Effect of Curing on Strength Characteristics of Red Mud-Fly Ash Mixes

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Abstract

Inherent and advantages of industrials waste with respect to their bulk quantities, non plastic and pozzolanic nature increases the engineers to select these wastes as alternative in place of natural soils. The present study mixes of Red mud and Fly ash were prepared and tested for compaction, strength and CBR characteristics. These mixes are also exposed for curing periods. Based on the above test results Red mud-Fly ash mixes with respect to strength can be explained.

Keywords : *Industrial waste, CBR, Strength*

I. INTRODUCTION

Construction of structures requires good bearing materials. Some of the soil grounds are not good enough with respect to strength and settlement in saturated condition. When these grounds are loaded excess deformation is going to takes place. To avoid these grounds and to reduce cost of construction with respect to ground modification searching for alternative materials is necessary. Red mud and Fly ash are come under these category. Red mud is an industrial waste obtained from aluminium industry and its annual production is 65 tons. Whereas Fly ash is also an industrial waste obtained from thermal power plants. To reduce the cost of construction and increasing the durability of the structures, introduction of alternative materials is necessary some of the earlier researchers have done their research on Fly ash and Red mud individually and the combination of these two also. In the present work Red mud and Fly ash were mixed at various proportions such as 10-100 and vice-versa. Tests like compaction, unconfined compressive strength, CBR were performed and analysed the suitability of construction material.

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. Hanumanth Rao. C.H.V (2012) studied the use of GGBS stabilized Red mud in road construction as sub-base and base course material. Satyanarayana. P.V.V (2012) studied the use of lime stabilized red mud in road construction as sub-base and base course materials. 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 to 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 with filler.

II. MATERIALS

A. Red mud

Red mud is a solid waste obtained from the Bayer's process during Aluminium production, which was collected from the Red Mud ponds of NALCO (National Aluminium Company), Damanjodi, Orissa, India. The collected Red Mud was dried and tested for various physical and geotechnical properties.

B. Fly ash

It is an unused product disposed from Thermal power plants. It is obtained during the process of burning of Coal from Thermal power plants. In the present study fly ash was collected from the NTPC (National Thermal Power Corporation) which is located at Parawada in Visakhapatnam, Andhra Pradesh. Collected Fly ash was dried and tested for required Physical and Geotechnical Parameters as per IS 2720.

III. EXPERIMENTS

Red mud and Fly ash samples were dried and the dried samples were tested for physical properties and engineering properties such as gradation as per IS2720-part-4-1985, consistency as per IS2720-part-5-1985, compaction as per IS2720-part-8-1983, shear strength as per IS2720-part-13-1986, CBR as per IS2720-part-16-1987, Seepage as per IS2720-part-17-1986, Swell as per IS2720-part-40-1977,and Compression characteristics as per IS2720-part-15-1986.

IV. RESULTS & DISCUSSION

To study the interaction between red mud an Aluminium industrial waste and fly ash this is a thermal power industrial waste. These are available in huge quantities and their utilization in bulk quantities in geotechnical applications such as roads, embankments and landfill liners are essential. In this connection red mud - fly ash mixes were prepared such as 90+10, 80+20 ….10+90. Red mud and fly ash mixtures were subjected to Geo technical characterization such as Consistency limits as per IS:2720, Part-V & VI and compaction as per IS:2720 part VII&VIII and the results are shown in the following figures and tables.

Table 1.0 Geotechnical properties of Red mud & Fly ash

Property	Values	
	Red mud	**Fly ash**
Physical Properties		
Colour	Dark Red	Grey
Texture	Fine	Fine
Grain Size Distribution		
Gravel(%)	0	0
Sand (%)	0	18
Fines (%)	100	82
a) silt (%)	88	52
b) clay (%)	12	30
Consistency Limits		
Liquid limit	32	32
Plastic limit	24	Non plastic
Plasticity Index	8	Non plastic
IS Classification	ML	ML
Specific Gravity	3.05	2.2
Compaction characteristics		
Optimum moisture content (%)	22	20
Maximum Dry density(g/cc)	1.65	1.28
Shear Parameters		
Angle of shearing resistance	32^o	33^o
California Bearing Ratio % (Soaked)	4	4

A. Geotechnical Characteristics of Red Mud:

1. Grain Size Distribution:

To determine the particle size distribution of red mud sample the dried red mud sample is washed through 75µm sieve from which coarse grained material(>75 µm) is sieved and the finer fraction(<75µm) is carried out for wet analysis (hydrometer analysis)as per IS:2720 Part - IV. The test results of grain size distribution is shown in fig 1.

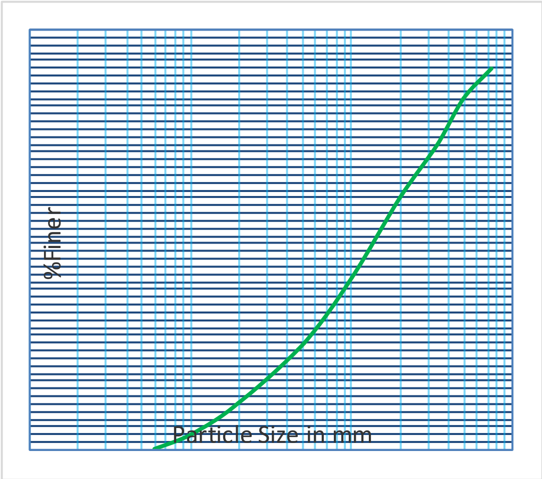

Figure 1:Grain Size Distribution of red mud

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

2. Compaction Characteristics:

Modified Proctor test was performed to develop the relationship between moisture content and dry density of Red mud and also to determine its optimum moisture content (OMC) and maximum dry density (MDD) as per IS 2720 part VIII and the test results are shown in figure:2

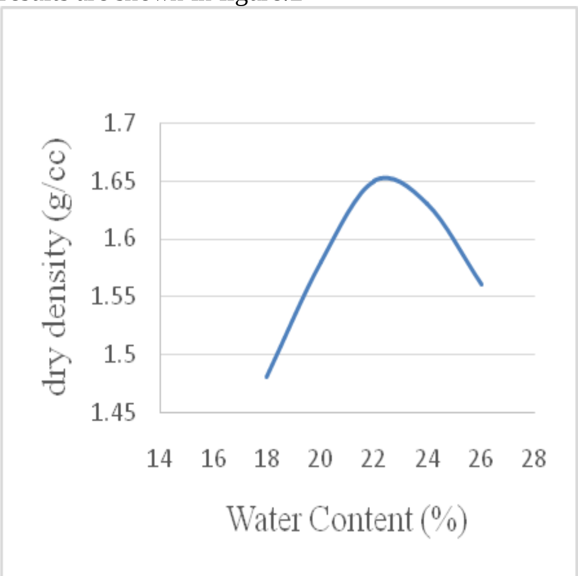

Figure2: Compaction curve for Red mud

From the test results OMC &MDD of red mud are found to be 22% and 1.65 g/cc respectively. Comparing the other industrial wastes such as fly ash, bottom ash, GGBFS, pond ash RHA and it is identified that red mud attained high maximum dry density and high optimum moisture content values. High MDD is due to presence of heavy elements such as Ferric oxides and other heavy elements. It is also due to occupation of more number of solids in the volume under a given compaction energy. High OMC is due to dominance of silt and other lower size particles which increases the fineness and the specific surface of the matrix along with the shape of particles. Therefore Red mud need more water to attain effective packing under a given compaction energy.

3. Chemical Composition:

To know the chemical composition Red mud was exposed under Energy Dispersive spectroscope the following results are obtained

Table 2 Chemical composition of red mud

Compound formula	Percentage
Na_2O	7.75
Al_2O_3	22.84
SiO_2	19.84
CaO	1.24
TiO_2	7.87
V_2O_5	0.68
FeO	39.32
ZnO	0.45

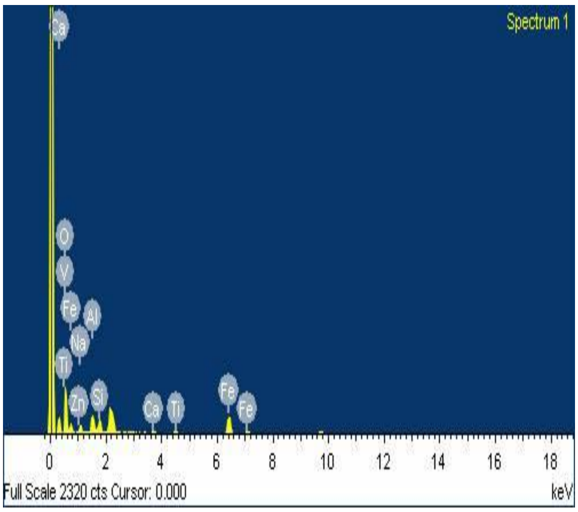

Figure 3: composition of elements in red mud

B. Geotechnical Characteristics of Fly ash:

1. Grain Size Distribution:

To determine the particle size distribution of Fly ash sample the dried red mud sample is washed through 75μm sieve from which coarse grained material(>75 μm) is sieved and the finer fraction(<75μm) is carried out for wet analysis (hydrometer analysis)as per IS:2720 Part - IV. The test results of grain size distribution is shown in fig 4.

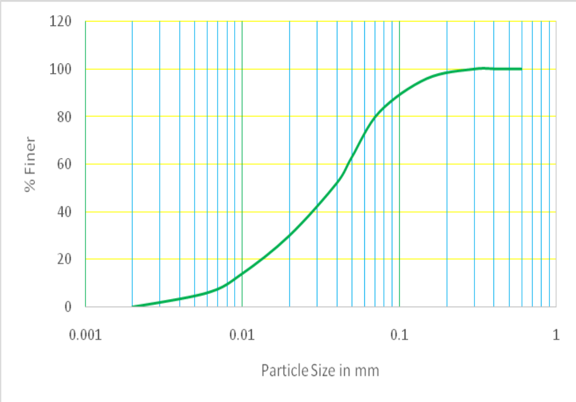

Fig 4: Grain Size distribution of Fly ash

The Particle Size distribution of Fly ash represents that it is Fine-grained material and it consists of 82% of Silt size particles, remaining 18% is sand Size particles and Clay size particles are absent. Majority of the particles are in the range of 20µm to 75µm. Among all the particles 60% of particles are less than 45µm which are very much useful in improving pozzolanic activity. In that half of the particles i.e. 30% are less than 20µm so that it can play a vital role in enhancing the compressive strengths of the mixes.

2. Compaction Characteristics:

Modified Proctor test was performed to develop the relationship between moisture content and dry density of Fly ash and also to determine its optimum moisture content (OMC) and maximum dry density (MDD) as per IS 2720 part VIII and the test results are shown in figure:5.

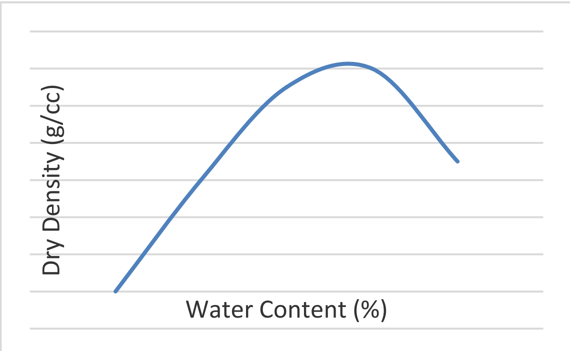

Figure 5:Compaction curve for Fly ash

From the test results of OMC & MDD of flyash are found to be 20% and 1.28 g/cc respectively. Fly ash secured high value of OMC is due to the presence of silt size particles especially >75µm size and further lower size (<45micron) particles are in major quantity so that the high specific surface attracts more water to coat the particles low value of MDD is due to occupation of less number of solids nature of particles (high volume ash) shape of particles (cenospheres), presence of light weight elements and i.e. low specific gravity.

3. Chemical Composition

To know the chemical composition and arrangement of particles the dry powder of fly ash was exposed under Scanning Electron Microscope and Energy Dispersive Spectroscopy.

Table 3 Chemical composition of fly ash

Compound	**Formula**	**Percentage (%)**
Silica dioxide	SiO_2	59.83
Aluminium trioxide	Al2O3	30.48
Calcium oxide	CaO	1.74
Magnesium oxide	MgO	0.86
Titanium oxide	TiO_2	6.91
Zinc oxide	ZnO	0.09

From the chemical composition it is identified that it has less percentage of CaO(1.74<15%) classified under Fly ash(ASTM) and presence of high percentages of $sio_2$and Al_2O_3 (90%) make the Fly ash pozzolanic with addition of lime, Cement and other additives.

C. Geotechnical Properties of red mud and fly ash mixtures:

Proportions of red mud- fly ash sample as mentioned above were tested to identify their index properties such as liquid limit, plastic limit and plasticity index. The values are as shown in below table 4.

Table 4 consistency characteristics of red mud with fly ash mixes

RM (%) +FA(%)	Liquid Limit (%)	Plastic Limit (%)	Plasticity Index (%)
100+0	32	24	8
95+5	29	24.5	4.5
90+10	27	25	2
85+15	NP	NP	NP
80+20	NP	NP	NP

Test results shows that increasing the percentage of fly ash decreases liquid limit and plasticity index values. Red mud is a low compressible material requires low quantities of fly ash (15%) to make the red mud to non-plastic. This nature of non-plasticity imparts the material to additional characteristics in terms of strength.

1. Compaction Characteristics

The fly ash stabilized red mud samples are also tested for OMC and MDD characteristics as per IS:

2720 part-VIII-1983 and the experimental findings are as shown in the following table 5 and figures6&7.

Table 5 Variation of OMC & MDD for red mud-fly Ash mixes

RM (%)+FA (%)	OMC (%)	MDD (%)
100+0	22	1.65
90+10	21.8	1.63
80+20	21.6	1.6
70+30	21.4	1.56
60+40	21.1	1.52
50+50	20.8	1.47
40+60	20.6	1.42
30+70	20.4	1.38
20+80	20.2	1.34
10+90	20.1	1.31
0+100	20	1.28

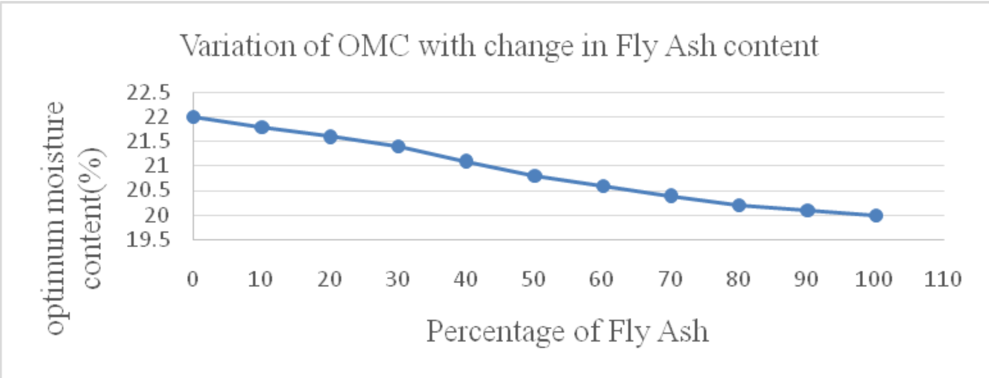

Figure 6: variation of OMC for red mud with fly ash mixes

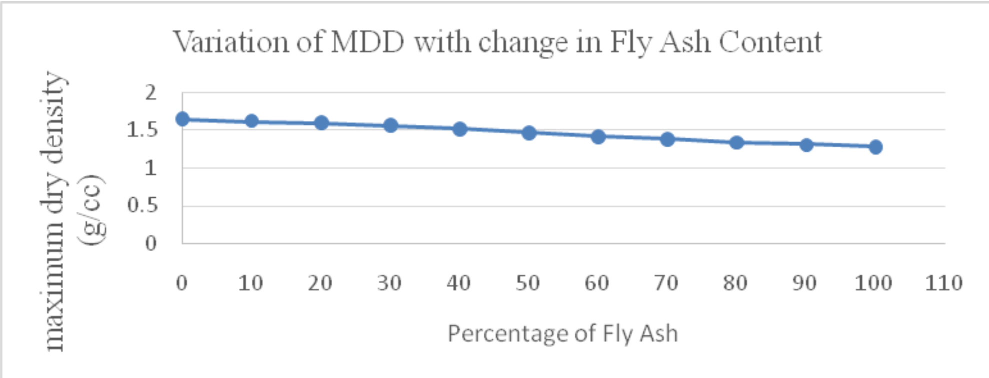

Figure 7: variation of MDD for red mud with fly ash mixes

From the test results it is identified that with the increase in the percentage of Fly ash, optimum moisture content values and maximum dry density values of Red Med and Fly ash mixes are decreasing which are less than OMC and MDD of individual Red Mud and are greater than that OMC and MDD of Fly ash. The decrease in the maximum dry density of composite materials is due to replacement of Red mud particles by fly ash particles and the weight of solids contributed by fly ash particles less than that of Red Mud particles. The decrease in OMC values is due to replacement of red mud particles by fly ash particles and the fly ash particles are also less in sizes than red mud particles which require less water to coat the particle due to less specific surface of fly ash particles compared to red mud particles.

2. Strength Characteristics

To study the interaction between Red Mud and Fly ash in terms of strength characteristics parameters such as unconfined compressive strength and California bearing ration test values are considered.

(a) Unconfined Compressive Strength (Mpa):

Samples of Red Mud and Fly ash mixes were prepared at their Optimum Moisture Contents by Compacting at their maximum dry densities with respect to their proportions such as RF1,RF2,RF3, .etc. and kept for curing in 3,7,28 days and tested for unconfined compressive strength as per IS 2720 part-10.

Table 6 variation of UCS of red mud with fly ash mixes

RM	RM (%) + FA(%)	UCS in (Mpa)		
		3 Days	7 Days	28 Days
RF_0	100+0	0.154	0.156	0.16
RF_1	90+10	0.19	0.195	0.2
RF_2	80+20	0.232	0.245	0.25
RF_3	70+30	0.27	0.275	0.28
RF_4	60+40	0.29	0.292	0.295
RF_5	50+50	0.255	0.258	0.26
RF_6	40+60	0.214	0.22	0.225
RF_7	30+70	0.188	0.192	0.195
RF_8	20+80	0.165	0.17	0.175
RF_9	10+90	0.144	0.148	0.15
RF_{10}	0+100	0.124	0.126	0.128

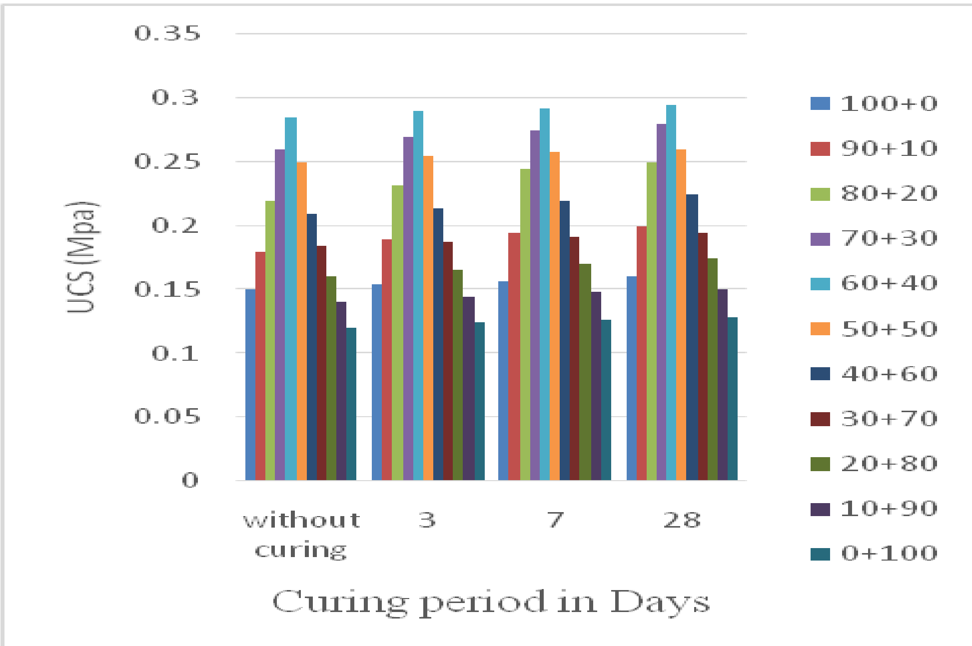

Figure 8 Variation of UCS for red mud with fly ash samples at different curing periods

From the test result the following identifications are made. Increasing the percentage of fly ash increases unconfined compressive strength value increases up to 40 % (RF_4) and then decreases. The increase in unconfined compressive strength values are due to better bond between red mud and fly ash particles. Red Mud and Fly ash particles are in the same Range of silt particles (0.075 mm to 0.002 mm) and comparatively Red Mud has small size particles than Fly ash particles make the interaction between these two stronger by filling up of voids by both fly ash and red mud particles make the red mud and fly ash mixes cohesive than individual red mud and fly ash particles mix.

(b) California Bearing Ratio (CBR):

To know the CBR values the samples were prepared at their optimum moisture contents and maximum dry densities w.r.t their proportion such as RF1, RF2, RF3 etc and cured for 1 day, 3 day, 7 day, 28 days and after compaction of curing period these samples were soaked for 4 days and tested for CBR values as per IS: 2720 Part-17. The test results are shown in the table 7and figure 9.

Table 7 variation soaked CBR values for red mud with fly ash mixes at different curing periods

RM (%) + FA (%)	CBR (%)		
	3 Days	7 Days	28 Days
100+0	5	5	5
90+10	6.5	7	7
80+20	8	9	9
70+30	9	10	10
60+40	10	11	11
50+50	9	10	10
40+60	8	9	9
30+70	7	8	8
20+80	6	7	7
10+90	5	6	6
0+100	4	4	4

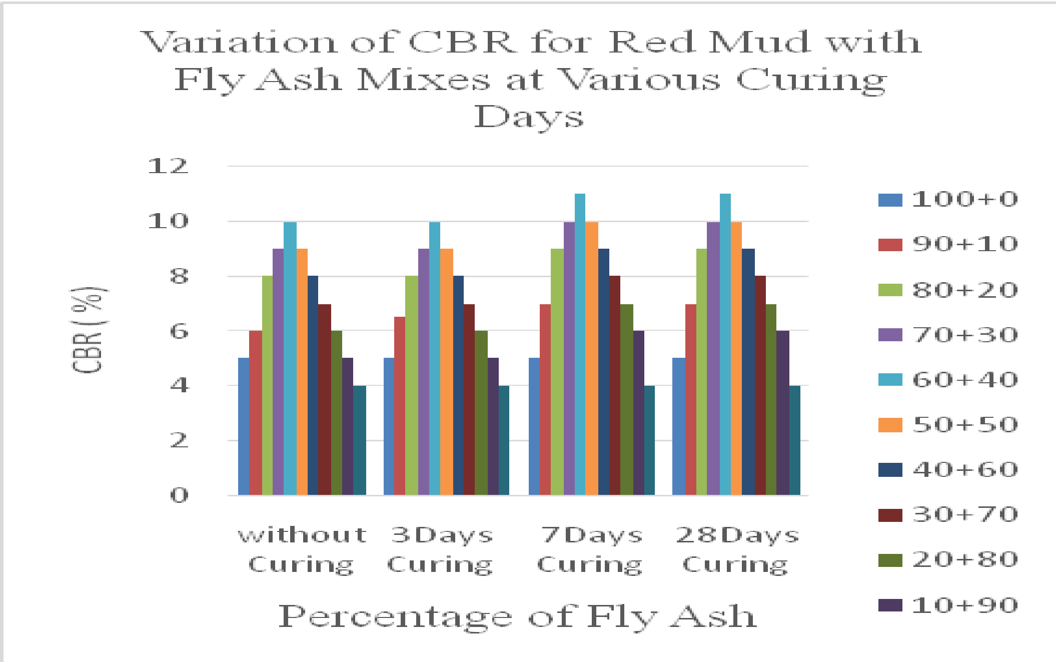

Figure 9 variation of soaked CBR for red mud with fly ash samples at different curing periods

From the test results of CBR shows that increasing the percentage of fly ash in the red mud- flyash mixes (R-F) increases CBR values up to 40% dosage and then decreases. CBR values are nominally increased w.r.t to curing period from 1day to 28 days. Maximum values attained at 40% flyash $(R\text{-}F)_4$ i.e., 10 – 11 for all curing periods, finally addition of fly ash with 28 days curing period increases CBR values of red mud from 4 to 11. The increase in CBR values are due to better bonding between red mud- fly ash mixes than individual red mud and flyash particles i.e. the range of red mud particles is75µm to 1µm and that of fly ash particles is 150µm to 75µm.

A marginal increase in CBR values is due to

- Formation weak cementation bonds between Red mud and fly ash particles.

- Non availability of free lime due to very less percentage of CaO in Red mud and fly ash particles
- Very less adherence of calcium ions on Red mud surface
- The net pH value of Red mud-fly ash mixes is decreasing and pH of the pore fluid is no sufficient to create an environment for the formation of cementitious compounds.
- These cementitious compounds are still amorphous with time.
- Finally Red mud-fly ash mixes offers less penetration resistance against loading.

Decrease in CBR values are due to

- Loss of bond between Red mud and fly ash particles,
- Decrease of the net amount of Red mud particles
- Decrease of pH values abnormally mixes are attaining slowly the behaviour of fly ash
- pH of pore fluid is not conduce to create environment of formation of effective cementitious compounds.

D. P^H TEST:

Red mud-fly ash mixes were tested for pH values to study the chemical behaviour. The variation in the values are as shown below

Table 8 variation of P^{H}values for red mud with fly ash mixes

Red mud-Fly ash mixes	Value of P^H
100-0	10.30
90-10	10.16
80-20	10.04
70-30	9.88
60-40	9.72
50-50	9.54
40-60	9.36
30-70	9.20
20-80	9.05
10-90	8.84
0-100	8.50

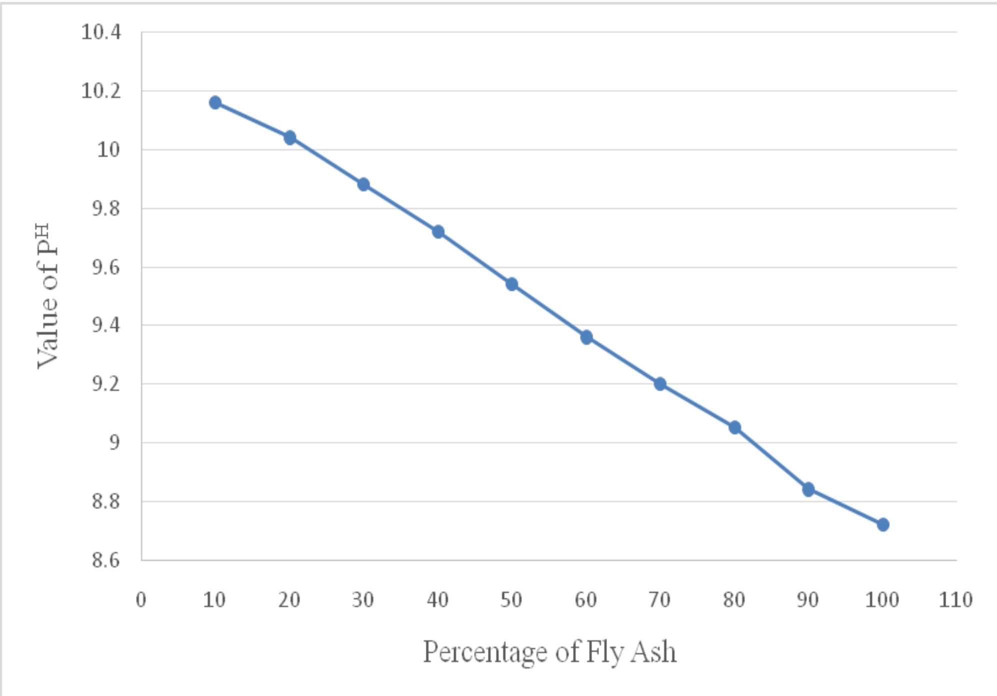

Figure 10 Variation of P^H values for red mud with fly ash samples

From the test results of red mud-fly ash mixes it is identified that pH values is decreasing with increasing the percentage of fly ash in the given Red mud-fly ash mixes. Individually pH of Red mud is 10.3 and that of fly ash is 8.5. increasing the percentage fly ash in the Red mud-fly ash mixes reduces pH value is due to the decrease of pH of the pore fluid because both the industrial wastes has minimum percentage of lime particles and Red mud particles are replaced by the fly ash particle. The net results is decrease of pH value since fly ash has less pH values comparatively with Red mud.

E. Scanning Electron Microscope

The red mud fly ash mixes placed under scanning electron microscope to check the variation in the particle arrangement. The magnified photographs are as shown below

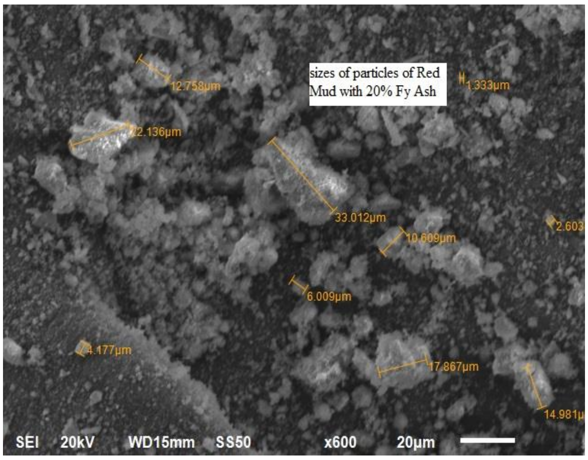

Figure 11 variation in the particle arrangement for RM+20%Fly Ash

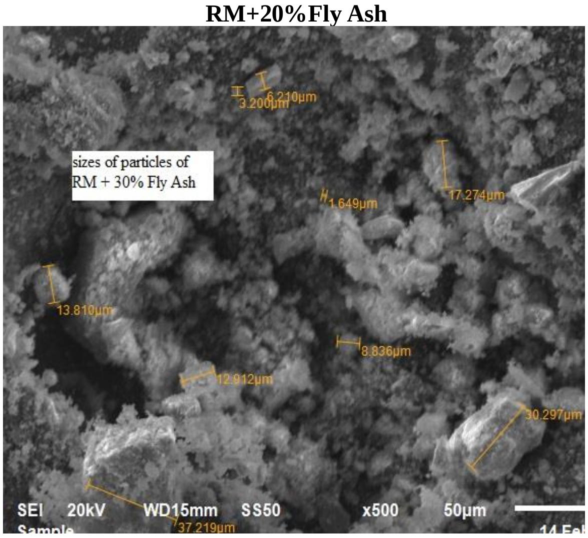

Figure 12 variation in the particle arrangement for RM+30%Fly Ash

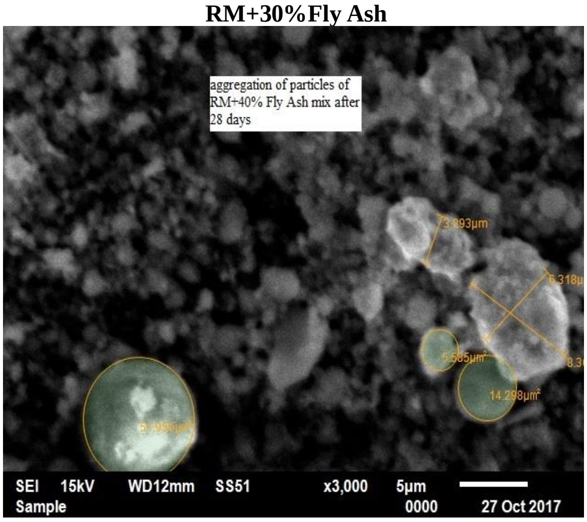

Figure 13 variation in the particle arrangement for RM+40%Fly Ash

V. SUMMARY

Test results of fly ash and red mud show that these are fine grained materials dominated by the particles in the range of 425µm to 75µm for fly ash whereas for Red Mud 75µm to 2µm. addition of fly ash to red mud decreases plasticity index values and made it non plastic at 15% of fly ash addition and low plastic at 10% of fly ash.

When red mud – fly ash mixes tested for UCS and CBR values a reasonable increase was observed. This is due to absence of Cao in fly ash. red mud and fly ash both are non – self Pozzolanic. This can also reflected in P^H values of red mud – fly ash mixes. The Increase in fly ash content to red mud results in decrease of P^H due to non availability of free lime which made the alkaline environment in the mixes. presence of Cao in diminished quantities (<2%) is not sufficient to make the mixes Pozzolanic and to form C-S-H gels.

VI. APPLICATIONS

- Addition of 30-40% of fly ash to red mud gives CBR value of 10% with non plastic characteristics can be used as subgrade material in road constructions such as highways, expressways and state highways.
- In the red mud – fly ash mixes 30-40% addition of fly ash has exhibited UCS values of 280-290kPa and MDD 1.52-1.56 g/cc so that these mixes can be used as embankment and fill material.

VII. CHEMICAL ANALYSIS

From the chemical analysis it is seen that fly ash was dominated by siliceous and aluminous material $SiO_2$and Al_2O_3 which contributes nearly 90%. It is also seen that in Fly ash a very low percentage of calcium oxide is available. The presence of high quantities of silt and aluminium trioxide ($SiO_2$and Al_2O_3) can make the Fly ash pozzalanic and cementitious when it interacts with lime and cement.
From the test results it is identified that Fly ash is a fine grained material dominated by silt size particles of 96%. from consistency test data it is non plastic , incompressible and it is classified under ML group. It attains low maximum dry density with high OMC(optimum moisture content) is due to nature of particles including shape of particles and fineness.
It also exhibits high strength values at its optimum moisture content, Φ=35° and CBR=4. hence fly ash is a non Plastic material dominated by fines which are incompressible and exhibits low dry density with wide moisture content due to its low specific gravity and shape of particles.

VIII. CONCLUSIONS

- Addition of fly ash increases MDD values and decreases OMC values.

- Increase of fly ash increase ucs values for all curing periods.
- Maximum values attained at 40%.
- Addition of fly ash increases CBR values for all curing periods and maximum values attained at 40% dosage.

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