Utilization of Industrial Sludge in Construction Materials

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Abstract— Many attempts have been made to incorporate wastes into production of building material. It is a practical solution like cost expenditure on waste management and its effect on environment. The sewage treatment process as well as many industries which using effluent treatment plant generates sludge, that must be disposed in environmentally sound manner among all disposal options. The use of sludge in producing constructional elements is considered to be the most economic and environmentally sound option. Advancing solid waste management, results in alternative construction material like, brick, block, aggregate and cement to safe guard environment. Efforts are being made for recycling different waste and utilize them in value added application. In this project we are going to experimentally describe the recycling of waste product like industrial sludge and fly ash by incorporating them in to the brick.

Key words: Blocks, Bricks, Ceramic, Compressive Strength, Concrete, Material, Water Absorption, Industrial Sludge

I. INTRODUCTION

Rapid Industrialization and Urbanization is causing serious environmental problems. One of the major concerns amongst these is safe and sound disposal of solid wastes. There is a strong demand for environmentally safe reuse and effective disposal methods for sludge due to the increasing amount of sludge generated by the industries. While sanitary landfills are commonly used for disposal or sewage sludge, rapid urbanization has made it increasingly difficult to find suitable landfill sites. Therefore Co-processing of industrial sludge is great alternative.

Co-processing is the use of waste as raw material, or as a source of energy, or both to replace natural resources. Co-processing is proven sustainable development concept that reduces demands on natural resources, reduces pollution and landfill space. Storing the waste materials and the resulting global environmental hazard has increased the demand and development of sustainable alternatives. For this reason, industrial attention has focus on developing environmentally friendly, low cost and lightweight construction materials obtain from waste.

Researchers have attempted reuse and recycle waste to enhance a sustainable environment. Attempts have been made to incorporate industrial sludge in the production of bricks; for instance, the use of paper processing residues, cigarette butts, flu ash, textile effluent treatment plant sludge, polystyrene foam, plastic fibre, straw, polystyrene fabric, cotton waste, dried sludge collected from an industrial wastewater treatment plant, rice husk ash, granulated blast furnace slag, rubber, Kraft pulp production residue, limestone dust and wood sawdust, processed waste tea, petroleum effluent treatment plant sludge, welding flux slag and waste paper pulp.

Co-Processing, Reuse or recycling such waste to develop sustainable construction materials as proved to be a practical solution to disposal and environmental problem.

II. LITERATURE REVIEW

The following gives the details on materials and methods used in the study so far conducted.

Bricks were developed using mixture of sludge with clay and shale, called bio brick. It was discovered that conventional clay and shale ingredients could be partially supplemented with wastewater sludge has solid content 15-25% to produce bio bricks. The bio brick had the look, feel and smell of regular bricks. [1]

Brick developed using dried waste water sludge and clay, samples with varied sludge percentage was produced and fired in a kiln, the results on the mechanical and physical properties shows that dry sludge can be used with clay at percentage ranges of 0-40 of brick weight and the compressive strength decreases with increase in sludge content. Due to the burnt off organic content of sludge during firing process, uneven texture surface and porosity arises. This problem was solved by introducing or replacing dry sludge with sludge ash which has zero organic content and it was determined that the maximum sludge percentage that can be used is 50% and results showed that the bricks containing pulverized sludge ash had a higher strength than bricks containing sewage sludge. Bricks containing 10% of sludge ash have strength as high as normal clay bricks. [7]

The potential use of dry pulverized sludge in brick production was performed. Dry pulverized sludge was introduced in the production of prefabricated bricks using 2% into the prepared samples and the properties of the specimen were tested, the results shows a significant increase in compressive strength, decrease in porosity and water absorption compare to bricks without sludge. [8]

The utilization potential of Sludge and co-generation ashes generated by the paper industry in producing bricks; bricks were fired at 1000°C. The products made from the material have exhibit some good properties in term of water absorption and compressive strength, which met the required standards though the bricks are only recommended for use as non-load bearing spacing construction material. [9]

The potential use of dried sludge from water treatment plant with agricultural waste and rice husk ash in production of novel light weight bricks was performed. The results for the mechanical properties show that bricks with 40% by weight rice husk heated at 1100ºC exhibit a high strength required for lightweight bricks, use in future green building in accordance with Taiwan standards. Results of Toxic Characteristic Leaching Procedure (TCLP), shows that the concentrations of Cu, Zn, Cr, Cd and Pb in the products were lower than allowable level in the standard regulation. [10]

Bricks produced from industrial waste water treatment plant sludge, all necessary properties test were performed. Results show that the quality of the product depends on sludge proportion and the firing temperature. Strength of bricks with up to 20% sludge content at temperature ranges of 960-1000°C met the required standards. The leaching result on the product shows a low metal leaching level. [11]

Bricks developed using sewage sludge as a raw material. The bricks were tested for physical and mechanical properties. Results show that the products met the required standard, though the use of sludge content more than 30% was not recommended for it high brittleness. [12]

The use of Municipal Solid Waste Incineration fly ash slag (MSWI) on fired clay bricks, bricks were fired at 1000°C. The mechanical properties and environmental effect of the leachate from the products were tested. Results indicate that the mechanical properties satisfy the Chinese National Standard code for second-class brick and leachate were within acceptable level. Result also shows that increase in the MSWI content leads to increase in the compressive strength though will decreased the water absorption of the sintered bricks. [15]

Bricks are produced from the mixture of clay and recycled industrial wastes. The result shows that compressive strength increased with the increase of sintering temperature. The products satisfy standard requirement for the water absorption and compressive strength. [16]

Lightweight bricks manufactured by sintering mixes of dried water treatment sludge and rice husk. Bricks products with up to 20% by weight of rice husk were fired to obtain effective organic burn-out. Addition of rice husk increased the porosity of sintered samples and increase in sintering temperatures leads to increased compressive strengths. Materials containing 15% by weight of rice husk sintered at 1100°C produced low bulk-density and higher compressive strength that were compliant with relevant Taiwan building code standards for use as lightweight bricks. [17]

The production of bricks using textile laundry wastewater, sludge and clay was performed. Bricks were produced with different quantities of the sludge, dried at 100°C then firing was done at 900°C and the mechanical properties were determined. Mechanical properties of ceramics as flexural strength and water absorption were satisfactory within the Brazilian legislation. The obtained results showed that bricks with 20% sludge content give the best mechanical properties and the leaching test conducted show that the product is safe without any adverse health effect on the user. [18]

The environmental effect of the use of bricks manufactured from sewage sludge examined, considering the leach ability and toxicity the results show that the sludge can be successfully incorporated into bricks with sludge additions ranging from 5 to 25% in weight (and even more if we do not consider mechanical properties), Without any significant adverse effect on the health of the user and the environment. [19]

The replacement of clay brick using sludge, agricultural and industrial wastes (such as Rice Husk Ash (RHA) and Silica Fume (SF)) was developed. Bricks samples were fired at different temperatures. The properties of the product were investigated and compare with conventional brick in accordance with Egyptian standard specification. Products with 25% SF and 50% sludge showed superiority over the conventional bricks. [20]

III. MATERIAL & SLUDGE ANALYSIS

Brick is one of the most common masonry units as a building material due to its properties. It has the widest range of products, with its unlimited assortment of patterns, textures and colours. Many attempts were made to incorporate wastes into the production of bricks, for examples, cement, flyash, and sludge. Recycling such wastes by incorporating them into building materials is a practical solution for pollution problem.

Bricks were made using cement, flyash, and sludge (obtained from UPL, Ankleshwar). The raw materials used for casting of bricks were soil, clay, fine sand and waste materials (fly ash and sludge).The sludge used for casting of bricks were collected from UPL, Ankleshwar.

Sr. no.	Physical Properties	Result
1	pH	12
2	Moisture	43.38%
3	Non-volatile matter	49.7%
4	Residue on ignition	46%
5	Loss on ignition	54%
6	Total nitrogen	0.11%

Table 1: Physical Properties of Sludge

Sr. no.	Compound	Compound in ppm
1	Ni	725
2	Cr	107
3	Co	15
4	Al	377
5	Cu	134
6	V	1526
7	Ti	670
8	Na	4550
9	Hg	15
10	Pb	30
11	Cd	73

Table 2: Chemical Properties of Sludge

Sr. no.	compound	Compound in %
1	K	0.75
2	Fe	2.66
3	Zn	8.72
4	Mg	12.58
5	Ca	15.42

Table 3: Chemical Properties of Sludge in Percentage

IV. PRE-TREATMENT OF SLUDGE

Rapid industrialization is creating lot of problems in present scenario; the total volume of hazardous waste increases significantly which can adversely affect our environment and human health. The dangerous character and eco-toxicity of industrial sludge is related to high concentrations of leachable metallic species, particularly the transition metals like chromium, nickel and copper. In recent years, with the rapid development of the electroplating industry, electroplating sludge has reached much attention. Electroplating sludge contains heavy metals such as nickel, copper, cadmium and chromium. To avoid these metals from leaching into the ground water, solidification and stabilization method have been evaluated. Solidification and stabilization method have been analyzed for electroplating sludge using different stabilizing materials such as ordinary Portland cement, fly ash, bentonite and kaolinte in different proportions such as 10%,20% and 30% for fly ash, bentonite, kaolinite and 2%,4%,8% for ordinary Portland cement ,for a curing period of 7 days and 28 days.

Leaching of heavy metals is a huge problem for industries generated hazardous waste containing high amount of heavy metals and recovery of metals from waste is not feasible all the time so various technologies have been developed to convert hazardous waste into non-toxic form.

Stabilization and solidification is one of the techniques used to convert hazardous waste into stabilized product. Day by day the generation of hazardous waste is increasing significantly which can adversely affect our environment and health. Therefore, appropriate management is required. Due to limited sites, cost, technology and strict environmental standards for landfilling, waste disposal has become a major concern in most of the industries of India.

Recycling of all industrial wastes is not feasible and with the increasing contamination of the natural environment, the problem of heavy metal mobilization becomes more and more significant. Various technologies have been developed to convert hazardous waste into non-toxic form or to reduce the potential release of the toxic compounds into the environment.

Stabilization and solidification are physicochemical processes widely used in management of hazardous waste. The terms solidification/stabilization and stabilization/solidification are often used interchangeably and are referred to as S/S. Both techniques are incorporated as one treatment method for immobilization of waste containing high amount of heavy metals using different binding material.

Solidification and stabilization refer to a group of cleanup methods that prevent or slow the release of harmful chemicals from wastes, such as contaminated soil, sediment, and sludge. These methods usually do not destroy the contaminants. Instead, they keep them from “leaching” above safe levels into the surrounding environment. Leaching occurs when water from rain or other sources dissolves contaminants and carries them downward into groundwater or over land into lakes and streams.

A. *Stabilization & Solidification*

Solidification/Stabilization improves the handling and physical characteristics of the waste and decrease the surface area across which transfer or loss of contaminants can occur.

Stabilization and Solidification have been widely applied in the management of hazardous wastes. The technologies are being applied to

1) The treatment of industrial waste,
2) The treatment of wastes prior to secure landfill disposal,
3) The treatment of contaminated land

Where, large quantities of soil containing contaminants are encountered. Thus, stabilization may be described as a process employing additives by which the physical nature of the waste (as measured by the engineering properties of strength, compressibility, and/or permeability) is altered during the process. Thus, objectives of stabilization and solidification would encompass both the reduction in waste toxicity and mobility as well as an improvement in the engineering properties of the stabilized material.

The U.S. Environmental Protection Agency (EPA) has identified S/S as the best demonstrated available technology for 57 RCRA (Resource Conservation and Recovery Act)-listed hazardous wastes.

Stabilization is a process employing additives (reagents) to reduce the hazardous nature of a waste by converting the waste and its hazardous constituents into a form that minimizes the rate of contaminant migrating into the environment, or reduces the level of toxicity.

Fixation is often used synonymously with stabilization. Stabilization is accomplished through the addition of reagents that

1) Improve the handling and physical characteristics of the waste
2) Decrease the surface area across which transfer or loss of contaminants can occur
3) Limit the solubility of any pollutants contained in the waste
4) Reduce the toxicity of the contaminants.

In contrast, solidification is described as a process by which sufficient quantities of solidifying material, including solids, are added to the hazardous materials to result in a solidified mass of material. Solidifying the mass is accomplished through the addition of reagents that increase the strength, decrease the compressibility, and decrease the permeability of the waste.

The category of solidified/ stabilized material (other x hazardous) is always defined by the categories of modified waste. If the solidified/ stabilized wastes are disposed of in landfills, Waste Act defines the obligation to pay a fee for the total amount of solidified/ stabilized waste disposal.

B. *Selection of Stabilizing Agents*

1) *Ordinary Portland cement*

Ordinary Portland cement of 53 grades was selected as one of the stabilizing agents for this study because of its high binding capacity. This cement was mixed with the sludge in the ratio of 2%, 4% and 8% with the water to sludge ratio of 0.6 and left for curing for a period of 7days and 28days.Water in the sludge reacts chemically with Portland cement to form hydrated silicate and aluminate compounds. Sludge act as an aggregate to form a “concrete”. The optimum combination of the sludge and Portland cement will vary with the type of sludge and its composition.

2) *Flyash*

Low calcium fly ash (ASTM class F) was collected from Tuticorin Thermal power plant. Fly ash was mixed with the sludge in the ratio of 10%, 20% and 30% with the water to sludge ratio of 0.6 and left for a curing period of 7days and 28days.

3) *Bentonite*

Bentonite is a clay mineral consisting mostly of montmorillonite. It forms from the weathering of volcanic ash. It was mixed with the sludge in the ratio of 10%, 20% and 30% with the water to sludge ratio of 0.6 and left for a curing period of 7 days and 28 days.

4) *Kaolinite*

Kaolinite is a clay mineral, with the chemical composition of $Al_2Si_2O_5(OH)_4$.It is produced by the chemical weathering of aluminium silicate minerals like feldspar. It was mixed with the sludge in the ratio of 10%, 20% and 30% with the water to sludge ratio of 0.6 and left for a curing period of 7days and 28days.

5) *Excess Lime*

The process of lime stabilization involves adding lime to wastewater- derived sludge in quantities sufficient to raise the pH of the sludge to 12.0 for a contact period of at least 2 hours. The high pH reduces levels of pathogenic (disease-causing) bacteria and viruses in the sludge and controls putrefaction and odours.

The process has been accepted by the U.S. Environmental Protection Agency (EPA) as a Process to significantly reduce pathogens, meaning that lime stabilized sludge meets minimum requirements for disposal or co-processing.

C. *Efficiency of Immobilization*

Fly ash has immobilized chromium with greater efficiency of 98.23% for a proportion of 30%.

Curing period : 28 days

S.NO	Stabilizing Agent	Percentage Immobilization					
		Cr (%)	Pb (%)	Cu (%)	Ba (%)	Al (%)	As (%)
1	Flyash 10%	94.14	96.77	86.13	95	77.10	80
	Flyash 20%	97..47	98.38	91.47	100	100	80
	Flyash 30%	98.23	99.20	95.73	100	100	100
2	Cement 2%	96.01	93.50	87.20	97.50	77.14	80
	Cement 4%	96.69	95.15	89.33	97.50	36	80
	Cement 8%	97.41	96.77	91.47	100	0	90
3	Bentonite10%	93.34	95.96	80.80	100	90.86	90
	Bentonite20%	93.41	96.77	84.00	100	81.80	90
	Bentonite30%	94.82	97.58	87.20	100	81.80	90
4	Kaolinite10%	96.43	97.58	91.47	92.50	100	90
	Kaolinite20%	96.97	98.38	93.60	97.50	100	90
	Kaolinite30%	97.34	98.38	94.67	97.50	77.14	100

Table 4: Efficiency of Immobilization

D. *Identification of Best Stabilizing Agent*

1) From the study, it has been found that 30% of fly ash with a curing period of 28 days exhibits excellent characteristics in immobilizing
2) Cement was also found to be an efficient stabilizing agent for all the metals.
3) Bentonite was not found to be very effective in immobilizing
4) Kaolinite exhibits maximum efficiency in immobilizing lead, copper and chromium. It could immobilize up to 98.38% for 30% kaolinite in 28 days period.

V. PRODUCT DESIGN & MANUFACTURING PROCESS

A. *Mix Design*

Different Percentage of sludge	Cement	Sand	Fly Ash	water
10%	52%	26%	12%	40 lit.
20%	45%	23%	12%	42 lit.
30%	38%	20%	12%	44 lit.
40%	31%	17%	12%	42 lit.
50%	24%	14%	12%	45 lit.

Table 5: Mix Design for Bricks

B. *Manufacturing Process*

1) Step 1: Crushing of Industrial Sludge to powder form.
2) Step 2: Sieving of sludge from 75 micron sieve to finely divided sludge particles.
3) Step 3: Mixing the sludge and fly ash and other raw material according to various proportion.
4) Step 4: Moulding the paste of sludge and fly ash is filled in the brick mould and compacted.
   Mould is made of standard dimensions of conventional brick.
   (22.5 cm X 10 cm X 7.5 cm)
5) Step 5: Taking out the raw brick from the mould and keep that in sunlight for proper weathering.
6) Step 6: Firing of raw brick in Muffle furnace at 1000 ºC for 4 hours.

Fig. 1: Experiment procedure

VI. TESTING

Following tests are performed on different specimens of bricks:

A. *Water Absorption Test*

When tested as above, the average water absorption shall not be more than 20% by weight up to class 12.5 and 15% by weight for higher class.

	Conventional Brick	10%	20%	30%	40%
Initial weight	2340 gm	2130 gm	1980 gm	1810 gm	1790 gm
weight after water absorption	2700 gm	2490 gm	2280 gm	2130 gm	2060 g

Table 6: Weight of Bricks Before and After Water Absorption Test

SLUDGE INCORPORATED BRICKS	% WATER ABSORPTION IN SLUDGE INCORPORATED BRICKS	% WATER ABSORPTION IN CONVENTIONAL BRICK
10% SLUDGE	14.45%	13%
20% SLUDGE	15.15%	13%
30% SLUDGE	14.03%	13%
40% SLUDGE	13.10%	13%

Table 7: % Water Absorption in bricks

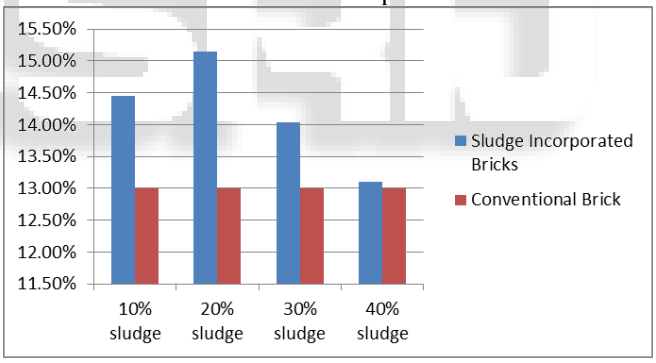

Fig. 2: Water Absorption Test Result Graph

1) *Hardness Test*

A good brick should resist scratches against sharp things. So, for this test a sharp tool or finger nail is used to make scratch on brick. If there is no scratch impression on brick then it is said to be hard brick.

- Scratch is made on the brick surface with the help of finger nail or any sharp tool.
- There is no impression on the surface, the brick is sufficiently hard.

2) *Soundness Test*

Soundness test of bricks shows the nature of bricks against sudden impact. In this test, 2 bricks are chosen randomly and struck with one another. Then sound produced should be clear bell ringing sound and brick should not break. Then it is said to be good brick.

- Two brick stuck with each other.
- Brick of good quality should not break and produce the ringing sound.

3) Compressive Strength Test

Crushing strength of bricks is determined by placing brick in compression testing machine. After placing the brick in compression testing machine, apply load on it until brick breaks. Note down the value of failure load and find out the crushing strength value of brick. Minimum crushing strength of brick is 3.50N/mm^2.if it is less than 3.50 N/mm^2, then it is not useful for construction purpose.

Fig. 3: Compressive Strength Testing

4) Procedure

1) Place the specimen prepared with flat faces horizontal and mortar filled faces (i.e., frog face) upwards between two 3mm plywood sheets and carefully centred between plates of testing machine. The plywood sheets will ensure that the load is transferred uniformly.
2) Now apply axial load at a uniform rate of 14 N/mm2 (or 140 kgf/cm2) per minute till failure occurs.
3) Note the maximum load at failure and repeat the procedure for other specimens

– Crushing strength = Maximum load / Area of the bearing face.
– Minimum compressive strength of the brick is 3.5N/mm2.

No. of Bricks	Conventional Brick (N/mm^2)	10% sludge (N/mm^2)	20% sludge (N/mm^2)	30% sludge (N/mm^2)	40% sludge (N/mm^2)
1	4	3.7	3.55	3.45	2.9

Table 8: Compressive strength of bricks (N/mm2)

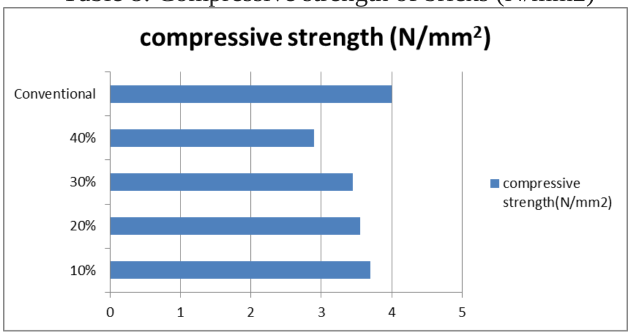

Fig. 4: Compressive Strength Result Graph

VII. COST ESTIMATION & ENERGY CONSUMPTION

A. Cost Estimation

– Total Weight of One Brick = 2 kg
– For % Proportion of SLUDGE: CEMENT: SAND: FLYASH = 30:38:20:12
– Weight of Sludge = 0.6 kg,
– Weight of Fly ash = 0.24 kg
– Weight of Sand = 0.4kg
– Weight of Cement = 0.76 kg
– Cost of fly ash (including Transportation) = Rs 500 / Ton = Rs 0.5 / kg =0.5*0.24 =Rs 0.12 per Brick
– Cost of Sludge (Including Transportation) = Rs 0 per Brick (According to Indian Government Provisions it is mandatory for Authorities of STP to dispose off Sludge free of cost at required places).
– Cost of sand = Rs. 800 / Ton = Rs 0.88/ kg= 0.88*0.4 = Rs 0.35 per Brick
– Cost of Cement =Rs 320 / 100 kg = Rs.2.43 per Brick
– Cost of Labour = Rs 300 / 1000 bricks = Rs 0.3 per Brick

Total Cost = Cost of (fly ash + Cement + Sand + Sludge+ Labour)
= 0.12+2.43+0.35+0+0.3
= Rs 3.2 per Brick
Conventional Brick Prize = 5 Rs / Brick

B. Benefit Cost Ratio Analysis

Manufacturing cost per Brick = Rs. 3.2
Let Selling price per Brick =Rs. 4
Benefit Cost Ratio = 4/3.2 = 1.25 > 1
Hence it is Profitable.

C. Energy Consumption

Electricity required to Brick manufacturing machine = 2.61 kWh

Slab, Rate	Units	Amount
1-50, Rs 3.05	3	9

Table 9: Energy Consumption Charges

Total time required to press full mould of bricks = 5 min
Total cost of Electricity per unit of brick
= Rs. 9 X 5 Min /14 (Total number of brick in one mould) X 60 min
= Rs. 0.053 per one unit of brick

VIII. RESULT & CONCLUSION

A. Key Findings

The most successful composition of Brick is=

B. Sludge: Cement: Sand: Flyash = 30:38:20:12

– Crushing strength = 3.45 N/mm^2
– Water absorption = 13.4 %
– Successfully passed the hardness and soundness test.
– Manufacturing Cost =Rs 3.2
– BENEFIT COST RATIO = 1.25

IX. CONCLUSION

A. Economic Feasibility

It utilizes waste material such as sludge & fly ash whose management leads to expenditure of millions of fund by the Indian government.
Since BENIFIT COST RATIO = 1.25 >1
Hence, it is Economically Feasible.

B. Environmental Feasibility

Sludge and Fly ash both harm the environment in number of ways. Such as fly ash causes pulmonary diseases and sludge causes pollution of land. Since this project utilizes use of both wastes in making of Brick which is non-harmful in nature. Hence, it is Environmentally Feasible.

Technical feasibility Sludge Bricks can be made just like Clay Bricks i.e. no additional technology is required. Hence, it is Technically Feasible.

- Dry sludge is available free of cost so, it will reduce cost of brick.
- In this project we have incorporated the use of Dry Sludge in brick up to 40% by replacing soil. (Dry Sludge 10%, 20%, 30%, and 40%)
- Based on limited experimental investigation concerning the water absorption and compressive strength of brick, the following observations are made regarding the resistance of partially replaced Dry Sludge.
- The water absorption decreased up to 20% replacement of soil by Dry Sludge. Compressive strength decrease when replacement of Dry Sludge percentage increase when compare to traditional Brick
- From this project, replacement of soil with this Dry Sludge material provides good compressive strength at Dry Sludge 30% replacement. Thus, this project shows that replacement of soil with the Dry Sludge material reduces the weight of brick and it's become light weight product.
- Use of Dry Sludge in brick can save the ferrous and non-ferrous metal industries disposal, land pollution, cost and produces a "greener" brick for construction.
- Environmental effects from wastes and disposal problems of waste can be reduced or controlled through this research.

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