CHAPTER 2

LITERATURE REVIEW

2.1 GENERAL

The present investigation deals with studies on the Papercrete building bricks and so an attempt has been made to review briefly the available literature on the following topics:

i. Waste utilization in construction industry  
ii. Flyash bricks  
iii. Papercrete bricks and  
iv. Masonry infilled walls

A large number of investigations are available in the literature on the above topics and only those investigations that are related to the strength, durability, ductility and energy absorption capacity on the above topics are discussed here. The scope of the present study is mentioned at the end of the Chapter.

2.2 WASTE UTILIZATION IN CONSTRUCTION INDUSTRY

Human and his activities produce a lot of wastes. At the same time, man consumes many things. Amongst the various things man consumes, building materials happen to be the largest in terms of weight being about 5 tons per capita per year, next only perhaps to water. Out of the total cost of house construction, building materials contribute 70% cost in developing
countries like India. One of the construction sector’s major contributions to the preservation of the environment and sustainable development is the reuse and recycling of the waste materials it generates, i.e. reducing, reusing, recycling and regenerating the residues that originate the constructive activity. This has increased the life cycle of these materials, thereby reducing the amount of waste dumping and natural resource extraction.

Carter et al (1982) dealt with the incorporation of ungrounded rice husks into handmade, kiln–fired bricks. Bricks with a range of rice husk contents were prepared and then fired in either small electric kiln or a commercial Hoffman kiln. The properties like density, compressive strength, modules of rupture, water absorption and initial state of absorption were measured. They concluded from the results that it was possible to incorporate upto 50% rice husks (by volume of clay) into bricks without causing brick properties to fall outside the limits acceptable in developing countries.

Weng Chin-Huang et al (2003) demonstrated suitable conditions for using dried sludge as a clay substitute to produce engineering quality of brick. The proportion of sludge in the mixture and the fixing temperature are the two key factors affecting the quality of brick. After the experimental study, they recommended that the proportion of sludge in brick was 10% with 24% optimum moisture content, prepared in the molded mixtures and fixed between 800°C and 960°C to produce a good quality brick.

Teo et al (2006) presented the experimental results of an on-going research project to produce structural lightweight concrete using solid waste, namely the oil palm shell, as a coarse aggregate. Reported in this paper are the compressive strength, bond strength, modulus of elasticity and flexural behavior of oil palm shell concrete. It was found that although oil palm shell concrete has a low modulus of elasticity, full-scale beam tests revealed that
the deflection under the design service load was acceptable as the span-
deflection ratios range between 252 and 263. These ratios are within the
allowable limits provided by BS 8110. It was observed that the ultimate
experimental moment for the singly reinforced beams was about 19% to
35% greater compared to the predicted moments from BS 8110.

Luis Agullo et al (2006) presented an experimental study aimed at
evaluating the reuse of paper pulp waste generated from the manufacture of
paper for non-structural elements in the form a plaster-pulp composite
material. From their experimental work, they concluded that the use of paper
pulp waste in combination with plaster did not involve any difficulties in
respect of behavior of the fresh and hardened material although it is advisable
to dry the paper pulp before using it, to enhance the mechanical and
rheological properties of the material. However, the breaking up or
fragmenting of the paper pulp is indispensable to ensure a homogeneous
mixture.

Kaves Taner et al (2006) determined the usability of clay and fine
waste of boron from the concentrator plant in Kirkar (Turkey) as a fluxing
agent in the production of red mud brick. Scale tests for production of bricks
were carried out. Clay and fine wastes have similar chemical composition but
include different types and amounts of oxides. They were added in amounts
of 5%, 10% and 15% of weight to red mud bricks. Those consist of high
amounts of Fe₂O₃, Al₂O₃, SiO₂, and alkalies. Six different sets of samples have
been produced and fixed at 700°C, 800°C and 900°C dry shrinkage of green
body, bending and compressive strength, drying shrinkage, water absorption,
frost resistance and harmful magnesia and line tests on heat –treated bodies.
The mineralogical and mechanical tests showed that usability of boron wastes
as fluxing agent in the production of red mud bricks was possible. In addition,
the samples obtained by adding 15% of weight of clay and fine wastes to red mud bricks showed the best mechanical characteristics.

Ismail Demir (2006) investigated the utilization potential of processed waste tea in clay brick. The effects of processed waste tea material addition on the durability and mechanical properties of the briks were investigated. Due to the organic nature of processed waste tea, pore-forming and binding ability in clay body were also investigated. Based on the experimental investigation, the concluded that processed waste tea addition increased the required water content for plasticity. It is easily burnt out and it has a wide range of burning from the clay body during fixing. No black coring and bloating were observed after fixing. According to test results, a mixture upto 5% processed waste tea additives can be used in the brick. Production and most economical firing temperature were determined at 900°C.

Tung-chai Ling et al. (2006) studied the potential of using crumb rubber as a partial substitute for coarse sand in the production of concrete paving block. Laboratory trials were conducted to compare and investigate the effect of using three particles size of crumb rubber 1-3mm, 3-5mm and combination of both (1-5mm) According to test results, the compressive strength of concrete paring block affected differently depending on the size and content of crumb rubber. Of these, the combined crumb rubber of 1-5mm performed better on the 28th day compressive strength. Also, the test results showed that there was a systematic reduction in the compressive and dry density with the increase in rubber content from 0% to 30%. The concrete paving block containing rubber particulars seems to provide better skid resistance and it gives better bonding characteristics to rubber and significantly improves the performance of crumb rubber concrete paving blocks.
Nuno Almedia et al (2007) developed a method to evaluate the mechanical behavior of concrete mixtures containing stone slurry. The results showed that the substitution of 5% of the sand content by stone slurry induced higher compressive strength, higher splitting tensile strength and higher modulus of elasticity. They concluded that natural stone slurry could be consumed by several industrial activities as to byproducts and the same could specifically be used as a fine aggregate and/or micro filler in concrete mixtures, inducing benefits on its mechanical properties.

Turgut Pakiet al (2007) investigated the physical and mechanical properties of brick samples with wood sawdust wastes and limestone dust wastes. They observed the effect of 10% - 30% wood sawdust waste replacements in wood sawdust waste. Limestone dust waste matrix does not exhibit a sudden brittle fracture even beyond the failure loads and indicates high energy absorption capacity by allowing lower labouring cost. The composition produces a comparatively lighter composite which is about 65% lighter than the conventional concrete bricks. Concrete, with 30% replacement level of wood sawdust waste which attained 7.2 MPa compressive and 3.08 MPa flexural strength values, satisfies the requirements in BS 6073 for a building material to be used in the structural application.

2.3 FLYASH BRICKS

Based on a study, Tutunlu and Atalay Umit (2001) reported the addition of flyash upto 60% at a firing temperature of 950°C and it did not have any harmful effects on the brick quality. Also they stated that the use of flyash as a raw material for the production of building bricks was not only a viable alternative to clay but also a solution to a difficult and expensive waste disposal problem.
Obada Kayali (2005) investigated the high performance of bricks from flyash. He concluded that the flyash brick had 24% better compressive strength and 44% higher bond strength than the good quality clay brick. Also, he reported that the tensile strength of the flyash brick was three times greater than the value for standard clay bricks.

Henry Liu et al (2009) probed the environmental properties of flyash bricks and reported that the flyash brick passed the Toxicity Characteristic Leaching Procedure (TCLP) test recommended by Environmental Production Agency (EPA) with large margins. Also it can absorb carbon-dioxide from the atmosphere causing carbon sequestration. Consequently, it reduces the CO$_2$ in the atmosphere which helps to mitigate global warming.

Based on their experimental study, Sameer Mistry et al (2011) reported that the flyash bricks with conventional masonry work save 28% in cost compared with common red brick and conventional masonry work. The masonry work with new technology Rat-Trap bond in flyash brick saves 33% cost as compared to common bricks.

Akhtar et al (2011) concluded based on their experimental work that the values of uniformity coefficient and coefficient of curvature of flyash should vary with the type of coal used. The addition of lime to the flyash increases the cementitious properties of flyash and it was found that at 1.5% of lime, dry density was maximum and optimum moisture content was minimum.

Flyash is a useful resource and not a waste product. However, major initiatives are needed in India to use it in large volumes in construction especially in housing and infrastructure projects. India should aggressively identify projects that can be registered with World Bank for carbon credits.
The World Bank has cautioned India that by 2015, land disposal of coal ash would require about 1000 km$^2$ of land. To overcome this problem and to encourage the utilization of flyash, Government of India in 2003 made it mandatory to use at least 25% flyash with soils on a weight to weight basis for manufacture of bricks within a radius of 100 km from coal or lignite-based thermal power plants. In the last several decades, attempts have been made to find a suitable method for the disposal and proper utilization of flyash (Tabin Rusad et al 2011).

2.4 PAPERCRETE BRICKS

India’s per capita consumption of paper is around 4.00 Kg. With the expected increase in literacy rate and growing economy, an increase in per capita consumption of paper is expected. The demand for upstream market of paper products like tissue paper, tea bags, filter paper, lightweight online-coated paper, medical grade coated paper etc., is shooting up. Due to this tremendous increase in use of paper, 1600 m$^3$ papers are wasted in India per day. Even though the waste papers are recycled in the paper industry only 29% of waste paper is recycled. It is lower in comparison to the global average of 36%. Paper is principally wood cellulose, which is considered as fibrous material. Cellulose is the second most abundant material on earth after rock.

Even though the chemical behaviour of paper is suitable for papercrete, the physical behaviour of paper is having an impact on physical behaviour of papercrete. The tensile strength of paper also seems to be sufficient for the task. When applying a pull on a single sheet of paper on its edges, it has great strength. Ripping a piece of paper is easier than pulling it apart. So it denotes the shear strength of paper is not as great as its tensile strength. But ripping hundreds of sheets of paper is not an easy task. So it shows that it has more shear strength.
Parviz et al (1994) proffered the durability and moisture effects on waste paper – fiber – cement composites. They posited that the increase in the moisture content of virgin and recycled composites reduced the flexural strength and stiffness while it increased the toughness of the composites. The effects of long-term immersion in hot water on the flexural strength, stiffness and toughness of recycled composites were not statistically significant at 95% level of confidence. The flexural stiffness of virgin and recycled composites was affected differently by this ageing process. Also, they reported 30% replacement of cement with silica fume in recycled fiber and that cement composites appeared to be highly effective in controlling the aging mechanisms and moisture effects. This approach presents a practical, economic and efficient way of enhancing the durability and moisture resistance of waste paper – fiber – cement composites.

Ahmadi et al (2001) 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 concrete 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$^3$. 

Farrell et al (2002) furnished the results of a preliminary study into the properties of concrete manufactured with various binder blends incorporating Portland Cement (PC), Waste paper Sludge Ash (WSA) and Ground Granulated Blast-furnace Slag (GGBS). The PC was practically replaced with either WSA or a 50:50 blend of WSA:GGBS at replacement levels of 0%, 20%, 40%, 60%, 66% and 80%. The results obtained indicated that it was possible to partially replace PC with WSA or a 50:50 WSA:GGBS blend to produce an effective binder for concrete. The optimum mixture compositions with respect to strength development involve replacement of 40% of PC with either WSA or WSA – GGBS blend. WSA has a significant effect on the water demand and setting times of the mixtures investigated. The use of retarder/plasticizer is essential at replacement levels in excess of 20% WSA and 40% WSA:GGBS to achieve a mix of workability similar to that of the control.

Solberg (2002) stated that landfills in most parts of the country were clogged with wastepaper and cardboard. Millions of people lived in substandard housing or have no housing at all. When wastepaper is recycled as papercrete to construct houses for these people and when landfills are removed, these problems can be solved.

John S. Manuel (2002) reported paper houses and Professor Leonard has done experiments with papercrete that reveal less desirable qualities. He opined that the physical characteristics of papercrete vary widely, depending upon the relative amounts of sand and portland cement used. Mixtures with a lot of sand and cement tend to have a high density and a relatively high tensile strength, but a low R-value. Mixture with less sand or Portland cement tends to have lower density, a relatively low tensile strength, but a higher R-value. This researcher also endorsed that he would not recommend the use of papercrete for any structural components. Instead, it
should be used as in-fill in a building with an independent metal, pole or wood frame. Alex, an Executive Editor of Environmental Building News, reported that papercrete has not yet been approved under commonly used building codes such as the international building code. But builders generally use it in areas that do not have building codes or that allow experimented permits.

Pera et al (2003) pinpointed the properties of calcined paper sludge and inferred that when the paper is calcined at 650°C it can be mixed with metakaoline and calcite. This can consume hydroxide more rapidly than pure metakaoline. It can replace 20% of ordinary Portland cement with beneficial effects on compressive strength and the size of pores. When calcined at 800°C, paper sludge becomes a mixture of calcite, quick lime and metakaoline. It presents both hydraulic and pozzolanic properties. To be used in concrete, this ash needs to be slaked. The experts suggested that paper sludge could replace 20% cement without affecting the strength but it was less pozzolanic than the sludge calcined as 650°C.

Tarun R. Naik et al (2004) derived experimental results on concrete containing pulp and paper mill residuals. They concluded that the dosage of high range of water reducing agent was proportional to the amount of wood fibers in concrete. Paper Mill residuals do not affect the strength development of concrete. At a small lower compressive strength, concrete containing residuals showed equal length change (drying shrinkage) compared with the reference concrete made without residuals.

Using the data from their experimental studies, Frias et al (2004) formulated that the highly pozzolanic materials were obtained by calcining paper sludges. At this juncture, it is important to remember that the calcining conditions (temperature and time in furnace) play an important role in their activation. The pozzolanic activity of calcined sludge decreased with the
increasing calcining temperature and time in furnace. According to the aforesaid experimental work, they declared that the best conditions for the pozzolanic activation of paper sludge occurred at 2.5 hours at 700°C. In this condition, the pozzolanic activity of calcined sludge was similar to that obtained from commercial metakaolin.

Tonks et al (2004) conducted an experiment on buildings constructed by utilizing discarded telephone books. The researchers believed that these are viable and in fact this method conformed to the requirements of the Newzeland Building Act. They also suggested that the construction process is labour-intensive, rather than skill-based, but care is needed when selecting the volumes and placing them into position. Services, power and communication can be accommodated within the walls, while it is preferable to run wet services within the slab. This construction method is analogous to both earth and straw buildings and in a similar manner is suited to the “do it yourself” building owner / constructor.

Fuller et al (2006) formulated that for decades intrepid environmentalist have been building homes and other structures with materials that recycle waste paper into an alternative construction material made with cement and other ingredients. They claimed that these “Papercrete” structures are strong and good at durable and insulating. But they had no research to backup their claims until now. They were cast into seventeen group of papercrete mix proportions. The samples were then tested under a uniaxial compression force using a 100 tonne compression machine. The loading rate was 9 mm per minute, and all of the samples were loaded to approximately 45 kN, unloaded and then reloaded to approximately 66.72 kN. Since the material is not brittle, failure was defined by deformation criteria rater than by the development of a fracture point. In fact, the stress- strain curve increases monotonically and the sample compresses rather than
They also reported the sound absorption and creep characteristics. At last, they concluded that, it stands to reason, papercrete could have wide-ranging implications for residential construction and for the natural environment. The challenge facing engineers now is the lack of information about papacrete and meaningful research is needed in order to learn more about the material and its properties. Only then, the full potential of this recycled material can be realized.

Gallardo et al (2006) focused their investigation on the viability of using paper mill sludge as an alternative material. This can be applied as a partial replacement of fine aggregates in manufacturing fresh concrete intended to be used for low cost housing project. Based on the results of this study, they concluded that the most suitable mix proportion is 5% to 10% replacement of paper sludge to fine aggregates. Any further percentage replacement higher than 10% would result in a decrease in both compression and tensile strength. The reduction of concrete strength can be attributed to the high – water cement ratio and the absence of silica compound in paper sludge, which is essential for bonding and structuring of fresh concrete. Superplasticizer was only beneficial to concrete with paper mill sludge in terms of water and reduction density.

Dunster Andrew et al (2007) concluded from their research work that the addition of 20% calcined paper sludge with cement paste modified initial setting-time by accelerating the process in 60 minutes. Workability was reduced when using calcined paper-sludge. The incorporation of 10% and 20% thermally activated paper-sludge leads to an increase in the drying shrinkage of mortar 2 and 2.5 times more than that shown by the ordinary portland cement used as control.

Jesus (2008) investigated the reuse of sludge in the paper and board industry and suggested that the reuse of the sludge could do away with the
problem of disposal and this is a cost-effective management alternative. They concluded that the approximate economic analysis is better than the reuse of sludge in the pulp and paper industry could be feasible.

Millogo Younoussa et al (2008) examined micro structural changes of adobe bricks made of lime – clayey raw materials by X-ray diffraction, infrared spectrometry, differential thermal analyses, scanning electron microscopy and energy dispersive spectrometry tests. From these tests, they found that lime additions resulted in the development of calcite and poorly crystallized Calcium Silicate Hydrate (CSH) which is mainly formed from the reaction of lime and tiny silica. The excessive formation of portlandite and calcite, and the minor development of CSH affected negatively the mechanical resistance of adobe bricks. For the elaboration of strong and compact lime-clayey adobe bricks it is necessary to reduce the grain size of quartz, increase the duration of hydration and use pressure paste from air.

Claire et al (2010) manufactured papercrete building elements for pre-fabricated houses and they answered the questions from questioners through website http://www.econovate.com. In this website, they stated that papercrete is made from low-grade waste paper which would otherwise go to the landfill. Though its carbon foot print is very low it provides excellent thermal insulation. As a matter of fact, it is suitable for use in high performance, low cost housing.

2.5 MASONRY INFILLED WALLS

Masonry is commonly used for the construction of foundations and in many superstructures throughout the world. A variety of masonry units (stones, burnt clay bricks, concrete blocks etc) and mortars are used for masonry construction. In these kinds of work, codes of practice on masonry design give guidelines to assess masonry compressive strength by considering
compressive strength of the masonry unit, height of masonry unit and the mortar.

Masonry is an assemblage of masonry units and mortar and the behaviour of masonry largely depends on the characteristics of masonry units, mortar and the bond between them. For the masonry under compression, the nature of stress developed in the masonry unit and the mortar depend upon the relative modulus (stiffness) of the brick and the mortar.

Strength and stress-strain characteristics of burnt-clay bricks vary depending upon the characteristics of clay mineral used for brick production and manufacturing process employed. Another important aspect is that low strength and low modulus bricks are commonly used for low-rise buildings in India and in many other developing countries.

Magenes et al (1992) conducted an experimental programme on the seismic behaviour of brick masonry walls. The experimental results were discussed with reference to some of the existing models for the estimation of the strength of structural walls. The experimental shear-compression tests on full scale walls have shown a prevalence of failure modes triggered by stress situation in the center of the panels, with two possible outcomes: (i) Frictional failure of the marked joints, typical of a lower axial action and (ii) Tensile cracking of bricks, typical of a higher axial action.

Miha Tomazevic (2000) correlated the experimental results with the observed effects of earthquakes on masonry buildings. They indicated reliable information as regards the global seismic behaviour and failure mechanism obtained by testing small-scale models of buildings subject to earthquake. To do this simulators are used to create seismic ground motion upon prototype buildings. The limitations in the capacity of the actuator and
resonant frequency of the testing facility are of great importance when
deciding upon the size and structural configuration of the models.

Murthy et al (2000) presented experimental results on cyclic tests
of R. C. frames with masonry infills. It is seen that the masonry infills
contribute significantly to lateral stiffness, strength, overall ductility and
energy dissipation capacity. With suitable arrangements to provide
reinforcement in the masonry that is well anchored into the frame columns, it
should be possible also to improve the out-of-plane response of such infills.
Considering that such masonry infill RC frames are the most common type of
structures used for multistory constructions in the developing countries, there
is an imperative need to develop robust seismic design procedures for such
buildings.

Milad M. Alshebani et al (2001) conducted an experimental
investigation on half-scale sand plast brick masonry panels to study the
behaviour of the material under uniaxial cyclic compression in two orthogonal
directions, normal and parallel to the joints. The result data derived indicated
strength deterioration and stiffness degradation and these factors increase as
the number and intensity of load cycles increase. The linear elastic analysis of
sand plast furnace brick masonry can only be performed over the constant
stiffness range with spans upto 20% of load ratio. The relation between plastic
strain and energy dissipation can be used to define the permissible stiffness
degradation of masonry under cyclic loading.

Syrmakezis et al (2001) suggested a method for the analytical
determination of the failure surface of an orthotropic masonry under biaxial
stress. The main advantages of the method can be summarized as the ability to
ensure the closed shape of the failure surface. The unique mathematical form
for all possible combinations of plane stress makes it easier to include it into
existing software for the analysis of masonry structures. It showed
satisfactory approximation with the results of the real masonry behaviour under failure conditions.

Jorge I Cruz-Diaz et al (2002) came up with experimental results on the racking strength of hollow block masonry infilled frames. The experimental results show the influence of both the blocks’ slenderness and the blocks’ orthotrophy. For each test, the wall behaviour shows three main parts: a first and short step corresponding to an elastic behaviour without any visible cracking, a second step corresponding to a progressive crack development following either the half-brick diagonal or wall diagonal and a third step corresponding to the wall failure by excessive compression of the compression strut. In the case of the unfilled vertical joints, the strut inclination is governed by the brick slenderness. A numerical model based on finite element analysis is being developed in order to extend the signified model to the other kind of bricks. Its validity and reliability are for the moment limited to the types of brick and wall geometry close to those considered.

Asteris (2003) ascribed a new finite element technique for the analysis of brickwork infilled plane frames under lateral loads. The results show the increase in the opening percentage leading to a decrease on the lateral stiffness of infilled frames. This decrease can reach 87% for a bare frame (100% opening). For openings exceeding 50%, the stiffness factor remains practically constant. The overall action between the frame and the infill is adversely affected as the opening position is moved towards the compression diagonal. In the case of infilled frame with infill walls in all the three storey contributed to up to a 77% decrease of the lateral displacements. In the case of infilled frame with a soft ground story, the shear forces acting on columns are considerably higher than those obtained from the analysis of the bare frames.
Investigations of Gumaste (2004), Sarangapani (2002), Matthana (1996) and Dayaratnam (1987) revealed that the compressive strength of the burnt clay bricks are: (a) 2 to 10 MPa in the southern peninsular India and in many other states and (b) 7 to 20 MPa in northern Indian states especially located in Indo-Gangetic planes. The modulus of bricks in case (a) is in the range of 300 to 1000 MPa, and in case (b) the range is 2000 to 8000 MPa. In contrast, the compressive strength of burnt clay bricks in Europe, USA and the developed world ranges between 20 to 100 MPa. The modulus of these bricks will be in the range 4000 – 35000 MPa. The modulus of even the leaner mortar mixes like 1:6 (cement:sand) and 1:1:6 (cement:lime:sand) is greater than 5000 MPa. As mentioned earlier, the nature of stresses developed in the masonry unit and the mortar, when the masonry is subjected to compression greatly, depends upon their relative elastic modulus (E). Now one can visualize two situations where \((E_{\text{brick}}/E_{\text{mortar}})>1\) or <1. In case of \((E_{\text{brick}}/E_{\text{mortar}})<1\), the brick will be under triaxial compression and mortar will be under biaxial tension-uniaxial compression for the masonry subjected to compression. The stress-state in bricks and mortar will be vice-versa in the case of \((E_{\text{brick}}/E_{\text{mortar}})>1\).

Ramamurthy et al (2004) reported from their experimental studies on brick masonry that rendering enhanced the flexural bond strength between 2.8 and 3.2 times and between 7 and 15 times in cases of masonry prisms with table-moulded and wire-cut bricks respectively. The strength of the rendering and bedding mortar influenced the flexural bond strength of prisms, significantly in prisms constructed with wire-cut bricks. Also they declared that the flexural strength of render masonry prisms built with cement-lime mortar was only marginally lower than that of masonry prisms rendered with cement-sand mortar.
Balasubramanian et al (2006) bettered a scientific methodology for estimating the expected seismic loss to the brick masonry buildings in Uttar Pradesh, Uttarakhand, Punjab and Tamil Nadu. In this study, expected seismic loss estimated at the reference point of a given region is considered to be the representative of that region.

Hemant B. Kaushik et al (2007) investigate experimentally the compressive behavior of masonry and its constituents and to develop the stress-strain curves. The result data derived indicated the compressive behavior of mortar with lime was found to be better because of greater ductility; failure strain was about 45% more than that for strong mortar although the compressive strength was about 35% less. For the same reasons, compressive behavior of masonry with lime mortar was found to be much better than that of masonry with lime less mortar; failure strain was about 50% greater and prism strength only about 13% less than those for prism with strong mortar.

Jahangir Bakhteri et al (2007) presented the numerical verifications of the experimental investigation on the effect of mortar joint thickness on compressive strength characteristics of axially loaded brick-mortar prisms and the results showed that, by increasing the mortar joint thickness, the strength of masonry will decrease. The maximum compressive strength of models obtained when the thickness of the mortar joint was 7.5 mm.

Basher Mohammed (2009) performed a test on papercrete infilled composite wall system and concluded that the papercrete is a better thermal insulation with thermal conductivity co-efficient, K value 0.85 compared to conventional concrete which has K value 1.28. A composite wall system can sustain upto 2 hours maximum temperature of 1030°C papercrete infill which is a good sound absorber. Such noise reduction co-efficient value 1 is greater than 0.35, based on noise control in Building Guidelines for
Acoustical problem solving. The energy required to fracture the papercrete gives the highest imparted energy, which is 1.12 J as compared to the conventional mortar which is 0.24 J. Therefore, papercrete is a ductile material as it undergoes ductile fracture, compared to conventional mortar which is brittle. The average screw withdrawal force for papercrete is 565 N. Papercrete is a better material in screw-holding when compared with cement bonded particle board with 37.5% to 47.5% stronger screw withdrawal.

Jaya Singhe et al (2010) conducted an experimental programme on compressed stabilized earth masonry and the results were compared with the values obtained for conventional masonry. It highlights the stability of compressed, stabilized earth masonry for wider application with confidence. The results indicated that the flexural strength of compressed stabilized earth masonry walls can be in the range of 0.25 N/mm² or above which can be comparable with conventional masonry such as burnt clay brick work.

Andreas Stavridis et al (2010) presented a finite element modeling scheme for assessing the nonlinear load-deformation behaviour and failure mechanisms of masonry infilled R. C. frames. A study has also been conducted to evaluate the sensitivity of the numerical results to the modeling parameters. It has been found that the initial stiffness and peak strength of an infilled frame can be estimated quite accurately as they are governed by material parameters that can be calibrated with relatively ease to obtain test data.

Mohammed et al (2010) determined the effect of scale on masonry structural behaviour under various loading conditions. The results of the masonry tests at different scales showed that the strength of masonry triplet in compression was higher than the prototype in the fourth and sixth model scales but similar to the prototype in the half scale. The same pattern was also repeated in the tests of the unit strengths, indicating the strong influence of the
unit in determining the masonry properties. It was found that triplet stiffness in the four scales was identical to each other and no scale effect was observed. The prototype masonry and model stiffness were in good agreement with the prototype and model mortar stiffness respectively. The flexural strength normal to the bed joint and parallel to the bed joint shows no clear effect of scale. But there is a slight increase in the flexural strength parallel to the bed joints as the scale was increased, perhaps because it is significantly influenced by the tensile strength of the units. The diagonal tensile strength tests show that there is no increase or decrease in the shear strength as the scale was increased.

Verstrynge et al (2010) conducted an experimental programme to characterize the time-dependent deformation behaviour of masonry, subjected to the crisp failure mode. Different types of short-term creep tests were performed on small masonry specimens, which were constructed with air-harden lime mortar. The results indicated that a rather limited difference in load has a large influence on the expected failure time. This indicates that the assessment of the long-term stability of masonry needs to be done very carefully and that a past long life time is no guarantee for future safety.

Nwofor (2012) presented experimental results on mechanical properties of clay brick masonry and simple analytical model has been proposed for prediction of the modulus of elastic masonry, to aid the numerical analysis of masonry structures. Finally, compressive test result obtained from test on brick units and mortar is enough to predict the elastic property of masonry, as simple relationships have been obtained for obtaining the modulus of elasticity of bricks, mortar and masonry from their corresponding compressive strengths.
2.6 SUMMARY OF EARLIER WORKS

The reviews of literature on earlier works reveal the following:

i. Industrial wastes can be consumed as by-products and can specially be used as fine-aggregate and / or micro filler in concrete mixtures, inducing benefits on its mechanical properties.

ii. Natural wastes like ricehusk-ash, coconut fiber, durain fiber, wood sawdust and limestone dust composition produce a comparatively lighter than conventional concrete brick. It does not exhibit a sudden brittle fracture even beyond the failure loads and indicates high energy absorption capacity by allowing laboring cost. Also, its compressive and flexural strength values satisfy the requirements of BS 6073 for a building material to be used in the structural application.

iii. Also, most of the investigations were carried out on a lot of industrial wastes like flyash, boron waste and blast furnace slag as replacement of fine aggregates in concrete blocks. Only very few literature surveys were available in regard to papercrete.

iv. In the earlier works, attempts have been made by a few authors to investigate the paper mill residuals and waste paper sludge ash on the strength and other engineering properties of concrete or building blocks.

v. There is a lot of scope for studying the papercrete bricks and its impact on the various engineering properties.
2.7 **SCOPE OF THE STUDY**

The review of literature indicates that the papercrete building brick enhances its various mechanical properties, dimensional stability and structural integrity. The review also indicates that the addition of paper mill residuals, namely waste paper sludge ash give the desirable strength and durability of brick significantly. In most of these studies, the industrial and natural waste like fly-ash, ricehusk-ash, boron waste, blast furnace slag, wood sawdust and limestone dust on the strength and other properties like durability, workability, energy absorption capacity etc. on the concrete blocks above are focussed. An attempt has been made in the present investigation to conduct an experimental programme to study the strength and other engineering properties like durability, energy absorption capacity and ductility of flyash based papercrete building bricks.