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Utilization of Ground Granulated Blast Furnace Slag and Pulverized Fly ash in the Manufacture of Stabilized Mud Blocks

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Abstract: The present research work is on manufacturing mud bricks with red mud and replacing cement totally with stabilizers. In both economic point of view and use of eco-friendly materials, compressed mud bricks are used extensively as a construction material. The main objective of this paper is to present a feasibility study on the characteristics of the red mud bricks with Stabilizers such as GGBS, PFA, Lime etc., under different testing parameters such as compressive strength, water absorption, initial rate of absorption, efflorescence, SEM, EDAX or EDS and XRD.

Keywords: *GGBS, Mud blocks, PFA and PC*

1. Introduction

Use of mud bricks have been started from Egyptian days and it has shown good performance for low cost construction. Compared to fired bricks mud bricks are shown better performance in environmental point of view. The only disadvantage of unfired or mud bricks is that they are less durable and are susceptible for damage due to water [9]. To overcome this we are using Portland cement but since the use of Portland cement costs high many researchers have done investigations on use of Ground Granulated Blast Furnace Slag (GGBS) and Pulverized Fly ash (PFA) in the replacement of cement as stabilizers. Blast furnace slag is used widely in the overall economy due to its performance characteristics and production. GGBS is obtained by quenching molted iron slag from a blast furnace in a water or stream to obtain a glassy granular product and then it is dried and ground into a fine powder. Fly ash is produced from the burning of pulverized coal in a coal-fired boiler. Fly ash is in the form of a fine-grained powdery particulate material that is carried off by the flue gas. Thus, the powdery particulate material is collected from the flue gas. From the past years it can be viewed that the use of GGBS and PFA can enhance good properties [9]. From previous researches, the samples of mud bricks were casted by different proportions of GGBS, PFA and Portland cement. In this present research work, the red mud bricks were tested for their compressive strength, water absorption, initial rate of absorption of water, efflorescence, SEM, EDAX and XRD.

Compressive strength of the brick is important because it is an indicator of masonry strength in the brick work design. Without using stabilizers the strength will be less for compressed stabilized earth block [2]. From the past researches shows that stronger bricks will give greater brick work strength. By using Geo-polymerisation that is the percentage of binder and the ratio of alkaline liquid to alumiosilicate solid ratio increases the strength of the brick [1]. Water absorption test is required to know the amount of water absorbed by bricks under specified conditions, red mud with fly-ash bricks has low water absorption of 12% [6]. The optimum moisture content of red mud is 33.5% and the maximum dry density of red mud is 1.53gm/cc, so red mud can be used as embankment material [4]. Efflorescence test is to know the presence of salts over the surface of bricks. In past researches it has shown that GGBS can replace Portland cement up to 50% and Fly ash can replace Portland cement up to 80% [11]. The presence of GGBS in the mud block reduces the shrinkage of the block [10]. For unfired mud bricks use of GGBS and PFA are good potential alternatives to PC [12]. The use of GGBS and HVFA can also enhance good properties for concrete in fresh and hardened state [5]. The value of pH decreases with the increase in the weight of red mud [3]. It is also stated that red mud can be used as a filling material, road material in village side & embankment material [7]. Red mud with fly ash bricks has high compression strength and low water absorption [8].Use of the stabilizers leads to lower environment burden which can reduce the energy consumption and also the reduction of carbon footprints. From investigations done by the researches on mud bricks states that there is demand for stabilized earth building materials in the construction economy development with respect to an energy conscious and ecological design, which intern fulfills all the strength and serviceability for the thermal transmittance. SEM and EDAX were essential parameters to understand the microstructure interaction and bonding between the particles and also the chemical composition of particles. Considerable research and development work on the utilization of red mud in civil engineering applications being

carried out all over the world. The main objective of this research is study is to bring the usage of waste materials in present constructions as building materials and also obtain the performance of Red Mud with stabilizers without addition of cement. The bricks of all mix proportions were compared for their Compression strength, Water absorption, and Initial rate of water absorption, Brick density, Efflorescence, Falling/Breaking, Hardness test and Dimensionality. The samples of bricks in all mixes were tested for SEM analysis, EDAX and XRD.

1.1 Objectives

The following are the objectives of the present research work:

(1) To calculate different mix proportions of stabilizers (GGBS, PFA and Lime), water, red mud and foundry sand.
(2) To test the mud bricks for Compression strength for dry and wet conditions, Water absorption, Initial rate of absorption, Dimensionality test, Falling test, SEM, EDAX or EDS and XRD.
(3) To compare different test parameters of various mix proportions (like Red mud with Portland cement, Red mud with Portland cement and Foundry sand, Red mud with GGBS, PFA and lime and Red mud with Foundry sand along with addition of GGBS, PFA and lime), so as to identify the well performed mix bricks.

2. Materials and Methods

2.1 Manufacturing Red Mud Brick

In the present research work, the raw materials required are red mud, GGBS, PFA, foundry sand, lime and water in different mix proportions. Six mix proportions were evaluated. 80% of red mud is made constant throughout all mixes and 20% stabilizers with varying proportions are used for casting. Mardini brick making machine with mould size 230mm x110mm x 100mm is used for manufacturing bricks. Total 120 bricks were casted and each mix 20 no's. Table 1 shows the mix proportions evaluated by varying stabilizers.

Table 1: *Mix proportions by varying stabilizers*

MIX	Type of Stabilizer	Raw Materials	% of Stabilizer
MIX I	PC	Red Mud	80
		PC	20
Mix II	PC	Red Mud	80
		Foundry sand	10
		PC	10
Mix III	GGBS & PFA	Red Mud	80
		PFA+Lime	15
		GGBS	5
Mix IV	GGBS & PFA	Red Mud	80
		PFA+Lime	10
		GGBS	10
Mix V	GGBS & PFA	Red Mud	80
		Foundry sand	5
		PFA+Lime	10
		GGBS	5
Mix VI	GGBS & PFA	Red Mud	80
		Foundry sand	10
		PFA+Lime	10
		GGBS	0

These raw materials were mixed in a mixing pan to form a homogeneous mix. Bricks were casted by using Mardini machine. The bricks were dried in open air for 3 days and curing is done in accelerated curing for 8 hours at 50^0c. Also normal curing for 28 day is done for bricks.

2.2 Chemical Composition of Materials

Table 2 to Table 5 show the chemical composition of different materials used in the casting of mud bricks.

Table 2: *Chemical composition of red mud*

Constituents	Percentage (%)
SiO_2	7.87
Fe_2O_3	70.90
Al_2O_3	6.34
CaO	1.36
MgO	0.35

Table 3: *Chemical composition of Fly ash*

Constituents	Percentage (%)
SiO_2	66.87
Fe_2O_3	4.41
Al_2O_3	23.34
CaO	1.17
MgO	0.31

Table 4: *Chemical composition of GGBS*

Constituents	Percentage (%)
SiO_2	31.79
Fe_2O_3	0.49
Al_2O_3	17.07
CaO	38.78
MgO	6.23

Table 5: *Chemical composition of Foundry sand*

Constituents	Percentage (%)
SiO_2	60.21
Fe_2O_3	6.37
Al_2O_3	5.96
CaO	2.22
MgO	1.43

2.3 Compressive Strength Test

The bricks are dried in room temperature for minimum 2-3 days. In this test five bricks in each set of mix are taken for testing. The surface of the bricks was cleaned properly with a cotton cloth to make an even contact. Each brick is placed on the bearing plate of CTM/UTM machine. Load is applied gradually at a uniform rate of 550kg/cm^2 per minute. The load is

applied until the specimen fails. Note the reading and the average of five specimens gives the Dry compression strength of brick in MPa.

The formula used for the calculation of Dry compression of the brick = $\frac{P}{A}$ in MPa.

Where,

P = Ultimate load at which the specimen fails in KN.
A = Loading area of the specimen in mm^2.

2.4 Water Absorption Test

Five numbers of bricks were taken for this test. Take each brick and weigh its dry weight in weighing machine. Note the readings as W_{dry}. The bricks are completely immersed in clean water for24 hours.

After 24 hours the bricks are taken out from water and the surface of bricks were wiped properly with a dry cloth. Then all the five bricks were weighed and wet weight is noted as W_{wet}.

The formula for the calculation of percentage of the absorbed water = $\frac{Wwet-Wdry}{Wdry}$ x 100.

2.5 Initial Rate of Absorption Test

Initial rate of water absorption (IRA) of bricks was determined by keeping the bricks half immersed in water for one minute. IRA is defined as the water absorbed by the bricks in grams after one minute over 30 square inches of the brick area of bed.

As per ASTM: C67-94 the acceptable value of water to be absorbed by the bricks should be within 10 to30 grams. The bricks which are having IRA above 30 grams are used for construction only after wetting the surface of bricks.

Therefore, IRA (Kg/m^2/minute) = Dry weight-Weight of brick after 1 minute/ Immersed area of brick.

2.6 Efflorescence Test

This test was done by taking a flat bottom panel filled with distilled water and the bricks are placed inside in such a way that the sides are immersed in water up to 25mm.

The bricks are allowed to get saturated and the whole set up is placed in proper room in warm temperature between 20^0c to 30^0c. The panel is covered with a glass cylinder so that the excess of evaporation is avoided. When the bricks absorbed water completely the same amount of water is placed inside the panel and the same process is repeated. Observe the bricks after second evaporation and to examine the bricks for efflorescence.

Figure 1 shows the formation of salts over the surface of Red Mud bricks.

Figure 1 *Formation of salts over the surface of Red Mud bricks*

3. Results & Discussion

3.1 Specific Gravity

Table 6 shows the specific gravity of different materials used.

Table 6: *Specific gravity of materials*

Materials	Results
Red mud	2.503
Foundry sand (Four samples mixed)	2.354
Foundry sand grey colour	2.448
Foundry sand Grain size crispy	2.482
Foundry sand Cement colour	2.441
Foundry sand Black colour	2.321
GGBS	2.6
PFA	2.174
OPC	3

The fineness modulus of red mud obtained is 2.333

3.2 Brick Density

Table 7 shows the density of red mud bricks.

Table 7: *Results for Density of Red mud bricks*

Designation of bricks	Dry density (kg/m^3)	Wet density (kg/m^3)
Mix I	1783.329	1804.479
Mix II	1716.073	1812.289
Mix III	1561.923	1904.479
Mix IV	1681.817	1882.081
Mix V	1582.344	No Value
Mix VI	1580.368	No Value

The dry and wet brick density of Mix I bricks is high than other mix bricks. There is no value obtained for Mix V and Mix VI bricks during wet tests such as wet density, wet compression and water absorption. Since, Mix V and Mix V bricks are dissolved in water after 24 hours soaking in water due to insufficient bonding.

3.3 Compressive Strength

Table 8 shows compression strength test results for bricks which are cured in accelerated curing tank for 3 days and Table 9 shows the compressive strength for

bricks which were cured normally in open air for 28 days.

Table 8: *Compression strength results of bricks after 3 days accelerated curing*

Designation of bricks	Dry compression strength (MPa)	Wet compression strength (MPa)
Mix I	4.281	3.175
Mix II	5.217	3.741
Mix III	2.041	1.607
Mix IV	1.067	0.618
Mix V	1.396	No Value
Mix VI	0.776	No Value

Table 9: *Compression strength results of bricks after 28 days normal curing*

Designation of bricks	Dry compression strength (MPa)
Mix I	6.534
Mix II	5.651
Mix III	3.016
Mix IV	1.501
Mix V	1.211
Mix VI	0.961

It is clearly shown that, the compressive strength obtained for accelerated cured bricks are less when compared to normally cured bricks. The dry compression strength obtained for normally cured bricks is more than accelerated cured bricks. Figure 2 shows the dry compressive strength of red mud bricks. It also stated that, the strength increases there is a decrease in water absorption [1].

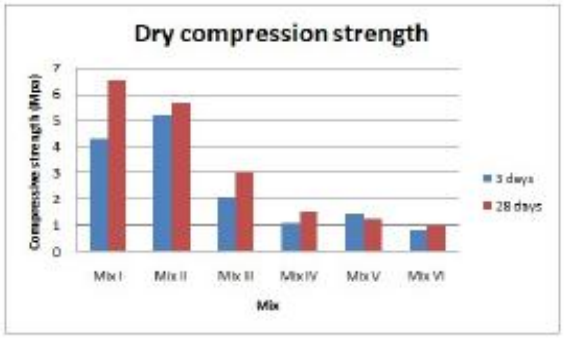

Figure 2 *Dry compressive strength test results*

3.4 Water Absorption

Table 10 shows results for bricks cured in water for 24 hours.

Table 10: *Water absorption results of Red Mud bricks*

Designation of bricks	Water absorption (%)
Mix I	6.376
Mix II	8.540
Mix III	21.308
Mix IV	19.481
Mix V	No Value
Mix VI	No Value

The water absorption value is acceptable only for Mix I, Mix II and Mix III bricks. As per code the water absorption of bricks should not be more than 20%.

3.5 Initial Rate of Absorption

Table 11 shows initial rate of water absorption results of Red Mud bricks.

Table 11: *Initial Rate of Water Absorption results of Red Mud bricks*

Designation of bricks	IRA (kg/m^2/min)	Absorbed water (grams)
Mix I	1.646	41.667
Mix II	2.893	73.333
Mix III	5.401	13.667
Mix IV	2.898	73.333
Mix V	2.766	70
Mix VI	2.305	58.333

The Initial rate of water absorption of bricks should be within 10 to 30grams.

3.6 Efflorescence Test

This test is done according to the specifications given in the code book IS: 3495-Part III-1992. Table 12 shows the efflorescence test results.

Table 12: *Efflorescence test of Red Mud bricks*

Designation of bricks	Tested results	IS permissible limits
Mix I	SLIGHT	Efflorescence for higher class bricks should not be more than slight
Mix II	SLIGHT	
Mix III	NIL	
Mix IV	NIL	
Mix V	NIL	
Mix VI	NIL	

SLIGHT – The particle deposited on the area of brick is not more than 10% with a thin deposit of salt layer.

3.6 Scanning Electron Microscopy (SEM)

Figure 3 to Figure 8 shows the SEM analysis image for different mix.

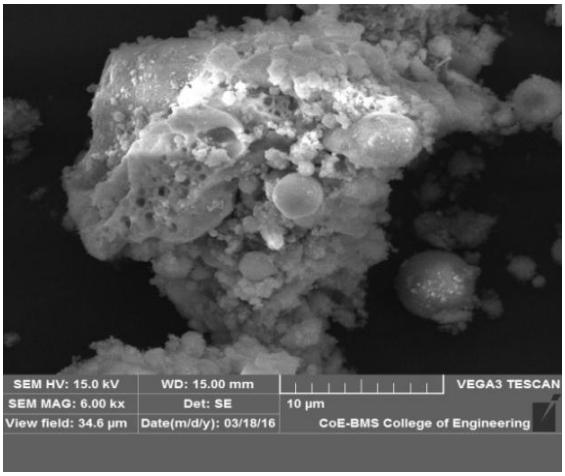

Figure 3 *SEM analysis image for Mix I*

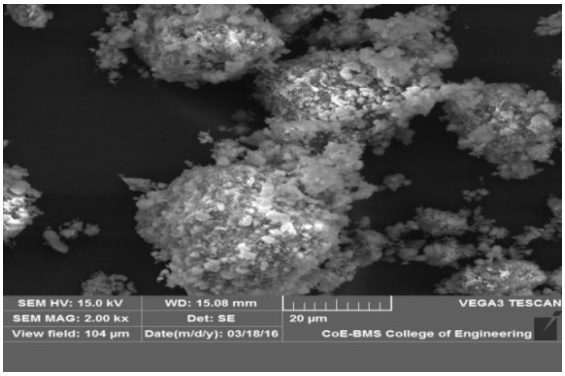

Figure 4 *SEM analysis image for Mix II*

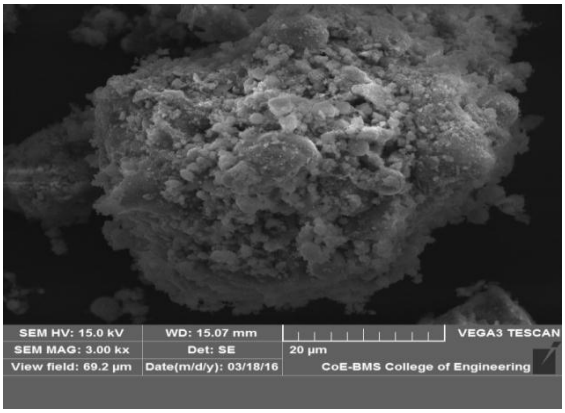

Figure 5 *SEM analysis image for Mix III*

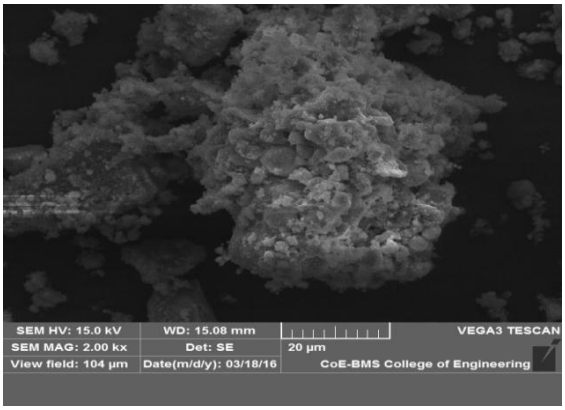

Figure 6 *SEM analysis image for Mix IV*

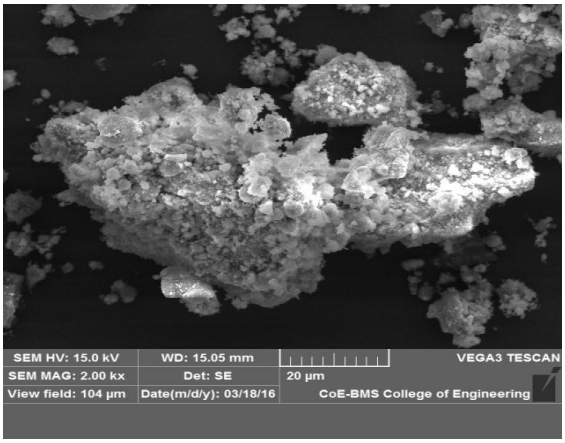

Figure 7 *SEM analysis image for Mix V*

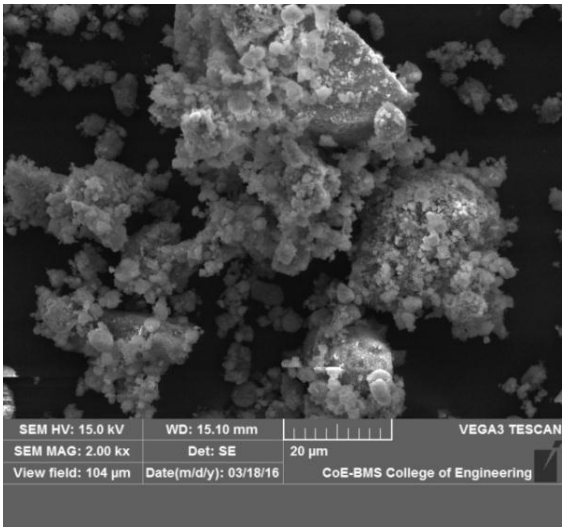

Figure 8 *SEM analysis image for Mix VI*

3.7 Energy Dispersive X-ray Spectroscopy (EDAX or EDS)

Figure 9 and Figure 12 shows the selected area of Mix I and Mix II respectively. Figure 10 and Figure 11 shows the EDAX analysis spectrum of Mix I and Mix II respectively. Figure 11 and Figure 14 shows the smart quant results for Mix I and Mix II respectively.

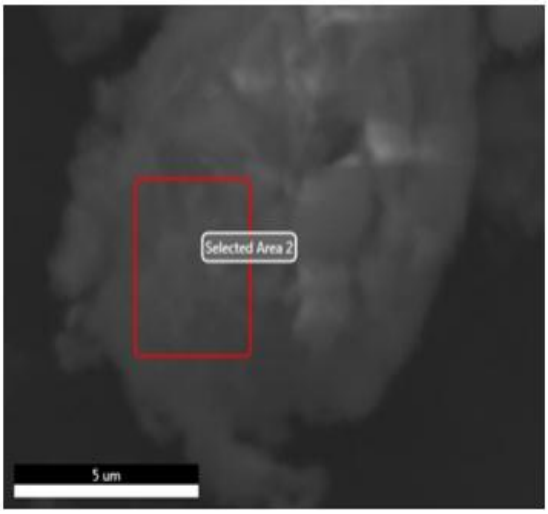

Figure 9 *Selected sample area in Mix I*

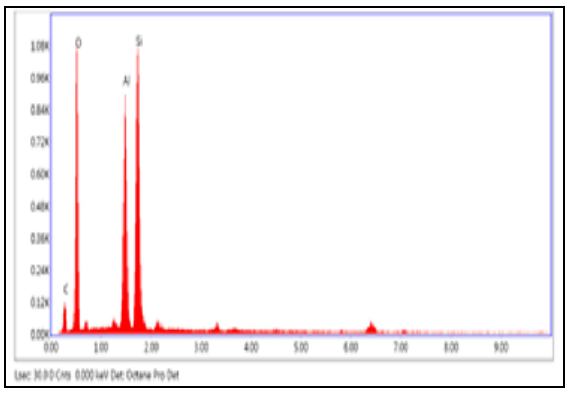

Figure 10 *EDAX analysis spectrum of Mix I*

Element	Weight %	Atomic %	Net Int.	Error %	K ratio	Z	R	A	F
CK	17.54	26.08	19.44	14.59	0.0324	1.0832	0.9653	0.1708	1
OK	43.96	49.05	194.58	9.01	0.1678	1.0313	0.9858	0.3702	1
AlK	15.55	10.29	199.23	4.85	0.1187	0.9094	1.0232	0.8297	1.012
SiK	22.95	14.59	269.6	4.76	0.1697	0.9281	1.0291	0.7951	1.0027

Figure 11 *Smart Quant result of Mix I*

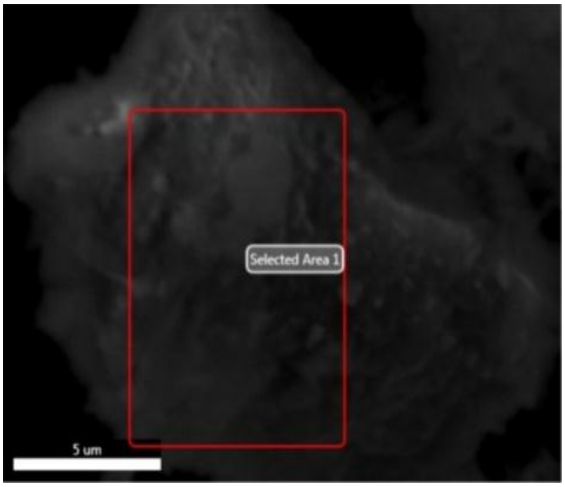

Figure 12 *Selected sample area in Mix II*

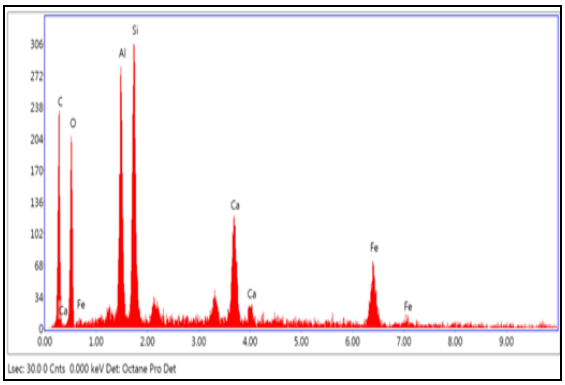

Figure 13 *EDAX analysis spectrum of Mix II*

Element	Weight %	Atomic %	Net Int.	Error %	K ratio	Z	R	A	F
C K	31.58	51.05	32.53	12.27	0.0921	1.1176	0.9407	0.2606	1.0000
O K	19.83	24.06	34.49	13.15	0.0503	1.6660	0.9628	0.2378	1.0000
AlK	8.38	6.03	57.17	7.93	0.0576	0.9427	1.0039	0.7227	1.0075
SiK	10.04	6.94	70.24	7.16	0.0747	0.9625	1.0106	0.7683	1.0067
CaK	10.40	5.04	38.86	7.92	0.0959	0.9038	1.0418	0.3825	1.0389
FeK	19.77	6.87	26.22	10.94	0.1649	0.7982	1.0543	1.0011	1.0437

Figure 14 *Smart Quant result of Mix II*

3.9 X-Ray Diffraction (XRD)

This test is mainly used to identify the crystalline particles that are present in the brick sample. The following graphs of different mixes show which particle is present in high composition. Figure 15 to Figure 20 shows the XRD spectrum analysis of Mix I to Mix VI.

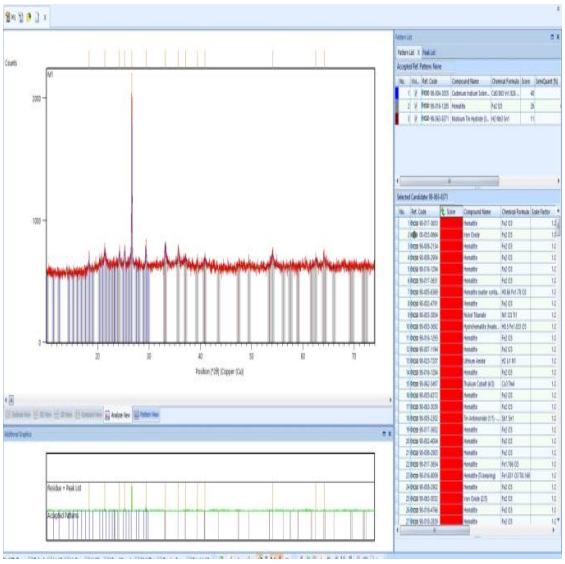

Figure 15 *XRD spectrum analysis of Mix I*

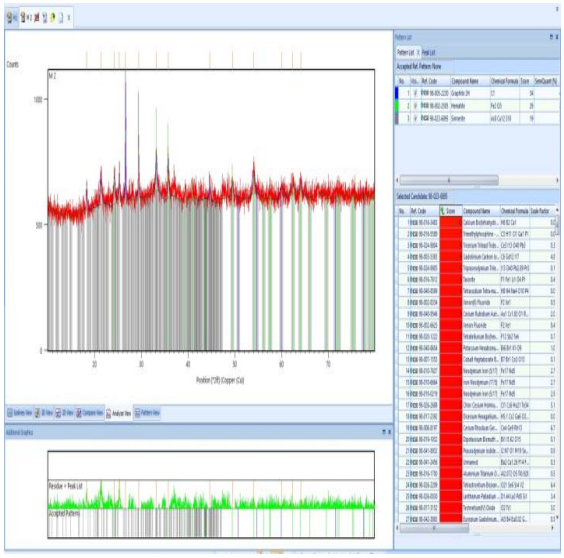

Figure 16 *XRD spectrum analysis of Mix II*

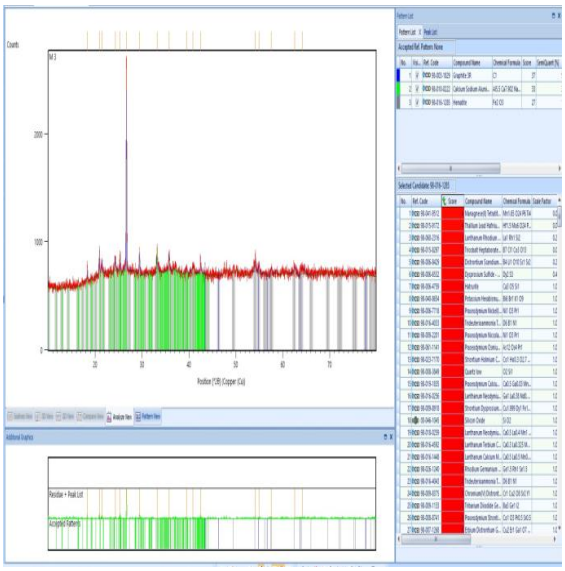

Figure 17 *XRD spectrum analysis of Mix III*

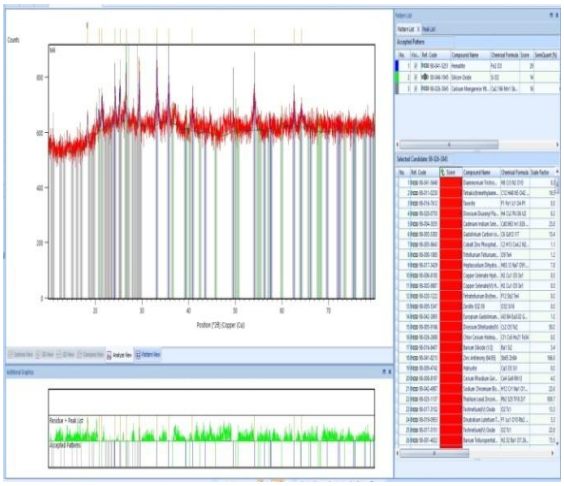

Figure 18 *XRD spectrum analysis of Mix IV*

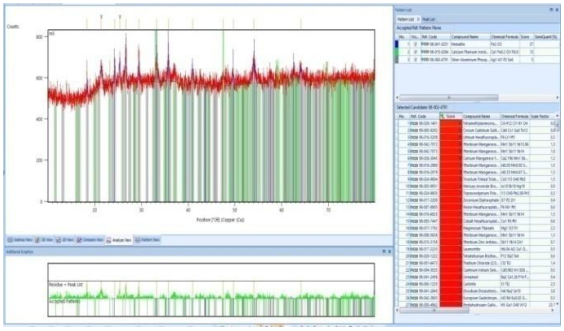

Figure 19 *XRD spectrum analysis of Mix V*

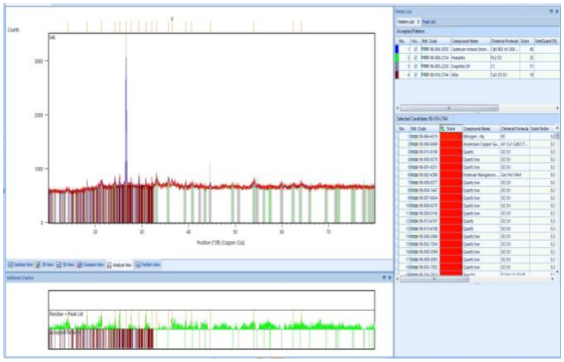

Figure 20 *XRD spectrum analysis of Mix VI*

4. Conclusion

The following are the conclusions that can be drawn from the present research work:

- Red mud possesses more Iron content and less Magnesium content.
- The compression strength of Red Mud bricks increased with the addition of more cement content.
- The dry compression strength obtained for Accelerated curing Mix II bricks is 5.3MPa, since 10% of cement and 10% of Foundry sand is used.
- The dry compression strength obtained for normally cured bricks is more than accelerated cured bricks.
- Mix I normally cured bricks achieved good strength up to 6.5MPa and the Wet compression strength of bricks is less and it is not acceptable.
- Mix V and Mix VI bricks are completely dissolved in water after 24 hours due to improper bonding and addition of 80% red mud.
- Use of stabilizers increases the strength of the bricks and also these stabilizers possess some cement properties [2].
- Red mud bricks with stabilizers have shown good performance in Efflorescence test, as there is no formation of salt layer over the surface of Mix III, IV, V and VI bricks.
- The water absorption of bricks shown higher values which are not acceptable as the absorbed water is more than 20%.
- Mix I and Mix II bricks have absorbed less water.
- Initial rate of water absorption for Mix III bricks is 13.667grams which is an acceptable value as per IS recommendations.
- From SEM, it can be understood that Mix V and Mix VI bricks have less particulate bonding.
- From the results, of EDAX it shows that the bricks are having high silica and carbon content.
- XRD shows that the bricks having highest composition of cadmium, graphite and hematite.
- Use of red mud up to 50% and along with stabilizers can achieve good strength as that of cement bricks.
- More research work should be done to understand the properties of red mud.

5. Acknowledgements

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