Journal of Engineering Research and Application *www.ijera.com ISSN : 2248-9622 Vol. 9,Issue 7 (Series -IV) July 2019, pp 66-72*

RESEARCH ARTICLE OPEN ACCESS

Development of Sustainable Bricks as a Thermal and Acoustic Comfort Building Units

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ABSTRACT

The awareness for the need to reduce the over exploitation of natural resources has been increased in recent days among the general public as well as among engineers. Theneed for the sustainable materials development in the construction industry can be met by implementing alternate source of raw materials in the production of the construction materials. The use of waste as an alternate material in the brick production not only enhances sustainable development but also will have a great positive impact in the environment by reducing the need for waste disposal. The waste materials used in this study are fly ash and phosphogypsum, obtained from power plants and phosphate fertilizer industries respectively. Along with fly ash and phosphogypsum,the Sewage Treatment Plant (STP) waste are added in two forms (dried sludge and sludge ash separately) in the manufacture of brick. The mechanical, thermal and acoustic behavior of the brick is studied and the results concludethat the sewage ash bricks give better results when compared with the sewage sludge bricks. It is observed that 25% incorporation of sewage sludge ash along with fly ash and phosphogypsum shows better results in all the mechanical, thermal and acoustic properties.

Keywords— Sustainable bricks, Alternate raw material, Thermal resistance, Sound resistance, Waste incorporation, Sewage sludge, Sewage ash

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Date Of Submission: 30-06-2019 Date Of Acceptance: 20-07-2019

I. INTRODUCTION

In the present scenario, more than 30% of world's total population is still depending on bricks for construction of houses. China alone produces 700-800 million bricks in a year. India, Bangladesh, Pakistan and Vietnam together produce 260 million bricks per year [1]. These statistics clearly depicts that any improvement in brick will have a great positive impact over a large population. Using clay inbrick manufacturing leads to the depletion of the natural resources.In order to conserve the naturally available resources, there is a great need of an alternative raw material for manufacturing of bricks. Instead of producing or searching a for new raw material, the large quantity of available wastes can be incorporated in the production of bricks. This waste incorporation in brick also gives the solution to the problem of waste disposal, which is also another major threat in our present society. Thus, the waste incorporation in brick has aremarkable and notable positive impact in the society in terms of waste management also.Apart from sustainable development, the economic aspect of the brick also promoted it to the next level. The urbanization led to the increase in the need for more housing projects in Indian cities. On the other hand, all the estimation reports show that the construction materials require more than 60% of the total cost of the building [2]. The zero economic value of the waste materials supports the incorporation of waste materials in brick to produce low cost brick, which ultimately reduces the total cost of the construction material. Thus, the waste incorporation in brick not only improves the sustainable development but also make the brickmore much affordable to the users, especially for economically weaker population. In olden days, the people had less knowledge about the significance and need for thermal comfort in their habitats. Hence, during the past decade, the design and construction phase had not concentrated much on providing thermal comfort.Nowadays, the temperature rises drastically due to the increase in global warming. This rise in temperature is a serious issue, which created the need for thermal comfort. Later, the internal thermal comfort is achieved by mechanical air–conditioning systems. These systems are not only energy intensive but also eco-destructive. These air conditioning systems release the gases, which enhances global warming. Thus, these systems ultimately increase the atmospheric temperature even higher and they do not provide the permanent solution to the problem of thermal comfort. This created the great need of a construction material with better thermal resistance property.The proposed construction material will not only reduce the energy consumption but also reduces the environmental destruction by the HVAC systems. In recent days, the level of sound has been increased to great extent. There increase in the noise level is due to many reasons such as increase in traffic, industries, factories, etc. This high level of noise reduces the mental comfort of the home dwellers and creates high stress. This clearly shows that the enhancement of sound resistance in building is also great importance in the present scenario.This acoustic comfort can be achieved by converting the construction material to besound resistant, which will provide a solution to these problems.

II. LITERATURE STUDY

Murmu and Patel [3]produced sustainable bricks by incorporating mining, industrial and solid municipal wastes. The mechanical properties of the bricks produced using waste has been studied and reported in the paper. The results showed that the soils with plasticity index of 15 to 25 are most suitable for bricks. Further increase in plasticity index affects bonding. They also stated that thecement content more than 10% makes the brick uneconomical. When Sludge is incorporated in brick,they observed a decrease of 19% in the compressive strength and increase of 8% in thermal efficiency of the brick.Subashi et al. [4]researched about the addition of RHA with clay in the manufacture of the brick and studied its impact on the structural, thermal and acoustic properties of fired clay bricks. They observed that the optimum amount of the waste RHA that could be replaced with the clay to produce fired clay bricks was 4%. For the 4% RHA incorporation in bricks, the compressive strength achieved was 3.55 N/mm^2. Water absorption of 4% RHA blended clay bricks were found to be 19%, satisfying the recommended level for moderateweathering resistance. Due to the porous nature of the SiO_2, the increase in SiO_2 content increases the thermal resistivity of the brick. This porous nature of the SiO_2 has its beneficial impact not only in terms of thermal resistance but also in sound resistance (acoustic performance) of the brick. The incorporation of waste materials in the manufacture of brick increases the porosity, which thereby enhances the thermal and acoustic performance of the brick.Rajput et al. [5] attempted to incorporate a mix of cotton and paper mill waste in various proportions in the production of bricks. They clearly showed the variation of the physical and mechanical properties of brick samples with addition of Paper waste (PW), Cotton waste (CW) and cement.They made the cement content to be constant and the paper waste and the cotton waste are added in different proportions. The results depicted that the bricks with 1–5% addition of CW and 10% cement to PW exhibit a compressive strength of 21–23MPa. The optimum composition for making bricks is found to be PW–85% CW–5% and cement 10%. The thermal performance of the brick diminished with the decrease in the proportion of the Cotton Waste.Ingunza et al. [6]studied the use of sewage sludge as a raw material in soft-mud bricks manufacturing in order to determine the maximum incorporation of sludge that results in technically sound and eco-friendly bricks. The addition of sludge not only reduces the mass of the brick but also it reduces the compressive strength of the brick. Thesludge incorporation of 5% in brick manufacturing depicted that the bricks with sludge achieved only 55% strength obtained by the control brick.For higher concentration of 25% and 30%, only 10% of the strength is achieved. Their studies also depict thatthe incorporation of high sludge concentrations had zero effect on odor of the brick.Sunil Kumar [7] studied the mechanical behavior of the bricks, that were made with different proportions of Fly ash, Lime and Calcined phosphogypsum. The study concludes that the FaL-G hollow blocks have sufficient strength and have potential to be a replacement for conventional hollow burnt clay bricks and hollow concrete blocks. The use of phosphogypsum along with lime has more pronounced binding action. Being lighter in weight, FaL- G will reduce the dead weight and material handling cost in multi-storied constructions. The light weight of the brick also has its own application in construction aseismic regions.Sunil Kumar [8] investigated the mechanicalbehavior and durability properties of Fly ash – Lime – Gypsum (FaL-G) bricks and hollow blocks. The bricks were made in various proportions of Fly ash, lime and gypsum. In the economical point of view, the component percentage of bricks is fly ash 80%, lime 10% and gypsum 10%. This proportion of the raw materials have low compressive strength but satisfied the minimum standards as per IS code. In strength point of view,the component percentage of bricks is fly ash 60%, lime 10% and gypsum 30%. The increase in gypsum content not only increases the strength of the brick but also increases the cost of the brick. But the total cost of the brick still remains lower as 60% is made of brick is made with Fly ash, which is a waste material.Joo-Hwa Tai [9] depicted us the comparative study between the mechanical behaviors of the bricks made from sewage sludge and sewage sludge ash. The study concluded that the maximum percentage of clay to be replaced by dried sludge and sludge ash for brick making is 40% and 50% by weight respectively. Further increase in waste content affects the bonding of the mixture. Bricks made with sludge ash showed better durability properties in terms of lower water absorption values when compared with those with dried sludge.

III. MATERIALS AND METHODOLOGY

3.1. Materials

3.1.1) Fly ash

Fly ash is the waste material of thermal power plants. In recent times, there is a rapid increase in the capacity of thermal power generation in India. This increased power generation resulted the thermal power plants to produce a huge quantity of fly ash of about 50 million tons per year as waste [10]. The problems associated with disposal of fly ash are requirement of vast area and non-ecofriendly nature of the methods involved in fly ash disposal. Instead of disposing the abundant quantity of fly ash by using a non-ecofriendly method, we can incorporate the fly ash in the manufacturing bricks. The chemical properties of the fly ash is obtained from [8] is given in Table 1.

Table 1 Chemical analysis of fly ash

Components	Percentage
SiO_2	57.01
Al_2O_3	23.83
Fe_2O_3	6.66
CaO	3.34
MgO	1.77
SO_3	0.56

3.1.2) Lime

Lime is simply an inorganic mineral obtained from naturally occurring limestone rocks. Lime contains oxides and hydroxides of calcium. This clearly gives the idea that lime is nothing more than calcium oxide or calcium hydroxide. Lime enhances the durability of the material. This can be evident from the past construction practices. The lime has its own benefits both in plastic and hardened state. In the plastic state, workability and water retention are enhanced by addition of lime. In the hardened state, lime and carbon dioxide react with each other to regenerate calcium carbonate or limestone. This slow and gradual process leads to increase in the hardness of the finished surface, which closes the hairline cracks by the process of autogenous healing. The oxide composition of lime obtained from [8] is given in table 2.

Table 2 Chemical analysis of lime

Components	Percentage
SiO_2	25.00
Al_2O_3	
MgO	4.70
CaO	63.25

3.1.3) Phosphogypsum

The Phosphoric acid fertilizer industry yields phosphogypsum as a by-product. India generates approximately 5 million tons of phosphogypsum each year as a waste [11]. Apart from the non-ecofriendly nature of the disposal method of phosphogypsum, they also add some problems such as vast area requirement and tedious process involved in disposal. Hence, incorporation of the phosphogypsum waste in the manufacturing of brick as a raw material will have notable positive impact in the environment. The phosphogypsum incorporation enhances the bonding of the raw materials in the brick. There are also some impurities in phosphogypsum. These impurities affect only the retarding property of phosphogypsum [11-14]. These impurities have zero impact on the binding properties of Phosphogypsum [11-20]. The mechanical property of the brick is enhanced in terms of its compressive strength by using phosphogypsum as a binder. This high compressive strength is due to the formation of CSH gel in the bricks. This gel formation reduces the internal voids in the brick. This leads to the enhancement of mechanical behaviour of the brick in terms of high compressive strength and low moisture content. An importance should be given to voids in the brick as the reduction in voids not only increases the compressive strength but also decreases the thermal insulating property and sound insulating property of the brick. Table 3. gives the chemical composition of phosphogypsym as per [8].

Table 3 Chemical analysis of phosphogypsum

Components	Percentage
$CaSO_4.2H_2O$	91.12
SiO_2	1.02
Fe_2O_3	0.30

3.1.4) Sewage sludge waste

The thermal and acoustic behaviour of the brick can be enhanced by incorporating sewage sludge waste. The sewage sludge are added to brick in two forms – driedsewage sludge and sewage ash. The waste from sewage treatment plant after proper processing is sun dried in drying beds for 14 days to get dried sludge. The dried sludge is heated in furnace for 600℃ for 20 minutes to get the sludge ash. Both the dried sludge and sludge ash are added in powdered form. From XRF analysis, it is evident that there is a presence of high amount of CaO, which is usually porous in nature. Hence, addition of these materials creates voids, which can be able to absorb the heat and sound energy. Thus, the addition of these materials decreases the compressive strength. As the brick is not the main load bearing part in framed structures, this reduction in strength is not a big concern, if the brick satisfies the minimum standards [7]. The sludge and sludge ash is added to brick in various percentages, and the maximum content of waste to be incorporated in the brick is found out. This quantity should satisfy the minimum compressive strength of the brick as per codal provisions. The proportion, which gives better mechanical, thermal and acoustic property, has to be found out. Table 4. and Table 5. shows the oxide composition of dried sludge and sludge ash respectively, obtained from XRF analysis.

Table 4 XRF Spectrometer analysis - Dried Sludge

Components	**Percentage**
SiO_2	8.96
CaO	79.45
Fe_2O_3	11.59

Table 5 XRF Spectrometer analysis - Sludge Ash

Components	**Percentage**
CaO	90.67
Fe_2O_3	9.33

3.2. Mix Proportion

The mix proportion of FaL-G brick is obtained from [8] is shown below.

Table 6 Mix proportion

Components	**%**
Fly Ash	60
Lime	10
Gypsum	30

The waste is incorporated as a replacement for fly ash lime gypsum mixture in varying percentages (5%, 10%, 15%, 20% and 25%).

3.3. Tests to be carried out

3.3.1) Compressive Strength Test

The compressive strength test is done according to IS 3495 (Part 1) – 1992 [21]. Place the specimen with flat faces horizontal. Apply the load axially at a uniform rate of 14 N/mm^2 per minute till failure occurs and note the maximum load at failure. The compressive strength is found out by diving the maximum failure load with the bed faces area of the specimen.

3.3.2) Water Absorption Test

The water absorption test is done as per IS 3495 (Part 2) – 1992 [21]. Dry the specimen in a ventilated oven at a temperature of 105°C till it substantiallyattains constant mass. Cool the specimen to room temperature and obtain its weight (M_1). Specimens warm to touch shall not be used for the purpose. Immerse completely dried specimen in clean water at a temperature of 27 ± 2°C for 24 hours. Remove the specimen and wipe out any traces of water with a damp cloth and weigh the specimen. Complete the weighing 3 minutes after the specimen has been removed from water (M_2). The water absorption of the brick can be obtained in terms of percentage by using the formula given below.

Water absorption (%) = $(M_1-M_2)/ M_1 \times 100\%$.

3.3.3) Thermal Performance Test

The thermal property of waste incorporated brick samples is evaluated by using guarded hot plate apparatus. The brick is made in the form of a slab of dimensions 300mm x 300mm x 30mm. After 14 days, the slab is placed between hot plate and cold plate of the guarded hot plate apparatus. The temperature of the hot plate is fixed at 120℃ while that of cold late is fixed as 60℃. This test yields thermal conductivity of the material once it achieves uniform transfer of heat from both the plates.

3.3.4)Acoustic Performance Test

The acoustic property of the brick can be measured based on the study of G. H. M. J. Subhashi et al [4] using sound level meters and speaker. Initially, a hollow section is made in such a way that brick perfectly fits in the hollow section. The brick is placed in position. The sound is created using speaker and the intensity of sound is measured using sound level meters on both the sides of the brick. The reduction in sound intensity gives the acoustic performance level of the brick.

IV. RESULTS AND DISCUSSIONS

The graphical representation of the results helps in better understanding of the behavior of the bricks under various aspects. From the results, we can conclude the percentage of waste to be added to get better performance in all the mechanical, thermal and acoustic aspects. The results of the various tests conducted are discussed as follows.

4.1. Compressive Strength Test

The bricks are manufactured with various proportions of sewage sludge and sewage ash incorporation. The bricks are subjected to compressive strength test and the results obtained are depicted graphically in Fig 1.

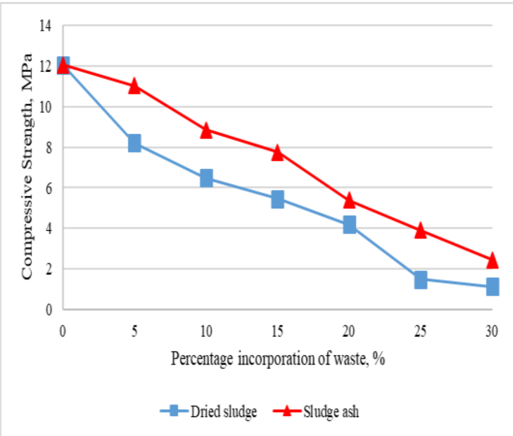

Fig 1. Compressive strength

It is observed that the dried sludge and sludge ash can be added up to a maximum percentage of 20% and 25% respectively in order to satisfy the minimum standard specification. The maximum percentage incorporation of waste is 25% sewage sludge ash. The compressive strength of 20% dried sludge incorporated brick is 4.19 MPa whereas the compressive strength of 25% sludge ash incorporated brick is 3.91 MPa.

4.2. Water Absorption Test

The water absorption of the brick with various percentages of waste incorporation is depicted in fig 2. It is observed that increase in waste content increasesthe water absorption. The dried sludge waste bricks have high water absorption than sludge ash bricks.

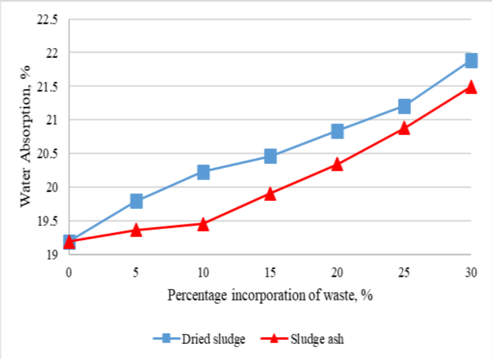

Fig 2. Water absorption

As per ASTMC67-07a, for moderate weathering resistance, the water absorption should be within 17% to 22%.Water absorption of 25% sludge ash bricks was found to be 20.88%, satisfying the recommended level in IS 1077 [23] and recommended level for moderate weathering resistance ASTMC67-07a [22]. The maximum water absorption value obtained is 21.89%. This shows that all the bricks can be used in moderate weather conditions as per ASTMC67-07a.

4.3. Thermal Performance Test

The thermal conductivity results of the samples obtained by guarded hot plate apparatus is shown in fig. 3.

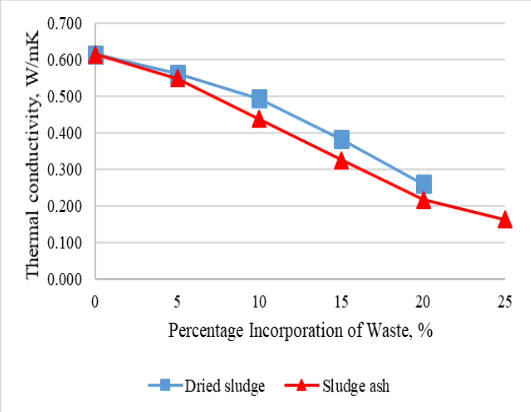

Fig 3. Thermal conductivity

From the graph, it is clear that the increase in waste content enhances the thermal performance of the brick.The minimum thermal conductivity is achieved in specimens incorporated with 25% sludge ash. The thermal conductivity of the 25% sludge ash incorporated specimen is 0.164W/mK, which is a 73.45% increase in thermalperformance when compared with specimens without waste.

4.4.Acoustic Performance Test

The results show that the sound insulating property of waste incorporated bricks is found to be superior to that of the conventional bricks. The increase in amount and size of pores due to addition of waste, contributed to increase sound absorption. The constant input of 120 dB is applied on one side of the brick and the sound intensity on other side is measured. The bricks made with wastes shown better acoustic behavior by achieving a maximum sound reduction of about 48.9dB.This depicts that the bricks with 25% sludge ash performs 65.21% better in acoustic aspect when compared with bricks without waste. The percentage noise reduction for different percentage of dried sludge and sludge ash incorporation is depicted in the Fig 4.

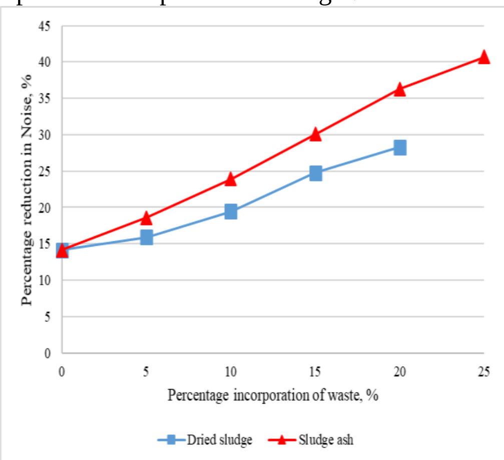

Fig 4. Acoustic performance testing of bricks

From the fig. 4, we can conclude that the increase in the percentage of dried sludge as well as sludge ash, enhances the acoustic behavior of the brick. It is also observed that the sludge ash incorporation is much better in terms of sound reduction when compared with dried sludge incorporation. The bricks with 25% of sludge ash incorporation showed the maximum of 40.71% of reduction in noise.

V.CONCLUSION

The following conclusions can be made from the results obtained.

- The sustainable development can be achieved by using wastes such as fly ash, phosphogypsum, dried sludge and sludge ash as alternate raw materials.
- The compressive strength test depicted that the maximum percentage incorporation of dried sludge and sludge ash in the brick manufacturing is 20% and 25% respectively. Beyond that, the bricks do not satisfy the minimum standards during compressive strength test as per the code provisions.
- The compressive strength of 20% dried sludge incorporated brick is 4.19 MPa whereas the compressive strength of 25% sludge ash incorporated brick is 3.91 MPa.
- The water absorption test depicts that all the bricks satisfy the criteria for moderate weathering resistance bricks as per ASTM 67 – 07a as no brick have water absorption more than 22%.
- The thermal and acoustic behavior of the brick is directly proportional to the percentage incorporation of dried sludge and sludge ash due to the presence of voids in the wastes to be added.
- The sludge ash incorporation of 25% in bricksshows the betterthermalbehavior. The thermal conductivity of 25% sludge ash incorporated brick is 0.163W/mK, which is 73.45% improvement when compared with bricks not incorporated with sludge.
- The bricks with 25% sludge ash performed 65.21% better that the bricks without waste. The percentage sound reduction of 25% sludge ash incorporated brick isfound to be 40.71%.

ACKNOWLEDGMENT

This project was funded and supported by Mepco Schlenk Engineering College through the Student Project Scheme, without which the study would not have been done. We thank the Technicians and all members who helped in this project.

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Balaji K& Venkatesh A" Development of Sustainable Bricks as a Thermal and Acoustic Comfort Building Units"International Journal of Engineering Research and Applications (IJERA), Vol. 09, No.07, 2019, pp. 66-72