# AN EXPERIMENTAL STUDY ON PAPERCRETE BRICKS

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*Abstract :* Utilization of conventional materials used in the construction industry is increasing day by day. The increasing demand for conventional materials in the future is the major issue, for which an alternate option is to find out at a reduced or no additional cost and to reduce the environmental impact due to increase of cement industries that are important ingredient to economic development. It turns out urgent to find out alternate for cement, as natural sources of aggregates are becoming exhausted. As large quantity of paper waste is generated from different countries all over the world which causes serious environmental problems, so in this present study abandoned paper waste was used as a alternative material in bricks.

Papercrete brick is one of the most innovative, eco-friendly brick. Papercrete brick comprises of various materials such as paper, flyash, sand, water and cement respectively in different proportions. In the preparation of Papercrete bricks, we use alternate materials such as paper, fly ash in combination with sand and cement respectively with mix proportions of 1:3 of Paper and cement, 1:1:5 of paper : cement : sand, 1:0.7:5:0.3 of paper : cement: sand : flyash, 1:0.5:0.5 of paper : cement : flyash, in the preparation of this brick. The paper can be prepared in various stages such as soaking, grinding, drying and then sieving through 2.36mm. The paper which passes from 2.36mm is taken for preparation of brick. Fly ash can be taken which passes from sieve of 90µ. The materials of different proportions are weighed and then mixed by adding water to the mix until uniform paste is achieved. The mix can be placed into moulds of standard size 190mm X 90mm X 90mm by applying lubricant to the moulds for easy removal of bricks. After that, these moulds have been dried up to 24hrs-48hrs for sun drying. Only dry curing is sufficient for these bricks.

The various tests such as weight, compressive strength, water absorption test, efflorescence test, soundness test, fire resistance test have been done in order to calculate their properties. These bricks are used only for non load bearing walls because of low compressive strength.

***IndexTerms* - Papercrete Brick, Sun Drying, Compressive Strength, Fire Resistance Test, non load bearing walls, water absorption test**

## 1.INTRODUCTION

Since the last decade, there is a large demand on building material industry owing to the increasing population which is causing a chronic shortage of building materials. This has become a major challenge to civil engineers to produce and use alternate materials. The constant developmental activities in civil engineering and growing industrial activities have created a continuous demand for building materials which satisfy all the requirements regarding the short-term and long-term performance of the structure. Shelter is the most essential element of any life style. In the countries like India, Africa, Australia, millions of people are homeless..

One exclusive recycle opportunity is using waste paper as a construction material. Since the construction industry uses up a great amount of nonrenewable resources, therefore the potential function of waste paper for producing a low cost and light weight composite brick for construction not only delivers the potential use of waste paper recycling but it will likewise bring down the demand pressure on global natural resources.

In recent years, there has been a renaissance of interest in traditional building material, particularly those made from renewable or recycled materials "Papercrete" is one of such materials attracting public interest. Papercrete Brick is a complex material comprising of Portland cement, flyash, waste paper, water and sand. The combination of these materials, which may provide a way to provide affordable housing on a large scale. Papercrete brick have been proved to be cheap alternative building material; to have good sound absorption and thermal insulation; to be a light weighted and fire- resistant material.

## 1.2 INNOVATION OF PAPERCRETE BRICK (PCB)

Papercrete Brick (PCB) was first invented by Eric Patterson and mike mc Cain in the year 1928. Later In 1976, John Hall, an art student majoring in sculpture, experimented with paper Mache and added gypsum plaster in the mix. Papercrete got its name from the very formula used to make it a mixture of cement with cellulose fiber and water. The compound has the texture and appearance of oatmeal, which is poured into moulds and placed under the sun to dry.

Although it is originally developed 98 years ago, but it has only recently been rediscovered and only few research works have been done to determine their structural suitability. It should be noted that Papercrete brick is a comparatively new concept with limited scope. Papercrete is known by alternative names such as fibrous concrete, Padobe and Fidobe. Fibrous concrete is a mixture of paper, Portland cement and water. There are no harmful byproducts or excessive energy use in the production of Papercrete. Padobe has no Portland cement. Here, instead of Portland cement, clay is the binding material. It is a mix of paper, water and earth with clay. Here clay is the binding material. Instead of using the cement, earth is used in this type of brick. This earth should have clay content of more than 30%. With regular brick, if the clay content is too high the brick may crack while drying, but adding paper fiber to the earth mix strengthens the drying block. It gives flexibility which helps to prevent cracking. Fidobe is like Padobe, but it may possibly contain other fibrous material.

## 2. LITERATURE REVIEW

**Ahmadi et al (2001)**

He reported the results of an investigation on the utilization of paper waste sludge obtained from a paper manufacturing industry, as a replacement to the mineral filler material in various mortar mixes. The physical and chemical properties of the waste material were studied. The test results revealed that as the content of the waste increased the water to cement ratio for the mix also increased, since the waste has a high degree of water absorption. Therefore, an additional amount of water was required for cement hydration. The results obtained showed that as the amount of the waste increased, the basic strengths, such as compressive strength, decreased. A maximum of 5% content of the waste as a replacement to the fine sand in concrete mix can be used successfully as construction materials, such as in concrete masonry construction with a compressive strength of 8 MPa, splitting strength of 1.3 MPa, and water absorption of 11.9% with a density of 20 kN/$m^3$.

**Fuller (2006)**

In 2006, Fuller conducted a research to determine whether or not Papercrete brick has suitable mechanical and physical properties to be used as construction material for homes. The parameters that he studied are the Young's modulus (E), thermal conductivity (K), thermal resistance (R), bond characteristics, and creep behavior. The stress versus strain graphs suggest that Papercrete is a ductile material that can sustain large deformations. Cement plays an important role in the compressive strength and behavior. Specimens with higher proportion of cement exhibit larger Young's modulus.

## 3.MATERIALS & PROPERTIES

The materials given below are used in preparing the Papercrete bricks. The efficient use of any material for construction depends on its properties. The properties have to be studied in-depth for assessing the structural and durable characteristics. The physical and chemical properties of each of the ingredients invariably affected the Papercrete bricks. It influences the behavior of structure which is made of Papercrete brick. Hence, the physical and chemical properties of ingredients used in Papercrete bricks have been studied in this chapter.

The various materials include:

- Cement
- Flyash
- Sand
- Paper
- Water

### 3.1 CEMENT

The Portland cement was invented by Joseph Aspidin in 1824, which is fine gray powder.Among the various kinds, cement it is the most commonly used as binding material. It is a mixture of chalk or limestone together with clay.Cement is a binder, a substance used in construction that sets, hardens and adheres to other materials, binding them together. Cement is seldom used solely,but is used to bind sand and gravel (aggregate) together. Cement is used with fine aggregate to produce mortar for masonry, or with sand and gravel aggregates to produce concrete. In India, we are manufactured the three grades of OPC, namely 33grade, 43 grade and 53 grade. As per the standard testing procedure, the compressive strength of cement will be obtained after 28days. Cement is the important building material in today's construction world, 53 grade Ordinary Portland Cement (OPC) conforming to IS: 8112-1989. Table 3.2 and 3.3 gives the physical and chemical properties of cement used.

#### 3.1.1 TESTS ON CEMENT:

a) **Consistency of cement**
b) **Initial and Final setting time of cement**
c) **Fineness of cement**

Table 3.1.2: Physical properties of cement

| S. No | Physical Properties | Cement |
|---|---|---|
| 1 | Colour | Grey |
| 2 | Density | 1440kg/$m^3$ |
| 3 | Specific gravity | 3.15 |
| 4 | Type | OPC grade 53 |
| 5 | Specific surface area | 343$m^2$/kg |
| 6 | Compressive strength | 53MPa |
| 7 | Consistency | 30% |
| 8 | Initial setting time | 30 min |
| | Final setting time | 10 hours |
| 9 | Fineness | 6% |

Table 3.1.3: chemical properties of cement

| S .No | Compound | Chemical composition |
|---|---|---|
| 1 | Cao | 57.84 |
| 2 | $Sio_2$ | 20.33 |
| 3 | $Fe_2 o_3$ | 4.68 |
| 4 | $Al_2 o_3$ | 3.40 |
| 5 | Mgo | 1.51 |
| 6 | Mno | 0.10 |

### 3.2 FLYASH:

Flyash, is also known as fuel-ash, is one of the residues generated in combustion, and comprises the fine particles that rise with the flue gases.In an industrial context, flyash usually refers to ash produced during combustion of coal. Flyash is generally captured by electrostatic precipitators or other particle filtration equipment before the flue gases reach the chimneys of coal-fired power plants and together with bottom ash removed from the bottom of the furnace is in this case jointly known as coal ash.Depending upon the source and process of the coal being burned, the components of flyash vary considerably, but all fly ash includes substantial amounts of silicon dioxide (SiO2) and calcium oxide (CaO), both being endemic ingredients in many coal-bearing rock strata. Flyash often replaces by mass of Portland cement, but can be used in higher dosages in certain applications. In some cases, flyash can add to the concrete's final strength and increase its chemical resistance and durability. Cement production requires huge amounts of energy and Partial replacement of cement with flyash is economical. In the case of mass concreting and large scale works, it is proved to be most economical. It is practically revealed that up to 40 to 50% cement replaced and the designed strengths are achieved.

Two classes of flyash are defined by ASTM C618:

**3.2.1CLASS F FLYASH:**

The burning of harder, older anthracite and bituminous coal typically produces Class F flyash. This flyash is pozzolanic in nature, and contains less than 7% lime (CaO). Possessing pozzolanic properties, the glassy silica and alumina of Class F flyash requires a cementing agent, such as Portland cement, quicklime, or hydrated lime mixed with water to react and produce cementitious compounds. Alternatively, adding a chemical activator such as sodium silicate (water glass) to a Class F ash can form a geo-polymer.

**3.2.2CLASS C FLYASH:**

Flyash produced from the burning of younger lignite or sub-bituminous coal, in addition to having pozzolanic properties, also has some self-cementing properties. In the presence of water, Class C flyash hardens and gets stronger over time. It generally contains more than 20% lime (CaO). Unlike Class F, self-cementing Class C flyash does not require an activator. Alkali and sulfate (SO4) contents are generally higher in Class C flyash.

The chief difference between these classes is the amount of calcium, silica, alumina, and iron content in the ash. The chemical properties of the flyash are largely influenced by the chemical content of the coal burned (i.e., anthracite, bituminous, and lignite).

Table 3.2.3: physical properties of flyash

| S. No | Physical Properties | Flyash |
|---|---|---|
| 1. | Specific surface area | 355$m^2$/kg |
| 2 | Specific gravity | 2.28 |
| 3 | Colour | Whitish grey |
| 4 | Bulk density | 0.994 g/$cm^3$ |
| 5 | Moisture | 3.14 % |
| 6. | Average particle size | 6.92 |

Table 3.2.4: chemical composition of flyash

| S .No | Chemical properties | Chemical composition |
|---|---|---|
| 1 | $Sio_2$ | 59.94 |
| 2 | $Al_2\ o_3$ | 22.87 |
| 3 | $Fe_2\ o_3$ | 4.67 |
| 4 | Cao | 3.08 |
| 5 | Mgo | 1.55 |
| 6 | $Na_2\ o_3$ | 0.63 |
| 7 | $K_2\ o$ | 2.19 |
| 8 | Loss of ignition | 3.34 |

**3.3 SAND**

Fine aggregate is similar to building mortars in its composition and certain properties. Sand particle consists of small grains of silica (SiO2). It is formed by the decomposition of sand stones due to various effects of weather. According to the natural resources from which the sand is obtained. The absence of coarse aggregate (crushed stone or gravel) substantially facilitates the preparation, transport, and placing of the concrete, particularly when concrete pumps are used. A disadvantage of fine-aggregate concrete is the increased consumption of binder compared to other types of concrete and the associated greater shrinkage and creep. The quantity of binder in the concrete can be reduced by pulverizing some of the sand, by the use of plasticizers, or by autoclaving of products. The sand which was locally available is used. It is termed as Pit sand, River sand and Sea sand. According to the size of grains, the sand is classified as fine, coarse and gravel. The properties were studied as per BIS standard

**3.3.1TESTS ON SAND**

**A)Bulking of sand**

**B)Specific gravity**

Table 3.3.2: Physical properties of sand

| S .No | Physical properties | Sand |
|---|---|---|
| 1 | Particle shape | Irregular |
| 2 | Appearance | Brownish yellow |
| 3 | Specific gravity | 2.48 |
| 4 | Bulk density(g/cc) | 1.45 |
| 5 | Fineness modulus | 3.14 |

Table 3.3.3: chemical properties of sand

| S .No | Chemical properties | Chemical composition |
|---|---|---|
| 1 | $Al_2O_3$ | 1.52 |
| 2 | $SiO_2$ | 80.78 |
| 3 | CaO | 3.21 |
| 4 | $Na_2O$ | 1.37 |
| 5 | Mgo | 0.77 |
| 6 | $K_2O$ | 1.23 |
| 7 | $Fe_2O_3$ | 1.75 |

### 3.4 PAPER

Paper is a natural polymer which consists of wood cellulose, which is the most abundant organic compound in the planet. Cellulose is made of units of monomer glucose (polysaccharide).The links in the cellulose chain are a type of sugar as ß-D-glucose.Despite containing several hydroxyl groups, cellulose is water insoluble. The reason is the stiffness of the chains and hydrogen bonding between two OH groups on adjacent chains. The chains pack regularly in places to form hard, stable crystalline regions that give the bundled chains even more stability and strength. This hydrogen bonding is the basis of Papercrete strength. By applying a force on the paper the hydrogen bond between the water and the cellulose molecule is broken. Coating cellulose fibers with Portland cement creates a cement matrix, which encases the fibers for extra strength to the mix. The links in the cellulose chain are a type of sugar: ß-D-glucose and the cellulose chain bristles with polar -OH groups. These groups form many hydrogen bonds with OH groups on adjacent chains, bundling the chains together. Viewed under a microscope, it is possible to see a network of cellulose fibers and smaller offshoots from the fibers called fibril which becomes coated with Portland cement. When these networks or matrices of fibers and fibrils dry, they intertwine and cling together with the power of the hydrogen bond.

#### 3.4.1 PREPARATION OF PAPERCRETE

As the collected waste papers cannot be used directly, so first waste papers can be immersed in hot water at 70ºC to make waste paper into slurry form known as pulp, then grinded into a paste form and then drying should be done.

In this procedure there are three phases.

i) Soaking of Paper ii) Grinding of Paper iii) Drying of Paper

**(I) SOAKING OF PAPER:**

Firstly the collected paper is shredded into small pieces of different sizes and immersed in the desired amount of hot water at 70ºC for 24hrs - 48hrs to make it into slurry known as pulp.

Fig 3.4.1: Tearing of Waste Papers

Fig 3.4.2: Soaking of Teared Waste Papers

**(II) GRINDING OF PAPER:**

After the paper is soaked in hot water for 24 – 48hrs, the paper was grinded manually or by mechanical equipment. The soaked paper is made into fine paste, because the raw paper cannot be used due to lack of bonding nature in it. While grinding ensures that the lumps should be completely converted into paste.

Fig 3.4.3: Hand Mixing of paper

Fig 3.4.4: Machine Mixing of paper

**(III) DRYING OF PAPER:**

The grinded paper is completely in the form of paste, thus it has more water content present in it, which has the difficulty in the water cement ratio calculations. The water present in the paper is removed by squeezing process i.e., by manually or using any hydraulic machines. After that these paper can be dried under the sunlight for removal of moisture.

Fig 3.4.5: Squeezing Process

Fig 3.4.6: Drying Process

**3.5 WATER**

Fresh water is used for mixing of concrete in the required amount. The amount of water in concrete controls many fresh and hardened concrete including workability, compressive strengths, permeability and water tightness, durability and weathering, drying shrinkage and potential for cracking. For these reasons, limiting and controlling the amount of water in concrete is important for both constructability and service life.

**4.METHODOLOGY**

Projects are about doing things. To do something requires a procedure, a methodology, a process and so on. The methodology/procedure one uses is always extremely important to actually accomplishing the goals of any project. The key is to find/use processes that are designed for the type of project you are doing and are compatible with the people who are doing the doing. Google Maps directions from Philadelphia to New York will not get you from San Francisco to Los Angeles. Likewise, the procedure which we followed for the preparation of this Papercrete bricks has been explained in this chapter.

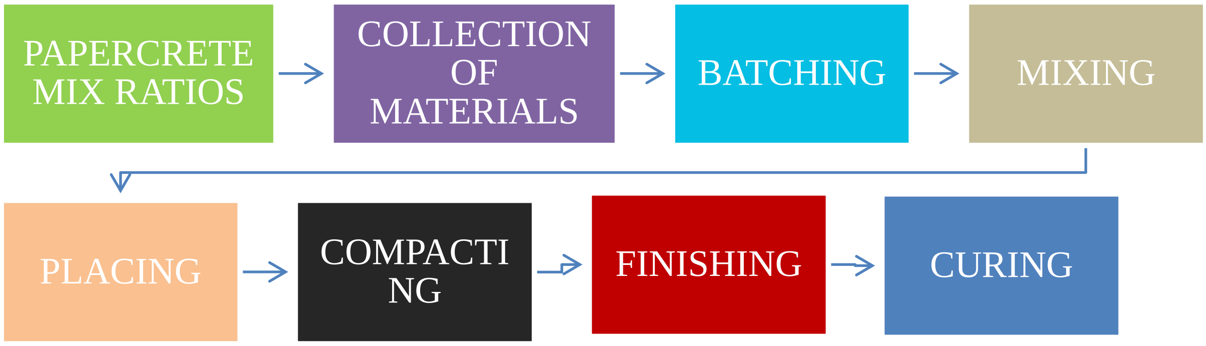


Fig 4.1: Methodology

**4.1 PAPERCRETE MIX RATIOS**
Volume of brick mould: 19 X 9 X 9cm = 1.539 X $10^{-3}m^3$
Density of cement = 1440 $kg/m^3$
Density of paper = 800 $kg/m^3$
Density of sand = 1600 $kg/m^3$
Density of flyash = 1440 $kg/m^3$
**TRAIL - I**
**Paper: cement = 1: 3**
**For 3 bricks**
Quantity of paper = $\frac{1}{4} * 1.539 * 10^{-3} * 800 * 1.54 * 3 = 1.422\ kg$
Quantity of cement =$\frac{3}{4} * 1.539 * 10^{-3} * 1440 * 1.54 * 3 = 7.678\ kg$
No of samples =3
Water content for one brick = 600ml
Water content for three bricks = 600x3 = 1800 ml
**TRAIL - II**
**Paper: cement: sand = 1: 1: 5**
**For 3 bricks**
Quantity of paper =$\frac{1}{7} * 1.539 * 10^{-3} * 800 * 1.54 * 3 = 0.81\ kg$
Quantity of cement =$\frac{1}{7} * 1440 * 1.539 * 10^{-3} * 1.54 * 3 = 1.461\ kg$
Quantity of sand = $\frac{5}{7} * 1.539 * 10^{-3} * 1.54 * 3 * 1600 = 8.1\ kg$
No of samples =3
Water content for one brick = 600ml
Water content for three bricks = 600x3 = 1800 ml
**4.2.PLACING**

After preparing the mix, the moulds of size 190 x 90 x 90 mm, are to be filled with this mix immediately, the mix is placed in the moulds by three layers and compaction should be done uniformly by using tamping rod. Level the top surface of the mould. Leave the mould for 24hrs to setting.

Fig 4.2.1: Placing by compacting

**4.3 COMPACTING**

In the process of placing mortar mix, air is entrapped. The entrapped air reduces the strength of brick up to 30%. Hence it is necessary to remove this entrapped air. This is achieved by compacting the paste, after placing it in its final position. Compaction can be carried out either by hand or with the help of vibrators.

**(A) HAND COMPACTION**

In this method, mortar mix is compacted by ramming, tamping, spading or by slicing with tools. In intricate portions, a pointed steel rod is used for poking the mix.

**(B) COMPACTION BY VIBRATORS**

Mortar mix can be compacted by using high frequency vibrators. Vibration reduces the friction between the particles and set the motion of particles. As a result, entrapped air is removed and the mortar mix is compacted. The use of vibrators reduces the compaction time. When vibrators are used for compaction, water cement ratio can be less, which also helps in improving the strength of concrete. Vibration should be stopped as soon as cement paste is seen on the surface of concrete. Over vibration is not good for the brick.

The following types of vibrators are commonly used for vibratory compaction:

(a) Needle or immersion vibrators
(b) Surface vibrators
(c) Form or shutter vibrators
(d) Vibrating tables.

**4.4 FINISHING**

The smoothness, texture, or hardness of a brick surface. Floors are troweled with steel blades to compress the surface into a dense protective coat. Walls that are exposed to the weather are often ground with a carborundum stone or wheel, with cement then added to fill the small voids. A smooth surface is desired so that water cannot enter the small holes, freeze, and deteriorate the surface.

The most commonly used techniques for finishing are:

- Trowelling or Floating
- Edging
- Broom Finish

**4.5 CURING**

Curing is the process in which the concrete is protected from loss of moisture and kept within a reasonable temperature range. The result of this process is increased strength and decreased permeability. Curing is done for 7, 14 and 28 days.

Good Curing gives strength and dimensional stability to Bricks. Bricks are cured either by air curing or high-pressure steam curing procedure. Because of great engineered properties, bricks have become popular in wide range of applications in construction sector. Curing compound would be the costly alternative. Standards call for a 24 day curing period for cement-based building members.

There are two types of curing namely,

1. Dry curing
2. Wet curing

**4.8.1 Dry curing:**

Dry curing is done by leaving the specimen or brick for respected time in the open dry air or sunlight. In this process no water is applied on the specimen in any form i.e., sprinkling, spraying. Dry curing is done for more than 28 days for best results.

**4.8.2 Wet curing:**

Wet curing is done by applying the water to the specimens through spraying or by sprinkling, this process is followed periodically daily two times upto 28 days.

**5.TEST RESULTS**

After casting the bricks, they were analyzed for using as a brick. Various tests were carried out to check the properties of the bricks. The following tests were carried out to check the strength of the brick. In this chapter, the results obtained for various tests are reported in the form of tables and graphs for various combinations.

**5.1 WEIGHT**


Fig 5.1: weight of different proportions of PCB

| Mix no | Material | Proportion | weight (kg) 28 days |
|---|---|---|---|
| 1. | Paper : cement | 1 : 3 | 1.162 |
| 2. | Paper : cement : sand | 1 : 1 : 5 | 2.359 |
| 3. | Paper : cement : sand : flyash | 1: 0.7 : 5 : 0.3 | 2.086 |
| 4. | Paper : cement : flyash | 1: 0.5 : 0.5 | 1.763 |

Table 5.1: weight of Papercrete bricks

Since, the ordinary conventional bricks weight varies from 3 to 3.5 Kg but the Papercrete bricks weight varies from 1 to 2.4 Kg (Table.6.1). The maximum weight is less than 2.4 Kg only. In this above proportions, these Papercrete bricks are having weight 2/3 rd of the conventional brick weight only. So this bricks are light weight and it will also reduce total cost of construction due to the reduction in dead load.

**5.2 COMPRESSIVE STRENGTH**

Fig 5.2: Before compressive testing

Fig 5.3: After compressive testing

**Table 5.2: compressive strength of Papercrete bricks**

| Mix no | Material | Proportion | Compressive strength (N/mm$^2$) ( Dry curing ) | | |
|---|---|---|---|---|---|
| | | | 7 days | 14 days | 28 days |
| 1. | Paper : cement | 1 : 3 | 0.17 | 0.87 | 1.25 |
| 2. | Paper : cement : sand | 1 : 1 : 5 | 0.35 | 1.28 | 2.13 |
| 3. | Paper : cement : sand : flyash | 1: 0.7 : 5 : 0.3 | 0.23 | 1.05 | 1.75 |
| 4. | Paper : cement : flyash | 1: 0.5 : 0.5 | 0.0 | 0.58 | 1.02 |

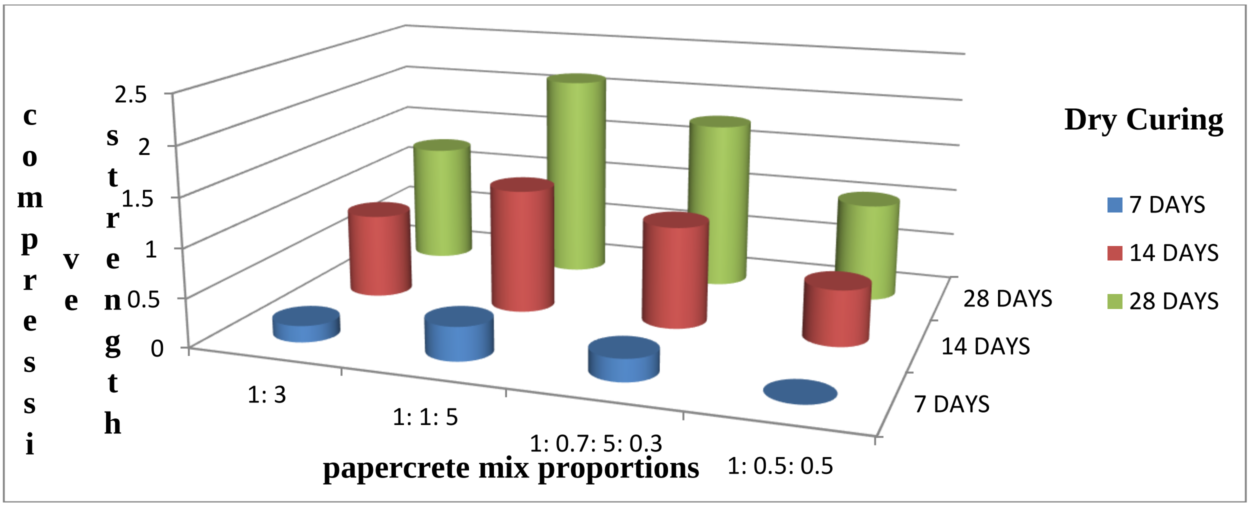


Fig 5.2.3: Graph on Results of compressive strength of Papercrete brick.

From the above results, we observed that the compressive strength of Papercrete bricks is less compared to conventional bricks. Hence, these bricks are suitable for non load bearing walls.

As flyash was used in two proportions in preparation of these bricks, the compressive strength has been increased as the time passes.

From the compressive strength test, we observed that Papercrete bricks never failed catastrophically, it just compressed like squeezing rubber. So load was applied up to half compression. When Papercrete brick failed at the higher load, the structure was not fully collapsed. Only the outer faces cracked and peeled out. The Papercrete brick are having elastic behavior and less brittleness.

**5.3 WATER ABSORPTION:**

Table 5.3: Water absorption of Papercrete bricks

| Mix no | Material | proportion | Water absorption (%) 28 days |
|---|---|---|---|
| 1. | Paper : cement | 1 : 3 | 14.45 |
| 2. | Paper : cement : sand | 1 : 1 : 5 | 18.60 |
| 3. | Paper : cement : sand : flyash | 1: 0.7 : 5 : 0.3 | 17.35 |
| 4. | Paper : cement : flyash | 1: 0.5 : 0.5 | 16.27 |

Water absorption value of bricks largely influences the bond between brick and mortar. If water absorption in bricks is more and bricks are not soaked before the masonry work, the water from freshly laid mortar is likely to be absorbed by bricks. This results into poor mortar strength as the sufficient quantity of water will not be available for hydration process.

From the above results, we observed that the water absorption of Papercrete bricks is less than 20%. Hence these bricks have maximum water absorption based on room temperature, compared to conventional bricks. Because of maximum water absorption, these bricks are only suitable for inner partition walls. Plastering is necessary for these brick walls.

**5.4 Efflorescence:**

From the results of efflorescence test, we observed that there is no noticeable deposit of efflorescence on surface of Papercrete bricks. Hence, the result of efflorescence shall be reported as nil.

Fig 5.4 After efflorescence test

**5.5 Fire resistance:**

From the test, it was observed that the Papercrete bricks did not burn with an open flame. They smoldered like charcoal. But these brick would be reduced to ashes after burning several hours. If the interior plaster and exterior stucco is provided on the Papercrete bricks, the bricks won't burn. The only weak point is inside the block, near electrical outlets, switches and other places where wires gives through walls, into boxes etc. Properly wired places never cause fire. If we apply the plaster without any hole or leakage on the bricks, it won't burn or smolder inside. Because there will be lack of oxygen for burning.

From the fire resistance test of Papercrete bricks, we have noticed that these bricks have good thermal insulation properties. The fibers present in the paper have great heat insulating properties when bonded with cement. Flyash adds fire resistance to the brick. Hence, Papercrete bricks have good fire resistance compared to conventional bricks.

Fig 5.5: result of fire resistance on brick

**5.6 SOUNDNESS:**

From the soundness test, we observed that these bricks gave clear ringing sound when struck with each other. Hence these bricks are good.

**7.CONCLUSION**

This experimental study was conducted with an aim to learn the small scale preparation of Papercrete bricks, its design and construction skills and also had a focus on the assessment of the properties of this building blocks.

From this experimental study, we conclude that

- A Papercrete brick consists of recycled material and therefore cost is low compared to conventional bricks.
- Papercrete can be easily moulded into any shape; bricks are much easier for someone to lift to any desired height due to less weight.
- Papercrete bricks are suitable for non-load bearing walls only.
- Papercrete bricks have good fire resistance.
- The weight of this brick is less compared with the weight of conventional clay brick. Due to less weight of these bricks, the total dead load of the building will be reduced.
- These bricks are potentially ideal material for earthquake prone areas as they are lightweight and flexible.
- These bricks are not suitable for water logging and external walls. It can be used in inner partition walls.
- The Papercrete bricks are good sound absorbent; hence paper was used in these bricks. So, these bricks can be used in auditoriums.
- Papercrete can be developed as a material which is suitable for low cost housing and temporary shelters and offices and can help reduce carbon footprint.
- Since, the waste materials are used, it will reduce the pollution.
- Using the Papercrete brick in a building, total cost will be reduced from 20% to 30%.

In this study, we recognized that Papercrete as a sustainable building material and emphasized on more research towards its performance parameters. The manufacturing, processing and construction techniques are still not developed enough to facilitate its use and this requires extensive amount of research. Its use remains limited, because of the lack of official data about its structural properties, mechanical properties and durability. In order to establish Papercrete brick as a standard material, further experimentation is needed.

- This study is just an initiation to Papercrete bricks. However, further studies are required on following issues:
  - Modification of mix proportions to achieve optimum properties.
  - Addition of materials like coconut fibres or flyash to improve compressive strength of Papercrete.
  - Colour and texture for better aesthetics and design versatility.
  - Addition of silicon, concrete sealer or epoxy compound to help in waterproofing of Papercrete.
  - Admixtures can also be added to improve setting and bonding properties.
  - Higher strength can be obtained by using higher grade of cement.
  - Papercrete made with certain mixes are resistant to fire, fungi, and pests to a larger extent.
  - Papercrete blocks made with a sufficient quantity of Portland cement and sand have improved fire resistance.
- It is thus evident that it can be looked upon as a sustainable building material and has a promising future.

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