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Experimental Investigation Of Hypo-Sludge Used In Fly-Ash Bricks Manufacturing With The Partial Replacement Of Lime

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Abstract - It is not possible to replace the paper waste for innumerable number of times. Since the paper fiber, after multiple recycling processes, becomes weak broken and unsuitable for manufacturing paper high quality. Thus the broken and low class paper fibers are alienated in order to make waste sludge known as hypo-sludge, which is available at very negligible rate and in huge quantity from paper industry. Hypo-sludge has a very good content of C_aO from C_aCO_3, SiO_2, and $MgCO_3$.This study probes the feasibility of using hypo-sludge by partially replacing the lime in making fly-ash bricks. The replacement of hypo-sludge by weight among lime of 5%, 10%, 15% and 20% is done in this study. These bricks were tested in compression test and water absorption test as per Indian Standards. The research aims at making economical and green bricks so as to maintain environmental balance and avoid the problem of ash disposal. Countries like India suffer from low availability of non-renewable resources and huge need building materials like cement and brick earth. Therefore it is essential to develop eco-efficient utilization of paper sludge. Combined with various proposition of mix and various tests are to be done make same the compressive strength, water absorption and the economical feasibility of the bricks.

Index Terms—**fly-ash, lime, hypo-sludge, quarry dust, gypsum**

1. INTRODUCTION

Bricks remain important building materials in the country. Brick industry has been thriving in India since the days of Indus valley civilization and has occupied as the major industry in the rural areas. The alarming development activity in the urban areas has necessitated the establishment of brick industry in India. It has directly or indirectly caused a series of environmental and health problems. At the local level (in the vicinity of a brick kiln), environmental pollution from brick-making operations becomes a major source affecting the health of human and other living organisms. At the global level, environmental pollution from brick-making operations contributes to the phenomenal increase of global warming and climate change.

Production of paper in India, totally 157 functional units manufacture paper approximately 14 million tons annually (1.6% of the world production) which is 15^{th} largest in world. A report estimated in 2014-15 the rise in paper production in the next five years as 20 million tones with 5 kg per capita (India paper Industry a glance in 2014-15).

As any other manufacturing industry, paper industry discharge waste in large quantity which often becomes a source of air pollution; much of the paper waste is burnt in open places. The fiber used for manufacturing paper becomes weak and broken when it is recycled again and again. The waste sludge, removed from the paper waste, could be substituted for lime to ascertain whether the hypo sludge could reduce the disposal coast of the waste or enhance the quality of bricks in terms of stability and eco-friendly nature. This study purposes an innovative supplementary cementious construction material. To investigate the compressive strength of the fly ash bricks using hypo-sludge, the density of fly-ash bricks and conventional bricks is to be compared to determine the water absorption capacity of the fly ash bricks. The materials used for making brick are selected from the conventional brick industry. Typical materials used for brick include fly-ash, lime, quarry dust, gypsum and mineral admixtures (hypo-sludge). Bricks can be designed and constructed using a broad range of normal brick materials.

2. MATERIALS AND THEIR PROPERTIES

Hypo- sludge can actually act as an adhesive material with cement and can be used as a successful building material. If it is mixed with cement, it will actually increase the strength of the cement. While comparing the constituents of cement and hypo-sludge, Hypo-sludge is produced in a large amount as a byproduct of paper industry and used in concrete production as partial replacement of cement. It contains low calcium and minimum amount of silica due to the presence of silica and magnesium properties and behaves like cement. Use of hypo-sludge in brick blocks can save the paper industry disposal costs and produces a sustainable low cost material for construction; it helps the nearby environment by reducing the eventual problems of odor nuisance. The sludge, fly-ash and press mud are basically the waste materials which can be converted in to useful constructional material with least amount of investment. It helps in providing the low-cost housing (Table 1).

Table 1 Chemical composition of Hypo- sludge (Paper waste)

Chemical	Percentage	Chemical	Percentage
Specific gravity of Hypo- sludge	2.16 to 2.25	**Effluent sludge**	
Lime (Cao)	46.20	Moisture	75 to 80

Silica (SiO_2)	9.00	Gross calorific value	2300 – 2700 Kcal/kg
Alumina	3.60	Organic	60 – 70
Magnesium	3.33	Inorganic	30 – 40
Calcium Sulphate	4.05		
Chemical	**Percentage**	**Chemical**	**Percentage**
Lime Sludge		**Lime grits**	
Moisture	45 to 50	Moisture	25 to 30
Acid insoluble's	6 – 7	Acid insoluble	10
Mixed Oxides (R_2O_3)	1.6	Silica as SiO_2	10
Calcium as $CaCO_3$	87.8	Oxides (R_2O_3)	3.1
Magnesium as $MgCO_3$	1.54	Calcium as $CaCO_3$	81.2
Free Cao	0.76	Magnesium as $MgCO_3$	2.76
Sodium as Na_2O	1.67	Free CaO	2.04
Pith		Sodium as Nazo	1.09
Moisture	45 to 50	**Sludge Containing**	
Volatile matter	72	Adorable organic Halides	AOX=3997 Mg /kg used as fuel boilers
Fixed Carbon	13		
Gross calorific vale	4000 – 4200 Kcal/kg		

Source: Tamil Nadu News Print and Paper Limited. (TNPL)

Objectives:

- To investigate the compressive strength of the fly-ash bricks using hypo- sludge.
- To compare the density of fly-ash bricks and conventional bricks.
- To determine the water absorption capacity of fly-ash bricks.

2.1Fly-ash:

As per the ASTM C 618 – 1993, there are two classes of fly-ash namely class F and class C. Class F fly-ash is produced from burning anthracite or bituminous coal and is pozzolan a in nature and class C is obtained from lignite or sub-bituminous coal. Class C fly-ash possesses both pozzolana and self-hardening property. Hence it is necessary to characterize the material scientifically to utilize it in different applications. Fine particles and flue gases remain as the residues when combustion takes place. In industrial context, fly-ash usually refers to ash produced during combustion of coal. The chemical and physical requirements in IS: 3812 Part 1 – 2003, is considered as the quality of fly-ash (Fig. 1).

Physical Properties of Fly-ash:

The specific gravity, loss on ignition (LOI) and specific surface area are the prominent physical properties of fly-ash. The specific gravity of fly-ash is not constant at all time and it ranges from 1.3 to 4.8. The iron oxide content plays a decisive role in the specific gravity of the material. The specific gravity is found more for fly-ash containing more iron oxide and vice versa. The specific gravity of the ash gets enhanced from 3.6 to 4.8 due to presence of opaque spherical magnetite and hematite particles. On the other hand, as the amount of quartz and mullet increases, the specific gravity decreases. However, the coal particles, with some mineral impurities, will have the lower specific gravity in the range 1.3 -1.6. The range of specific gravity of Canadian fly-ash is reported to be in the range from 1.91 to 2.94 and the American fly-ash to be in the range from 2.14 to 2.69.

Fig.1 Photography view of Fly-ash

Chemical Compositions of Fly-ash

The main chemical compounds of class-F fly-ash are silica, alumina and iron oxide. The minor constituents include oxides of calcium, magnesium, titanium, sulphur, sodium and potassium. Class-C fly-ash contains relatively higher proportion of calcium oxide and lesser proportion of silica, alumina and iron oxide unlike the class-F fly-ash (Table 2).

Table 2 Chemical composition of fly-ash

Sl.No	Chemical compositions	% of components
1	Unburnt carbon	12.00
2	Silica (SiO_2)	57.77
3	Aluminum oxide (Al_2O_3)	23.92
4	Iron oxide (Fe_2O_3)	9.56
5	Titanium oxide (TiO_2)	1.63
6	Calcium (CaO)	2.24
7	Potassium oxide (K_2O)	0.60
8	Magnesium oxide (MgO)	1.28
9	Molybdenum oxide (MO_2O_3)	0.13

Morphology of Fly-ash:

Fly-ash is a heterogeneous material with the degree of heterogeneity persisting at all levels viz macro, micro and nano structural levels (Sun Wei at al 2003). By using the scanning electron microscopy and energy dispersive X-ray analysis (EDXA) technique, the particle shape and surface characteristics of fly-ash can be studied. Some of the particles are hollow and spherical which are termed as the cenospheres. These cenosphere are also called the floaters, as they are light in weight. Fly-ashes contain small spherical particles within a large glassy sphere, and are called the plerosphere. Some particles, which have the regions of a spherical particle melted or eroded away are known as the clathrosphere.

Mineralogy of Fly-ash:

Fly-ash consists of both crystalline and amorphous phases. The crystalline phases could be a quartz, mullite, silimanite, crystallite, cristobalite, sulphates of iron, magnetite, etc. The amorphous phases could be of silica and silicates, predominantly of aluminum, but contain calcium, magnesium, and iron in varying concentration with and without traces of sodium and potassium.

2.2 Lime:

Lime is truly a versatile material used in construction projects. Lime can be used to prepare the construction site by stabilizing the soil or remediating the Brownfield sites. Lime can be used in the construction of masonry systems as a component of mortar or the masonry unit. Exterior (stucco) and interior plaster systems can also contain lime. Lime has been used in construction for thousands of years to create durable mortar and plaster. Lime provides benefits in the plastic and hardened state to the mortars and plasters. In the plastic state, lime can enhance the workability and water retention of plasters and mortars. In the hardened state, lime products react with carbon dioxide to regenerate calcium carbonate or limestone. Initial strength is needed in most applications; the additives such as gypsum, cement or pozzolan are mixed with lime in construction applications (Fig. 2).

Fig. 2 Photography view of Lime

Lime can react with pozzolanic materials in the mortar or plaster to produce cement-like product. The strength of lime-based mixes can be modified depending upon the application. This is beneficial in the restoration applications where low strengths and high vapor permeability are needed. The hydrated lime is used for fly-ash brick making should conform to the class-C grade as specified by IS: 712:1984. The testing ensures the quality specified in the IS: 1514:1990 (Table 3).

Table 3 Chemical Composition of Lime

Sl.No	Chemical compositions	% of components
1	Silica (SiO_2)	> 2.5to 1.23
2	Aluminum oxide (Al_2O_3)	> 1.5 to 0.56
3	Iron oxide (Fe_2O_3)	> 2
4	Calcium (CaO)	> 83.3 to 94.3
5	Potassium oxide (K_2O)	1.23
6	Magnesium oxide (MgO)	> 0.5 to 1.23
7	Sulfur trioxide (SO_3)	< 0.5
8	Calcium carbonate ($CaCO_3$)	< 10
9	Carbon dioxide (CO_2)	< 5
10	Disodium (Na_2)	0.4 to 0.5

2.3 Gypsum

Gypsum is a very soft sulfate mineral having the composition of calcium sulfate dehydrate and the chemical formula CaSO4 2H2O. It is found in alabaster, a decorative stone used in Ancient Egypt; it is the second softest mineral on the Mohr's scale of mineral hardness; It forms as an evaporate mineral and a hydration product of anhydrite. Gypsum is a common mineral which has thick and extensive evaporate beds in association with sedimentary rocks. Deposits are known to have occurred in strata from as far back as the Archaean eon. Gypsum is found deposited in lakes and sea water, in hot springs, in volcanic vapors, and sulfate solutions in veins. Hydrothermal anhydrite, in veins, is commonly hydrated to gypsum by groundwater in near-surface exposures. It is often associated with the minerals halite and sulfur. Gypsum is also formed as a by-product of sulfide oxidation, amongst others by pyrite oxidation, when the sulfuric acid generated reacts with calcium carbonate. Electric power stations which burn coal with flue gas desulfurization produce large quantities of gypsum as a byproduct from the scrubbers. Calcium sulfate, commonly known as natural gypsum, is found in nature in different forms, mainly inde-hydrate (CaSO4 · 2H2O) and anhydrite (CaSO4). Apart from the origin of gypsum, its genesis, varieties and properties, the focus is then on the most common binding material produced from it, plaster of Paris. Gypsum block is a massive lightweight building material composed of solid gypsum, for building and erecting lightweight fire-resistant non-load bearing interior walls, partition walls, cavity walls, skin walls and pillar casing indoors. Gypsum blocks are composed of gypsum plaster, water and, in some cases, additives like vegetable or wood fiber for greater strength (Fig. 3). The purity of gypsum can be tested by the specified IS: 1288:1982 (Table 4).

Fig. 3 Photography view of Gypsum

Table 4 Chemical composition of gypsum

Sl.No	Chemical compositions	% ofcomponents
1	Silica (SiO_2)	0.86
2	Aluminum oxide (Al_2O_3)	0.56
3	Iron oxide (Fe_2O_3)	0.05
4	Calcium (CaO)	34.6
5	Phosphorus pent oxide (P_2O_5)	1.23
6	Sulfur trioxide (SO_3)	53.2
7	Sodium (Na_2O)	0.56
8	Loss on Ignition (LoI)	8.9

2.4 Quarry Dust

Quarry-dust is a byproduct of the crushing process which is a concentrated material used as the aggregates for concreting purpose, especially as fine aggregates. In quarrying activities, the rock is crushed into various sizes. During the process of crushing the dusts called quarry dust generated as waste. It is a useless material and a source of air pollution. Therefore, quarry dust is used in construction works; it would reduce the cost of construction and the construction material besides saving the natural resources properly. The Quarry dust is a residual product obtained during the crushing process of aggregates at quarries. The Quarry dust, used in the study, was obtained from stone Quarry (Fig. 4). The size particles of QD ranged from 75 μm to 4.75 mm. It has a specific gravity of 2.56 with a loose dry density ranging from 1660 kg/m3 to 1730 kg/m3. The water absorption of this QD ranged between 1.20% and 1.50%. The sand or stone dust which is used for concreting work, can also be used for making fly-ash bricks and the IS: 383: 1970 specify the requirements (Table 5).

Fig. 4 Photography view of quarry dust

Table 5 Chemical composition of quarry dust

Sl.No	Chemical compositions	% of components
1	Silica (SiO_2)	69.94
2	Aluminum oxide (Al_2O_3)	14.60
3	Iron oxide (Fe_2O_3)	2.16
4	Calcium (CaO)	2.23
5	Magnesium oxide (MgO)	0.38
6	Manganese oxide (MnO)	0.07

2.5 Hypo-Sludge

Hypo- sludge contains low calcium and maximum calcium chloride and minimum amount of silica. Lime sludge behaves like cement because of the presence of silica and magnesium properties. This silica and magnesium improve the setting of the Mortar (Fig. 5).

Fig. 5 Photography view of hypo-sludge

Paper fibers can be recycled only for a limited number of times before they become too short or weak to make high quality paper. It means the broken, low- quality paper fibers, separated become the waste sludge; this waste sludge is known as Hypo- sludge. To reduce disposal and pollution problems emanating from these industrial wastes, it is essential to develop profitable building materials from them. Keeping this in view, investigations were undertaken to produce low-cost Bricks by blending various ratios of bricks with hypo- sludge. Hypo- sludge contains low calcium and maximum calcium chloride and minimum amount of silica. Hypo- sludge has the character of cement because of the presence of silica and magnesium properties (Table 6).

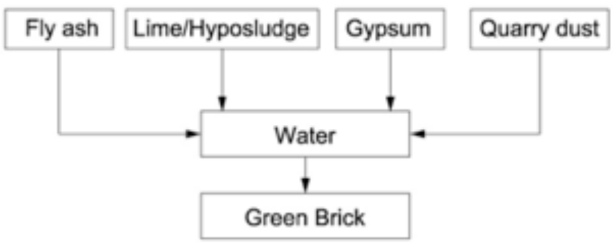
Table 6 Chemical composition of hypo- sludge

Sl.No	Chemical compositions	% of components
1	Silica (SiO_2)	5.28
2	Aluminum oxide (Al_2O_3)	0.09
3	Iron oxide (Fe_2O_3)	0.73
4	Calcium (CaO)	47.84
5	Magnesium oxide (MgO)	6.41
6	Sulfur trioxide (SO_3)	0.19
7	Loss on ignition (LoI)	38.26

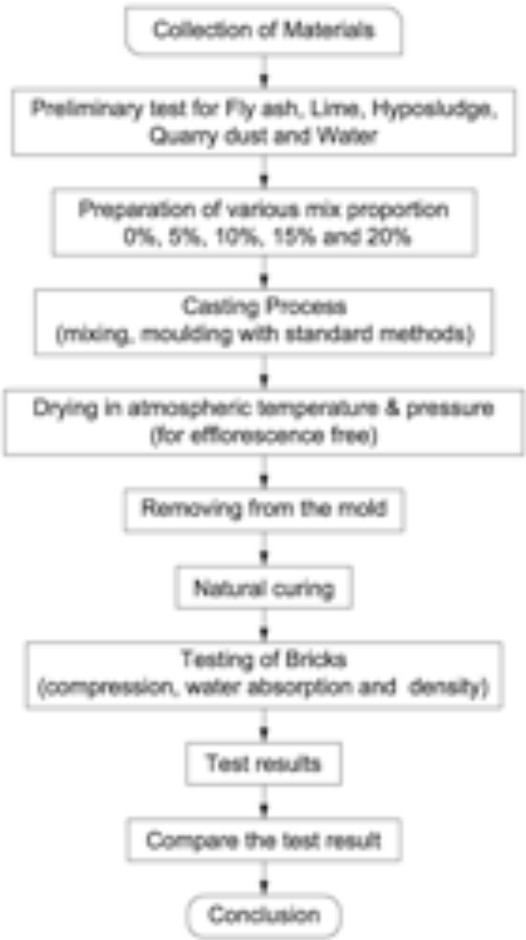
2.6 Water

Water is an important ingredient in the manufacture of bricks. It helps to bind all the raw materials and give proper mix. Water, used for making brick, should be free from impurities. Meteoric water is required for the preparation of various mix proportions. The pH of water should be over the value of ± 7 and free from organic and dissolute matter and satisfying the standard water quality for construction IS 3025.

3. MATERIALS AND METHODS



Flow chart for materials used for preparation of Brick



Methodology for experimental work

Mix proportions

Sl.No	Fly-ash%	Lime%	Hypo-sludge%	Quarry dust%	Gypsum%
1	60	20	0	15	5
2	60	15	5	15	5
3	60	10	10	15	5
4	60	5	15	15	5
5	60	0	20	15	5

Quantity of Materials used

Sl.No	Fly-ash kg/brick	% of Slag Added	Lime kg/brick	Hypo- Sludge kg/brick	Quarry Dust kg/brick	Gypsum kg/brick
1	1.698	0	0.566	0	0.4245	0.1415
2	1.698	5	0.4245	0.1415	0.4245	0.1415
3	1.698	10	0.283	0.283	0.4245	0.1415
4	1.698	15	0.1415	0.4245	0.4245	0.1415
5	1.698	20	0	0.566	0.4245	0.1415

3.1 Preparation of brick specimens

- The normal hand mould was used to cast the bricks with the standard size of 230 x 110 x 90 mm. They were cast according to the standard procedure with various mix proportions arrived.
- The required quantity of Fly-ash, Lime, Gypsum, Quarry dust, Hypo- sludge was calculated previously and accordingly the materials were mixed. Then, required quantity of water was added and mixed thoroughly.
- Next the prepared mix was poured in to the mould and was compacted. After compacting was over the mould was removed. Then the wet brick was kept under air curing for 2 days and water cured for a period of 7days (Fig. 6 and Fig. 7).

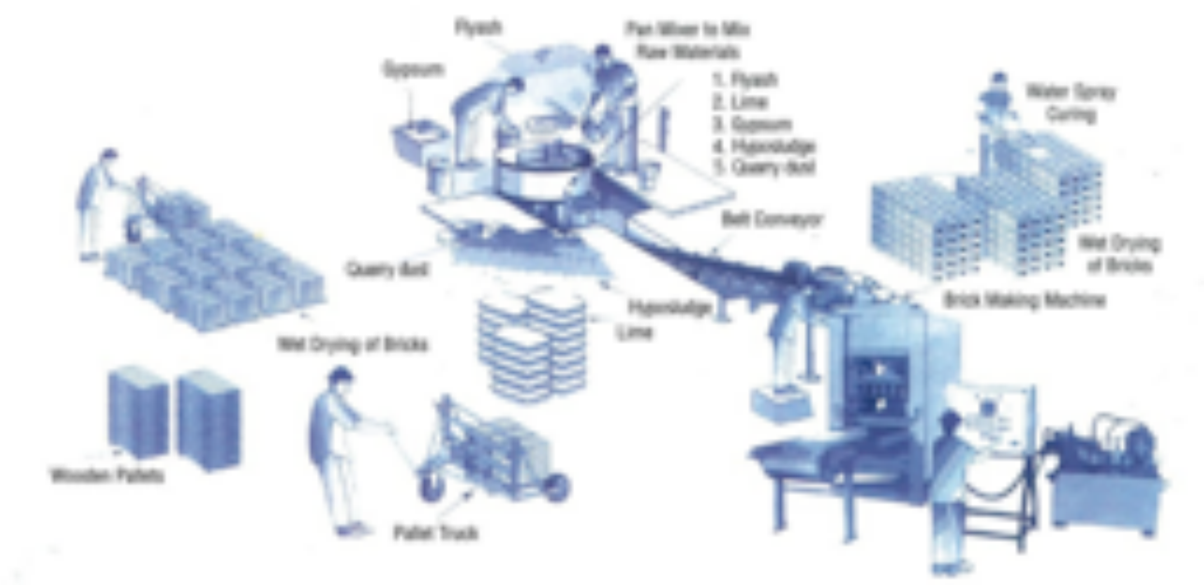


Fig. 6 Brick making process

Fig. 7 Automatic brick making machine and process

Compression test machine

Water Absorption Test

Density of Brick

Fig. 8 Photographic view of testing specimen

3.2 Testing of specimen with quality requirements

Compressive strength

The average compressive strength of brick shall not be less than 7.5 N/mm2 when tested as per IS – 3495(Part –I). The compressive strength of brick shall not fall below the minimum average compressive strength of more than 20% here the universal testing machine was used for the compressive strength test with the standard procedures.

3.3 Water absorption

The bricks were tested in accordance with the procedure lay down in IS: 3495 (Part-II) – 1976. After impression in cold water for 24 hours, the water absorption was not more than 20%.The average testing value of specimen were within the limits.

3.4 Drying shrinkage

The average drying shrinkage of the bricks, when tested with the method described in IS– 4139-1989, was the average of three units not exceeding 0.15% (Fig. 8).

4. RESULTS AND DISCUSSION

The main focus of this study is to utilize the Hypo- sludge and to attain maximum strength for making bricks obtained from the various tests are tabulated (Table 7). The results identified the properties such as split compressive strength, water absorption, density of brick corresponding to hypo-sludge and different mix proportion percentages (Fig. 9 and Fig. 10).

Table 7 Compressive strength

Sl. No.	Replacement of lime by Hypo-sludge %	Trail	Compressive Strength N/mm^2			Average Compressive Strength N/mm^2		
			7 Days	14 Days	21 Days	7 Days	14 Days	21 Days
1	0	1	1.12	4.50	5.17	1.17	4.43	5.20

		2	1.17	4.32	5.13			
		3	1.21	4.49	5.31			
2	5	1	1.57	5.31	6.31	1.52	5.22	6.36
		2	1.52	5.29	6.37			
		3	1.48	5.13	6.41			
3	10	1	1.72	5.65	6.91	1.68	5.61	6.62
		2	1.62	5.54	6.76			
		3	1.69	5.63	6.61			
4	15	1	1.97	5.87	7.88	1.79	5.90	7.65
		2	1.71	5.95	7.42			
		3	1.68	5.89	7.67			
5	20	1	1.21	5.59	6.87	1.22	5.63	6.68
		2	1.15	5.66	6.66			
		3	1.31	5.64	6.51			

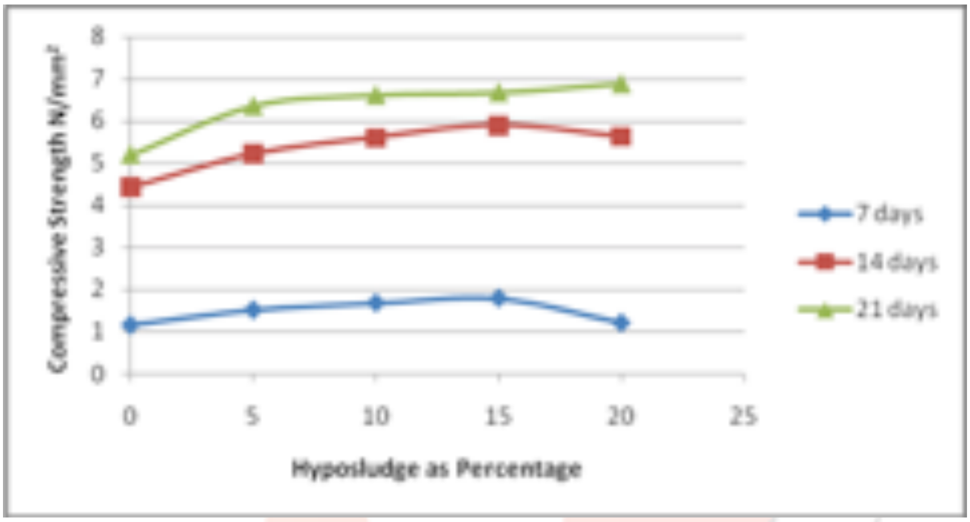


Fig. 9 Graphical representation of compressive strength Vs Hyposludge (CaO)

Experimental value of water absorption capacity

Sl. No.	% of slag added	W_1 (kg)	W_2 (kg)	$(W_1-W_2)/W_1$x 100%	Average %
1	0	2.85	3.19	11.9	11.8
		2.86	3.20	11.8	
		2.88	3.22	11.7	
2	5	2.80	3.166	11.0	11.2
		2.83	3.169	11.3	
		2.81	3.147	11.1	
3	10	2.80	3.108	11.0	10.9
		2.79	3.096	10.7	
		2.76	3.063	10.8	
4	15	2.74	3.041	10.9	10.7
		2.76	3.063	10.6	
		2.73	3.031	10.8	
5	20	2.75	3.053	11.0	11.20
		2.73	3.030	11.6	
		2.71	3.008	11.2	

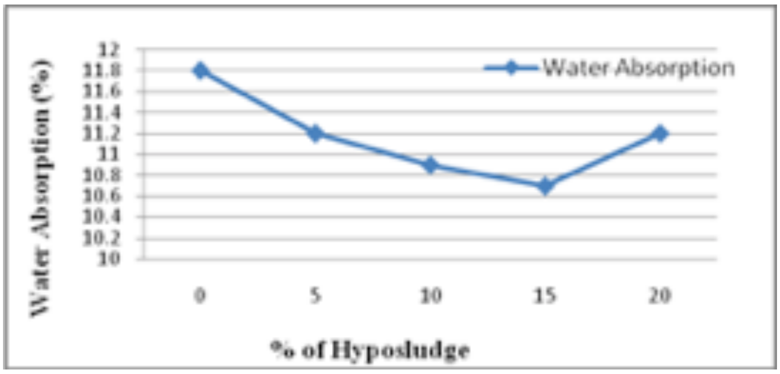


Fig. 10 Graphical representation of water absorption Vs hypo-sludge

Experimental values for density of bricks

Sl. No	Weight (kg)	Average Weight(kg)	Volume m^3	Density kg/m^3
1	2.89	2.86	$1.84X10^{-3}$	1559.78
	2.85			
	2.88			
2	2.85	2.83	$1.84X10^{-3}$	1538.04
	2.82			
	2.82			
3	2.79	2.79	$1.84X10^{-3}$	1516.30
	2.76			
	2.83			
4	2.75	2.76	$1.84X10^{-3}$	1509.91
	2.77			
	2.78			
5	2.88	2.82	$1.84X10^{-3}$	1535.21
	2.82			
	2.84			

5. CONCLUSION

This investigation chiefly is concerned with the compressive strength of bricks. The obtained results suggest the effective replacement of lime with hypo-sludge for making bricks; the results of the study also underline the performance of fly-ash, quarry dust, gypsum and hypo-sludge.

The compressive strength of bricks increases gradually when the Hypo- sludge is substituted for lime which has 15% content initially and declines, thereafter, slightly to 20%.

The above results indicate the water absorption rate as satisfying with 15% of slag giving 10.70 and 20% of slag giving 11.20.

- The compressive strength of bricks increases with the replacement of lime with Hypo- sludge (5%, 10%, and 15%).
- Fly-ash bricks reduce the density of brick masonry from 2000 kg/m3 (clay bricks) to1509.91kg/m3 (Hyposludge bricks).
- The water absorption capacity of the fly-ash bricks is reduced from 20 % (clay bricks) to 11.20% (Hypo- sludge bricks).

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