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Geopolymer Masonry Bricks production using Phosphogypsum and Fly Ash (Air-Dried samples) – A Detailed Feasibility study

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Abstract

The present-day world scenario is that about 760 million tonnes of fly ash is being produced from various industrial processes, some of them being manufacture of electricity (power plant), automobiles, steel production etc. With the advancement of human civilization, the working of these industries has become absolutely necessary for the sustenance and further advancement of human civilization and these might exist till the time humans exist on this earth. But these processes also bring a bane to the society that the fly ash produced, causes pollution and degradation of the environment not only in the near vicinity of the place of production but also to a greater area around the place of production. There have been several reports about entire village being covered with fly ash produced from near by power plants. The need of the hour is to make use of this fly ash to produce alternate materials that can be used in the building industry or other process industries. Fly ash is a pozzolanic material and help mainly in volumetric drying, however other properties like strength may not be achieved only by using fly-ash, so it becomes necessary to use it in combination with other materials so that material properties of the resultant mixer may be enhanced. It would be even more advantages to the environment if such material is a major cause of environmental degradation. One such material is Phosphogypsum, which is a by-product of Phosphoric acid-based fertilizer production. Annually nearly 122 million tonnes of Phosphogypsum is being produced, most of which ends up in landfills. There have been several reports of the soil being rendered useless for agriculture, when the land has been filled with Phosphogypsum. An experiment has been made by combining fly ash, Phosphogypsum and other materials to produce alternative masonry bricks. When fly ash, Phosphogypsum is combined with other materials and an alkaline solution, the resulting material under goes Geopolymerization and solidifies into a hard paste. This solidified paste of appropriate shape, size and other suitable properties of masonry brick, may be used as an alternative to standard masonry bricks.

Keywords: Geo-polymerization, masonry, Phosphoric acid, pozzolanic, power plant, civilization, Environmental degradation, Fly-ash, Phosphogypsum, alkaline solution, solidifies, fertilizer, agriculture, volumetric, drying.

I. INTRODUCTION

With the increase in construction and infrastructure development activity in India and also internationally, has led to increased demand for cement. This has led to production of cement in large quantities, hence resulting in increase in Co_2 emission, which is leading to drastic environmental pollution. Hence the search is on for alternative building materials with a low carbon foot print. Masonry bricks made with geo-polymers may present us with an opportunity to achieve this goal. Non-organic synthesised polymer materials primarily composed of allumino or silicate based, naturally formed or as fly-ash based by-product, is called geo-polymers. These Geo-polymers exhibit good material properties; like sulphate resistance, high resistance to acid attack, ceramic properties like resistance to fire, structural properties like high compressive strength. India being the second largest producer of masonry bricks in the world, has about 2 lakh kilns in operation each year and produces about 300 billion masonry bricks. And clay in large quantity is being used in this production process with masonry brick production. Clay is made by scraping the top soil and has led to erosion of soil. Also, during monsoons and rain seasons, the availability of good quality clay seems to be a problem and due to this there is huge variation in the quality and quantity of the masonry bricks being produced. It is therefore most essential in these times to produce alternative to conventional masonry bricks. Masonry bricks made with Phosphogypsum and fly ash seems to be a good alternative. Also burning of bricks in kilns, oven and other means requires a lot of energy in terms of electrical energy and heat energy. I would be really beneficial if we are able to reduce the utilization of this energy as well. Attempt has been made to this end to produce air dried Phosphogypsum and fly-ash based masonry bricks, which exhibit good structural and other properties similar to conventional masonry brick.

II. REVIEW OF THE EXISTING LITERATURE

Manugunta&Naveena Kanaboyana[1] concluded that when GGBS content increases the compressive strength also increases, based on their experiment on Geopolymer mortar with Fly-ash and GGBS. Compressive strength exhibited was in the range of 1.163 -33.59 N/mm^2 after 7 days of curing depending on GGBS content. The flow of mortar is very dry and exhibits greater percentage of flow for F/B ratios of 0.40 and 0.45 respectively. The compressive strength increases with age for all proportions, but maximum strength is obtained when F/B ratio is 0.45 at 7 days when combination of 80 % GGBS and 20 % fly ash is used. **E. Rabiaa,, R. A. S. Mohamed, W. H. Sofi, and Taher A. Tawfik[2],** studied the effect of two types of steel fibres, Nano-silica(NS), and Nano-metakaolin(NMK) on slag-based geopolymer, and concluded that as the percentage of the materials NS, NMK, increases and two different types of steel fiber (hooked end and crimped) also increases, which are combined in the Geo-polymer concrete(GPC) specimens or individually combined until a particular optimum values, the mechanical properties increases, then beyond this point the mechanical properties start decreasing with increase in the percentage of the materials. **B. Vijaya Rangan[3],** from studies on fly-ash based geo-polymer concrete concluded that, they mixture has excellent compressive strength and can be used for structural application. Mix design is also possible with this type of geo-polymer concrete and present IS Code specifications for mix design can be used with no or minor modifications for fly-ash based geo-polymer concrete also. When heat cured it shows high resistance to attack of sulphate, offers very good resistance to attack of acid, suffers very little drying shrinkage and undergoes very little or no creep. **Sourav Kr. Das, Amarendra Kr. Mohapatra and A.K. Rath[4],** concluded that higher compressive strength is achieved with higher fineness of fly ash, this happens because of more surface area with more Si-Al bond for polymerization. Higher strength is achieved when Sodium hydroxide and sodium silicate ratio is higher, generally with a ratio of 2.5. Under normal conditions heat cured geopolymer concrete gives higher strength but he same result can be attained at room temperature when fly-ash is replaced by GGBS. Geopolymer concrete can be used for rehabilitation and retrofitting works due to excellent mechanical properties. Due to early attainment of high strength it can also be used for road works. **Pawan Anand Khanna, Durga Kelkar, Mahesh Papal and S. K. Sekar[5],** from their studies concluded that the optimum molarity of 12M of Potassium hydroxide gives the maximum compressive strength to Fly-ash Geo-polymer concrete (FGPC). A temperature of 70^{0}C gives maximum compressive strength, beyond which the compressive strength starts decreasing. Maximum workability and compressive strength are obtained when the super-plasticizer content by weight of binder is 1.5 %. **S A. Arafa1, A Z M Ali, A.S.M. A. Awal and L Y Loon[6]**, showed that different fly-ash to alkaline liquid ratios and different concentrations of Sodium Hydroxide can give optimum compressive strengths and workabilities for any geo-polymer paste. The compressive strength was 78.2 MPa and the workability was 3.92 for a given sample specimen when the concentration of Sodium Hydroxide was 10 M and fly-ash to alkaline solution ratio was 0.5. The compressive strength was increasing with increasing temperature of curing and increasing concentration of sodium hydroxide but was decreasing when fly-ash to alkaline solution ratio was increasing. Workability was increasing with increasing fly-ash to alkaline solution ratio but was decreasing with increase in concentration of Sodium Hydroxide. Highest compressive strength of the paste was 87 MPa, which was achieved at 80^{0}C when cured for 24 hours, with concentration of sodium hydroxide being 12 M, fly-ash to alkaline solution ratio being 0.4 and sodium silicate to sodium hydroxide ratio being 2.5. Compressive strength increases with increase in curing time, maximum up to 24 hours, beyond 24 hours the increase in compressive is very minimal and not very significant. **Dr. Vaishali. G. Ghorpade, Dr. Sudarsana Rao, H., B.V. Ramana Prasad[7],** conducted experiments on self-compacting concrete using Phosphogypsum and concluded that when cement is replaced with Phosphogypsum in percentage of 0 to 10, the compressive strength of concrete increases from 32.08 MPa to 41.50 MPa and 47.95 MPa to 52.45 MPa when cured for 7 and 28 days, respectively. When percentage of Phosphogypsum is increased from 10 to 30, it causes decrease in compressive strength of concrete from 41.50 MPa to 19.20 MPa and from 52.45 MPa to 25.15 MPa when cured for 7 and 28 days respectively. The split tensile strength of concrete increase from 3.50 MPa to 3.61 MPa when cement is replaced by Phosphogypsum in percentages of 0 to 10. When Cement is replaced with Phosphogypsum in percentages between 10 to 30, it causes decrease in split tensile strength of concrete from 3.61 MPa to 2.15 MPa. When cement is replaced with Phosphogypsum in percentages of 0 % to 10 % the flexural strength of concrete increases from 4.92 MPa to 6.74 MPa. When cement is replaced by Phosphogypsum in percentages varying between 10 to 30, the flexural strength of concrete decreases from 6.74 MPa to 2.92 MPa. **P. Ukesh Praveen and K. Srinivasan[8]**, studied self-compacting concrete and concluded that the compressive strength of the paste increases with increasing concentration of sodium hydroxide however causes a decrease in fresh properties. GGBS helps increase the compressive strength at ambient temperature. When separate pastes made with GGBS and fly-ash at room temperature were tested for compressive strength, the GGBS based paste showed higher compressive strength for same percentage of fly-ash based paste. Segregation and bleeding occur when the concentration of water in the paste exceeds 15 percent by weight of binder. The compressive strength starts decreasing when water content exceeds 12 % by weight of binder. Highest compressive strength was obtained when cured at not more than 70^{0}C. **V Sathish Kumar, N Ganesan and P V Indira[9],** studied the effect of Molarity of Sodium Hydroxide and

Curing Method on the Compressive Strength of Ternary Blend Geopolymer Concrete and concluded that when GGBS content is increased from 0-25 % the compressive strength of ternary blended GPC increases, but when GGBS is increased beyond 25 % the compressive strength starts decreasing. When samples were cured for 7 days in both hot air oven and steam chamber separately and then cured for 24 hours at 60^0C for 24 hours and then kept at room temperature before testing, then 80-90 % of the 28 days compressive strength was achieved. When compressive strength obtained from samples of ternary blended GPC which were cured in hot air oven and steam bath were compared, then compressive strength of hot air oven cured were 10 % higher than compressive strength of samples which were steam cured. With 14M molarity of NaOH with ternary blend of 60% FA, 25% GGBS and 15% MK, maximum compressive strength was obtained. FA, GGBS and MK based ternary blended GPC is an effective sustainable alternative material to concrete. **M F Nuruddin, A B Malkawi1, A Fauzi1, B S Mohammed and H M Almattarneh**[10], studied the feasibility of geo-polymer concrete for structural applications concluded that GGBS and fly-ash based reinforced geo-polymer concrete beams, columns and slabs have high flexural, tensile and compressive strengths, comparable to that of conventional reinforced concrete. The existing design provision available in the ACI 318 code and the AS3600 code standards are reported to be applicable for the analysis and design of the RGPC structures and in most cases will give conservative results. However, it is recommended to apply an additional safety factor to adjust for the unexpected long-term behaviour. Compared to the OPC concrete, the stress-strain curves of the FA-based GPC show similar behaviour up to the ultimate strength, after which a rapid decline in stress occurs during the post-peak strain softening. The GPC displays a more brittle behaviour comparing to the OPC concrete members. The peak strain for the different mixtures of GPC was recorded in the range of 0.0015-0.0026, which is less than 0.003 known for OPC concrete. Regardless of the wide body of available literature on geopolymer concrete, there is still a significant gap regarding the engineering properties and the structural behaviour of the RGPC. It is required to clearly determine the relationships between the different properties of the GPC including elastic modulus, Poisson's ratio, tensile strength, flexure strength, compressive strength, shear strength, and bond strength. More research is required in these areas. The unavailability of the standards makes the major challenge for the acceptance of the GPC; evaluation of the GPC based on its performance characteristics seems to be the best way for acceptance of such a new material.

III. APPARATUS AND EQUIPMENT

- ➔ 90 mm x 92 mm x 192 mm size silicon moulds to make bricks.
- ➔ Up to 1000 kN capacity machine to test compressive strength.
- ➔ 1 cement bag capacity concrete mixer.
- ➔ Meter to test hardness of water.
- ➔ Meter to test P^H of water.
- ➔ Vernier Callipers.

Substances required

Fly-ash: Ramagundam NTPC thermal power plant is the source for obtaining fly-ash, it is finely ground material of Grade 2 (IS 3812, 60-65 %).

Fly-ash is produced as a by product from coal combustion. Electrostatic precipitators help collect ash, this type of ash is called fly-ash. Particulates are formed when coal-fired boilers drive out flue gases. These particulates so formed form fly-ash.

Phosphogypsum:

Coromandel fertilizers, Kakinada has been the source of obtaining Phosphogypsum. The contents of Phosphogypsum are: 3-4 % moisture, 22 % calcium and 18 % sulphur. (Refer to Fig 1.)

When phosphoric acid is produced in the fertilizer industry using phosphate rock as input, hydrate of calcium sulphate is formed as by-product. This is what is commonly known as Phosphogypsum. Due to its weak radioactivity it is not being widely used in the construction industry, though it's counter-part normal Gypsum is being widely used. It is being indefinitely stored in landfills or moulds, which is controversial since it is known to cause environmental degradation.

Fig 1: Finely ground Phosphogypsum.

Stone Chips (Coarse Aggregate): These aggregates have a specific gravity of 2.8. IS 383:1970 specifies that chips of stone that are retained on 4.75 mm IS sieve are to be classified as coarse aggregate. The stone chips conforming to this are being used.

Sand (Fine aggregate): Sand has specific gravity of 2.65. IS 383:1970 specifies that for sand to be of proper grade, it has to pass through 4.75 mm IS sieve. River sand conforming to IS specifications has been used.

Sodium Hydroxide: 10 M sodium hydroxide solution, of 99 % lab grade (pellets) is used. It is used as one of the ingredients in making detergent for washing clothes and also used as floor cleaner. It is commonly known as caustic soda. It is highly water soluble and absorbs carbon dioxide and moisture from air almost instantly. The reaction of water and sodium hydroxide is highly exothermic and produces high amount of heat. Care should be taken adequately when handling sodium hydroxide since they are known to cause chemical burns. (Refer Fig 2.)

Fig 2: Sodium hydroxide pellets.

Sodium silicate (Na_2Sio_3): Sodium silicate solution of 10 M is used. (Refer Fig 3.). It appears like glass but flows like water. So, it is commonly known as water glass. It is highly sticky and transparent in nature. It is counterion of silicate of inorganic sodium salt.

Fig 3: Sodium silicate crystals.

Provisions of Indian standard codes for specification of masonry Bricks:

Clause 7.1 of IS: 1707:1992 states the compressive strength for various classes of bricks as below:

- First class Bricks: > = 105 kg/cm^2.
- Second class Bricks: > = 75 kg/cm^2.
- Common building bricks > = 35 kg/cm^2.
- Sun dried bricks. > = 15 kg/cm^2 & < = 25 kg/cm^2.

Clause 7.2 of IS: 1707:1992 states the water absorbtion for various classes of bricks as below:

- For class of brick up to 12.5: < = 20 %.
- For class of brick above 12.5: < = 15 %.

EXPERIMENTAL PROCEDURE

IS 3495: PARTS 1-4 forms the basis of all experimental procedure. In this investigation, all experimental procedure followed is in strict conformity to IS code provisions.

Sodium Hydroxide and Sodium Silicate are mixed in suitable proportions as per Table 1 and an alkaline solution is formed in each case. Other substances are mixed as per proportions of Table 1 for each case, to this the previously prepared alkaline solution is added. Fly-ash is not added in some cases and it is added in some cases. The entire mixture is homogeneously mixed in concrete mixer. The mixture after through mixing is poured into brick moulds. After sometime the mould is removed and the resulting bricks are cured in open air under the sun for 24 hours. These cured bricks are subjected to standard brick test as per specifications of IS: 1707:1992. The test results are tabulated for further analysis.

Fig 4: De-moulded, casted bricks.

Fig 5: Air cured Bricks.

Procedure for testing compressive load capacity: (IS 3495: Part 1: 2019)

Measure the size of the brick with the help of Vernier callipers and scale, note down the dimensions of the brick. Now place the brick on the compressive testing machine with the larger area facing the load being applied. Now gradually apply the load on the brick sample. After some time when the load is just about exceeding the compressive strength of the brick the brick cracks. Note down the load at which the brick first cracks. This load is the failure load of the brick. This load so obtained is divided by the area of the face of the brick placed in the compressive testing machine. This gives the compressive strength of the brick. This procedure is repeated for several times for same proportions and the average is taken from all the compressive strength values. This average is the compressive strength of brick for that particular proportion of materials. This procedure is repeated for all proportions as per Table no 1.

Test for absorbtion and retention of water: (IS 3495: Part 2: 2019)

This test is used to determine by how much percentage by weight of brick, that the brick sample can retain water under severve exposure conditions.

A water bath is prepared with distilled water having a $\mathbf{P^H}$ equal to 7. The brick samples which were air cured for 24 hours, are weighed and then they are placed in this water bath for 24 hours. After 24 hours the brick samples are removed from the water batch and again weighed. The difference in weight of brick after placing in water bath and before placing in water bath as a percentage of weight of brick before placing in water bath, gives the water absorbtion capacity of the brick. The same procedure is repeated for samples of brick with same proportions and average value is taken. The procedure is repeated for different constituent material proportions as per table no 1.

Reaction with Acid Test:

The brick samples after being air cured are placed in the concentrated Hydrochloric acid of $\mathbf{P^H}$ equal to 0 and concentration of 1 M, for 24 hours. These bricks are taken out and all standard tests on bricks are performed. If even after reaction with acid, if the brick samples exhibit properties as per the specifications of the IS: 1707:1992, then the brick sample is said to have passed the acid reaction test.

Fig 5: Air cured Bricks after being submerged in acid for 24 hours. (Reaction with Acid test.)

Various proportions tried in the mixes:

Constituent materials like Phosphogypsum, Fly-ash, Fine aggregate and coarse aggregate are varied in 1 % intervals with proportions varying between 9 % to 25 %. (**Refer Table: 1)**

Sample Calculations of mix-proportions of constituent materials. (Refer Table: 1.)

Let us assume the proportion of Phosphogypsum in the mix is 18 %.

***Case 1: With Fly-ash*.**

Let us assume the proportion of Phosphogypsum in the mix is 18 %.

Also let us consider the mix to contain fly-ash.

Other materials in the mix like Fly-ash, Fine aggregates, Coarse Aggregates, Sodium-Hydroxide and Sodium-Silicate are mixed in equal proportions. Let the equal proportion each be equal to 'x' %.

Total proportions = 100 =18 + x + x + x + x + x= 18 + 5x

5x = 100-18 = 82

x = 82 / 5 = 16.4 %.

Proportions of materials in the mix = 18: 16.4: 16.4: 16.4: 16.4: 16.4:: Phosphogypsum: Fly-ash: Fine-Aggregate: Coarse Aggregate: Sodium-Hydroxide: Sodium-Silicate.

Dividing by 18, Mix proportions = 1: 0.91: 0.91: 0.91: 0.91: 0.91:: Phosphogypsum: Fly-ash: Fine-Aggregate: Coarse Aggregate: Sodium-Hydroxide: Sodium-Silicate. (Similarly, other mix proportions are calculated.)

***Case 2: With-out Fly-ash*.**

let us assume the proportion of Phosphogypsum in the mix is 25 %.

Also let us consider the mix not to contain fly-ash.

Other materials in the mix like Fine aggregates, Coarse Aggregates, Sodium-Hydroxide and Sodium-Silicate are mixed in equal proportions. Let the equal proportion each be equal to 'y' %.

Total proportions = 100 = 25 + y + y + y + y = 25 + 4y

4y = 75.

y = 75 / 4 = 18.75 %.

Proportions of materials in the mix = 25: 18.75: 18.75: 18.75: 18.75:: Phosphogypsum: Fine-Aggregate: Coarse Aggregate: Sodium-Hydroxide: Sodium-Silicate.

Dividing by 25, Mix proportions = 1: 0.75: 0.75: 0.75: 0.75:: Phosphogypsum: Fine-Aggregate: Coarse Aggregate: Sodium-Hydroxide: Sodium-Silicate. (Similarly, other mix proportions are calculated.)

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The mix proportions for air dried brick mixes are shown in table 1 below.

TABLE 1: MIX PROPORTIONS FOR AIR DRIED BRICK MIXES.

SL NO	% VARIATION	MIX PROPORTIONS WITH FLY ASH (PHOSPHOGYPSUM : FLY ASH : FINE AGGREGATE : CORASE AGGREGATE:SODIUM-HYDROXIDE:SODIUM-SILCATE)	MIX PROPORTIONS WITH OUT FLY ASH (PHOSPHOGYPSUM : FINE AGGREGATE : CORASE AGGREGATE:SODIUM-HYDROXIDE:SODIUM-SILICATE)	MIX PROPORTIONS WITH FLY ASH	MIX PROPORTIONS WITH OUT FLY ASH
PHOSPHOGYPSUM PERCENTAGE VARIATION					
1	9.00	1 : 2.02 : 2.02 : 2.02 : 2.02 : 2.02	1 : 2.53 : 2.53 : 2.53 : 2.53	ADPF1	ADP18
2	10.00	1 : 1.8 : 1.8 : 1.8 : 1.8 : 1.8	1 : 2.25 : 2.25 : 2.25 : 2.25	ADPF2	ADP19
3	11.00	1 : 1.62 : 1.62 : 1.62 : 1.62 : 1.62	1 : 2.02 : 2.02 : 2.02 : 2.02	ADPF3	ADP20
4	12.00	1 : 1.47 : 1.47 : 1.47 : 1.47 : 1.47	1 : 1.83 : 1.83 : 1.83 : 1.83	ADPF4	ADP21
5	13.00	1 : 1.34 : 1.34 : 1.34 : 1.34 : 1.34	1 : 1.67 : 1.67 : 1.67 : 1.67	ADPF5	ADP22
6	14.00	1 : 1.23 : 1.23 : 1.23 : 1.23 : 1.23	1 : 1.54 : 1.54 : 1.54 : 1.54	ADPF6	ADP23
7	15.00	1 : 1.13 : 1.13 : 1.13 : 1.13 : 1.13	1 : 1.42 : 1.42 : 1.42 : 1.42	ADPF7	ADP24
8	16.00	1 : 1.05 : 1.05 : 1.05 : 1.05 : 1.05	1 : 1.31 : 1.31 : 1.31 : 1.31	ADPF8	ADP25
9	17.00	1 : 0.98 : 0.98 : 0.98 : 0.98 : 0.98	1 : 1.22 : 1.22 : 1.22 : 1.22	ADPF9	ADP26
10	18.00	1 : 0.91 : 0.91 : 0.91 : 0.91 : 0.91	1 : 1.14 : 1.14 : 1.14 : 1.14	ADPF10	ADP27
11	19.00	1 : 0.85 : 0.85 : 0.85 : 0.85 : 0.85	1 : 1.07 : 1.07 : 1.07 : 1.07	ADPF11	ADP28
12	20.00	1 : 0.8 : 0.8 : 0.8 : 0.8 : 0.8	1 : 1 : 1 : 1 : 1	ADPF12	ADP29
13	21.00	1 : 0.75 : 0.75 : 0.75 : 0.75 : 0.75	1 : 0.94 : 0.94 : 0.94 : 0.94	ADPF13	ADP30
14	22.00	1 : 0.71 : 0.71 : 0.71 : 0.71 : 0.71	1 : 0.89 : 0.89 : 0.89 : 0.89	ADPF14	ADP31
15	23.00	1 : 0.67 : 0.67 : 0.67 : 0.67 : 0.67	1 : 0.84 : 0.84 : 0.84 : 0.84	ADPF15	ADP32
16	24.00	1 : 0.63 : 0.63 : 0.63 : 0.63 : 0.63	1 : 0.79 : 0.79 : 0.79 : 0.79	ADPF16	ADP33
17	25.00	1 : 0.6 : 0.6 : 0.6 : 0.6 : 0.6	1 : 0.75 : 0.75 : 0.75 : 0.75	ADPF17	ADP34
FLY-ASH PERCENTAGE VARIATION					
35	9.00	2.02 : 1 : 2.02 : 2.02 : 2.02 : 2.02	---	ADFF35	---
36	10.00	1.8 : 1 : 1.8 : 1.8 : 1.8 : 1.8	---	ADFF36	---
37	11.00	1.62 : 1 : 1.62 : 1.62 : 1.62 : 1.62	---	ADFF37	---
38	12.00	1.47 : 1 : 1.47 : 1.47 : 1.47 : 1.47	---	ADFF38	---
39	13.00	1.34 : 1 : 1.34 : 1.34 : 1.34 : 1.34	---	ADFF39	---
40	14.00	1.23 : 1 : 1.23 : 1.23 : 1.23 : 1.23	---	ADFF40	---
41	15.00	1.13 : 1 : 1.13 : 1.13 : 1.13 : 1.13	---	ADFF41	---
42	16.00	1.05 : 1 : 1.05 : 1.05 : 1.05 : 1.05	---	ADFF42	---
43	17.00	0.98 : 1 : 0.98 : 0.98 : 0.98 : 0.98	---	ADFF43	---
44	18.00	0.91 : 1 : 0.91 : 0.91 : 0.91 : 0.91	---	ADFF44	---
45	19.00	0.85 : 1 : 0.85 : 0.85 : 0.85 : 0.85	---	ADFF45	---
46	20.00	0.8 : 1 : 0.8 : 0.8 : 0.8 : 0.8	---	ADFF46	---

47	**21.00**	**0.75 : 1 : 0.75 : 0.75 : 0.75 : 0.75**	---	**ADFF47**	---
48	**22.00**	**0.71 : 1 : 0.71 : 0.71 : 0.71 : 0.71**	---	**ADFF48**	---
49	**23.00**	**0.67 : 1 : 0.67 : 0.67 : 0.67 : 0.67**	---	**ADFF49**	---
50	**24.00**	**0.63 : 1 : 0.63 : 0.63 : 0.63 : 0.63**	---	**ADFF50**	---
51	**25.00**	**0.6 : 1 : 0.6 : 0.6 : 0.6 : 0.6**	---	**ADFF51**	---

V. RESULTS AND DISCUSSIONS:

The results obtained for different bricks properties for different Phosphogypsum percentages are presented in table 2 below.

TABLE 2: AIR-CURRED BRICK: % OF PHOSPHOGYPSUM VS BRICK PROPERTIES.

SL. NO.	% OF PHOSPHOGYPSUM IN MIX	COMPRESSIVE STRENGTH (WITH FLY ASH), Mpa	COMPRESSIVE STRENGTH (WITHOUT FLY ASH), Mpa	% WEIGHT GAIN (ABSORBTION) (WITH FLY ASH)	% WEIGHT GAIN (ABSORBTION) (WITH OUT FLY ASH)	DRY DENSITY (WITH FLY ASH) IN Kg/m^3	DRY DENSITY (WITH OUT FLY ASH) IN Kg/m^3	DRY DENSITY (WITH FLY ASH) IN Kg/m^3	DRY DENSITY (WITH OUT FLY ASH) IN Kg/m^3
1	9.00	18.31	14.67	13.30	12.12	2322.63	2512.67	2631.57	2978.33
2	10.00	19.84	15.12	13.84	12.23	2252.15	2498.32	2565.22	2923.45
3	11.00	20.77	15.79	14.21	12.78	2216.38	2476.77	2530.69	2877.11
4	12.00	21.14	16.27	14.50	13.12	2187.89	2392.18	2504.59	2712.77
5	13.00	21.38	16.57	14.78	13.16	2161.77	2376.32	2480.74	2692.85
6	14.00	21.37	17.87	15.05	13.52	2138.18	2371.36	2459.38	2690.59
7	15.00	21.23	18.67	15.31	13.52	2115.71	2366.30	2438.90	2686.17
8	16.00	20.94	18.84	15.54	13.51	2093.84	2360.90	2418.61	2679.87
9	17.00	20.47	18.82	15.76	13.50	2072.08	2355.03	2398.05	2673.06
10	18.00	19.85	18.79	15.95	13.53	2049.69	2348.63	2376.45	2666.41
11	19.00	19.14	18.86	16.15	13.53	2026.41	2341.55	2353.54	2658.43
12	20.00	18.30	18.92	16.25	13.53	2001.13	2333.66	2327.80	2649.48
13	21.00	17.39	18.77	16.32	13.55	1971.38	2324.62	2297.31	2639.58
14	22.00	16.41	18.50	16.14	13.51	1937.50	2314.12	2261.23	2626.77
15	23.00	15.31	17.28	17.08	13.53	1889.28	2301.61	2209.33	2613.04
16	24.00	14.22	16.62	16.93	13.52	1782.88	2286.21	2086.61	2595.35
17	25.00	13.92	15.37	16.17	13.65	1701.32	2266.55	2017.45	2571.88

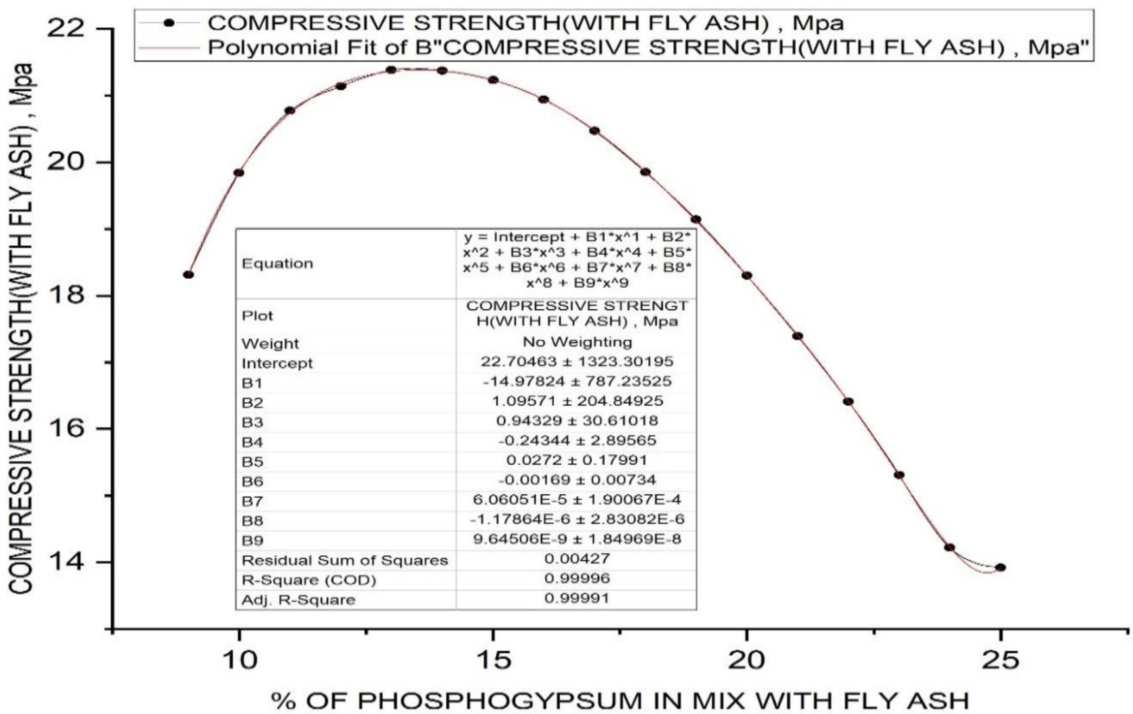

Fig 7: Compressive strength variation with Percentage of Phosphogypsum for Bricks with Fly-ash.

From Fig 7 and table 2, it can be inferred that in case of air-dried sample (air dried for 24 hours.) containing fly-ash, as the percentage of Phosphogypsum increases from 9 % to 13 %, the corresponding compressive strength increases from 18.31 MPa to 21.38 MPa respectively. With further increase in percentage of Phosphogypsum from 14 % to 25 %, the compressive strength decreases from 21.37 MPa to 13.92 MPa. Other materials may also play a dominant role and so with increase in Phosphogypsum percentage the compressive strength decreases. The maximum and minimum values of compressive strength are 21.38 MPa and 13.92 MPa corresponding to Phosphogypsum percentages of 13 and 25% respectively. The mean compressive strength corresponding to Phosphogypsum percentage of 17 % is 20.47 MPa.

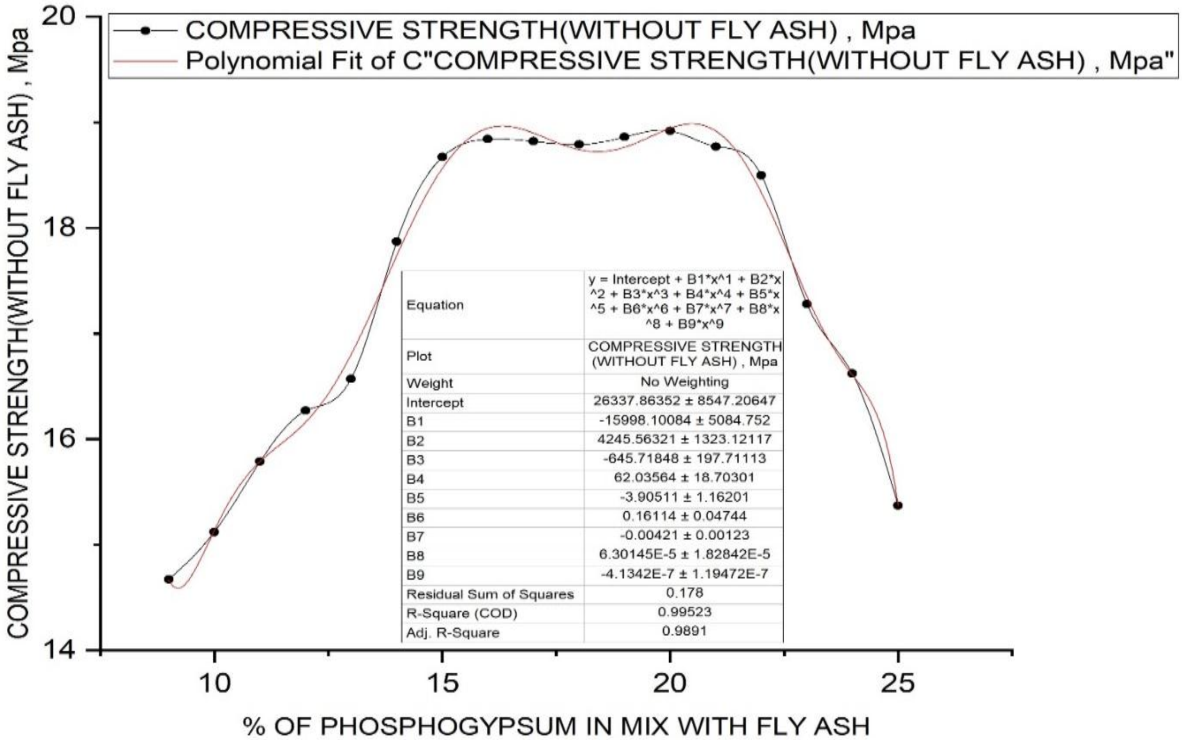

Fig 8: Compressive strength variation with Percentage of Phosphogypsum for Bricks without Fly-ash.

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From Fig 8 and table 2, it can be inferred that in case of air-dried sample (air dried for 24 hours.) without containing fly-ash, as the percentage of Phosphogypsum increases from 9 % to 16 %, the corresponding compressive strength increases from 14.67 MPa to 18.84 MPa respectively. With further increase in percentage of Phosphogypsum from 17 % to 25 %, the compressive strength decreases from 18.82 MPa to 15.37 MPa. The exception to this is shown at Phosphogypsum percentage of 19% and 20% where the corresponding compressive strengths are 18.86 MPa and 18.92 MPa. The maximum and minimum values of compressive strength are 18.92 MPa and 14.67 MPa corresponding to Phosphogypsum percentages of 20 % and 9 % respectively. The mean compressive strength corresponding to Phosphogypsum percentage of 17 % is 18.82 MPa.

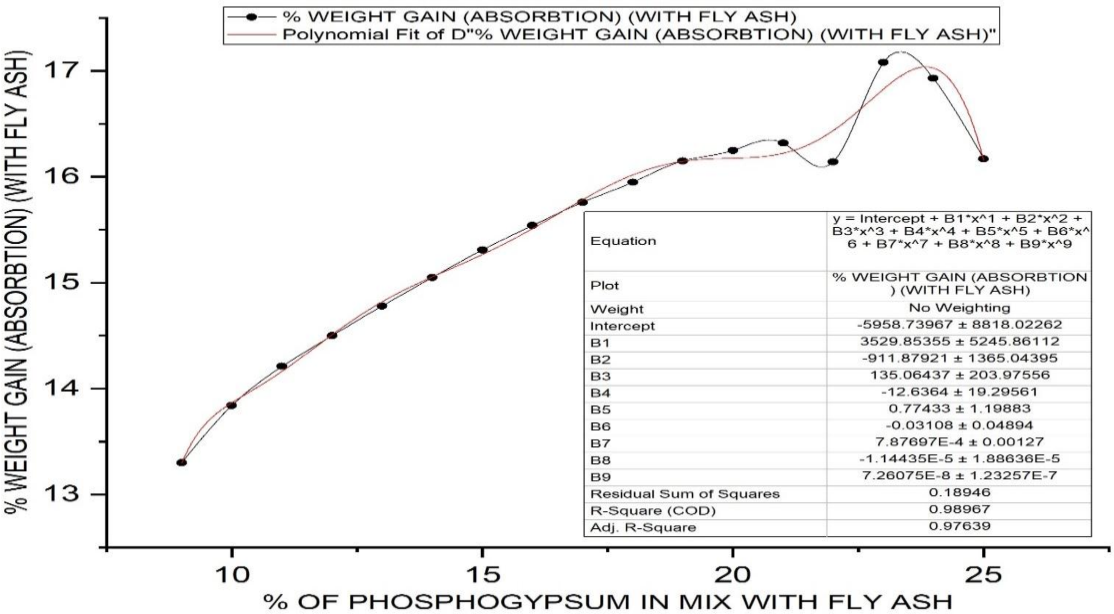

Fig 9: Percentage weight gain variation with Percentage of Phosphogypsum for Bricks with Fly-ash.

From Fig 9 and table 2, it can be inferred that in case of air-dried sample (air dried for 24 hours.) containing fly-ash, as the percentage of Phosphogypsum increases from 9 % to 20 %, the corresponding weight gain increases from 13.30 % to 16.25 % respectively. Further increase in percentage of Phosphogypsum from 21 % to 25 %, the variation in weight gain is completely random and does not tend to follow any distinctive trend. The maximum and minimum values of weight gain are 17.08 % and 13.30 % corresponding to Phosphogypsum percentages of 23 % and 9 % respectively.

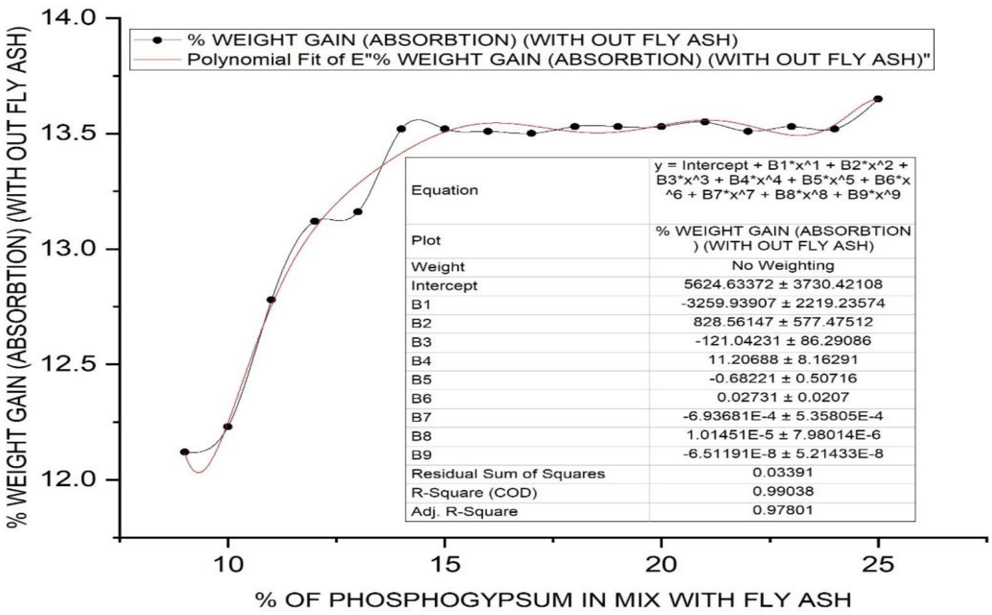

Fig 10: Percentage weight gain variation with Percentage of Phosphogypsum for Bricks without Fly-ash.

From Fig 10 and table 2, it can be inferred that in case of air-dried sample (air dried for 24 hours.) without containing fly-ash, as the percentage of Phosphogypsum increases from 9 % to 15 %, the corresponding weight gain increases from 12.12 % to 13.52 % respectively. Further increase in percentage of Phosphogypsum from 16 % to 25 %, the variation in weight gain is completely random and does not tend to follow any distinctive trend. The maximum and minimum values of weight gain are 13.65 % and 12.12 % corresponding to Phosphogypsum percentages of 25 % and 9 % respectively.

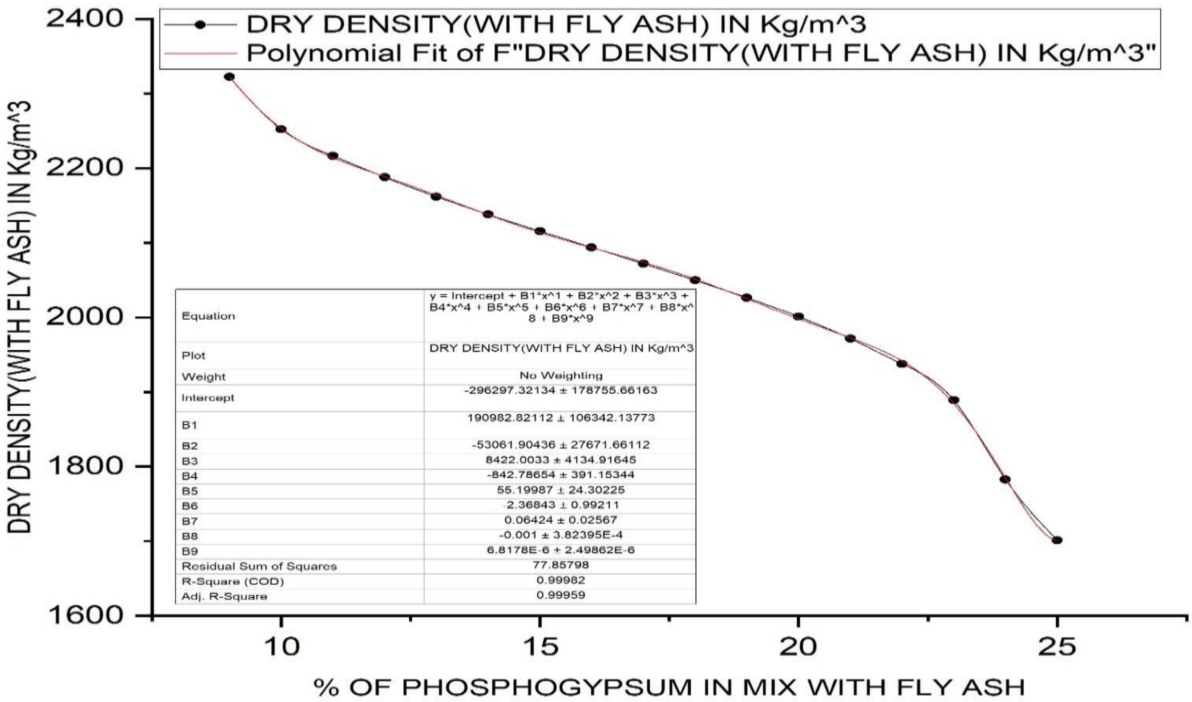

Fig 11: Dry density variation with Percentage of Phosphogypsum for Bricks with Fly-ash.

From Fig 11 and table 2, it can be inferred that in case of air-dried sample (air dried for 24 hours.) containing fly-ash, as the percentage of Phosphogypsum increases from 9 % to 25 %, the corresponding dry density decreases from 2322.63 Kg/m^3 to 1701.32 Kg/m^3 respectively. The maximum and minimum values of dry density are 2322.63 Kg/m^3 and 1701.32 Kg/m^3 corresponding to Phosphogypsum percentages of 9 % and 25 % respectively.

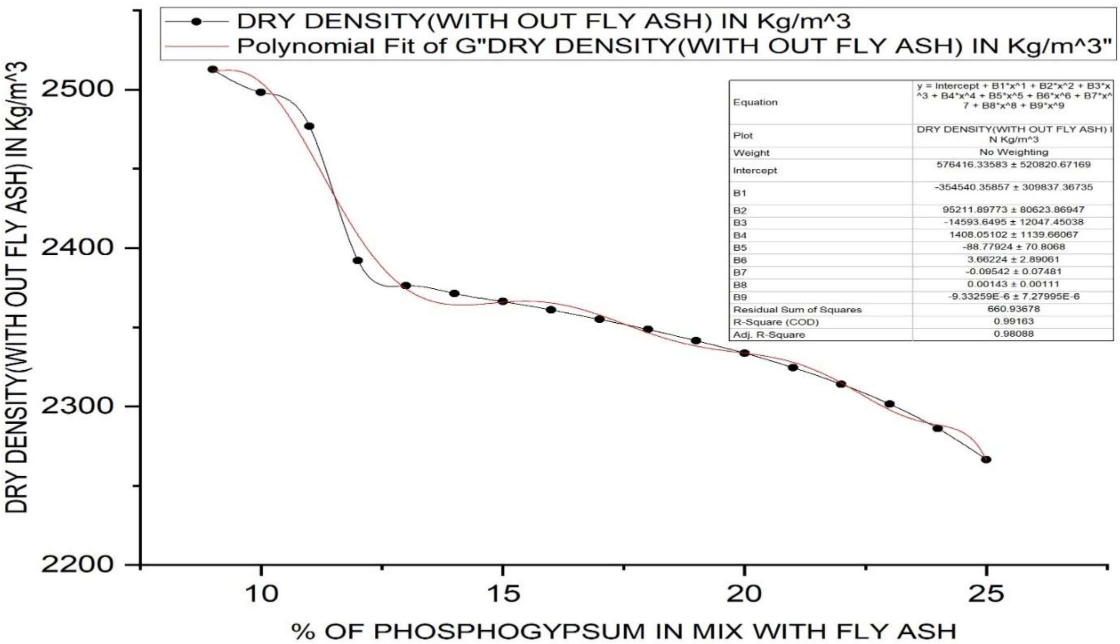

Fig 12: Dry density variation with Percentage of Phosphogypsum for Bricks without Fly-ash.

From Fig 12 and table 2, it can be inferred that in case of air-dried sample (air dried for 24 hours.) without containing fly-ash, as the percentage of Phosphogypsum increases from 9 % to 25 %, the corresponding dry density decreases from 2512.67 Kg/m^3 to 2266.55 Kg/m^3 respectively. The maximum and minimum values of dry density are 2512.67 Kg/m^3 and 2266.55 Kg/m^{3}c corresponding to Phosphogypsum percentages of 9 % and 25 % respectively.

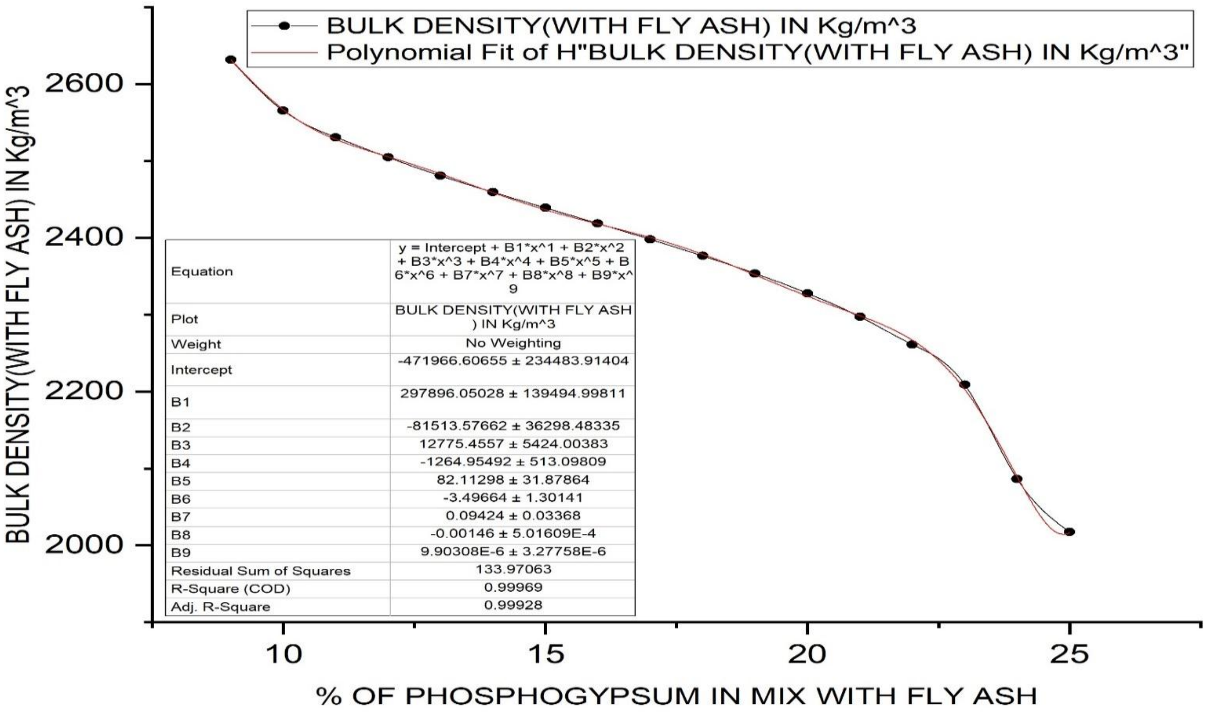

Fig 13: Bulk density variation with Percentage of Phosphogypsum for Bricks with Fly-ash.

From Fig 13 and table 2, it can be inferred that in case of air-dried sample (air dried for 24 hours.) containing fly-ash, as the percentage of Phosphogypsum increases from 9 % to 25 %, the corresponding bulk density decreases from 2631.657 Kg/m^3 to 2017.45 Kg/m^3 respectively. The maximum and minimum values of bulk density are 2631.657 Kg/m^3 and 2017.45 Kg/m^3 corresponding to Phosphogypsum percentages of 9 % and 25 % respectively.

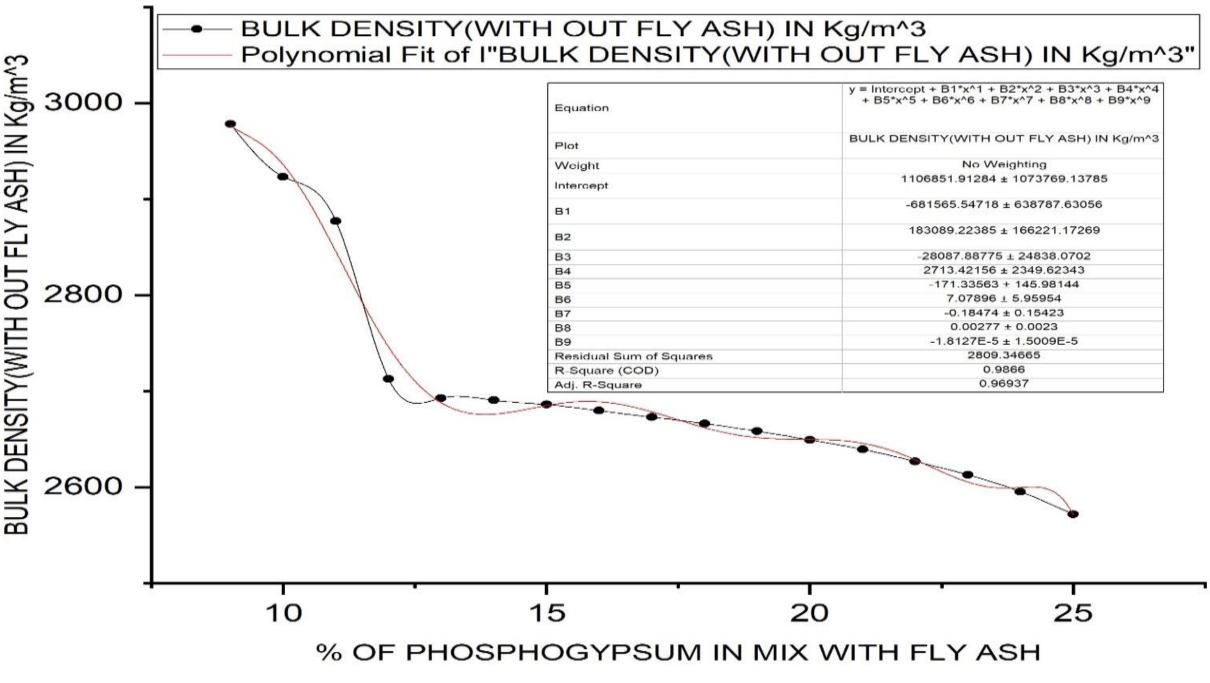

Fig 14: Bulk density variation with Percentage of Phosphogypsum for Bricks without Fly-ash.

From Fig 14 and table 2, it can be inferred that in case of air-dried sample (air dried for 24 hours.) without containing fly-ash, as the percentage of Phosphogypsum increases from 9 % to 25 %, the corresponding bulk density decreases from 2978.33 Kg/m^3 to 2571.88 Kg/m^3 respectively. The maximum and minimum values of bulk density are 2978.33 Kg/m^3 and 2571.88 Kg/m^{3}c corresponding to Phosphogypsum percentages of 9 % and 25 % respectively.

The results obtained for different bricks properties for different Fly-Ash percentages are presented in table 3 below.

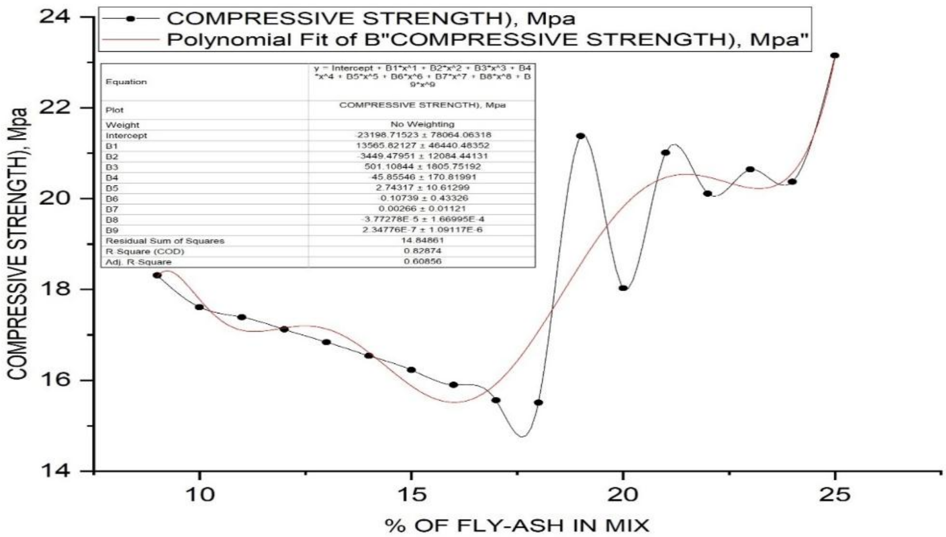

TABLE 3: AIR-CURRED BRICK: % OF FLY-ASH VS BRICK PROPERTIES.					
SL. NO.	**% OF FLY-ASH IN MIX**	**COMPRESSIVE STRENGTH), Mpa**	**% WEIGHT GAIN (ABSORBTION)**	**DRY DENSITY, Kg/m^3**	**DRY DENSITY Kg/m^3**
1	9.00	18.31	16.38	2014.20	2344.18
2	10.00	17.61	16.49	2006.62	2337.54
3	11.00	17.39	16.56	1998.64	2329.59
4	12.00	17.12	16.62	1989.58	2320.23
5	13.00	16.84	16.67	1980.12	2310.17
6	14.00	16.54	16.72	1969.70	2298.97
7	15.00	16.23	16.76	1958.10	2286.21
8	16.00	15.90	16.81	1945.31	2272.27
9	17.00	15.56	16.85	1930.49	2255.67
10	18.00	15.51	16.89	1919.47	2243.49
11	19.00	21.38	15.91	2076.60	2406.98
12	20.00	18.03	16.48	1980.34	2306.28
13	21.00	21.01	16.03	2065.70	2396.86
14	22.00	20.11	16.21	2036.99	2366.87
15	23.00	20.64	16.13	2054.70	2386.02
16	24.00	20.37	16.15	2045.65	2375.91
17	25.00	23.15	14.84	2148.20	2466.91

Fig 15: Compressive strength variation with fly-ash percentage.

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From Fig 15 and table 3, it can be inferred that when the fly-ash percentage increases from 9 % to 18 %, the compressive strength decreases from 18.31 Mpa to 15.51 Mpa. When fly-ash percentage increases from 19 % to 25 %, the effect on compressive strength variation is completely random and does not tend to follow any distinctive trend. The compressive strength varies between a maximum value of 23.15 Mpa and minimum value of 15.51 Mpa corresponding to Fly-ash percentage of 25 % and 18 % respectively.

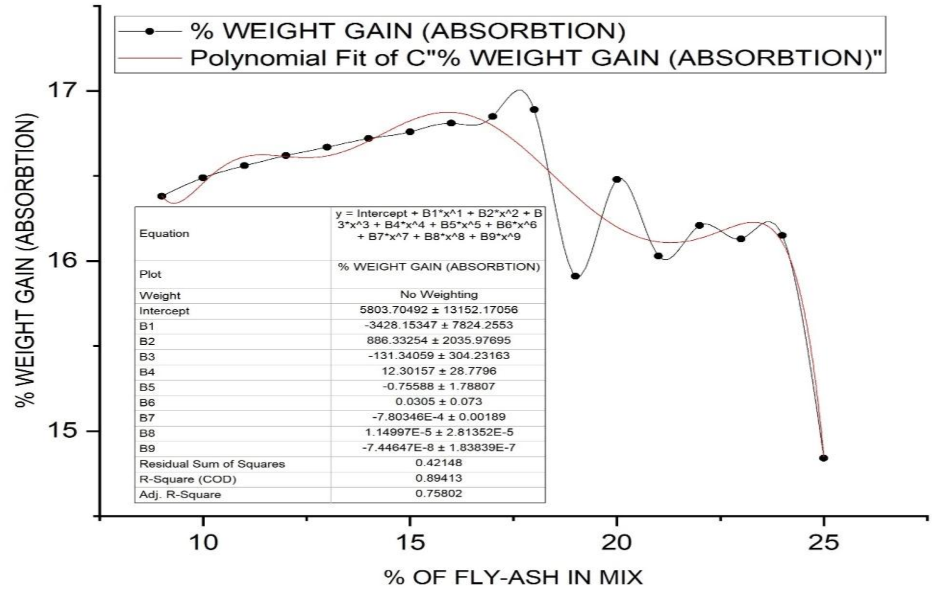

Fig 16: Percentage weight gain variation with fly-ash percentage.

From Fig 16 and table 3 it can be inferred that; when the fly-ash percentage increases from 9 % to 18 %, the water absorbtion increases from 16.38 % to 16.89 %. When fly-ash percentage increases from 19 % to 25 %, the water absorbtion variation is completely random and does not tend to follow any distinctive trend. The water absorbtion varies between a maximum value of 16.89 Mpa and minimum value 14.84 Mpa corresponding to Fly-ash percentage of 18% and 25 % respectively.

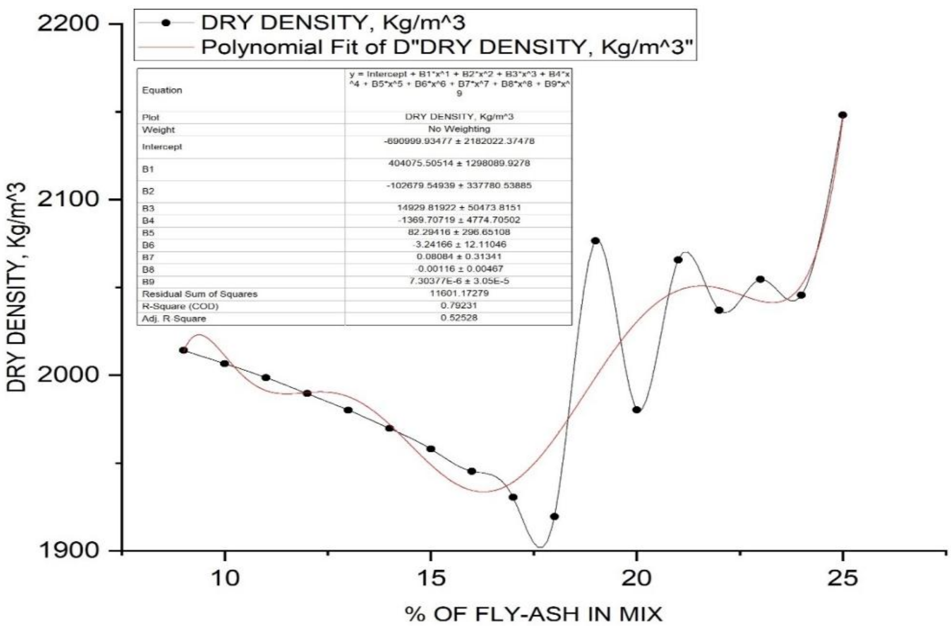

Fig 17: Dry density variation with fly-ash percentage.

From Fig 17 and table 3 it can be inferred that; when the fly-ash percentage increases from 9 % to 18 %, the dry density decreases from 2014.20 Kg/m^3 to 1919.47 Kg/m^3. When fly-ash percentage increases from 19 % to 25 %, the dry density variation is completely random and does not tend to follow any distinctive trend. The dry density varies between a maximum value of 2148.20 Kg/m^3 and minimum value of 1919.47 Kg/m^3 corresponding to Fly-ash percentage of 25 % and 18 % respectively.

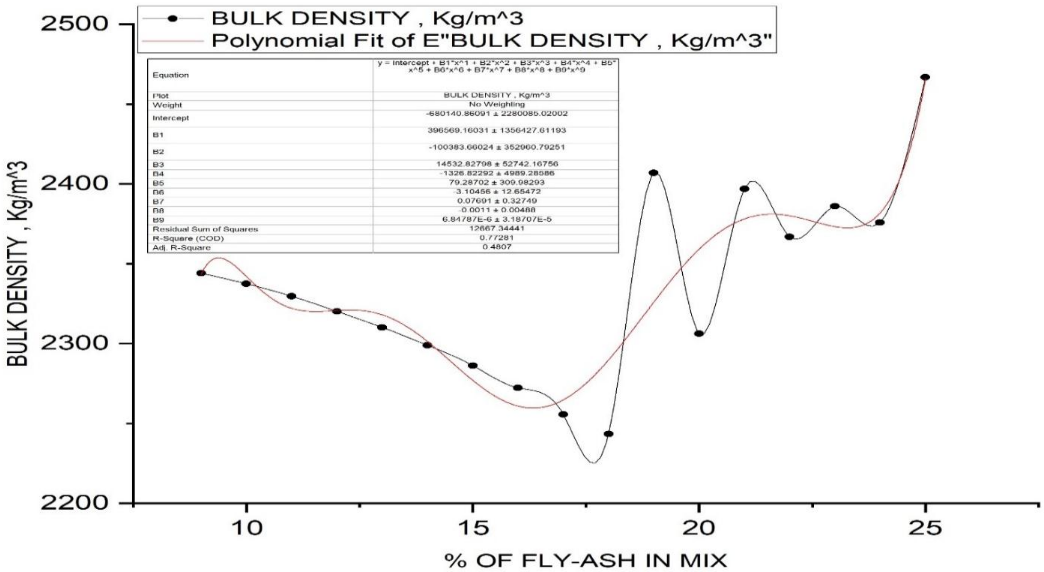

Fig 18: Bulk density variation with fly-ash percentage.

From Fig 18 and table 3 it can be inferred that; when the fly-ash percentage increases from 9 % to 18 %, the bulk density decreases from 2344.18 Kg/m^3 to 2243.49 Kg/m^3. When fly-ash percentage increases from 19 % to 25 %, the bulk density variation is completely random and does not tend to follow any distinctive trend. The bulk density varies between a maximum value of 2466.91 Kg/m^3 and minimum value of 2243.49 Kg/m^3 corresponding to Fly-ash percentage of 25 % and 18 % respectively.

VI. INFERENCE AND CONCLUSIONS

From detailed experimental studies, it is shown here that air-dried geo-polymer bricks made from Phosphogypsum are feasible and can produce desirable properties. The compressive strength of such bricks is in excess of 12.5 MPa, even when cured in air and can be used for both structural and non-structural load bearing members. When fly-ash is used the compressive strength is slightly higher, densities (dry and dry) are lower in most cases however with increase in Phosphogypsum content certain decrease in compressive strength is seen with or without fly-ash. In certain cases, the absence of fly-ash causes the increase in densities beyond the density (2000 Kg/m^3) of conventional masonry bricks, even with the presence of fly-ash the densities in most cases are greater than 2000Kg/m^3 of conventional masonry bricks. Since the presence of fly-ash causes effect on density and not on compressive strength, whether to add it or not can be considered from case to case basis. If the particular mix proportions produce higher densities, they may be used in the building constructions by considering their densities in design in place of density of conventional bricks. Since these bricks have a maximum water absorption of 16.93%, less than 20 % and slightly higher than 15 %, they can be used for construction of liquid retaining structures such as water tanks. High resistance to attack of acid and low porosity make the use of this brick's durable for a long period of time.

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