coarse Aggregate : 2.78
7. Bulk Density
   i. Fine Aggregate (gm/cc) : 1.537
   ii. Coarse aggregate (gm/cc) : 1.663
8. Fineness Modulus :2.926

CALCULATION OF MIX DESIGN ANALYSIS (AS PER IS-10262)

Step 1: Calculation of target strength

Characteristics Compressive strength of concrete at 28 days = 25 N/mm^2
f_{ck}= 25 N/mm^2
Target Strength, $f'_{ck}= f_{ck}+ 1.65(s)$

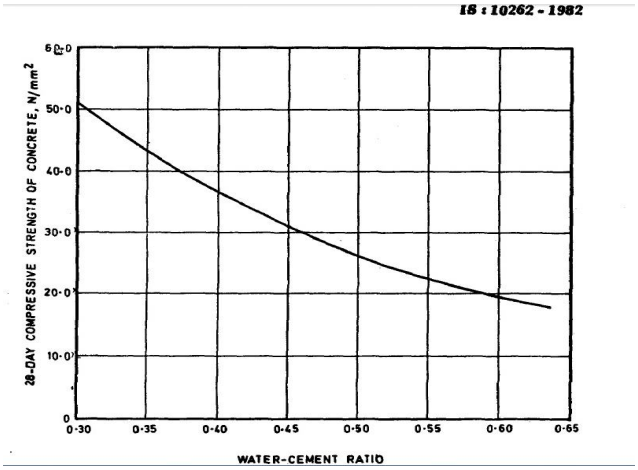
Where

f'_{ck} = target average compressive strength at 28 days
f'_{ck} = characteristic compressive strength at 28 days
s = standard deviation

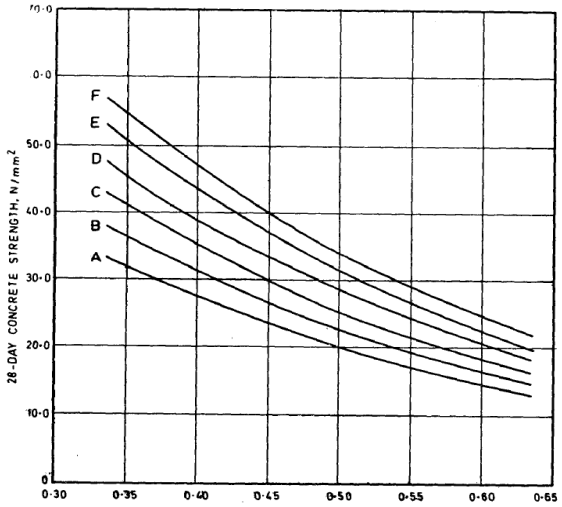
Standard deviation (s) from table (1) IS 10262
For M_{25}, s = 4.3
$f'_{ck}= 2.5+ (1.65*4.3)$
f'_{ck} = 32.095 N/mm^2

Step 2: Selection of w/c Ratio

Selection of w/c ratio from curves



From the above graph the W/c ratio = 0.43



Water Cement Ratio's

The water cement ratio obtained from curve is 0.43.

A = 31.9-36.8 N/mm^2
B = 36.8-41.7 N/mm^2
C= 41.72-46.6 N/mm^2
D= 46.52-51.5 N/mm^2
E=51.52-56.4 N/mm^2
F=56.42-61.3 N/mm^2

Step 3: Estimation of Air Content

According to IS 10262 – 1982
Nominal maximum size of aggregate i.e. 20 mm – 2%

Step 4; Estimation of Water Content

According to IS code 10262 – 1982
The approximate water content and sand content for concrete grades upto M_{35}
Maximum size of aggregate = 20 mm
Weight of water content = 186 kg.m^2
Note: From table maximum water content for MSA 20 mm aggregate is 186 litres up to 50 mm and w/c ratio 0.43

Step 5: Estimation of Cement Content

W/c ratio = 0.43
Water used = 186
Cement content = 186/0.43
= 432.55kg/m^3

Calculation of aggregate content as per IS 10262-1902.

$$V= (W +\frac{C}{SC} + \frac{1}{P} * \frac{fa}{sfa}) * \frac{1}{1000}$$

And

$$V = \left[W + \frac{C}{SC} + \frac{1}{1-P} * \frac{ca}{sca}\right] * \frac{1}{1000}$$

Where,

V = absolute value of fresh concrete – entrapped air content

= 1-0.02

= 0.98m

W = 186 litres = mass of water

C = 432.55kg/m^3

S_c = specific gravity of cement

= 3.21

P = 0.231

Now, (For Fine Aggregate)

$$1\text{-}0.02 = (186 + \frac{432.55}{3.21} + \frac{1}{0.315} * \frac{fa}{2.67}) * \frac{1}{1000}$$

Or, 0.980 = (186 + 134.75+1.18 f_a)

F_a = 558.68 kg/ m^3

For Coarse Aggregate

$$0.98 = (186 + \frac{432.55}{3.21} + \frac{1}{1-0.315} * \frac{Cag}{2.78}) * \frac{1}{1000}$$

980 = 186 + 134.75+ 0.52 C_{ag}

C_{ag} = 1267.78 kg/m^3

Now,

Cement = 432.55 kg/m^3

Fine aggregate = 558.68kg/m^3

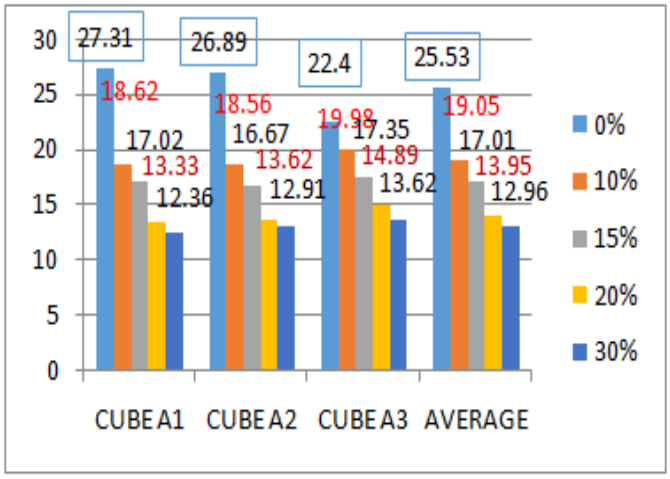
Coarse aggregate = 1267.78 kg/m^3

Ratio = 1:1.29:2.93

Or 1:1.3:3

VI. RESULTS AND DISCUSSIONS

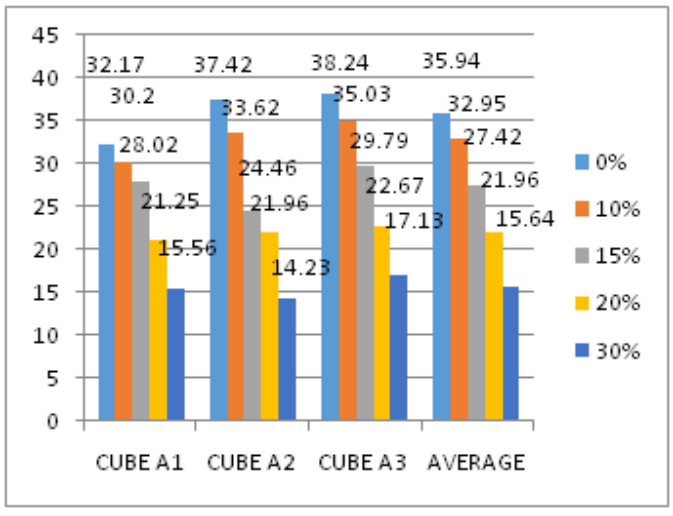
7 Days compressive strength of OPC and 10%, 15%, 20% and 30% replacement of cement.



Tensile strength test

SL. NO	CUBES SIZE	TENSILE STRENGTH N/mm²				
		OPC (0 %)	10 %	15 %	20 %	30 %
1	150mmx150 mmx150mm (A1)	2.49	2.34	2.28	2.20	2.08
2	100mmx100 mmx100m(A2)	2.55	2.30	2.24	2.22	2.12
3	100mmx100 mmx100m(A3)	2.51	2.36	2.26	2.19	2.14
4	AVERAGE	2.5	2.33	2.26	2.20	2.11

S No.	CUBES SIZES	COMPRESSIVE STRENGTH N/mm²				
		OPC (0%)	10%	15 %	20 %	30 %
1	150X150X150(A1)	27.31	18.62	17.02	13.33	12.36
2	100X100X100(A2)	26.89	18.56	16.67	13.62	12.91
3	100X100X100(A3)	22.4	19.98	17.35	14.89	13.62
	AVERAGE	25.53	19.05	17.01	13.94	12.96



VII. RESULTS AND DISCUSSIONS

The percentage economy increased with the increase in the grade of concrete but at the same time there is a reduction in the percentage increase in the compressive strength.

1. When expressing compressive strength versus water cement ratio we can find relatively good linear relationship which indicating that red mud may just function as inter filler and has no cementations effect for contribution to the strength development.
2. The red mud was received in the form of a paste containing about 40% free water. In the present work the material was dried and crushed and then used as a powdered additive.
3. Beyond 10% replacement of cement by red mud the setting time are increased.
4. Red mud cannot be considered strictly an artificial pozzolan since it does not meet some requirements. This applies particularly to the mechanical strength of mixtures containing lime after 7 days of curing which is below standard required value.
5. The cost of M25 grade of concrete that is 15% replacement is around less than the conventional concrete with increase of compressive strength for 28 days.
6. The maximum compressive strength of concrete cube for M25 grade about 15% replacement of red mud in concrete for 28 days of curing is 29.79 N/mm2.
7. Considering all above points it is interesting to say that the optimum utilization of red mud in concrete is 15% as partial replacement.
8. Considering all above points it is interesting to say that the optimum utilization of red mud in concrete is 15% as partial replacement.

VIII. CONCLUSIONS

1. The compressive strength of concrete is initially increases and then decreases due to increasing of red mud.
2. Optimum percentage of the replacement of cement by weight is found to be 15%.By this replacement the results were obtained nearly equal to the results of controlled concrete.
3. The prepared concrete by using red mud is suitable in ornamental works which will gives aesthetic appearance.
4. The workability of concrete will get affected due to increase of red mud it can be developed by mixing of super plasticizers.
5. We use mixture of red mud & cement for non-structural work. There is future scope for the use of red mud concrete in structural point of view.
6. As red mud is very cheaper than cement, the cost of concrete also decreases up to 15% replacement of cement.
7. As the slump cone value of smaller, the red mud concrete is suitable for road construction like cement road pavements.
8. Red mud did not affect the cement properties it will improved the cement quality by decreasing the setting time and improved compressive strength.
9. Red mud is used for road construction material as embankment landfill with high energy and large volume reuse
10. The physical properties of red mud are affected by calcinations process in which the surface area and unitary mass decreases when the specific gravity increases.

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