Study on Utilization of Different Lightweight Materials Used in the Manufacturing of Lightweight Concrete Bricks/Blocks

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https://doi.org/10.26782/jmcms.2019.04.00005

Abstract

Conventional clay bricks are heavier in weight which increase the overall dead load of the structure. Its formation creates smoke, loss of agricultural land and high energy consumption. To avoid these problems, Lightweight concrete is used in the construction due to its applications such as reduction of dead loads, seismic loads, environmental pollution and labor cost. In this study, the lightweight concrete is used to make lightweight concrete bricks/blocks. The lightweight materials used are; shale aggregate, expanded polystyrene and gypsum, paper pulp. The compressive strength and weight test of the samples were carried out. The papercrete was selected because of its lightweight, reasonable price and local availability. The results indicate that the papercrete bricks are 15% lighter in weight than conventional clay bricks. Due to low compressive strength these bricks are acceptable only for non-load bearing walls and are potentially ideal material for earthquake prone regions.

Keywords: Lightweight Concrete, Dead Loads, Compressive strength, Papercrete, Non-load bearing walls

I. Introduction

One of the important building material used to make walls, masonry construction and pavements is brick. Normally, the term brick is a building material made up of clay but nowadays it refers to something rectangular which is used with mortar for its laying. The main constituents of a brick are sand, clayey soil, and a binding material i.e. lime or concrete. The production of bricks are done according to different classes,
types and sizes depending upon its usage in different places and era, through bulk production as its usage is more. The bricks can be divided into two different categories

Ia. Brick Types
The bricks are divided into two types
- **Fired bricks:**
  Fired brick is one of the most reliable building materials, even the artificial stone is sometime called as this type of brick, since 4000 BC it is proved that this type have been used in the construction of different structures.
- **Non fired / air dried bricks:**
  Air-dried bricks, sometime called as bricks made up of mud have been used even before the fired bricks were used, it differs from the fired brick due to an addition of a constituent in its production and that is use of a straw etc. which acts as a mechanical binder. In developing countries, building materials are frequently the largest expense of construction, often making up to 70% of the total cost. An affordable innovative approaches and technologies are needed in the design and construction because of increasing population and need. There is dire need to design a new and sustainable option to act as a substitute for the contemporary construction materials by introducing lightweight materials as shale and slate, expanded polystyrene, paper pulp and gypsum etc. In this regard, lightweight concrete is one of the options for affordable construction.

II. Literature Review
The classification of lightweight concrete and the study that has been carried out on different lightweight materials for the manufacturing of lightweight concrete bricks/blocks. This study helps in selection of lightweight materials that will be used for further experimentation.

IIa. Classification of lightweight concrete:
The use of air voids instead of the solid material used in concrete can help in reducing its density. The solid material can be replaced by these option available: first is that there is possibility the we use certain aggregate which have inbuilt voids commonly available as lightweight aggregate; by using such cement paste which can potentially give us the desired result known as cellular concrete; and through the exclusion of fine aggregate resulting in a concrete without fine aggregate

The concrete have the density of 2200-2600 kg/cum (140-160lb/ft3) consequently; it means that the concrete have some constituents which make it heavier and due to this heavier weight it majorly contribute to the overall load of a structure. We can achieve much reduction in foundation sizes and the reduction of loads through the usage of such concrete which have low density. Now when the overall load of the structure is reduced it will ultimately allow
us to make structure on a places which have low load bearing ability, ultimately it will reduce the sizes and cost of the framework which would have more sizes and cost if normal weight concrete was to be used. The higher thermal insulation value and higher usage of cement in the lightweight concrete are some of its pros and cons.

IIb. Natural aggregates:

The natural aggregates are not easily available for use except for the places which are belonging to volcanic areas. Although the natural aggregates are considered good aggregates, resulting in the moderate strength concrete but the availability of these is a major concern for its low usage. [I] Diatomite, pumice, scoria, volcanic cinders, and tuffare considered as lightweight aggregates all of them are of volcanic origin with the exception of diatomite. [II]

II c. Manufactured Aggregate

The nomenclature of manufactured aggregates depends upon the their commercial names but the raw material used in it is the main basis for its classification, similarly the expansion caused by different manufacturing processes causing reduction in specific gravity are also considered for its classification. Shale, slate and clay are the natural materials used in the manufacturing of the lightweight aggregate. The manufacturing process consist of heating the raw materials in the rotary kiln at high temperature of 1000°C to 1200°C, different gasses are generated during heating process and the materials viscous pyro plastic mass helps to entrap the gasses produced during this process. [III] To attain the required the apparent specific gravity of the aggregate this material is kept on cooling so that it can achieve it porous structure. The higher viscosity of these material helps in retaining the gases within itself. The water absorption of these impervious aggregates are also low than uncoated aggregates, and achieving high workability and easy handling during its use in the production of lightweight concrete. [IV] The expanded clay or shale coarse aggregates which are Oven-dried seems to have apparent specific gravity of 1.2 to 1.5 while 1.3 to 1.7 is the range for fine aggregate. Higher strength concrete is obtained while using the expanded shale and clay aggregates than lightweight aggregates when used for production of lightweight concrete. [V]

II d. Air Aerated Concrete

Air aerated is concrete which is obtained when we insert very small air pockets to it. The hydrogen peroxide is used which through chemical reaction generates gas which remains entrapped in the concrete mass causing expansion and ultimately reducing its weight. It is considered to be one of the most environment friendly concrete due the low consumption of energy during
it production and its easy handling during the construction. [VI] Its usage is increasing day by day due to its beneficial properties which make it a preferable option. [VII]

![Figure 1: Air aerated concrete block](image)

### II e. Fly ash bricks:

Fly ash, lime, gypsum and sand are the main constituents of the Fly Ash bricks, obtained through proper mixing according to prepared ratio for each constituent and passing it through a compression stage which may be achieved by using mechanical compressors. It has numerous good properties i.e. it has higher compressive strength, absorbs low water, well defined shapes with respect to dimensional accuracy, for it given weight it have higher strength, environment friendly as during its manufacturing it doesn’t emit any greenhouse gasses, have no efflorescence, and is economical in use as it need lesser quantity of cement mortar during the construction [VIII]

#### i. Production Process

The production of fly ash brick is a stepwise process i.e. to avoid heterogeneous mixture, before the addition of water put the desired amount of Lime and gypsum in the mixing machine. After that add sand and after due mixing add fly ash. Now the ingredients are mixed for ten minutes and then the material is putted in the pressing machine which gives us the bricks of desired shape and dimension, followed by the process of drying and curing. Curing start on the second day of manufacturing and before the bricks are sold in market the bricks are passed through the curing period is 15 days. Due to dangerous environmental consequences and problematic in nature for environment the use of fly ash in the manufacturing of the bricks is gaining its importance to be used in bricks rather than being wasted away. It also reduce
the usage of clay of cultivable land which is used during the production of fired clay brick. Similarly if fly ash is used, its energy efficient method of production is helpful in reducing the generation of greenhouse gas effect resulting from the firing of bricks in kilns. Fly ash bricks gives good material properties and its response to compression can be seen from the stress strain properties. [IX]The main priority was to use such material they are environmentally feasible, economical and locally available Therefore the following types were tested initially for its mechanical properties Firstly comparison was done on the basis of its weight and compressive strength.

II f. Expanded shale aggregate and slate:

Shale aggregate is a manufactured lightweight material. The aggregate is structurally strong, physically stable and light in weight. Using this aggregate reduces dead loads, lowering thermal conductivity of building products.

II g. Expanded polystyrene and Gypsum:

To replace the aggregate in the concrete the expanded polystyrene is used. Gypsum is used as binding material in concrete. EPS in combination with Gypsum produces lightweight concrete bricks/blocks which is also environmental friendly.

Since old times Gypsum is considered as a good construction material. The archeologists traces back the usage of gypsum to 7000 BC. Since the gypsum can not only be obtained in its natural form but it can also be acquired from industrial waste which consists of different forms of gypsum. It is low in cost and have environment friendly properties. It is used in the form of plaster in the interior finishing of the
Figure 3 gypsum powder

buildings. It has wider uses in the construction industries despite the above discussed functions. We can induce pores through different chemicals and lightweight aggregates and can be used in the lightweight concrete. The main methods to produce lightweight Gypsum blends which involves low density gypsum aggregates pattern with higher density aggregates and higher density pattern with low density aggregates. [X]

II h. Mixing of paper pulp in concrete:

Keep the paper waste in a water tank for 3-4 days. The paper degrades into paste like form. Then take out and make paper pulp through mixer machine. Proper mixing procedure is to be followed to make lightweight concrete bricks/blocks. From preliminary testing papercrete was finally selected on the basis of lightweight, low cost, environmental friendly and local availability of the paper waste. This was practiced in detail in order to have reasonable mix proportion. Also the compressive strength and weight was investigated carefully.

II i. Papercrete

It is a recently discovered lightweight concrete which is made by mixing cement with sand, paper pulp and optimum amount of water. It is noticed to be environmental friendly material having good insulation properties and has light weight. There is good bond among cement, sand and paper Crete. The waste paper is not mixed directly but is first kept in water for 3-4 days and is then shredded into small pieces, it is not shredded too much so that paste is formed. The fiber of the paper helps in controlling cracks and gives good sound reducing insulating properties. While the cement present helps in drying early. [XI]
III. Methodology

A flow chart is given to help us understand how the objective was achieved

![Methodology flow chart](image)

**Figure 4 Methodology flow chart**

III. a. Lightweight Materials

There are many lightweight materials that can be used but keeping in view the main goal of the project is to make the lightweight concrete economical as well as selection of appropriate lightweight material. Therefore, on the basis of local availability and the rates of material in order to achieve the lightweight concrete, three different raw materials were selected to form lightweight concrete, which are as follows:

a. Shale aggregate:

b. Expanded polystyrene and Gypsum

c. Papercrete

III a. a. Shale Aggregate

The introduction of lightweight aggregate has revolutionized the lightweight concrete industry. Shale is one of the lightweight aggregate used in the manufacturing of light weight concrete. It has excellent structural characteristics. The trading and merchandise is done under many names. These aggregates have density from 40lb/ft$^3$ to 60lb/ft$^3$. It produces concrete of density ranging from 90lb/ft$^3$ to 100lb/ft$^3$ when it is in dried form while in contrast the concrete made up of normal aggregate the values of density tends to be in the range of 140lb/ft$^3$ to 150lb/ft$^3$. The use of this aggregate gives us the same strength concrete having low weight. One of the other good
property of the lightweight concrete is its thermal and sound insulation. Due to its fire resistant nature it has been used to cover the structural elements to protect it from fire.

Shale aggregates were obtained from industry in the vicinity of study location (Peshawar, Pakistan), after locating the shale samples from industry they were cleaned by distilled water and is made sure that there is no organic material or any other impurity attached to the shale’s samples. After washing the shale’s were dried by room temperature, so that they can be effectively used in the preparation of lightweight sample brick and block and the water present in shale's should not disturb the water cement ratio which can ends in the reduction of the strength. After cleaning the shale sand and cement were arranged in the lab. The shale’s aggregate samples were prepared in the mix ratio of 1:3:6 (cement: sand: shale aggregates), for which all of them were measured by weight as well as in volume. The size of the brick was kept standard as 9*4.5*3 inches, whereas the water to cement ratio was kept w/c = 0.6. After preparation of the brick proper curing was done so to achieve the desired strength

![Figure 4 shale aggregate brick](image)

**III a. b. Expanded polystyrene and Gypsum bricks:**

Expanded polystyrene is a mixture of polystyrene a chemical agent which have the capability to swell. Substituting the heavyweight aggregate with lighter one gives us lightweight concrete having different range of the strength and durability. Here the usage of beads of expanded polystyrene keeping in view its strength and endurance is studied. The protection from heat and sound achieved through the usage of lightweight concrete. It also helps in saving the amount of steel and the dimensions of the structural members. It is observed that gypsum is not used in the manufacturing of the hollow blocks which are normally used in the partition walls locally is. Similarly due heavier density of the produced material, gypsum is rarely used. It is found that the beads of expanded polystyrene can be used with the gypsum the same way as the cement is used with polystyrene foam.
The manufacturing of the building materials by the usage of the gypsum along with polystyrene aggregate foam was found to be more useful with respect to the use of other gypsum mixtures. The usefulness is due the low price and low density concrete products.

i. **Polystyrene foam beads used as aggregate:**

There are two steps in the production of bricks from polystyrene foam beads being used as an aggregate. The first step is to expand the polystyrene foam bead which is unexpanded at the start. The second step is to merge the beads into blocks, boards or pre molded shapes. Now when to use the blocks they are heated in steam and the blocks expands to form beads of diameter 1.5mm to 6mm.

ii. **Gypsum**

Gypsum hemi-hydrate was the focus of this research which is the traded in market its chemical formula is CaSO₄.½ H₂O. The gypsum under focus is generally used for the interior decoration in the buildings. The compressive strength of this gypsum was found to be 16MPa (160kgf/cm²) after its setting time.

III a. c. **Papercrete**

The paper takes time to decompose and heaps of the waste paper tend to form due to this reason posing serious environmental threats. The researcher are trying to find a solution of these waste materials by finding different ways to use it in building materials.

For years the paper which is found in garbage is a part of building material as a binding material. Extensive research is being carried out to find innovative techniques which can boost its strength including tensile, flexural and compressive strength. The environmental problems created by the waste paper can be controlled by using it in the construction materials along with its economic benefits.

Since the basic objective of the project was to use such materials that are lighter, cheaper, locally available and are eco-friendly. Thus the preliminary selection was done on the basis of weight, cost comparison and local availability of the materials. The following lightweight material were selected namely slate and shale whose queries are in Attock, expanded polystyrene and rice husk ash that can be obtained from electronic packing waste and burning rice husk, gypsum that has large queries in Jhelum and other parts of country. It can be imagine from the fact that Pakistan exports about 80 trucks or 3000 tons/day of gypsum into India. Papercrete that is made up of simple materials i.e. paper pulp, cement and or sand. The paper pulp is made by mixing paper in water and kept for three to four days. The solid waste in Pakistan contain about 6% of paper that is dumped daily. According to international report on solid waste (Project Procurement International) in Pakistan, the paper waste that is dumped annually is about 1.8 million tons.
III b. Types of tests conducted for the samples of bricks/blocks.

i. Compressive Strength test:
Compressive strength defines the basic properties of the material. It shows the accuracy of the concreting process whether it is done accurately or not. After testing at least three samples at every step the result of compressive strength test comes in the range of 100 pounds per square inch to 2500 pounds per square inches.

Water to cement ratio of the concrete mix quality of cement, and the accuracy of the process influence the compressive strength of the concrete.

ii. Weight test:
Specimens were weighted in order to quantify the range of lightweight concrete. These specimens were also compared with conventional clay brick and normal weight concrete brick. The density ranges of lightweight concrete is mentioned below. Structural lightweight concrete (85 to 120pcf). Low density concrete (20 to 50pcf). Moderate strength concrete (50 to 80pcf). In our case the specimens were lying in the range of Moderate strength concrete and structural lightweight concrete.

iii. Corresponding results

- **Shale Aggregate**
The lightweight concrete was prepared using shale aggregate in different mix proportions and finally 1:3:6 (cement: sand: shale aggregate) was selected. In these samples the w/c ratio was kept 0.50. It had the compressive strength of 2952 psi and weighs 8.63lbs which is 25.84% heavier than conventional clay brick.

- **Expanded polystyrene and Gypsum bricks:**
Expanded polystyrene is used to replace coarse aggregate and gypsum partially replaces cement in lightweight concrete bricks. In some samples gypsum is also used to replace fine aggregate. The water to cement ratio is kept between 0.45-0.6. The optimum strength of 300 psi is achieved for the standard brick size, mixed at the ratio of 1:2:4 (cement: gypsum: sand) whose weight is 5.43lbs making it 17.86% lighter than normal conventional clay brick. However the lower compressive strength make it unsuitable for construction purposes.

- **Papercrete**
Paper pulp in papercrete has cement properties because of its hydrogen bonding among its molecules. Because of presence of paper content in papercrete special care should be taken during curing in the first two to three days. The water/cement ratio should be kept in the range of 0.55-0.60.
The papercrete samples (bricks/blocks) were prepared in different mix proportions. The table shows the weight of bricks and their percentage differences with the clay brick. Also compressive strengths are mentioned.
UTM is used to find the compressive strength of the samples after the drying and curing period of 28 days. The bricks were tested under a uniaxial compressive force using universal testing machine. Special attention should be given to the process and the papercrete bricks should be handle cautiously during the testing process. The failure pattern of the papercrete brick is in the compression resembles to the squishing of the rubber material. Upon the application of higher compressive forces it failed but the brick did not disintegrated. The nature of the papercrete bricks showed to be of more of a ductile nature and less brittle. The suitable mix proportion for the papercrete bricks is 1:1:3 (cement: sand: paper) which is obtained from the above different trials has the brick weight of 5.43lb which is 17.86% lighter than conventional clay brick with its compressive strength of 1300 psi.

- **Test results for Compressed and Non Compressed Papercrete Blocks**

Mechanical properties of papercrete blocks are also determined and are correlated with normal concrete blocks. In the block factory compressed as well as non-compressed blocks were made using papercrete. The blocks were compressed mechanically and were cured for 28 days. Both compressed as well as non-compressed blocks have good surface finishing. The block size was 30cm*18cm*17cm.

  - **Strength test:**
    Universal testing machine is used for determination of compressive strength of the blocks. The compressed block showed the strength of 900 psi. While non-compressed block had strength of 750psi

  - **Weight Comparison:**
    The concrete block weighs 40lbs approximately. The papercrete block (compressed) weight was 33.33lbs. The papercrete block (non-compressed) weight was 30lbs.

### Table 1 weight, % difference and compressive strengths of bricks

| S.No | Lightweight material | Mix Ratio | Weight(lbs) | % difference | Compressive Strength |
|------|----------------------|-----------|-------------|--------------|---------------------|
| 1    | Paper Pulp           | 1:2:3     | 6.13        | 4.4          | 778                 |
| 2    | Paper Pulp           | 1:1:3     | 5.43        | 17.86        | 1300                |
| 3    | Paper Pulp           | 1:1:4     | 4.93        | 29.82        | 400                 |
| 4    | Paper Pulp           | 1:2:6     | 4.86        | 31.69        | 350                 |
| 5    | Paper Pulp (with gypsum) | 1:1:4 | 4.87        | 31.42        | 450                 |
| 6    | slate aggregate      | 1:8:6     | 8.63        | -25.84       | 2925                |
| 7    | expanded polystyrene with gypsum | 1:2:4 | 5.43        | 17.86        | 300                 |
Comparison of papercrete bricks with blocks (compressed and non-compressed):
The failure pattern of papercrete bricks was different than papercrete blocks. The bricks squeezed and only cracked while non-compressed blocks were completely demolished during compression test as shown in figure. However the non-compressed bricks and compressed blocks have similar behavior of cracks when compressed into its full strength.

![Image of brick completely demolished](image1.jpg)

*Figure 5 completely demolished (non-compressed)*

![Image of cracks in compressed block](image2.jpg)

*Figure 6 cracks in compressed block*

**IV. Conclusion**

a. The test showed that bricks made up of papercrete are acceptable for non-load bearing walls i.e. partition walls.
b. The density of papercrete in 77.5lb/ft\(^3\) which lies in the range of lightweight concrete
c. The average compressive strength of the bricks is 1300psi in the mix ratio 1:1:3 (cement: sand: paper).
d. The estimated cost of the papercrete brick is PKR 9
V. Recommendation

Due to lesser weight these bricks are ideal for areas which are located in the earthquake zones

a. Papercrete bricks has high thermal insulation and sound absorption properties

b. If waste paper are used, it will increase the life span of landfills site and will reduce pollution caused due to the burning of paper

c. The bricks made up of papercrete when used in outside portion of the walls gives unwanted results due to the presence of paper as one of its constituent so it is advisable that these bricks should be worked with in the inner portion of the walls.

d. The suitable mix proportion for the papercrete bricks is 1:1:3 (cement: sand: paper) which is obtained from different trials

e. Because of the lesser weight of the papercrete it is preferable to be used in earthquake prone region

f. Water cement ratio should be in the range 0.55 – 0.6

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