

A Review on Paper Crete: A Sustainable Building Material

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Abstract :- Papercrete is a sustainable building material due to reduced amount of cement usage and recycled paper being put to good use. Papercrete is a one type of fibrous cement, made by shredding paper such as old newspapers, prints, cardboards etc. as pulp in water, Portland cement and sandy soil. It has numerous advantages in construction industry, namely low carbon footprint, recycled material usage, low embodied energy, high strength to weight ratio, high thermal insulation, high sound absorption, aesthetic and cost effective. There are many varieties of Papercrete possible when the constituents mixed in different proportions. It gains its inherent strength due to presence of hydrogen bonds in microstructure of paper. This thick mix can then be poured into moulds and cast like concrete, to make it into any desired shape and size. Moreover papercrete bricks can also be manufactured. Papercrete bricks are relatively light and more flexible so, they are potentially ideal material for earthquake prone areas. Different parameters such as strength, durability, density and water absorption is determined to check the feasibility. This paper reviews about the environment impact caused by the paper pollution. Further it discusses about the numerous advantages and disadvantages of papercrete in the construction industries. Properties like absorption, crushing strength, hardness, presence of soluble salts, etc. are studied. Certain measures to overcome the limitations in the properties are also mentioned. Much research is being carried out globally on the material but it is yet to be acknowledged by Indian standard practices and codes and recognized by major building material organizations in India.

Key Words: Paper Crete, Sustainable construction, Building blocks, Environmental friendly, Recycled material.

1. INTRODUCTION

Papercrete is also known as fidobe, fibrecrete, padobe etc. Papercrete is an innovative composite material developed to build an environmental friendly house made up of paper, cement and water. It has been reported to be a cheap alternatively building construction material, to have a good absorption and thermal insulation, to be a light weight and fire resistant material as shown in figure 1. When paper is mixed with cement, it creates a very good bond and the final product is both lightweight and strong. Fibres contribute to sound insulation properties and help in crack control. Portland cement is an integral component of the mix and acts as a binder. Cement reduces the drying time and the effect of pulp shrinkage and increases the strength and dimensional stability. However it adds weight to the mix and makes it more brittle. Adding coir, sand, dirt or pumice increases the volume and the mineral content. Sand adds thermal mass and makes the mix stronger and impervious to water but results in heavier structure.

The environment impact of paper is significant, which has led to changes in industry. With the use of modern technology, harvesting wood, disposable paper has become a cheap commodity which has led to a high level of consumption and waste. The production and use of paper has a number of adverse effects on the environment which are known as paper pollution. Discarded paper is a major component of it. Taking this issue into account, construction material known as papercrete is invented.

There are three derivatives of papercrete namely fibrous concrete, padobe and fidobe.

- i) Fibrous concrete – mixing of paper, Portland cement and water.
- ii) Padobe – mixture of paper, water and earth with clay.
- iii) Fidobe- It is like padobe, but it may contain other fibrous material.



Figure 1: Papercrete brick [8]

2. LITERATURE REVIEW

Manuel (2002). He studied that physical characteristics of papercrete are mainly depending upon the relative amount of sand and Portland cement used.

Dunster (2007). He said addition of 20% calcined paper sludge with cement paste accelerate setting time by 60 minutes, but results in reduction of workability.

H. Yun et al (2010). They have found that density of papercrete was decreased when the replacement of waste paper increased. When paper replacement ratio was 5%, density was measured 1.88g/cm^3 , and it was reduced to 15% and 22%, respectively by increasing paper ratio 10% and 15%. The shrinkage of papercrete was increased according to increase of paper-cement replacement ratio.

Ms. S. Suganya (2012). She stated that papercrete bricks are relatively light weight, good sound absorbent and more flexible but it has high percentage of water absorption than conventional bricks. It can be easily cut into desirable shape. And also it does not expand or contract due to surround environment.

J.N Akhtar et al (2011). They computed six different mix proportions by utilizing the Paper pulp and industrial by products like Fly ash, Rice husk ash. And also, due to the addition of paper pulp the bricks have low thermal conductivity, and it reduces the energy requirement for temperature control. While using paper pulp to make bricks, it will reduce approximately 50% of weight of the brick. Therefore these bricks will reduce the dead weight of the structure to considerable amount. So it changes our design and building as economical one.

Akinwumi et al (2014). They found the water absorption and fire resistance of papercrete to be high and increased with increasing waste paper content while the bulk density and compressive strength of papercrete were low and decreased with increasing waste paper content. Papercrete was recommended to be an effective and sustainable material for the production of lightweight and fire-resistant hollow or solid blocks to be used to make partition walls of especially high-rise buildings. Mix proportions were recommended for production of hollow and solid blocks using papercrete. It was first patented in USA in 1928 but for next 50 years did not move into mainstream usage. In 1980 two Americans Eric Patterson and Mike McCain independently invented mixers (tow mixers) that allowed papercrete to be made quite easily and started a revival of the material.

3. PREPARATION AND DEVELOPMENT:

Khonica Keisham et al (2017). They suggested the following materials can be used for the preparation of papercrete :

a) CEMENT:

Cement is a binding substance used as a construction material that sets, hardens and can bind other materials together. In today's construction world, cement is the most important building material 53 grade OPC conforming to IS: 8112-1982 gives the properties of cement used.

b) GROUND GRANULATED BLAST FURNACE SLAG (GGBS):

It is a by product which is obtained during the manufacturing process of pig iron in blast furnace. Its chemical composition indicates the presence of silica glass which contains calcium, magnesium and aluminium. It also has a cementitious character which enhances lower heat of hydration, higher durability and higher resistance to chemical attack (mostly sulphate and chloride).

c) QUARRY DUST:

They are the remains obtained after the process of quarrying. The dust should have uniform size for proper utilisation. It should be devoid of impurities but often contains organic impurities and salts. The dust from the quarry sites has become a major source of pollution but if they are used in the construction industry as an alternative material for sand, pollution may be reduced to some extent. Using quarry dust in replacement of sand also reduces the cost of construction and construction material would be saved.

d) PAPER:

Paper is principally wood cellulose. Cellulose is natural polymer. The cellulose chain bristles with polar -OH groups. These groups form hydrogen bonds with -OH group on adjacent chains, bundling, and the chain together. In order to form a hard and a stable crystalline region, the chains are packed regularly so that the bundled chains gain more stability and strength.

e) WATER:

Water is an important ingredient of papercrete as it actively reacts with cement in the chemical reaction and the pH value should be between 6 and 7.

f) WATER PROOFING COMPOUND FOR CONCRETE AND PLASTER:

Dr. Fixit Pidiproof LW+ is a special liquid waterproofing compound composed of surface active plasticizing agents, polymers & additives which is used as an additive to enhance and modify the properties of cement concrete, mortar & plasters. It makes concrete cohesive and prevents segregation.

4. SPECIMEN MAKING FOR PAPERCRETE BRICKS

Paper is the major constituent of the mix proportions. **H. Umarfarook et al (2017)**. They used papers with cement, fly-ash, sand, paper pulp are used as ingredients of the mix with various proportions. From these materials, 9 mix proportions were used and studied in terms of compressive strength and percentage of water absorption.

Table 1 shows the details of mix proportions used in the study.

Sl. No.	Mix Designation	Cement: Flyash: Sand: Paper
1	A1	1:3:4:6
2	A2	1:3:3:6
3	A3	1:3:2.5:6
4	B1	1:2:3:4
5	B2	1:2:4:4
6	B3	1:2:2.5:4
7	C1	1:1.5:2.5:2
8	C2	1:1.5:4:2
9	C3	1:1.5:3:2

All the proportions were taken on a weight basis. Papers were taken in wet condition, i.e. slurry form. Flyash was taken from Shrinivasan Enterprises. In this project, Koromandal king 53 grade Pozzolona Portland cement has been used in all times.

4.1 Formation of Pulp for Papercrete Bricks

- a. As the collected papers cannot be used directly so first papers were converted into slurry form, known as pulp then is mixed with other ingredients.
- b. Pins, threads and other materials attached to the collected paper were removed.
- c. Then papers were torn into small pieces and all the torn pieces of papers were immersed in water.
- d. The papers were kept in water for 3 to 4 days, and they soon degraded into a paste like foam.
- e. After that period, the papers were taken out from water tank and shredded into little pieces by manually on large wire mesh. The shredded papers were converted into pulp.
- f. The paper pulp had residual water in itself, and it was not good enough for mixing the ingredients. So the required amount of water was added at the time of mixing.



Figure-2: Casting the papercrete brick [9]

4.2 Casting of Specimen for Papercrete Bricks

The paper pulp is mixed uniformly with flyash, cement and sand. The specimen was casted in form of cuboids of dimension 235mm x 105mm x 90mm, as shown in figure 1.

5. PROPERTIES OF PAPERCRETE BRICKS:

H. Umarfarook et al (2017). They tested the above lab scale manufactured papercrete brick for key properties and following values were obtained.

a. Presence of Soluble Salts:

The soluble salts, if present in bricks will cause efflorescence on the surface of bricks. In order to find out the presence of soluble salts in a brick, this test was carried out which includes immersion of the papercrete bricks in water for 24 hours. Then the bricks were taken out and were made to dry in shade. Grey or white deposits were not found on the bricks surface which concludes that the bricks are free from soluble salts.

b. Soundness Test:

In this test, two bricks which are of the same proportion were taken and they were struck with each other. The bricks did not break and a clear ringing sound was produced which means that the bricks are good.

c. Structure Test

In this test, a brick is broken and the structure of the broken brick was closely observed. If there are any defects like holes, lumps, etc., then the bricks are not of good quality.

d. Hardness test:

In this test, a scratch was made on brick surfaces. This test was carried out for all the three proportions of brick. While the scratch was made with the help of finger nail on the bricks, very light impression was found on the surface of the fibrous concrete brick. So this test results that fibrous concrete bricks are sufficiently hard.

e. Nailing:

When compared to conventional bricks, fibrous concrete bricks are less hard. So, in order to find out whether the brick can hold the nail or not, this test was carried out. Two specimens of bricks were taken. Out of the two bricks, a nail was hammered on the surface of one brick and a screw is also screwed on the other brick. The fibrous concrete brick could not hold nails but screws worked well and hold a considerable weight. So, the screws are the anchors of choice for fibrous concrete bricks.

f. Cutting and Glue:

The labours could not able to cut the bricks exactly what they need. But, fibrous concrete bricks can be cut into exactly two pieces by using conventional saw blades. So, we can get any shape and size of fibrous concrete brick. Many cut bricks are wasted in now a day. But if we apply a sufficient amount of glue on the bottom piece, the two fibrous concrete can be hold together and hence will not come apart.

Installing plumbing lines requires cutting holes and channels in papercrete. Using a circular or chain saw, the electrical runs were cut. To make holes for outlets, horizontals and vertical slits was cut with a circular saw. Then unwanted pieces were removed with the help of a screwdriver. Home fires start, where the wiring enters the outlet boxes. So, non-flammable mortar should be put behind the outlet boxes for safety. Once the electrical wiring and outlets are installed and then tested, the channels for the electrical runs are for filled with papercrete.

g. Fire:

A brick which is used for construction should not flammable in open flame, so this test was carried out for the bricks. This test was carried out only for fibrous concrete bricks but not for padobe bricks for padobe bricks were already heated in kiln at high temperature so, it won't burn. The following are the steps involved in this test:

- First, the brick was wiped with cloth to remove and all the foreign matters.
- Then some of the flammable sticks were fired. After that, the bricks were held on the flame for five minutes.
- After five minutes fixing was stopped and the bricks were observed.

From the test conducted above, it was observed that the fibrous concrete bricks did not burn with an open flame. They smouldered like charcoal. But after burning for several hours, these brick would be reduced to ash. If the interior plaster and exterior stucco is provided on the fibrous concrete bricks, the bricks won't burn.

6. RESULTS FOR PAPERCRETE BRICKS

Table 2 shows the physical characteristics based on the study.[9]

Sl. No.	Mix Designation	Cement: Flyash: Sand: Paper	Water Absorption (%)	Weight (kg)	Compressive Strength (N/mm ²)
1	A1	1:3:4:6	39.54	2.2	1.86
2	A2	1:3:3:6	41.94	2.085	1.66
3	A3	1:3:2.5:6	48.11	1.99	1.37
4	B1	1:2:3:4	34.46	2.355	2.43
5	B2	1:2:4:4	31.81	2.45	2.51
6	B3	1:2:2.5:4	37.47	2.26	2.35
7	C1	1:1.5:2.5:2	23.26	2.80	2.91
8	C2	1:1.5:4:2	18.95	3.07	3.24
9	C3	1:1.5:3:2	33.3	2.52	3.03

7. SPECIMEN PREPARATION FOR PAPERCRETE BLOCKS

J. T. Sheth et. al illustrated the methods adopted for manufacturing building blocks, studied the mechanical properties of papercrete building blocks associated with the construction technology.

The main materials used for papercrete mix preparation were waste paper (newspaper), Portland cement PC-53 grade, Sand, Potable water and Soil.

The following paragraphs illustrate the aspects of production, testing and construction based on this work. Four types of mixes were prepared for the experiment.

Table 3 shows the mix proportions by volume

Sl. No.	Mix Designation	Wet paper pulp: damp earth: Portland cement: dry sand
1	Type 1	5:3:1:1
2	Type 2	6:2:1.5:1.5
3	Type 3	6.5:2.5:1
4	Type 4	7:1.5:1.5

Damp earth typically indicates sandy dirt, clay or clay-sand mix.

Typically, earth may be sandy dirt, clay or clay-sand mix. It is desirable to have earth with high clay content.

The major steps for preparation of blocks and related equipment used are described below:

1. IS sieve 4.75mm was used to remove all coarse aggregate from the sand and soil.
2. Shredded newspaper was wetted in water in the curing tank and a motor run machine called the pulp beater machine was used to obtain wet paper pulp.
3. Next, the soil, sand, pulp and cement were mixed into a more uniform and consistent mass with help of a cement mixer. The mixer machine was allowed to work for around 3 to 4 minutes to obtain papercrete.
4. Wooden moulds were prepared in the experiment but acrylic or plastic sheets can also be used for mould. The moulds were then greased with burnt oil or taping was done on the moulds which may help in releasing the blocks quickly and easily.
5. The papercrete mix was then poured into moulds and compacted on a vibrating to remove voids and achieve more density, resulting in stronger and more durable product. Temping bar was also used for the same purpose.
6. The mix was then levelled to achieve satisfactory dimensions and finish.
7. After 40 hours, papercrete seemed to attain sufficient amount of strength after which the moulds were released and casted blocks were allowed to sundry for further strength gain and development of load carrying capacity.

The first mix results in a hard and dense material and the following mixes result in comparatively lighter and softer finished material.

J. T.Sheth et.al. Also studied small structures in compression such as compound wall and arch as shown in figure 3.



Figure 3: papercrete interlocking arch [10]

The masonry unit was bonded using mortar for the compound wall and fitted without mortar using a key and hole mechanism inbuilt in the form of the block. Three types of mortar were prepared for bonding: (a) Cement, sand and water (C: S-1:4) (b) Cement, sand, water and paper pulp (C:S:P- 1:4:6) and (c) Cement, paper pulp and water (C:P:W-2:4:1). The last one was found to be most appropriate and it was used for providing proper strength and bonding in the papercrete masonry.

When it hardens up, papercrete is lightweight (its 80 percent air), an excellent insulator (R 2.8 per inch), holds its shape even when wet, and is remarkably strong (compressive strength of 260 psi). And, since it contains paper fibers, it has considerable tensile strength as well as compressive strength (Solberg, 2000).

Papercrete is suitable for making low cost homes with limited longevity and durability. It is also suitable for making community rooms, sale booths, storage rooms and dwellings for livestock. Papercrete can also be used as a plaster. It can be sprayed on walls to give them good sound and heat insulating properties.

8. PROPERTIES OF PAPERCRETE BLOCKS

J. T. Sheth et. al. They tested the above lab scale manufactured papercrete blocks for key properties and following values were obtained:

Compressive Strength

Compressive strength tests on 15 cm x 15 cm x 15 cm papercrete cubes revealed an average compressive strength of 0.57 N/mm² after 3 days of cube preparation. Other research also suggests similar results. [1, 5]. For more strength, higher grade of cement can be used.

Weight and Density

Density of the material increased with increase in the percentage of cement in the mixture and reduced with increase in the amount of the paper in the mixture. Average weight of 8 cubes casted was observed to be 3.624 kg, thus block density was about 1.07 gm /cc. This is therefore lightweight in comparison to standard concrete or brick masonry units.

Shrinkage

Shrinkage measured was between 8-9% in each block.

Water absorption

Water absorption of the blocks was about 30% in all cases.

Drying time

40 hours at least are needed for drying of papercrete before it can be demolded. After this it should be sundried for 4 days before usage for better strength. Or it can be placed in oven at nearly 70 °C for 40 hours after casting. Putting it at higher temperature than this can result into segregation of material.

Tests for other properties such as 7 day and 28 day compressive strength, thermal resistance, sound insulation, behavior under fire etc. are under progress.

Standardization and commercial acceptance:

Papercrete gets its name from the fact that most formulas use a mixture of water and cement with cellulose fibre. The fibre is usually acquired from recycled newspaper, lottery tickets and phone books. The mixture has the appearance and texture of oatmeal and is poured into forms and dried in the sun, much like the process for making adobe.

As of 2007, papercrete lacks approval from the International Code Council. This limits its range of use within the city limits of most incorporated United States cities where building codes apply. It is not used as a load-bearing wall where building codes apply. However, its strength in model structures has been proven, and homes and small commercial buildings are being constructed. There is little or no evidence of its long-term durability at present.

In these small building projects, papercrete is being used as an in-fill wall in conjunction with structural steel beams or other load-bearing elements.

Dried papercrete has very low strength, but fails by slow compression (due to the large air content and hence compressibility) rather than in a brittle manner. Concrete and wood are not known for their insulating qualities; however, papercrete also provides good insulation.

Papercrete's R-value is reported to be within 2.0 and 3.0 per inch (2.54 cm); papercrete walls are typically 10 to 12 inches thick (about 25–30 cm). Unlike concrete or adobe, papercrete blocks are lightweight, less than a third of the weight of a comparably-sized adobe brick. Papercrete is mold resistant and has utility as a sound-proofing material.

Structural tests have been completed on several papercrete formulas and Fuller claims the compressive strength of papercrete to be in the 140-160 psi range (0.96 - 1.1 MPa), while others like Kelly Hart claim 260 psi (1.7 MPa).[1] For comparison, the compressive strength of concrete ranges from 15 MPa to over 70 MPa (2200 - 10000 psi) depending on the application. A more useful measure of papercrete's properties is its stiffness - i.e. the extent to which it compresses under load. Its stiffness is many times less than that of concrete, but sufficient for the support of roof loads in some low-height buildings.[citation needed]

Dried, ready-to-use papercrete has a rough surface. This increases its surface area and provides a very strong bond from one block to the next.

Papercrete has also been tested for its tensile strength. Fuller notes that a papercrete block is the equivalent of hundreds of pages of paper - almost like a catalogue. Papercrete has very good shear strength as a block. Lateral load involves sideways force - the wind load on the entire area of an outside wall for example. Because papercrete walls are usually a minimum of twelve inches thick and usually pinned with rebar, they may be strong laterally.

Zach Rabon founded Mason Greenstar in Mason, Texas for the purpose of producing and selling a commercially viable papercrete block. His product, Blox Building System, is at present the only mass-produced commercial papercrete block in the market. He has built several residential structures with it.

The Mason Greenstar block had its genesis in a journey Rabon's father, Kent Rabon, made to Marathon, Texas. The elder Rabon made the acquaintance of Clyde T. Curry, the proprietor of Eve's Garden Organic Bed & Breakfast and Ecology Resource Center.

Mr. Curry was an early proponent of papercrete and benefited from the lack of building regulations in the small mountain community of Marathon. Curry built four of the rooms at the bed and breakfast either partially or entirely out of papercrete and is in the process of building two more, in addition to a library and reception area, entirely out of papercrete.

Papercrete's ready moldability provides considerable flexibility in the designed shape of structures. Domed ceilings/roofs may be commonly constructed with this material.

Along with Fuller's work at Arizona State University, Curry's establishment has become a resource center for people interested in papercrete, and workshops are intermittently held there.

The Rabons had prior experience as homebuilders and are owners of a ready-mix cement plant in Mason. They have invested in research and testing on their product for several years. However, they consider their product a proprietary formula. They have filed for a separate patent even though a patent for papercrete had already been filed in 1928. The block developed by Mason Greenstar is known for its uniform shrinkage (all papercrete blocks go through a lengthy dry-time that involves some shrinkage), giving it a sharper edge.

Fuller has remarked that in tests he has performed on the Rabon block, it has outperformed other formulas.

Papercrete is claimed to have benefit of being a project that involves little cost to start. The materials are claimed to be cheap and widely available. Machinery suitable for small-scale construction is simple to design and construct.

When properly mixed and dried, the papercrete wall can be left exposed to the elements. In its natural state, it is a grey, fibrous-looking wall. For a more conventional look, stucco can be applied directly to it.

A study model home made of papercrete has been built at the Lyle Centre for Regenerative Studies. This study model is a sample of homes to be built for a sustainable community in Tijuana by students of California State Polytechnic University, Pomona

Since 2006 a small company based in England, Econovate Ltd has developed, with the support of Cambridge and Bath University, a papercrete formula and production process for breeze blocks to be accepted by British Standard and a green certification for Europe. This new mixture of papercrete is to withstand the wet and harsh English weather. As of 2009 Econovate was in the process of developing this product and reaching manufacturing trials stage. A patent was filed in 2011 for the production process of breeze blocks with this material. De design of machinery was necessary to achieve a successful scale up of production. In January 2013 Econovate became fully funded to set up its first demonstration plant capable of producing up to 1.5m blocks a year which expected to achieve certification by October 2015. The company has tested the product at UKAS register testing houses for 18 rigours test such as fire, strength, moisture movement, acoustics, thermal, durability and others toward the product certification. This certification by LABC was achieved in dec 2015. The company was also in the process of achieving ISO 9001, 14001, 18001 and BS eN 6001 (responsible sourcing). Its ISO 9001 certification was achieved in October 2015. Econovate with its product Econoblok is producing a breeze block, UK standard size (440mmx215mmx100mm) with 5Mpa and another with 7Mpa. The difference between the two will be the amount of fibre within the mixture and this can range between 55% to 79%. The more strength the less fibre thus less thermal. After gaining Certification the company has increased

production and the product is called "econoblok®". Initial commercialization will be in the UK until the production process is fully tested and ready for up scaling to a full size plant. From January 2017 the company will start preparing for the full size plant of 5-6 million block production, this will be based in the UK. Econovate plans to expand to other region of the world where some basic recycling system exist.

Compressive test on papercrete block reveals that papercrete can withstand load up to its 30% axial compressive strain.

9. APPLICATIONS:

1. They are largely used in the building of houses.
2. They can be mould into any different shapes to decorate houses, flowerpots, etc.
3. Can be used as sound proofing material.
4. It is less catastrophic then materials like concrete so they can be used in high rise buildings in seismic zones.
5. They can be also used in simple furniture in interiors as it provides aesthetic and opportunity for diverse designs. Literature illustrates its uses for partition walls, and façade material where benefit of dead load reduction of the structure is obtained. It can be used in interiors as it provides aesthetics and opportunity for diverse designs. High rise buildings in seismic zone can use papercrete as it is less catastrophic then other materials like concrete but due to limitations in some other properties such as behavior towards fire, durability concerns, biodegradability etc. it requires a significant amount of research for justifying its applications. Houses of paper may be trend of future.[4]

10. ADVANTAGES OF PAPERCRETE:

1. They are lightweighted but strong:

Unlike concrete or adobe, papercrete blocks are lightweight, less than a third of the weight of a comparably-sized adobe brick. It is strong enough to hold up the load of roof on "low height" buildings.

2. Easy to use:

It is quick, easy to make and durable as well as fairly inexpensive and while most municipalities would not recognise it as an acceptable building material.

3. Low cost:

Papercrete is suitable for making low cost homes with limited longevity and durability. They are remarkably inexpensive, since all the ingredients except for the cement are available for free or nearly free.

4. They can be easily made by everyone:

As the basic constituents of papercrete are only paper, cement and water, it can be easily made by following the steps.

5. They are environmentally friendly:

By the term environmentally friendly, it simply means having a lifestyle that are better for the environment. By using paper in buildings we can significantly decrease amount of paper landing in the landfills. Using the concept of recycling of waste materials, papercrete is not only reducing the amount of cement using but also making it environmentally friendly.

6. They provide good insulation:

According to Jeododibroto (1983), raw material of paper contains a lot of fiber cellulose. The content and coating of paper contain aluminium fiber influence to the heat resistance to building material, so that it can save heat energy to cool the room. Unlike those of concrete where heat from the sun heats the wall up and the concrete allow that heat to pass all the way through and radiate into the interior of the house.

7. Papercrete can be produced by harnessing solar energy. The only power needed is for the purpose of mixing. Papercrete is far lighter in weight and has remarkable insulating qualities, unlike concrete which is relatively heavy. It can be easily shaped when cured and dried. The most important benefit of papercrete is the reduction of cement in the mix. Carbon footprint during production, the total cost and weight are reduced, resulting in an eco-friendly and lightweight material. Paper fibers result in excellent heat and sound insulating properties. Papercrete incentivizes the recycling of waste paper, especially in communities

with no recycling services. Papercrete is viable option for low cost housing and temporary shelters and offices. Crises of building materials lead to high demand and need for recycling industrial waste or finding alternative source. Wastepaper helps in low- cost, eco friendly and therefore, sustainable design. In India's context only a fraction of paper is recycled annually. This means that the rest is still disposed off, mostly ending up in landfills for slow degradation and capacity consumption of dumpsites. Conservatively speaking, it takes about 15 trees to make 1 ton of paper. [2] As it is recycled material, there is a benefit in embodied energy due to reutilization. It has good thermal and sound insulation properties.

11. DISADVANTAGES:

1. Papercrete is not structural:

It means that they cannot be used over doors and windows without some additional support i.e. either by wood or concrete.

2. It is water absorbent:

Another disadvantage to papercrete is that it absorbs water. One must be careful to put a good protective coating on all exterior surfaces that are meant to expose to rain. It is also not actually to be used on the ground as it will absorb water from the surrounding earth.

3. They have low durability:

Durability is another major issue owing to the tendency of paper to degrade due to thermal, biological and chemical actions like fire, micro-organisms and sulphate and chloride attacks respectively.

4. Papercrete is a brittle material:

In brittle materials, fracture happen mainly due to the presence of flaws on the surface or inside the material where flaws act as crack initiation site. Therefore, they tend to break before their stated limit and the point where such type of failure occurs depends on the size of flaw which again depends on how material was processed or handled. Also brittle materials are much more (10 to 15 times) prone to failure due to tension than compression. They also stretch elastically when loaded to a certain point but they tend to shatter very quickly if loaded beyond this point.

5. The cost of raw paper will increase:

As papercrete grows in popularity, it will become harder to find enough paper. Right now, there is an overabundance of excess paper, and one can get as much paper as we want for free. As papercrete grows in popularity, people will realize there is a market for old paper and start selling it – thus the cost of building with papercrete will go up.

6. Unavailability of suitable equipments:

Machinery designed for use with traditional concrete are built for use with very heavy materials, therefore the machines are heavy and costly. The extreme durability is not necessary for those machines which certainly work for papercrete. Since papercrete weighs a small fraction of traditional concrete, lighter- weight machinery would easily suit. However, because of the less number of people building with papercrete at this time, that type of machinery is not commercially available, which means that one must either buy the expensive machines or build their own.

Certain limitations in the properties can be overcome by below measures:

1. Modification of mix proportions can help achieve optimum properties.

2. Addition of reinforcement like coconut fibre (5%-10%) or fly ash can be done to improve compressive strength of papercrete.

3. Color and texture can be added to papercrete for better aesthetics and design versatility.

4. Addition of silicon, concrete sealer or epoxy compound can help in waterproofing of papercrete.

5. Admixtures can also be added to improve setting and bonding properties.

6. Higher strength can be obtained by using higher grade of cement.

7. Papercrete made with certain mixes are resistant to fire, fungi, and pests to a larger extent.

8. Papercrete blocks made with a sufficient quantity of Portland cement and sand have improved fire resistance.

12. CONCLUSIONS:

This study was conducted with an aim to learn the small scale preparation of papercrete blocks, its design and construction skills and also had a focus on the assessment of the properties of this building blocks. The study recognized 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. 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. It is thus evident that it can be looked upon as a sustainable building material and has a promising future. The study recognized papercrete as a sustainable building material and emphasized on more research towards its performance parameters. Papercrete bricks are suitable for non-load bearing walls only i.e. buildings made from this could be only of one storey. The weight of this brick is 1/3rd to 2/5th lesser than conventional clay brick. These bricks are not suitable for water logging and external walls. It can be used in inner partition walls as they are water absorbent. Due to less weight of these bricks, the total dead load of the building will be reduced. Since, these bricks are relatively light weight and more flexible, they have now become an ideal building material for earthquake prone areas.

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. But the papercrete should have the following characteristics.

- i) Affordable price
- ii) Eco friendly
- iii) Thermal insulation
- iv) Less weight
- v) Less water absorption

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