CHAPTER 6

STRENGTH AND DURABILITY OF FLYASH BASED PAPERCRETE BUILDING BRICKS

6.1 GENERAL

Strength and durability are the important parameters of any building material. This chapter focuses on flyash based papercrete building bricks and shows how they are cast along with a discussion of its properties. Normally, properties of building materials are studied depending on their strength and durability. Compression test, water absorption, acid resistance, resistance to high temperature, sorptivity and thermal conductivity tests are also studied.

6.2 PREPARATION OF PAPERCRETE SPECIMEN

As per the mix optimization, cement, flyash, sand and paper were mixed with 1 : 1.5 : 0.5 : 4 proportion by weight basis. Powder water proof 105 admixture added as 20% of cement weight to the mix and 50ml of SBR latex modified polymer also added to the mix at the time of mixing. Depending on the strength and durability study, the papercrete was cast as brick (size: 230mm x 110mm x 70mm), disc (size: 180mm diameter and 25mm thickness) and prism (size: 230mm x 230mm x 460mm, using papercrete bricks and 10mm thickness of 1:3 cement sand mortar).
6.2.1 Papercrete Bricks

The bricks were manufactured by brick pressing machine. All the ingredients were mixed as per mix proportion, ground and mixed by mechanically. After uniform mixing, the mixtures of ingredients were transported to a pressing unit by conveyor belt. The mixtures were poured into the brick mould and pressed with 10 N/mm² hydraulically. Immediately then, the bricks were taken out from the mould and kept in open air. After being dried in the air, i.e. on hearing the metallic sound when striking out the brick surface, the specimen was coated externally with water proofing admixture (Primeseal 604 + Rain coat) and it was dried 24 hours. Then the brick was ready for testing.

Figure 6.1 Casting of flyash based papercrete bricks

6.2.2 Papercrete Discs

For casting the test specimens, split-type Poly Vinyl Chloride (PVC) moulds specially made for this purpose were used. The mixtures were poured into the mould (180mm diameter and 25mm thickness) and then cast
manually. Immediately then, the disc was taken out from the mould and kept in open air. After the air drying, i.e. on hearing the metallic sound when striking out the disk surface, the specimen was coated externally with waterproofing admixture (Primeseal 604 + Rain coat) and it was dried 24 hours. At this stage, the disk was ready for testing. Figure 6.2 shows casting of flyash based papercrete discs.

![Figure 6.2 Flyash based papercrete disc samples](image)

### 6.2.3 Papercrete Prisms

After casting the papercrete bricks, the prism was built with 1:3 cement sand mortar. First, two bricks were laid down and joints were filled with cement-sand mortar with 10 mm thickness. Over the cement sand mortar layer, another two bricks were laid opposite the base course, i.e. stretcher and header courses laid alternatively over the bricks. After casting the prism, the top and bottom faces are plastered with 10 mm thickness of 1:3 cement sand mortar. For the curing purpose, water was applied over the plastering surface by spraying. After the lapse of 28 days of curing, the prism was coated with
water proofing admixture (Primeseal 604 + Rain coat) and it was dried for 24 hours. With the breadth of the prism considered as ‘L’, the height of the prism should reach ‘2L’. The dimension of the prism appears in Figure 6.3.

![Figure 6.3 Dimensions of the papercrete prism](image)

### 6.3 TESTING PROCEDURE

During the testing procedure, the strength and durability of flyash based papercrete building bricks were studied experimentally and compared with conventional bricks.

#### 6.3.1 Compression Test

Brick is one of the building elements used in the construction of a wall and the wall is a compression member. So the use of good brick indicates how much amount of compressive strength it has. This test is carried out as per the guidelines given in IS 3495-1992. A compression test of flyash based papercrete brick was carried out by 100 tonne capacity UTM. Since the longitudinal deformation rises more and more, the plunger of the UTM comes out of the cylinder in a fast manner. To safeguard the machine, the machine
movement of the plunger has to be rectified. Because of this, the ultimate load was determined based on the deformation capacity. When the brick failed at the higher load, the brick did not fully collapse because, papercrete bricks never failed catastrophically. It just compressed like squeezing rubber. So only the outer faces cracked and peeled out. From the inference of this test, the papercrete bricks are found to have elastic behavior and less brittleness. Figure 6.4 displays the compression test set up of papercrete brick.

![Compression test setup of papercrete brick](image)

**Figure 6.4** Compression test setup of papercrete brick

### 6.3.2 Water Absorption Test

This test is carried out as per the guidelines given in ASTM C-67. The specimens were dried in an oven at a temperature of 105°C to a constant weight \(W_1\) and then immersed in water after cooling them to room temperature. The specimens were taken out of water at regular interval of time, wiped quickly with wet cloth and weighed \(W_2\) immediately, using an
electronic balance. The percentage of water absorption at various time intervals and the average of three values were used in calculations.

6.3.3 Test on Chemical Attack

The failure mechanism for disintegration of building material due to chemical attack is complicated, but the major cause involves expansive chemical reactions. It is also known that the chemical composition and physical properties of building material are the two main factors affecting the concrete deterioration. The test was carried out as per the guidelines given in IS 14959 (Part-2) 2001.

In the present study, the deteriorating effects of sulfuric acid, sodium chloride and sodium sulphate solution on concrete were ascertained through strength reduction tests. Brick samples were immersed in the respective solutions with controlled pH values. For the sodium chloride and sodium sulphate, the pH values were controlled between 8 and 9.5, while the pH value for the acid was kept between 1.9 and 3.2. The reduction in strength was found after 7, 14, 21, 28, 90, 180 and 365 days of immersion in each solution and used for comparing the durability of the brick samples in the three cases.

6.3.3.1 Acid Attack

The acid attack was one of the primary chemical deterioration conditions of building material for many years. Brick was not a chemically stable material under the condition of acidic environment. Acids came from the external sources to the wall such as the earth surrounding structure, groundwater, rainwater and pollutants in the air. Flyash based papercrete building bricks also contain silica and calcium. Silica is not attacked by acid, but calcium readily reacts with acids. Mineral acids like hydrochloric, nitric,
sulfuric and chromic acids are some of the most dangerous substances to the building material. Sulfuric acid solution in sewage, wastewater treatment plants and hot springs deteriorates building structures hard by reacting with cement hydrates.

The brick samples were placed in a sulfuric acid solution (0.1N normality) for one year. The weight and the compressive strength of the specimens were measured after 7, 14, 21, 28, 90, 180 and 365 days.

6.3.3.2 Chloride Attack

A large numbers of structures are exposed to sea water either directly or indirectly. The coastal and offshore structures are also exposed to simultaneous action of a number of physical and chemical deterioration processes. Similarly, the structures in sea water are subjected to chloride induced freezing and thawing, salt weathering, abrasion by sand held in water and other floating bodies.

In the study, the brick samples were placed in a sodium chloride solution (0.02N normality) for one year. The weight and the compressive strength of the specimens were tested after 7, 14, 21, 28, 90, 180 and 365 days.

6.3.3.3 Sulphate attack

Most soils contain sulphate in the form of Calcium, Sodium, Potassium and Magnesium. They occur in soil or ground water. Because of the solubility of calcium sulphate being low ground waters contain more of other sulphates and less of calcium sulphate. Ammonium sulphate is frequently present in agricultural soil and water from the use of fertilizers or from sewage and industrial effluents. The decay of organic matters in marshy
land, shallow lakes often leads to the formation of hydrogen sulphide, which can be transformed into sulphuric acid by bacterial action. The water used in construction of building can also be a potential source of sulphate attack on buildings. Therefore sulphate attack is a common occurrence in natural and industrial situations.

In the Thesis, the brick samples were placed in a sodium sulphate solution (0.1N) for one year. The weight and the compressive strength of the specimens were measured after 7, 14, 21, 28, 90, 180 and 365 days.

### 6.3.4 Behaviour of Papercrete Bricks Under Elevated Temperature

The property of a building element, component or assembly, prevents or retards the passage of excessive heat, hot gases or flames under conditions of use. The duration of time, determined by the test on resistance to high temperature (up to 300°C) based on a building element, component or assembly, maintains the ability to confine heat and continues to perform a given structural function. The papercrete brick samples are laid down in a hot air oven as shown in Figure 6.5. After the bricks were subjected to elevated temperature, the bricks were kept in open dry place. After 24 hours of open air curing, the sample was tested.
6.3.5 Sorptivity of Papercrete bricks

Sorptivity measures the rate of penetration of water into the pores of mortar by capillary suction. To determine the sorptivity of mortar specimens, oven dry specimens due to water absorption were measured. The test was conducted by ASTM C1585. Sorptivity of the mortar is given by,

\[ S = \frac{Q}{A\sqrt{t}} \]

where, 
- \( S \) – Sorptivity in kg/mm\(^2\)/\( \sqrt{\text{min}} \)
- \( Q \) – Quantity of water penetrated in kg
- \( A \) – Surface area of specimen through which water penetrated
- \( t \) – Soaking time (30 minutes)

6.3.6 Thermal conductivity test on papercrete disc

The apparatus is designed and fabricated according to the Guarded Hot Plate Principle. The guarded hot plate method has been recognized by scientists and engineers in USA, the West, Scandinavian countries, USSR and India as the most dependable and reproducible for the measurement of thermal conductivity of insulating materials. The test was conducted by ASTM C-202-93.

For the measurement of thermal conductivity (k) it is necessary to have a one dimensional heat flow through the flat specimen. This serves as a suitable arrangement for maintaining its faces at a constant temperature and some metering method to measure the heat flow through a known area. Temperatures are measured by calibrated thermocouples that are either attached to the plates or to the specimens at the hot and cold faces. Here it is
important to know the heat input to the central plate heater, the temperature
difference across the specimen, its thickness and the metering area. Using this
information one can calculate thermal resistance (R) value of the specimen by
the specific formula. Figure 6.6 illustrates the guarded hot plate test set up for
papercrête disc.

Figure 6.6 Guarded hot plate test setup for papercrète disc

6.3.7 Behaviour of Masonry Prism

From the compression test on papercrète brick prism, the prism was
subjected to vertical axial load by 100 tonne capacity Universal Testing
Machine. The loading rate was 10 mm per minute. The four number of dial
gauges (having 50 mm maximum and least count of 0.01mm) were fitted with
four sides of the prism as shown in Figure 6.7. The value of longitudinal
deformation was recorded automatically by a digital UTM and lateral
deformations with corresponding load values were also recorded. Based on
the values, stress Vs strain and lateral Vs longitudinal deformation graphs
were plotted.
6.4 RESULTS AND DISCUSSION

From the compression test, it could be seen that coated flyash based papercrete building bricks attained 4.20 N/mm². The coated flyash based papercrete bricks resist the compressive strength more than 4.5% of the uncoated bricks and also they are 65% less than the conventional clay bricks. As per IS:3495, the brick which has a compressive strength of more than 3.5N/mm² was applicable for masonry work. But it is more suitable for non-load bearing wall, because of the ductile nature of the brick. Figure 6.8 and 6.9 illustrate the behavior and compressive strength of flyash based papercrete bricks.
The water absorption of flyash based papercrete bricks without water proofing admixture was 40%. For coated flyash based papercrete bricks with water proofing admixture, the water absorption was 12.75%. It was less than 68% of uncoated flyash based papercrete bricks and it was more than 15.7% of conventional clay bricks. Uncoated flyash based papercrete bricks (UCFAPB) absorbs more water because the texture of brick was more porous.
in nature. Figure 6.10 shows percentage of water absorption of various brick samples.

![Graph showing water absorption of brick samples](image)

**Figure 6.10 Water absorption of brick samples**

The changes in weight and the compressive strength of the coated flyash based papercrete brick specimens kept in sulphuric acid, sodium chloride and sodium sulphate solution were measured after 7, 14, 28, 90, 180 and 365 days. Figures 6.11, 6.13 and 6.15 present the percentage of loss in weights of flyash based papercrete bricks with water proofing admixture (CFAPB) and conventional clay bricks (CCB) in sulphuric acid (H₂SO₄), sodium chloride (NaCl) and sodium sulphate (Na₂SO₄) solutions at various periods. It was observed that the losses in weights are increased up to 90 days and beyond 90 days it remains constant, because the bricks would by then reach saturated level. The reaction between the acid and the calcium compounds forms calcium salts, which can be soluble in water. These salts then be leached away, causing a loss of volume and cohesion of the paste.
Figure 6.11 Loss in weight of flyash based papercrete brick in sulphuric acid solution at various time duration

![Graph showing loss in weight of flyash based papercrete brick](image)

Figure 6.12 Loss in strength of flyash based papercrete brick in sulphuric acid solution at various time duration

![Graph showing loss in strength of flyash based papercrete brick](image)

At the end of one year, percentages of weight loss of the flyash based papercrete brick, immersed in sulphuric acid, sodium chloride and sodium sulphate solution was 0.83, 0.48 and 0.73 respectively. This is increased 2.3 times, 4 times and 3.2 times respectively on the 7th day result.
At the end of one year, the result of the acid attack of brick was 15% higher than the sulphate attack and 75% higher than chloride attack.

**Figure 6.13** Loss in weight of flyash based papercrete brick in sodium chloride solution at various time duration

Figure 6.12, 6.14 and 6.16 delineate the loss in strength and changes in strength of flyash based papercrete bricks with water proofing admixture in H$_2$SO$_4$, NaCl, Na$_2$SO$_4$ solutions. From the figure, it is noticed that the loss in strength increased gradually. Regarding the mechanism of papercrete deterioration caused by sulfuric acid, it is described that the sulfuric acid penetrating into papercrete reacts with calcium hydroxide of cement hydrates to produce gypsum. At this time, the volume of solid substances increases largely, which causes expansion of reaction products resulting in erosion. Disintegration of hardened cement paste as a result of interaction with the environment causes a reduction in the compressive strength of papercrete. In regard to the mechanism of papercrete deterioration caused by sodium chloride, it is described that the diluted chloride solution enters into the pores. This reacts with the calcium compounds of cement paste forming the hydrated calcium silicate compounds.
Figure 6.14  Loss in strength of flyash based papercrete brick in sodium chloride solution at various time duration

Sodium sulphate solution is hard to penetrate into papercrete while sulphate ions penetrate very much into the papercrete. The reaction of cement hydrates and sulphate ions occurs only in the surface portion of specimens. The layer of surface was peeled out from the specimen. Since reaction products precipitated on the surface when the specimen was immersed statically, it allows penetrating the sulfate ions into the papercrete surface. Also the insoluble calcium salts are precipitated in the voids and they slow down the attack.

Figure 6.15  Loss in weight of flyash based papercrete brick in sodium sulphate solution at various time duration
Figure 6.16 Loss in strength of flyash based papercrete brick in sodium sulphate solution at various time duration

At the end of one year, the percentage of strength loss of the flyash based papercrete brick, immersed in sulphuric acid, sodium chloride and sodium sulphate solution was 12.12, 3.67 and 4.89 respectively, which was increased 3.3 times, 3.2 times and 2.3 times respectively on the 7th day result. At the end of one year, the result of the acid attack of papercrete brick was 0.75 times and 2.5 times increased by the result of sulphate attack and chloride attack of the brick.

In conventional clay bricks, at the end of one year, the percentage of weight loss was 62%, 22% and 50% in sulphuric acid, sodium chloride and sodium sulphate solutions respectively. At the end of one year, the percentage of strength loss due to immersion in sulphuric acid was 5 times more than that of the 7th day loss. When clay bricks were immersed in sodium chloride solution the percentage loss in weight and strength were less compared than in sulphuric acid solution. The conventional clay brick is rich in silica and alumina and also it is fired. So the resistivity property of the conventional brick is higher than that of the papercrete brick material.
Figure 6.17  Weight reduction of flyash based papercrete brick in 300°C at various time duration

Figure 6.17 and 6.18 show the percentage of weight reduction and percentage of strength reduction of flyash based papercrete bricks at various time durations. The resistance to high temperature on coated flyash based papercrete bricks with water proofing admixture was conducted at a constant level of temperature of 300ºC. As the time period was increased the percentage of weight reduction and strength reduction also increased, but in the shape and size of the papercrete bricks there were no more changes. The residual compressive strength of brick after it is subjected to elevated temperature was 3.7N/mm². It is 10% loss in strength of papercrete brick (4.2N/mm².)

Figure 6.18  Strength reduction of flyash based papercrete brick in 300°C at various time duration
The sorptivity of the uncoated papercrete brick is higher when compared to the conventional and flyash brick, which was 50% higher than the conventional clay and flyash brick. The sorptivity of the coated papercrete bricks showed 73% less than the uncoated papercrete brick. The sorptivity of various brick samples is shown in Figure 6.19.

![Image showing sorptivity of various brick samples](image)

**Figure 6.19 Sorptivity of various brick samples**

From the thermal resistance study, thermal resistance (R value) was determined by thermal conductivity (k). Thus the computed thermal resistance value was in the range of 1.9 to 2.2 per inch.

![Images of brick prisms](image)

(a) Conventional Brick Prism  
(b) Papercrete Brick Prism

**Figure 6.20 Crack propagation of papercrete prism**
In literature support (Fuller et al, 2006) confirmed that certain papercrete mixes can attain R value of upto 3 per inch (25mm).

The value of modulus of elasticity is calculated as the slope of initial tangent to the curve. Stress Vs strain relationship graphs of papercrete brick prism and conventional clay brick prism are shown in 6.21 and 6.22 respectively.

![Stress-Strain curve for papercrete prism](image)

**Figure 6.21 Stress-Strain curve for papercrete prism**

Young’s Modulus and Poisson’s ratio of coated flyash papercrete brick prism was determined as 8.043 N/mm$^2$ and 0.40 respectively. These values are very low compared to the other building materials, but in literature support (Fuller et al, 2006), the young’s modulus of different type of papercrete brick units was in between 6.25 N/mm$^2$ and 14.4 N/mm$^2$. The lateral deformation is almost half (that is 0.40 times) of the longitudinal deformation. But Young’s Modulus and Poisson’s ratio of conventional clay brick prism were determined as $3.7 \times 10^3$ N/mm$^2$ and 0.171 respectively. The obtained values are correlated to literature support (Hemant et al, 2007, Dipetsh Das et al, 2004).
CONCLUDING REMARKS

From the test results, it is found that the papercrete bricks satisfy the limits specified by the code for conventional clay bricks. Coating of the papercrete bricks is absolutely necessary for durability purpose.

From the test results, it is observed that the coated and uncoated flyash based papercrete bricks are higher than 4 N/mm². As per IS code recommendation, the brick that contains minimum 3.5 N/mm² of compressive strength is acceptable for masonry work. So flyash based papercrete bricks are acceptable in building construction and also they are applicable only for framed structures because of the ductile nature. The uncoated papercrete bricks are not suitable for the construction of exterior unprotected walls because they have very high water absorption. The coated papercrete bricks may be used for the construction of exterior walls if the plastering has to be done.