PERFORMANCE EVALUATION OF LIGHT WEIGHT BRICKS FABRICATED USING WASTE MATERIALS

Thesis Submitted for the Award of the Degree of

DOCTOR OF PHILOSOPHY

in

Civil Engineering

By

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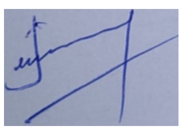
2025

DECLARATION

I, hereby declared that the presented work in the thesis entitled *"Performance Evaluation of Light Weight Bricks Fabricated using Waste Materials"* in fulfilment of degree of **Doctor of Philosophy (Ph.D.)** is outcome of research work carried out by me under the supervision of **Dr. Anshul Garg** working as Associate Professor in the **School of Civil Engineering, Lovely Professional University, Phagwara.** In keeping with general practice of reporting scientific observations, due acknowledgements have been made whenever work described here has been based on findings of other investigator. This work has not been submitted in part or full to any other University or Institute for the award of any degree.



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CERTIFICATE

This is to certify that the work reported in the Ph.D. thesis entitled "*Performance Evaluation of Light Weight Bricks Fabricated using Waste Materials*" submitted in fulfillment of the requirement for the award of degree of **Doctor of Philosophy (Ph.D.)** in the **School of Civil Engineering,** is a research work carried out by **Jimmy Gupta, 41800179**, is bonafide record of his/her original work carried out under my supervision and that no part of thesis has been submitted for any other degree, diploma or equivalent course.

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ABSTRACT

Sustainable brick production is an innovative approach aimed at reducing the environmental impact of traditional brick-making methods, which often rely on the extraction of clay and energy-intensive firing processes. These conventional methods contribute to soil depletion, pollution, carbon emissions, and the loss of fertile land. As an alternative, sustainable brick production uses alternative materials like fly ash, slag, and industrial waste to minimize resource extraction, energy consumption, and environmental damage. Fly ash, a by-product of coal combustion in power plants, has gained attention as an eco-friendly material in brick production. However, the availability of fly ash is limited, necessitating the exploration of other materials to meet the growing demand for bricks.

In this study, the use of agro-waste and rubber waste as substitutes for natural sand in the production of lightweight fly ash-based bricks is explored. Agro-waste, including agricultural residues, and rubber waste are non-biodegradable materials that are often discarded, leading to environmental pollution. By incorporating these wastes into brick production, the study aims to address both waste disposal issues and the environmental concerns associated with traditional brick manufacturing.

A total of 25 different brick mixes were prepared, varying the proportions of agro-waste and rubber waste. The physical and mechanical properties of the bricks, including compressive strength, water absorption, and density, were analyzed to determine the optimal mix. The results showed that the compressive strength of mix S19A6R5, containing 6% agro-waste and 5% rubber waste, achieved compressive strength 3.6% more after 14 days and a 4% more after 28 days as compared to the control specimens made using a standard fly ash mix. Additionally, the weight of the same mix brick was found to be 6% lighter than the control bricks.

These waste-based bricks, including the optimized mix, successfully passed durability tests, demonstrating their strength, longevity, and resistance to environmental factors. The inclusion of agro-waste improved the pore structure of the bricks, enhancing their strength, while the rubber waste slightly reduced strength as its percentage increased. Despite this, the optimized mix produced lightweight bricks, which offer advantages in reducing building stresses without compromising durability or safety. These bricks provide a promising alternative to traditional clay bricks, offering an environmentally friendly, cost-effective, and durable construction material.

From an economic perspective, the production cost of the waste-based bricks using the optimum mix is 6.6% lower than the cost of standard fly ash bricks made using the control mix. This cost reduction makes the waste-based bricks not only a more sustainable option but also a more affordable alternative for the construction industry.

Overall, this study highlights the potential of agro-waste and rubber waste in producing sustainable bricks, offering a solution that addresses both environmental and economic challenges. These waste-based bricks show promising mechanical properties, durability, and cost advantages, making them a commercially viable and environmentally friendly option for construction. Further research and development can enhance their performance and expand their use in the building industry, promoting a more sustainable future.

Keywords: fly-ash brick, agro-waste, rubber waste, compressive strength, durability testing, weight and cost analysis.

TERMINOLOGY

%	Percentage
HYSD	High Yield Strength Deformed Bars
Fe250	Mild Steel having yield strength 250MPa
Fe415	High Yield Strength Deformed Bars having yield strength 415MPa
Fe500	High Yield Strength Deformed Bars having yield strength 500MPa
FAB	Fly ash brick
POP	Plaster of Paris
GCW	Granite Cutting Waste
OPC	Ordinary Portland Cement
HAP	Hazardous Air Pollutants
EPA	Environmental Protection Agency
TCLP	Toxicity Characteristic Leaching Procedure
ISAT	Initial Surface Absorption Test
RCPT	Rapid Chloride Penetration Test
UPV	Ultrasonic Pulse Velocity
W/C	Water-Cement Ratio
GHG	Greenhouse Gases
Fe_2O_3	Ferric Oxide
Al_2O_3	Aluminum Oxide
SiO_2	Silicon Dioxide
Na_2SiO_3	Sodium silicate
$Ca(OH)_2$	Calcium Hydroxide

MgO	Magnesium Oxide
NaOH	Sodium Hydroxide
FA	Fly-Ash
SCM	Supplementary Cementitious Material
NTPC	National Thermal Power Corporation
BIS	Bauru of Indian Standards
IS	Indian Standard
ASTM	American Society for Testing and Materials
P	Phosphorus
Mg	Magnesium
K	Potassium
Ca	Calcium
Cu	Copper
Zn	Zink
Fe	Iron
B	Boron
Pa	Pascal (equal to $1N/m^2$)
MPa	Mega-Pascal (equal to $1N/mm^2$)
°C	Degree Celsius
mm	Milli-Meters
cm	Centi-Meters
m	Meters
g or gm	Grams

kg	Killo-grams
Cu.m	Cubic-meter
Min.	Minimum
Max.	Maximum
W	Weight of Respective Material
AGW	Agro-Waste
RBW	Rubber-Waste
SAR	Sand (in %), Agro-Waste (in %), Rubber-Waste (in %)
UTM	Universal Testing Machine
CTM	Compression-Testing Machine
M2	Weight of Saturated Brick Specimen (kg)
M1	Weight of Dry Brick Specimen (kg)
CON	Control Mix

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CHAPTER-1 INTRODUCTION

1.1 GENERAL

Construction-brick is one of the important even earliest building materials for construction in the past history of professional construction methods. Given that there are still standing brick buildings, foundations, pillars, and road surfaces that were built thousands of years ago, it is also possibly the most resilient. Though "brick" doesn't refer to a specific material, you might picture a red brick school house or another type of classic architecture when asked to think of a brick building. Bricks can actually be created or manufactured for a wide range of construction applications and from a wide variety of materials. A brick is a kind of block that is used in masonry construction to make walls, pavements, and some other kind of structures. Although the term "brick" is originally/basically referred to a dried clay block, it is now often used colloquially to refer to various rectangular blocks used for construction that have undergone various curing. Bricks can be connected together by interlocking/interconnecting them as well as using mortar, or some adhesives available in market. Bricks are made large in numbers and available in a variety of classes as per its strength, materials, types, and sizes that vary depending on the area and time period. Bricks can be set as masonry walls in different types of mortar to keep them together to create a sturdy and strong structure. Bricks are laid in different courses as well as multiple patterns known as bonds, together known as masonry work or brickwork. Although the word "brick" basically referred to a building unit composed of moulded clay after burning at high temperature, it is now used to define or describe any piece of stone or clay-based construction unit that is bonded together for construction of building using cementitious mortar. In India, bricks are generally available in two sizes: 8 inches x 4 inches and 9 inches x 4.5 inches. The thicknesses of the bricks vary depending on the country. Bigger clay or stone building pieces used for foundations are referred to as "blocks."

1.2 SUSTAINABLE BRICK PRODUCTION

Sustainable brick production is an innovative approach to manufacturing bricks that minimizes environmental impact while promoting resource efficiency and long-term durability. The traditional methods of brick production, which often rely on the extraction of clay and the energy-intensive firing of bricks in kilns, can have significant environmental consequences, including the depletion of natural resources, high energy consumption, and carbon emissions. In response to these concerns, sustainable brick production seeks to reduce the ecological footprint of brick-making through the use of alternative materials, energy-efficient processes, and eco-friendly technologies. One of the core principles of sustainable brick production is reducing the environmental impact of raw material extraction. Traditional brick manufacturing requires the extraction of large amounts of clay from the earth, which can lead to soil erosion, habitat destruction, and depletion of fertile land. Sustainable brick production explores the use of alternative raw materials that are abundant, renewable, or recycled. Materials such as fly ash, rice husk ash, slag, and industrial waste byproducts are increasingly being used as substitutes for clay. Fly ash, a byproduct of coal combustion in power plants, is one of the most prominent materials in this regard. When mixed with lime and other additives, fly ash can be used to create bricks that are durable, lightweight, and energy-efficient. By utilizing these alternative materials, the reliance on natural clay is reduced, minimizing environmental damage.

In addition to sourcing alternative materials, another important aspect of sustainable brick production is improving energy efficiency. The traditional brick firing process is energy-intensive, with kilns requiring high temperatures (typically over 1,000°C) to fire the bricks. This process consumes large amounts of fuel, such as coal or natural gas, and releases carbon dioxide (CO_2) into the atmosphere. To reduce this impact, sustainable brick production focuses on energy-efficient firing techniques, such as the use of renewable energy sources like solar, biomass, or waste heat from industrial processes. These energy-efficient firing methods not only reduce the carbon footprint but also lower operational costs for brick manufacturers. Additionally, innovations like low-temperature firing and the use of alternative fuels are helping to further decrease energy consumption in brick production.

Another innovation in sustainable brick production is the development of low-carbon and carbon-negative bricks. These bricks are designed to absorb more carbon dioxide over their lifespan than is emitted during their production. For instance, some bricks incorporate materials like hemp, which can absorb CO_2 as it grows, or bio-based polymers, which help to lock in carbon throughout the lifecycle of the brick. Some advanced techniques also involve capturing and storing carbon during the manufacturing process, resulting in a product that has a net positive effect on the environment. This type of innovation is crucial for achieving long-term sustainability goals in the construction sector, which is one of the largest contributors to global carbon emissions.

Sustainable brick production also emphasizes the durability and performance of the final product. Bricks made with alternative materials such as fly ash or recycled content can often outperform traditional bricks in terms of strength, thermal insulation, and fire resistance. These properties enhance the energy efficiency of buildings and reduce maintenance costs, leading to more sustainable structures over time. Moreover, the production of sustainable bricks often results in lighter, more versatile materials that are easier to transport and handle, reducing transportation-related emissions.

Furthermore, the concept of circular economy plays a vital role in sustainable brick production. By incorporating recycled materials into the brick-making process, waste from other industries, such as construction or manufacturing, can be repurposed, reducing the demand for virgin raw materials. The use of recyclable and biodegradable materials in brick production further supports a circular approach, ensuring that bricks can be reused or recycled at the end of their lifespan, reducing waste sent to landfills. So, it can be said that sustainable brick production represents a significant step forward in creating environmentally friendly, energy-efficient, and durable building materials. By using alternative raw materials, energy-efficient production processes, and innovative technologies, sustainable brick production minimizes environmental impact while supporting the development of resilient, long-lasting infrastructure. As the construction industry continues to focus on reducing its carbon footprint, sustainable brick production will play a crucial role in achieving a greener and more sustainable built environment.

1.3 INNOVATION OF FLYASH BRICKS

Fly ash, a byproduct of burning coal in power plants, has become a critical material in the pursuit of more sustainable construction practices. Over time, the innovative use of fly ash has evolved, transitioning from a waste product to a valuable resource in various industries, especially construction. One of the most promising applications of fly ash is in the production of construction bricks, an innovation that significantly enhances sustainability in the building industry while addressing environmental and performance concerns.

Traditionally, fly ash was disposed of in landfills as shown in figure 1.1, contributing to environmental pollution and waste accumulation. However, as the demand for more eco-friendly building materials increased, researchers and engineers discovered that fly ash could be effectively used in the production of bricks. Fly ash bricks, or "ash bricks," are made by combining fly ash with lime, gypsum, and water. This mixture is then subjected to compaction and curing, producing a durable and strong building material. Unlike conventional clay bricks, which require energy-intensive processes such as firing at high temperatures, fly ash bricks require less energy and can be produced at ambient temperatures, significantly reducing the carbon footprint associated with brick manufacturing. Even, the production of fly ash bricks offers numerous benefits over traditional clay bricks. One of the key advantages is their lighter weight, which makes them easier to transport, handle, and install. This not only reduces transportation costs but also helps in lowering the overall structural load on buildings, making fly ash bricks particularly beneficial for projects in areas where weight reduction is essential. Additionally, fly ash bricks have excellent thermal insulating properties, which contribute to enhanced energy efficiency in buildings. By improving the thermal performance of a building, fly ash bricks help maintain a stable indoor temperature, reducing the need for excessive heating or cooling and resulting in lower energy costs over time.

Figure 1.1 Constructing and Managing Coal Ash landfills

Another important benefit of fly ash brick is its durability. These bricks exhibit higher resistance to weathering, chemical attacks, and water absorption compared to traditional clay bricks. Fly ash bricks are less prone to cracking, shrinkage, and breakage, which contribute to the longevity of structures. Moreover, fly ash is naturally resistant to fire, making fly ash bricks an ideal material for buildings requiring fire-resistant properties. This durability extends the life of buildings and reduces maintenance costs, offering both economic and practical advantages to property owners and developers. Moreover, the innovation of fly ash bricks also addresses some critical environmental challenges. One of the primary concerns with conventional brick manufacturing is the depletion of natural resources, as clay is excavated for brick production. The use of fly ash in brick-making helps alleviate this problem by repurposing a waste byproduct from coal combustion. Instead of being disposed of in landfills, fly ash is used as a valuable resource in construction, reducing the environmental impact of its disposal. Additionally, by using fly ash in brick production, the demand for clay and other natural raw materials is significantly reduced, helping conserve valuable resources and protect ecosystems.

Fly ash also offers environmental benefits beyond its use in bricks. The incorporation of fly ash in building materials contributes to lowering the overall carbon footprint of construction projects. By reducing the amount of cement required in concrete and mortar mixtures, fly ash reduces the carbon emissions associated with cement production, which is a significant contributor to global greenhouse gas emissions. Furthermore, the use of fly ash in construction helps to mitigate the environmental hazards associated with landfills, as it reduces the volume of fly ash that would otherwise accumulate and contribute to environmental pollution.

Ongoing research and development in fly ash brick production continue to explore new possibilities and innovations. High-strength fly ash bricks are being developed for use in applications requiring greater load-bearing capacity, such as high-rise buildings and infrastructure projects. Additionally, blending fly ash with other industrial byproducts, such as slag or rice husk ash, is being explored to further enhance the performance and sustainability of fly ash bricks. These innovations hold great promise for the future of sustainable construction. So, the use of fly ash in construction bricks is a groundbreaking innovation that represents a significant leap forward in sustainable building practices. By offering an eco-friendly, durable, and cost-effective alternative to traditional clay bricks, fly ash bricks contribute to environmental conservation, energy efficiency, and resource conservation. The ongoing development of new fly ash-based products and production techniques further reinforces the potential of this material to revolutionize the construction industry, offering a path to more sustainable, long-lasting, and energy-efficient buildings.

1.4 ROLE OF FLYASH AND FINE AGGREGATES IN BRICK MANUFACTURING

Fly ash and fine aggregates both play significant roles in brick manufacturing, contributing to the sustainability, durability, and performance of the final product. Their inclusion in the brick mix reduces the environmental impact of traditional brick-making processes, enhances the quality of the bricks, and helps optimize resource use. Understanding the role of each material is essential for recognizing their contribution to the development of eco-friendly and high-performance building materials.

1.4.1 ROLE OF FLYASH IN BRICKS

Fly ash is a byproduct of coal combustion in power plants, and its use in brick manufacturing offers numerous environmental and performance benefits. Traditionally, fly ash was discarded as industrial waste, but it is now being increasingly repurposed in construction materials, especially in the production of bricks.

One of the primary benefits of using fly ash in brick manufacturing is that it reduces the need for traditional raw materials like clay, thus conserving natural resources and minimizing the environmental impact of extraction. The use of fly ash also addresses the issue of fly ash disposal, which can otherwise contribute to environmental pollution and waste accumulation. By incorporating fly ash into bricks, this waste material is diverted from landfills, making it a sustainable alternative to conventional brick-making ingredients.

In terms of performance, fly ash improves several key properties of bricks. First, it enhances the strength and durability of the bricks. Fly ash contains silica, alumina, and iron, which, when combined with lime, form a cementitious compound that contributes to the compressive strength of the brick. The resulting bricks are stronger and more durable than traditional clay bricks, making them ideal for use in infrastructure projects and buildings requiring long-lasting performance.

Fly ash bricks are also more resistant to weathering and chemical attacks. This makes them suitable for use in a wide range of environmental conditions, including areas with high humidity or exposure to aggressive weather. Additionally, the inclusion of fly ash in brick manufacturing helps to reduce the carbon footprint of brick production. The energy-intensive process of firing clay bricks in high-temperature kilns releases large amounts of CO_2, but fly ash bricks can be made using less energy, leading to lower overall emissions.

1.4.2 ROLE OF FINE AGGREGATES IN BRICKS

Fine aggregates, typically sand as shown in figure 1.2, are another essential component in brick manufacturing. Fine aggregates are mixed with other materials like clay, fly ash, and binders to create the brick mixture. These aggregates help improve the texture, workability, and overall quality of the final product.

The primary function of fine aggregates in brick manufacturing is to enhance the workability and mold-ability of the brick mixture. Fine aggregates like sand provide bulk to the mix and allow the material to be easily shaped and molded into bricks. This makes the production process more efficient and reduces the likelihood of defects or inconsistencies in the final product.

Figure 1.2 Fine Aggregates

In fly ash brick manufacturing, fine aggregates are mixed with fly ash, lime, and other ingredients to improve the mixture's consistency and strength. The addition of fine aggregates ensures that the fly ash is evenly distributed throughout the mix and bonds properly with the other components, leading to uniformity in the final product.

Fine aggregates also improve the texture and appearance of fly ash bricks, giving them a smooth surface that is desirable for construction purposes.

Moreover, fine aggregates contribute to the strength of the final brick by increasing its compressive strength and durability. The right balance of fine aggregates can result in bricks that are not only lightweight but also strong and resistant to external forces. Moreover, fine aggregates can influence the thermal properties of bricks. By selecting the appropriate type and quantity of fine aggregates, manufacturers can create bricks with better insulation properties, improving the energy efficiency of buildings constructed with these bricks.

1.4.3 COMBINED ROLE OF FLYASH AND FINE AGGREGATES

The combination of fly ash and fine aggregates in brick manufacturing offers a more sustainable and high-performance alternative to traditional brick-making methods. Fly ash reduces the environmental impact of raw material extraction and enhances the strength and durability of bricks. Fine aggregates improve workability, texture, and the overall quality of the brick mix, ensuring consistency and optimal performance. Together, these materials contribute to the production of eco-friendly bricks that offer several advantages over traditional clay bricks. These benefits include reduced energy consumption in manufacturing, lower carbon emissions, greater durability, and improved thermal insulation, all of which make fly ash and fine aggregate-based bricks a promising choice for sustainable construction.

Fly ash and fine aggregates are integral to modern brick manufacturing. They help conserve natural resources, reduce environmental waste, and improve the quality and performance of the final product. By incorporating these materials into brick production, manufacturers can contribute to a more sustainable, energy-efficient, and durable built environment.

1.5 FLY ASH BRICK

Figure 1.3 illustrates waste-based fly ash bricks, are unique bricks prepared using industrial waste materials including fly ash, cement, and sand/stone dust. These days, bricks are utilised all over the world and are becoming more and more popular than clay bricks. The basic materials could consist of 58-60 percent fly ash, 25-30 percent stone dust or sand, and 8-12 percent lime or Portland cement. A building material that is used more presently, known as fly ash brick, is made of masonry units that contain water and either class F or class C fly ash. After being pushed to 28MPa, cured for 1-day means 24-hours in a 65-68 °C steam-bath, and strengthened with an (AEA) air-entrainment-agent, the rectangular-bricks can endure more to hundred freeze-thaw cycles. Bricks classified as "self-cementing" do so because class C fly ash contains a high proportion of calcium oxide. In addition to saving energy, the manufacturing process lowers environmental mercury pollution and is frequently 20% less expensive than conventional clay brick production. The fly ash brick produced with the aforementioned components has a strength that falls between 7.5 and 10 MPa. Compared to clay bricks, fly ash bricks are tougher and lighter.

Figure 1.3 Normal Fly Ash Bricks

1.5.1 DIFFERENT CHARACTERISTICS OF FLY ASH BRICK

Appearance: Fly ash bricks have a particularly appealing appearance because of its smooth texture, consistent size, and nice tint, which is similar to cement. Because of the consistent size, less mortar is needed for plastering and walls—about 49–50% less. Plaster does not need to be baked before applying a coating of POP. These bricks have nodules of free lime, organic debris, wrap age, cracks, or stones.

Strength: Fly ash bricks have an extremely high compressive strength of 9–10 MPa, approximately. High strength prevents breakage and waste during handling and transportation. Plaster cracking is less common in cases where joints and plaster are thinner. These bricks offer superior earthquake resistance without adding undue load to the structure's design. With time, it gets stronger and gives the building more strength.

Thermal Properties: Bricks made with coal based waste fly-ash have a range of thermal conductivity that is 0.9–1.050 w/m^2. They take in less warmth, and less heat produced by the pozzolanic-reaction in between fly-ash and binding substitute. It is most suited for Indian conditions since it keeps your building cooler in the summer.

Durability: These bricks are less permeable and extremely robust. Bricks can effectively be protected from the effects of efflorescence by the reduced permeability. Because they are less porous, these bricks absorb less water and lessen wall moisture. Fly ash bricks are highly resistant to weathering and chemical attacks. They are less susceptible to the effects of moisture absorption, reducing the risk of erosion or deterioration over time, particularly in harsh environments with high humidity or exposure to rain. Additionally, they are resistant to salt, alkali, and acid attacks, making them ideal for use in coastal or industrial areas where such conditions may cause damage to traditional clay bricks. These bricks also have excellent fire resistance, as fly ash itself is non-combustible, contributing to the overall fire safety of buildings constructed with fly ash bricks. Their enhanced durability extends the lifespan of structures, reducing maintenance costs and the need for frequent repairs. Overall, fly ash bricks offer a durable, sustainable, and long-lasting building material.

Sound Insulation: Buildings constructed with these bricks have reasonable sound insulation. Fly ash bricks provide excellent sound insulation due to their dense structure and microstructure, which absorb and block sound waves. Their weight and porosity help reduce airborne noise, making them effective in improving acoustic performance in buildings. This results in quieter environments, ideal for residential and commercial spaces.

Fire Resistance: Compared to typical clay bricks, these bricks have a great fire resistance. Fly ash bricks offer excellent fire resistance due to the non-combustible nature of fly ash. These bricks can withstand high temperatures without deteriorating, making them ideal for fire safety in buildings. Their ability to resist fire enhances the overall safety and longevity of structures constructed with fly ash bricks.

Sustainability: Because fly ash bricks are created from leftover products from the burning of coal in thermal-power-plants, they are environmentally benign. Since there is no pollution or harm to the environment, the product is classified as white.

Build ability: These bricks are less absorbent of water and are easily workable. It's not necessary to soak them in water for a full day like with clay bricks. It is sufficient to lightly mist before using. The construction method is the same as that with clay bricks, thus masons don't need any additional training.

Cost: Compared to bricks produced from burnt-red clay, the same quantity of light-weight bricks made up of fly-ash will cover a larger area of construction field. Additionally, less manpower is needed and less mortar is consumed. About 30% less money is spent here than on clay bricks.

Applicability: These bricks are appropriate for multi-story building projects because of their light weight. A lighter load puts less strain on the structure. These bricks can be used for external walls in high-rise buildings or non-load bearing interior, load-bearing external walls for low-loaded buildings or in low- to mid-rise structures, and non-load-bearing walls in low- to mid-rise structures.

1.5.2 DISADVANTAGES OF FLY-ASH BRICKS

- Not all fly ash is appropriate for building; some that comes from power stations is often fine to use with concrete, but other fly ash might require beneficiation.
- It is important to utilise solely premium fly ash to avert detrimental consequences on the building.
- Improper construction results in lack of strength and unsuitability for use. Concrete is negatively impacted by bricks of poor quality. It may lead to increased permeability and structural deterioration.
- The smooth finish of concrete reduces bonding.
- Bricks can only be made in modular sizes and have size restrictions. There will be more breaks in the larger size.
- Since these bricks don't retain heat, they are only appropriate for subtropical or warm climates. But it is useless throughout the winter.

1.6 IDENTIFICATION OF BRICK QUALITY ON SITE

It's critical to pay attention to material quality when building a high-grade structure. The topic of how to identify high-quality bricks at construction sites has been discussed here.

- Bricks should have a uniform, vivid colour.
- Bricks should have sharp edges, smooth surfaces, and a good burn.
- Bricks should be sound-proof and low thermal conductivity.
- When placed in fresh water, bricks should not absorb more than twenty percent of their own weight.
- When two bricks hit together, there should be ringing sound.
- Bricks should have a uniform, isotropic and homogeneous structure.
- When dropped from 1m height, the bricks shall not shatter.
- When a fingernail is used to make a scratch, the brick should not sustain any damage.
- After soaking brick in water for a whole day, there shouldn't be any white deposits on it.

1.7 DIFFERENT WASTE MATERIALS

Fly ash: As seen in figure 1.4a, fly ash is a trash that is produced in thermal power plants as a by-product of burning coal. The residue from burning coal in a thermal boiler is carried away by the smoke and ends up in chimney stacks. Coal based fly-ash is a fine-grained type, having good fineness property that is released into the flue-gas when pulverised coal is burned in a coal-fired boiler. A waste management plan results from the combustion of coal, which produces fly ash, a by-product that is used to generate power that is widely available worldwide. Therefore, fly ash-produced geo-polymer concrete is a great substitute for the plentiful fly ash by-product.

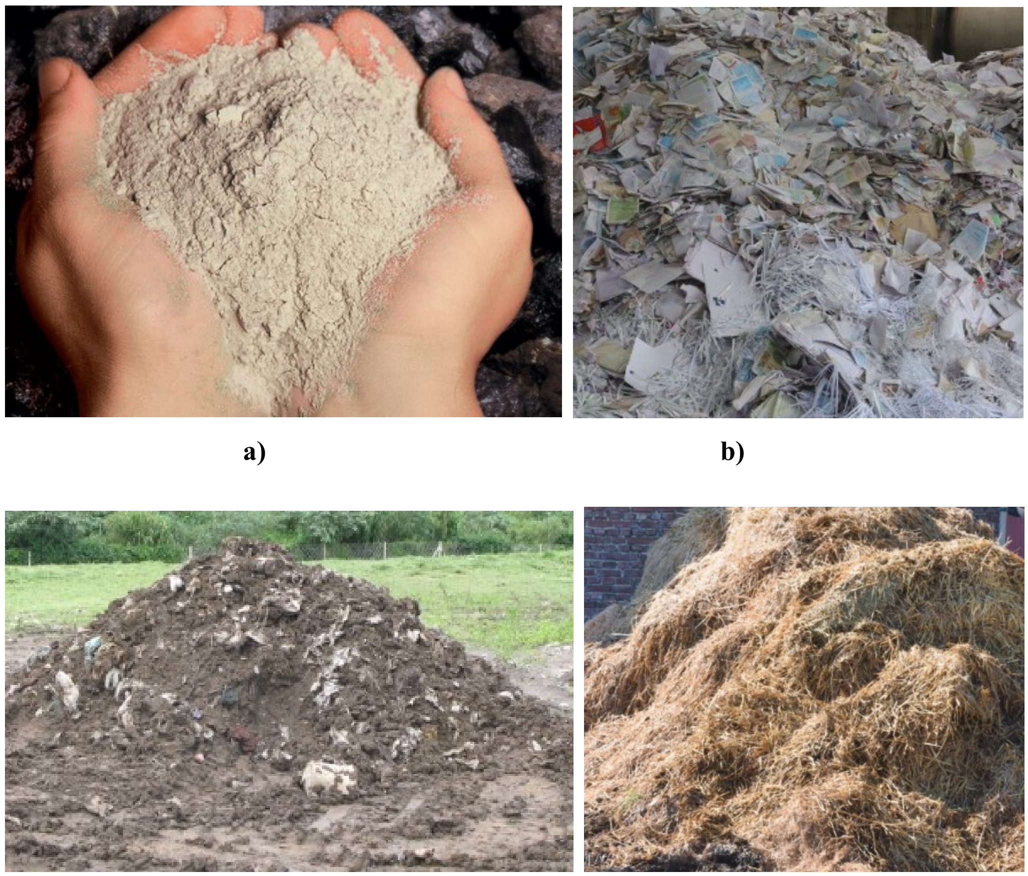
Because of its cementation qualities, fly ash, a pozzolanic substance, is utilised as a supplement in the manufacturing of Portland cement concrete. The performance or effectiveness of fly-ash is highly dependent on its different properties such as mineralogical and physical, even chemical qualities. When compared to concrete of the same workability using OPC-cement, the use of fly ash with a high level of the fineness and low carbon content diminishes the amount of fresh water required for concrete, allowing for decreased water content production.

Paper waste: Figure 1.4b illustrates how paper trash, which makes up around 26% of all garbage in landfills, is a significant contributor. Similarly, the amount of area required to contain trash must grow as its volume does. Furthermore, a lot of paper waste is burned, which pollutes the air and may harm the ecosystem due to certain substances in these products. Roughly 26% of solid municipal waste in landfill sites is composed of paper and paperboard waste, and pulp and paper factories are sources of pollution in the air, water, and land. The majority of industrial emissions into the air, water, and land come from the pulp and paper industry. As a result of the waste's widespread availability, numerous studies are being conducted to determine how to use it to lower paper pollution and make products more affordable.

Paper has substantial negative consequences on the environment, which has caused changes in corporate and personal behaviour as well as industry. Through the application of advances in technology such as the printing presses and highly automated wood harvesting, paper that can be recycled became a very inexpensive commodity, raising consumption and waste. Legislation from the government has grown and expanded in response to a growing array of worldwide problems with the environment, including as overflowing landfills, climate change, air and water pollution, and clear-cutting. The paper and pulp businesses are currently shifting or moving towards sustainability as it works to lessen its usage of water, greenhouse gas emissions, clear cutting, and fossil fuels, as well as to improve its impact on air pollution and local water supplies.

Sludge: Sludge is a kind of partially solid slurry or liquid generated through an array of industrial operations, comprising water treatment, wastewater treatment, and on-site sanitation systems (see figure 1.4c). It can be generated from sewage waste from wastewater-treatment approaches, faecal sludge from pit latrines and septic tank systems, or a settled suspension from conventional drinking water-treatment. In addition, the expression can be utilised to describe particles that have been withdrawn from suspension in a liquid; these soupy substances typically contain significant volumes of interstitial water (the liquid that resides between the solid particles). One form of particle found in sludge is dung from animals.

Sludge is a term used for the solids produced by industrial-wastewater treatment facilities. This can be produced by physical-chemical or biological mechanisms. In the wastewater treatment activated sludge process, the terms "waste activated sludge" and "return activated sludge" are employed.



a) **b)**

c) **d)**

Figure 1.4 a) Fly-Ash, b) Paper Waste, c) Sludge and d) Agro-Waste

Agro-waste: Unsalable or unwanted products produced or grown only from agricultural land or such operations directly or indirectly related to the crops and their growth or the breeding of animals for the main primary purpose of making a more profit or for a living are referred to as agricultural waste (figure 1.4d). Agricultural trash can take many forms, such as crop leftovers, weeds, leaf litter, sawdust, forest waste, and livestock manure, whereas agricultural waste includes vegetables, grape vines, etc. The primary source of agricultural solid wastes is farming activity. It does not, however, stop with production; it also includes food chain-related even other farming related operations.

The enormous volume of leftovers was created annually by industries centred around agriculture. Without following the correct disposal procedures, these residues could be released into the environment, posing a risk to human and animal health as well as environmental contamination. The majority of agro-industrial wastes are underutilised and untreated, therefore in most cases; they are disposed of by burning, dumping, or haphazard land filling. These untreated wastes increase the amount of greenhouse gases, which leads to various climate change issues.

Rubber waste: As environmental concerns have grown, experts have recently turned their attention to the applications of recycled products. Waste rubber, as seen in figure 1.5 a), is one of the recycled waste materials that is employed in a variety of fields, including energy sources, polymer composites, civil engineering, and tyre manufacturing. In order to process the rubber for recycling, it must be frozen. Remember that although though this method is less popular, it is still just as successful as de-vulcanization. This method uses liquid nitrogen to freeze the rubber. After that, it is ground into granules in mills during processing. Facilities that produce rubber tyres have been recognised by the EPA as significant emitters of hazardous air pollutants (HAPs). Although most discarded tyres are still recycled into fuel made from tyres, the trend is moving towards ground rubber and related goods. Asphalt, playground mulch, sports surfaces, and other moulded rubber products are the most popular applications. Today, there are billions of tyres in illegal dumps and landfills all over the world, posing a health danger due to mosquito breeding in trapped water and releasing harmful chemicals into the atmosphere.

Over the past 25 years, there have been significant developments in the global recycling industry's history. In the past, there was no concern about environmental issues because producing synthetic rubber was inexpensive due to low oil prices. The price of rubber has increased dramatically due to the record-high cost of oil, a major component of tyres. Environmental concerns have risen to the top of the political agenda globally, driven by abundant and compelling evidence of global climate change. Finding a practical method for recycling and reusing waste rubber, especially tyres, is urgently needed today. In actuality, the nations of Europe and numerous US jurisdictions have outlawed the disposal of tyres in landfills. It has frequently been discovered that wasting natural resources makes financial sense in the short term, but there are frequently long-term risks involved with this strategy.


a) b)


c) d)

Figure 1.5 Different Waste Materials a) Rubber, b) Plastic, c) Glass, and d) Iron

Plastic waste: The build-up of plastic items (plastic bottles and much more) in the Earth's environment that negatively impacts humans, wildlife, and wildlife habitat is known as plastic trash, or plastic pollution (figure 1.5 b). Pollution from plastic has the potential to alter natural processes and habitats, rendering ecosystems less adaptable to climate change. This has a direct impact on food production, societal well-being, and even the majority of people's livelihoods. Many initiatives have been launched to use plastic trash in various ways, particularly in the production of building materials like concrete, bricks, etc., as incorporating plastic waste into these products serves two purposes: it reduces pollution. It minimises the quantity of plastic trash that ends up in litter or landfills and, secondly, the amount of mined materials used in building, which helps to mitigate the damaging effects of the construction sector on the environment.

The energy efficiency of buildings is increased by the utilisation of plastic wastes to produce insulation materials, which also lowers the cost of building maintenance. Because of plastic's strong resistance, rust cannot form on it and cannot leak into the ground or water supplies. When employing parts underground or for water transportation, this is a huge plus. For instance, the packaging and textile sectors account for half of the world's plastic use and about 65 percent of its plastic garbage. In contrast, the building and construction sector produces only 4% of the plastic garbage produced worldwide and 10% of all plastics worldwide. To put it briefly, plastic waste management is the process of precisely and efficiently transforming plastic trash into new and improved, cost-effective, and environmentally beneficial products.

Glass waste: Glass is present in municipal solid trash (as illustrated in figure 1.5c), mostly in the form of bottles for food, cosmetics, and other products, as well as bottles of wine and liquor, beer, and soft drinks. Glass is now utilised in the construction industry for a variety of purposes, including structural support, external glazing, cladding, and the creation of delicate-looking fenestrations on facades in addition to traditional windows.

Glass has mechanical qualities similar to some other types of fine aggregate and resembles natural sand when crushed as per requirement and screened to pass through a sieve of 5mm. Therefore, careful thought is paid to using waste glass aggregate as a feedstock in place of construction aggregates. Glass debris can serve as a good replacement for fine aggregates in a variety of combinations, including concrete, because it is firstly environmentally benign, secondly strengthens and extends the mixture, and thirdly lowers the project's overall cost.

Iron waste: Iron and steel scrap, as illustrated in figure 1.5d, is a recyclable material that is left over after the production of iron and steel goods, the fabrication of ferrous materials, or the end of the life of the ferrous products. It is also referred to as "ferrous metal scrap." The waste products produced by the steel industry, such as blast oxygen furnace slag, mill scale, red dust, and iron ore fines, can be effectively substituted for fine aggregates in various mixes to create new composite materials with improved and novel features.

1.8 ORGANISATION OF THE THESIS

This thesis has been arranged in seven chapters, and a crisp description of each and every chapter is as below:

1.8.1 CHAPTER 1 INTRODUCTION

This chapter of this contribution begins by highlighting the significances and necessity of the development of sustainable and eco-friendly products in the construction sector. The role of fly ash and other substances in brick manufacturing is underscored. The scenario of solid waste generation is discussed. The discussion on the different waste materials that can be useful and used in the different construction materials are discussed thoroughly with their respective issues to understand the importance of their use. This chapter is the brief collection of the different construction materials as well, in which fly ash brick is defined with its key role as this contribution is fully about the light weight fly ash brick fabricated using waste materials. At the end of the chapter, a work plan of the current research program portrayed via a flow chart as well as shown in figure 4.1.

1.8.2 CHAPTER 2 REVIEW OF LITERATURE

This chapter presents and providing a brief review/study of literature related to various waste materials used in brick production; research findings on the different waste materials such as granite waste powder, fly ash and paper waste, agro-waste, rubber waste, plastic and glass waste, sludge etc are highlighted. Further, the studies on the different mechanical and durability performance of different types of bricks fabricated using different waste materials is also highlighted under different weather conditions and different loading conditions. Finally, the need for the present research is delineated.

1.8.3 CHAPTER 3 OBJECTIVES AND SCOPE

This chapter presents the detailed objectives of the whole thesis and the topic of the work with its importance and need. This describes all the keywords of the contribution with their significances, uses and also presents the scope of the work that how this study can be beneficial for the future researches in the same direction. Here, it is clearly define the type of waste materials used in the work. The overall research objectives with the scope as well as the research gap of the study are presented.

1.8.4 CHAPTER 4 MATERIALS, MIXES AND MAKING OF BRICKS

This chapter reviews the study on the properties of basic ingredients, various waste materials used for the production of waste – based, light weight and economical fly ash bricks. These fly-ash bricks are introduced in this contribution of non-modular size addition to powder formed agro-waste and rubber-waste with some replacement of sand in different percentages and prepared a total of 25 different mixes addition to control using cement as binding material, fly-ash as waste substitute and sand as fine aggregates as per Indian standards. These discussed powder formed waste materials like agro-waste and rubber-waste are replaced in the different percentages of sand. The detailed mix proportioning used for the study is tabulated. Also, the making process of waste - based bricks in an industrial plant is considered.

1.8.5 CHAPTER 5 PHYSICAL /MECHANICAL PROPERTIES OF LIGHT-WEIGHT BRICKS

This chapter outlines test methods of different physical/mechanical attributes of bricks consisting water absorption, weight density, dimension and tolerances, compressive strength. The mechanical strength test means compressive strength test by universal testing machine results of brick specimens made with sand replacement waste-materials like agro-waste and rubber waste at the age of 14 days are presented, and the significance is discussed. This chapter integuments comprehensively the detail description or exegesis of the experimental programme, which comprises the description and designation of specimens and their corresponding materials which used as well as the proposed preparation schemes by Agro-waste and Rubber waste, the experimental set-up, instrumentation and investigation, and also the test procedure from beginning to end. After preliminary finding on materials this chapter includes mix proportions of materials to build light eight bricks as per literature available on the same which helped to find standard proportion of materials by weight or by volume but in this investigation all materials quantities taken by as weight with standard water ratio throughout the project work. From the results, the optimum replacement levels of various waste materials reported. The physical and mechanical attributed are summarised to identify optimum brick mix is presented.

1.8.6 CHAPTER 6 DURABILITY OF BRICKS AND COST ANALYSIS

This chapter affords the test methods and results of durability characteristics of various wastes - based bricks made by fly ash with optimized percentage of replacement of sand with waste materials which are agro-waste and rubber waste. The durability of different waste - based bricks studied using Initial Surface Absorption Test (ISAT), Acid Attack, Weather Resistant Test, Thawing and Freezing Test and RCPT (Rapid Chloride Penetration Test).

The summary of the durability-study for the optimum brick mixes is presented in detail. The efflorescence study for the optimum brick mixes is also discussed.

1.8.7 CHAPTER 7 CONCLUSIONS AND SUGGESTIONS FOR FUTURE STUDY

This chapter presents the essence of various conclusions derived from the current research study and the suggestions for future research.

CHAPTER-2 REVIEW OF LITERATURE

2.1 GENERAL

Brick is one of the ancient construction materials being in use and brick making is considered as the easiest construction activity due to the use of readily available raw material such as soil. The continuous production of bricks imposes a massive strain in natural resources and hence the brick making is open to possible innovations to produce cost-effective and technologically enhanced bricks. Utilization of various industrial by-products and municipal rejects in the construction products are the prevailing study worldwide with a motto of environmental protection and sustainable development.

This chapter focused on reviewing literature in the areas of various waste materials used and their effects in strength even performance as well under various loading conditions, physical and mechanical attributes in construction materials. The influence of fly ash and other waste materials in concrete and bricks, the impact on the usage of agro waste and crumb rubber waste as construction materials with the partial replacement of sand are discussed. Also, the literature pertaining to durability performance using different durability tests are reviewed. The summary of earlier research findings, along with needs for the present study, is presented. There are many studies on the aforementioned subjects that may be found in the literature; only those studies that address the topics' strength, durability, ductility, and energy absorption capacity are covered in this article.

Present part of this thesis presents a comprehensive up-to-date- literature review or prerequisite points allocated by previous researches in same direction on the upgrading of scarcity bricks, which vindicated to achieve aim of this study with advance composite materials. This chapter also presents performance as well as benefits and limitations of each preparation scheme developed by some previous investigations on light weight bricks

2.2 UTILIZATION OF WASTE IN CONSTRUCTION INDUSTRY

Numerous wastes are produced by humans and their activities. Man consumes a wide variety of substances at once. Building materials are the most heavy commodity consumed by humans, weighing roughly five tonnes per person annually—only surpassed by water, possibly. In developing nations such as India, building materials account for 70% of the whole cost of building a house. The reuse and recycling of waste materials generated by the construction-industry, reuse, re-cycling, and regeneration of the wastes that originate the constructive activity, is one of the areas' significant contributions to environmental preservation and sustainable development. This has lengthened the materials' life cycle, which lowers the quantity of waste dumped and natural resource extraction.

Weng *et al.* (2003) has presented suitable conditions for use of dried sludge as shown in figure 2.1 a), where, the clay substitutes to produce engineering quality of rectangular brick. The amount of sludge in the mixture and the fixing temperature are the two most significant variables impacting brick quality. Following the experimental investigation, it was suggested that 10% of the sludge should have an optimal moisture content of 24%, be created in moulded mixtures, and be fixed between 800 and 960 degrees Celsius in order to produce high-quality brick[100] .

a) **b)**

Figure 2.1 a) Dried Sludge Brick, b) Light Weight Concrete using Solid Waste

Teo *et al.* (2006) demonstrated the experimental results with discussion of an on-going research project to fabricate structural light-weight concrete using solid-waste as shown in figure 2.1 b), namely the oil-palm shell, as a coarse-aggregate. This research reports on the oil palm shell concrete's flexural behaviour, modulus of elasticity, bond strength, and compressive strength. Although oil palm shell concrete has a relatively low modulus of elasticity, full-scale beam testing revealed that the span deflection ratios ranged from 252 to 263, indicating that the deflection under the specified service load was acceptable. These ratios fall within the permitted bounds that the codes provide. The final experimental moment for the singly reinforced beams was found to be between 19% and 35% higher than the values expected[93] .

Luis *et al.* (2006) presented an experimental study designed to assess the repurposing of waste paper pulp (as illustrated in figure 2.2 a), which is produced during the production of paper, for non-structural elements as a composite material consisting of plaster and pulp. Based on their findings experimentally, they concluded that using waste paper-pulp in conjunction with plaster had no effect on the conduct of the hardened and fresh material; however, it is recommended that the paper pulp be dried before use in order to improve the material's mechanical and rheological properties. But in order to guarantee a homogenous combination, the paper pulp must be broken up or fragmented[55] .

Kaves *et al.* (2006) determined the potential of fine boron waste and clay from Kirkar, Turkey's concentrator facility as a fluxing agent for red mud brick manufacturing. Scale tests were conducted in order to produce bricks. Although the types and quantities of oxides in clay and fine wastes differ, their chemical compositions are comparable. They were put to red mud bricks in weight proportions of 5%, 10%, and 15%. High concentrations of Fe203, Al203, SiO2, and alkalies are found in those. Furthermore, the best mechanical properties were demonstrated by the samples made by adding 15% of the weight of clay and fine wastes to red mud bricks[50] .

Demir (2006) investigated the possibilities for using processed waste tea in clay brick, as seen in figure 2.2b. Investigations were conducted into how the inclusion of processed leftover tea material affected the briks' mechanical characteristics and longevity. Owing to the processed waste tea's organic composition, the clay body's capacity to bond and form pores was also studied. The experimental examination led to the conclusion that adding processed waste tea increased the amount of water needed for plasticity. It has a broad range of burning from the clay body during fixing, and it burns off easily. Following repairing, there was no evidence of ballooning or black coring. Based on test results, the brick can incorporate up to 5% of processed waste tea ingredients. 9000 C was found to be the most economical fire temperature and the production temperature[45] .

a) b)

Figure 2.2 a) Paper Pulp Waste, b) Waste Tea

Tung and Hasanan (2006) studied the possibility of producing concrete paving blocks partially with crumb rubber in place of coarse sand. Three sizes of crumb rubber particles (1-3 mm, 3-5 mm, and a combination of the two) were tested in the lab to compare and investigate their effects. The size and amount of crumb rubber in a concrete paring block affected the compressive strength in diverse ways, according to test results. The mixed crumb rubber of 1–5 mm outperformed the others in terms of compressive strength on the 28th day. Additionally, the test findings demonstrated that when the rubber percentage increased from 0% to 30%, where the dry and compressive densities were found to be systematically decreasing. The performance of crumb rubber concrete paving blocks is greatly enhanced by the concrete paving block with rubber details, which also appears to offer higher skid resistance and rubber bonding properties[96] .

Nuno *et al.* (2007) developed a technique (shown in figure 2.3 a) for assessing the mechanical behaviour of concrete mixtures incorporating stone slurry. The findings demonstrated that adding stone slurry in place of 5% of the sand content increased the material's modulus of elasticity, splitting tensile strength, and compressive strength. They came to the conclusion that natural stone slurry may be employed as fine-aggregate or micro-filler in mixtures of concrete, improving the mechanical qualities of the concrete, and that it could be eaten by a variety of industrial processes as by-products[62] .

Turgut and Murat (2007) investigated the mechanical and physical characteristics of brick samples including waste wood sawdust (as seen in figure 2.3b) and waste limestone dust. They looked at the impact of replacing 10% to 30% of the wood sawdust waste with other materials. Even beyond the failure loads, the waste matrix made of limestone dust did not show an abrupt, brittle fracture. This suggests a high energy absorption capacity because it requires less labour. Compared to traditional concrete bricks, the combination yields a composite that is roughly 65% lighter. Concrete meets or exceeds the specifications outlined in BS:6073 for a structural construction material. Concrete obtained 7.2 MPa compressive and 3.08 MPa flexural strength values with 30% replacement level of wood sawdust waste[97] .

a) b)

Figure 2.3 a) Stone Waste Slurry, b) Wood Saw Dust Waste Brick

2.3 FLY ASH: AN OVERVIEW

Sinsiri *et al.* (2013) studied FA is an industrial waste that is produced when coal is burned to provide energy and is recognised as a pollutant to the environment. When coal heats up inside a boiler's grate, the carbon and volatile components completely burn off. Nevertheless, some of the inorganic-impurities of earthly substances, like feldspar or sand, are togetherly bounded and released through flue-gases. Fly-ash, which is tiny, spherical particles, is created when such kind of fused-materials are purely permitted to solidify. These FA particles are microscopic spheres encased in plerospheres, which are large spheres. Cenospheres are another name for hollow spheres. Because of the connection that takes place while the suspension of the boiler's or chimneys released flue gases, FA particles have a spherical morphology. These tiny particles are mostly made up of iron, silicon, and aluminium oxides.

There are also trace amounts of Mo, B, Fe, Mn, Ze, and Cu in addition to a few elements including P, Mg, K, and Ca. The characteristics of FA fluctuate between sources, within the same source over time, and depending on the methods employed for processing, storing, and generating variations in load. There are other names for fly ash, including coal based ash, pulverised flue-ash, even pozzolona. Fly-ash is defined by its low-weight, spherical form, even silicate-glassy appearance, polymeric nature, alkaline nature, and refractory nature. It is also characterised by its grey colour. FA furthermore possesses pozzolanic properties[87] .

Kumar and Kumar (2014) disussed when there is moisture present, the FA transforms into a hard, cementitious substance similar to calcium silicate hydrate and calcium aluminate hydrate. Fly ash and Portland cement exhibit nearly identical hydration processes, leading to comparable characteristics. FA offers certain unique qualities that make it advantageous to employ in place of cement in concrete. Fly ash concrete exhibits a number of noteworthy qualities, including improved textural consistency and finer detail. Fly ash resembles volcanic ash, which was utilised about 2,300 years ago to make hydraulic cements[14] .

Mir (2015) talked about Pozzuoli, a small Italian village where these types of cement were made, is where the term "pozzolans" originated. When moisture is present, a pozzolan—a substance rich in silica and alumina—forms a hard, cement-like combination. High strength bricks, cement, and aggregates can be produced thanks to the properties ofpozzolans and the fly ash's ability to bind lime. Fly ash is best recognised for this since it is one of the good pozzolans throughout. Fly ash from volcanoes is useless now days since it can be readily obtained from power plants. These coal based plants grind it to powder form before burning. Large amounts of fine-residue can be generated by such power plants exhaust after coal is burned and used again. Despite seeming structurally identical, fly ash and Portland cement may be separated with an optical microscope[12] .

Harijono (2020) said fly ash particles are nearly spherical, they can freely travel through and mix with any combination. Excellent mechanical, physicochemical, and thermal stability characteristics of fly ash include its low density and high strength, minimal porosity and shrinkage, high surface hardness, and superior resistance to fire and chemicals. FA's unique properties make it suitable for a wide range of civil, mining, and metallurgical uses, including the building, transportation, and aerospace sectors. The physical and chemical composition of Indian FA varies greatly, primarily as a result of the effectiveness of the incineration or combustion chamber. India's thermal plants are all managed and operated by one single unit, i.e. NTCs. The inability to get coal of a sufficient quality, inadequate maintenance, and the failure to replace various combustor parts even after their optimal life has been reached are among the factors contributing to the low efficiency of incinerators[39] .

2.3.1 PHYSICAL PROPERTIES

Harijono (2020) studied the FA's carbon content material has an angular form. The discrepancy in particle size of silt and bituminous coal FA is not very significant. It is often less than 0.075mm. Fly ash's specific surface area ranges from 180 to 1000 m^2/kg, whereas its specific gravity falls between 1.8 and 3.2. These fly ash particles range in size from 0.01 to 1000 micrometres, with an average diameter of less than 10 micrometres. The shape of spherical, least bulk-density even specific-gravity as well significantly restrict the height at which fly ash can be stacked and the height at which ash dykes can be created to increase the ash ponds' storage capacity[39] .

Tripathy and Mukharjee (2017) discussed the Fly ashes can be categorised for different technical purposes based on a number of physical features. FA is made up of tiny, powdered particles that are mostly spherical and can be hollow or solid. The majority of these particles are glassy, or amorphous, while they may occasionally exhibit crystalline phases. Fly ash contains very little carbon and nitrogen because oxidation happens during the burning of coal.Fly ash's colour varies from grey to black because of the small amount of volatile unburned carbon that it contains[72] .

Wei *et al.* (2015) studied a blend of fly ash and slag has been used as source material. The activator solution is made of a mix of sodium hydroxide and sodium silicate solution. The fly ash was replaced by slag at a percentage of 0%, 20%, 40%, and 60%. The results indicated that the workability increases with the addition of fly ash. The increase in alkaline solution also increases the workability. There was a decrease in the setting time when the amount of alkaline solution was increased to 1.5 % from 0.5% and 1%. But the greater replacement by fly ash resulted in the decrease in compressive strength. Thus keeping the fly ash content at an optimum and increasing the alkaline content, one can produce a geopolymer having high workability as well as strength. A highest compressive strength of 93.06 Mpa was obtained by the authors[99] .

2.3.2 USES OF FLY ASH

Shenbaga and Gayathri (2014) said fly ash is used in many different industries. Three general categories can be used to group together the use of FA. Large amounts of FA are used in many different sectors that don't really matter financially. Common applications include the brick business, mine filling, ridge filling, surfacing, and reclamation of fallow land, among others. Many organisations have worked very hard to manufacture bricks utilising gypsum, clay, lime, and various types of resins. These binders are combined with FA in varying proportions, and the market offers a variety of products[80] .

Sahu *et al.* (2017) examined that FA bricks are more notable since they preserve the important top soil layer. In a similar vein, the depletion of river-sands used for mine stowing in underground collieries would force extensive usage of ash to fill in mine excavations. Prior to usage, the Leaching action with coal based fly-ash must essentially be studied, even it is frequently used in paints and enamels, as insulating blocks, as light-weight filler for pre-stressed buildings, as a stabiliser for cement, as a herbicide in agricultural science to eradicate undesired plants, and as wall slates and roofing tiles[56] .

Gavali *et al.* (2019) reviewed the physico- mechanical and durability properties of the brick depending on the different factors. Recommendations regarding the better application of waste materials as raw materials were discussed. The bricks should be compacted within the range because compaction eliminates fluids and modifies the brick characteristics. Previous studies indicate that optimal values for molarity, alkali modulus, liquid-binder ratio, and water glass-NaOH ratio (ranging from 5–15 M, 0.15– 0.9, 0.2–0.48, and 0.5–2.5 respectively) can achieve compressive strengths between 5– 60 N/mm². Despite significant research, the application of industrial wastes in 16 manufacturing alkali activated bricks remains limited. The review suggests recommendations for further research. Geopolymeric bricks are particularly advantageous due to their ability to incorporate high levels of waste materials, highlighting their potential as a sustainable alternative for masonry construction[30] .

Gao and Yu (2019) examined the reaction at early stage of hydration, characteristics of gel and carbon emission by using the binder made of Ground Granulated Blast Slag (GGBS) and flyash and light weight aggregates with eco-olivine-nano-silica activators to efficiently use activators and to know the behavior of light weight aggregates with pastes in alkali environment. Reduction in the activator content resulted in late reaction and bound water content, hydrotalcites and carbonates reduction. Compared to Sodium 18 silicate, eco-olivine-nano-silica activators reduces the carbon emission[29] .

Qian *et al.* (2020) have reported a comparison studies on geopolymer flyash mortars and conventional mortar. The porosity of flyash based geopolymer mortars was nearly 2.5 times that of control mortars. Mechanical properties were slightly reduced or almost similar to the reference mix[73] .

2.3.3 DISPOSAL OF FLY ASH - ENVIRONMENTAL CURSE

Sikka and Kansal (2014) concluded that the thermal power plants have produced a significant amount of fly ash, a solid waste. These wastes are frequently used in a variety of industries, including construction materials. In addition to meeting necessities, disposing of FA is a major issue that impedes the development of a country free of pollution. Therefore, there should be serious concern. Particles of fly ash can be found both wet and dry. When large amounts of ashes are disposed of, thousands of hectares of land are taken up and the top soil's fertility is destroyed. Managing FA particles in a dry environment is a difficult task. Given that the nature of these ashes is dispersive and extremely fine. FA's minuscule particles damage structural shells and have an impact on culture. Through several modes of pollution, such as soil, air, and water, it damages the ecosystem. Because FA is disposed of in an open atmosphere, prolonged air intake eventually leads to a variety of airborne infections. Before any treatment, FA disposal in the surrounding areas also degrades the biological characteristics of the soil and reduces crop output overall[83] .

2.3.4 REVIEWS ON FLY ASH BRICKS

Banu *et al.* (2013) studied bricks made of fly ash have significant advantages over bricks made of ordinary clay. In an effort to enhance functional qualities, fly ash-based geo polymers are the subject of intense worldwide study. This chapter summarises some of the most current research on fly ash-based geo-polymers, their application in brick production, and their mechanical characteristics. Fly-ash rectangular bricks have received an immense amount of attention and awareness in the past few years due to the necessity of discovering an environmentally friendly, extremely strong material that can largely replace the currently utilized clay bricks[16] .

Bolden *et al.* (2013) discussed the characteristics of clay and fly ash bricks and came to the conclusion that fly ash bricks' mechanical qualities were superior to those of regular load-bearing clay based bricks. Tensile strength was over three times that of regular clay bricks, and compressive strength was 24% higher than that of high-quality clay bricks. Compared to regular clay bricks, fly ash bricks have a binding strength that is 44% stronger. Fly ash bricks have a density that is 28% lower than regular clay bricks. There are significant cost reductions in terms of raw materials and transportation when the weight of the bricks is reduced[47] .

Dhoka (2013) said the fly ash brick creates a surface cleaner for berating because it can readily absorb mercury from ordinary air that comes into contact with it. Additionally, a process known as carbonation happens when fly ash absorbs carbon dioxide from the surrounding atmosphere. This results in carbon sequestration, which lowers the quantity of carbon in the atmosphere and lessens global warming[59] .

Pahroraji *et al.* (2013) described a thorough analysis of documented fly ash brick work. He looked at the stability, porosity, density, flexural strength, and water absorption test of these solid and hollow bricks. He saw that these blocks and bricks are strong enough to be used in the construction of affordable homes. Tests were carried out to evaluate the impacts of curing over time, as well as to ascertain the compressive strength and hardening effects. When compared to regular water-cured compacts, the compacts treated in hot water exhibit superior strength and hardening properties. These bricks and blocks gain strength at first more quickly and subsequently at a slower rate. The absorption of water and FA are directly correlated. Water absorption rises in tandem with FA concentration. Conversely, when the density of the FA compacts increases, water absorption decreases. These FA bricks and blocks have better resistance to a strong sulphate environment when the phosphor-gypsum content is appropriate[66] .

Sankh *et al.* (2014) defined the several brick-making processes and comprehends the rationale behind these autoclaved FA bricks' reinforcing properties. The production of calcium silicate hydrate and calcium aluminate silicate hydrate is the primary cause of the hardness of the FA bricks. The hydrothermal reaction occurs between water, silica, and alumina when the compacts are typically cured in a steam bath at temperatures between 11,000 and 18,000 degrees Celsius. The capacity of the fly ash bricks to harden is further improved by the presence of the tobermorite phase. The relationship between the permeability of fly ash bricks and the different chemical and mineralogical configurations of the fly ash particles. FA bricks are also dependent on the firing temperature, which produces a more vitrified dense structure and a remarkable shape and size shift[4] .

Evendi (2015) said when synthesising FA-built geopolymers, water content has proven to be a crucial element in achieving improved mechanical strength.Water is important for suspension, poly condensation, and the many geo polymerization hardening junctures. The compressive strengths during the development of geopolymers are adversely affected by the presence of NaOH. Reduced compressive strength is the outcome of using geopolymers with varying NaOH concentration (aqueous phase) during synthesis. The obtained compressive strength of the geopolymers was significantly impacted by the concentration of sodium silicate (Na2SiO3) solution. The strength of the materials that are generated is increased by the regulation of main silicate classes and solvable silicate gathering in a geopolymeric system by Na2SiO3 solution[25] .

Kaur (2016) described the longevity of the FA, phosphor gypsum, and lime-based binder, as well as how well they work in water and how quickly they age. Compared to cementing binder cured at 27°C, binder cured at 50°C exhibits less porosity and better water resistance. With temperature increases and in cycles of alternate moist and dried conditions, the 50°C-cured binder shows minimal loss of mass and strength. When the temperature rises from 27°C to 50°C and when the heating and freezing sets are changed, the 50°C treated binder shows no decrease in strength and mass from the unadulterated standards. Thus, these are perfect for creating panels, slates, structural blocks, etc[49] .

Philip *et al.* (2019) investigated the geopolymer bricks made of alkali activated flyash, foundary sand and bentonite as additives for improving its properties.

Geopolymer bricks were tested for basic characteristics and found to have good performance compared to clay burnt bricks. The use of industrial wastes (flyash and foundary sand) found to reduce the production cost of the bricks[68] .

2.3.5 FLY ASH BRICKS

Abdurrohmansyah *et al.* (2015) concluded about rectangular bricks that these have been used as a main or key construction-building material. Aluminous-silicate and silica bricks have been used as refractory materials for a long time in various industrial applications because of their strong wear resistance, durability, and ability to support loads at high temperatures. China has partially banned the usage of traditional burnt bricks made from clay due to the scarcity of clay supplies. Finding raw materials other than clay for the manufacture of bricks is therefore the ultimate goal. Energy conservation is becoming a major environmental and financial concern. Approximately one-third of all energy use comes from buildings, where almost half of the energy is lost via the walls. Cutting the heat conductivity of brick or other wall materials is one of the most efficient ways to save energy. Bricks with a higher thermal conductivity are typically treated with inorganic products and organic leftovers including sawdust, polystyrene, paper sludge, coal, and coke. These leftovers are added to create pores in bricks to make them extremely porous. Several research have been done on fly ash-fired brick[1] .

Hwang and Huynh (2015) found that fly ash bricks exhibit superior mechanical and physicochemical qualities to conventional earthen bricks. These qualities include a low density structure with high strength, minimal porosity and shrinkage, exceptional thermal stability and durability, high surface hardness, and resistance to fire and chemicals[43] .

Shetkar *et al.* (2016) studied about light weight fly-ash bricks and resulted about such bricks that these are an environment friendly cost saving building or construction products. Fly ash bricks are long-lasting, use less mortar, absorb water at a rate of 8–18 percent, are economically stable, and emit no greenhouse gases. The longer the construction lasts, the more stable these bricks stay and the less impact they have from the environment. Compared to regular bricks with constant strength, FA bricks are three times more robust and resilient. The rapid acceleration in compact strength is caused by the presence of free lime. Because of this, these bricks are ideal for both load-bearing and non-load-bearing walls, both inside and outside. In order to ascertain the microstructure and compressive strength of the fractured samples, compacts containing fly ash, cold setting resin, and hardener in varying proportions are made and left in water at temperatures between 110^0C and 180^0C for 12-hours[13] .

Important characteristics of FA bricks include:

- Because of its great strength, virtually little damage can be noticed during usage or transit.
- Because bricks are all the same size, less mortar is needed for joints and plaster, almost fifty percent less.
- Because of its limited water penetration, bricks allow for a significant reduction in the seepage of water.
- Unlike bricks created from traditional clay, FA bricks don't need to be soaked in water for a full day before usage. A light misting of water will do the trick.
- There's no need to plaster[13] .

Gavali and Ralegaonkar (2020) developed bricks using co-fired blended ash (CBA) comprising 80% ash and 20 % rice husk as the base material, with stone dust (SD) as a filler. They studied the physical, chemical, mineralogical, and thermal stability properties. To determine the optimum mix design, tests were conducted by varying the sodium hydroxide concentration from 6 M to 10 M, with sodium silicate and sodium hydroxide ratios of 1:1, 1.5:1, and 2:1 for mix proportions of CBA : SD at 1:1, 2:1, and 3:1. With a fixed alkali activator concentration of 35 %, they found that 8 M sodium hydroxide with a sodium silicate and sodium hydroxide ratio of 1:1 for all three CBA : SD mixes was effective. Bricks of size 230x100x80mm were manufactured with the optimum mix and tested for various properties. The analysis revealed that the 2:1 CBA : SD ratio bricks exhibited higher efficiency. Increasing ash content led to reduced density and compressive strength but increased water absorption. Masonry strength, bond strength, durability, and thermal properties of the bricks proved to be a better option compared to conventional flyash bricks[31] .

Reema *et al.* (2020) worked on geopolymer flyash bricks with the percentage variation of flyash with alccofine. The mix of flyash, alccofine and fine aggregates are activated through sodium hydroxide ad sodium silicate. Compressive strength, water absorption and density of bricks are tested and the optimum properties is achieved by replacing 30% of Flyash with alccofine[75] .

2.4 USE OF FLY ASH AND OTHER VARIOUS WASTES IN BRICK PRODUCTION

Bhanumathidas and Kalidas (2003) stated that a 25% decrease in plant costs could be achieved by reducing energy consumption from 250 kcal/kg to 75 kcal/kg with the use of fly ash, lime, and gypsum technology without autoclaving[18] .

Tayfun and Tannverdi (2007) used fly ash, sand, and lime binder to create bricks that were steam-autoclaved. The best mix combinations were observed to be fly ash, lime, and sand at 68%, 12%, and 20%, respectively. The authors claimed that because fly ash contains significant amounts of SiO_2 and Al_2O_3, the C–S–H and C–A–S–H phases are primarily responsible for the hardening of fly ash/lime composites[92] .

Liu *et al.* (2009) investigated the environmental characteristics of fly-ash bricks and found that they passed the Environmental Production Agency's (EPA) recommended Toxicity Characteristic Leaching Procedure (TCLP) test by a wide margin. Additionally, it has the ability to sequester carbon by absorbing carbon dioxide from the atmosphere. As a result, it lowers atmospheric CO_2, which aids in slowing down global warming[41] .

Akhtar *et al.* (2011) came to the conclusion that the type of coal utilised should affect the fly-ash's uniformity coefficient and coefficient of curvature based on their experimental findings. Fly-ash's cementitious qualities are enhanced when lime is added, and it was discovered that the optimal moisture level and maximum dry density were reached at 1.5% of lime[3] .

Faria *et al.* (2012) conducted research on the consequences of using discarded sugarcane bagasse-ash as a raw material manufacturing clay bricks up to a 20% replacement level. The best replacement amount, according to the results, was 10%; more substitution increased water absorption and lowered compressive strength[27] .

Alaa *et al.* (2013) created bricks by substituting fine aggregate with billet scale debris, which was acquired from the steel processing processes. According to reports, bricks' allowable UPV values ranged from 1.453 to 2.758 km/s. The results of the UPV test in cement and clay brick were 1.501 km/s and 0.793 km/s, respectively[5] .

Zhang (2013) reported that the processes of fire, cementing, and geo-polymerization are the headings under which the ways of making bricks fall. It was stated that more research and development would be required to produce bricks from garbage[103] .

Vijayalakshmi *et al.* (2013) determined the best replacement options for the non-biodegradable granite fine powder wastes in the concrete by interpreting the implications of their inclusion. Granite wastes were added in increments of 5%, ranging from 0% to 25%, a greater increase in strength throughout the early ages as a result of the solid granite waste matrix. According to the study, 15% is the ideal amount of river sand to replace granite waste in concrete. The authors came to the conclusion that when the percentage addition was raised, the rough and angular texture of the granite waste affected the workability rate because of its large surface area[98] .

Ramos *et al.* (2013) examined the strength and durability impacts of using granitic quarry sludge waste in mortar in place of some cement. The findings show that when granite wastes are sufficiently finely ground, a very dense matrix is created and the expansion of the alkali silica reaction is decreased. Granite waste increases resistance to chloride attack by 70%[74] .

Bernardi *et al.* (2014) looked into the creation of "bio-bricks," or bricks made of sandstone that has been biologically bonded. As per the researchers, while in the cementation procedure, sand is combined with nutrients and bacteria, which ultimately results in calcite precipitation, which binds/ties the fragments collectively to produce sandstone. Such bricks could have strengths ranging from 1-2 MPa, according to the results[17] .

Jani and Hogland (2014) stated that the alkali-silica reaction between the leftover glass and cement prevented waste glass from being used as fine and coarse material in concrete. The pozzolanic characteristics of waste glass were mostly determined by the size of the particles[46] .

Ghannam *et al.* (2015) replaced the river sand with amounts of granite and iron powders of 5%, 10%, 15%, and 20% to observe how the concrete sample behaved. The study found that adding granite powder to 10% of the weight of sand improves both the compressive and flexural strength more than other mix ratios. Because granite powder has finer particles than sand, it has a higher surface area and increases the strength of concrete[33] .

Sivapulliah and Moghal (2015) performed and investigated that as the coal based fly-ash amount climbed, so did the brick's strength and UPV values. According to reports, fly-ash is a liquid (H_2O) absorbent material that boosts the hardened matrix's ability to absorb water. The range of acceptable starting suction rate values recorded was 0.25 to 1.5 $kg/mm^2/min$[88] .

Omran and Hamou (2016) investigated on the mixed coloured glass as an alternate supplementary cementitious material in concrete. Authors reported that 20% replacement of glass provides 35% enhancement of tensile strength and 4% enhancement of flexural strength. Result revealed that the resistance to chloride ion penetration improved due to the use of glass powder[63] .

Aliabdo *et al.* (2016) investigated the utilisation of waste glass powder blended cement as concrete additives. The replacement of glass up to 15% improved the concrete properties and enhanced 16% of compressive strength[7] .

Singh *et al.* (2016a) investigated whether Granite Cutting Waste (GCW) might be used in high strength concrete in place of river sand. The blends that had the highest and lowest strengths were those that had 25% and 70% GCW. The authors found that, depending on the water-to-cement ratios, 25–40% GCW might be used in place of sand in concrete[84] .

Sadek *et al.* (2016) used mixed powder, waste granite powder, and marble powder as mineral additions in self-compacting concrete. He also carried out research to determine the ideal ratio of mineral additives to cement content in order to achieve increased compressive strength. Results show that self-compacting concrete can be successfully made from waste powders up to 50% of weight[78] .

Singh *et al.* (2016b & 2016c) suggested that roughly 30% of the fine-aggregate should be replaced with the waste from granite cuttings. It has been established that using granite wastes to replace 25% of the fine aggregate in concrete improves its durability. The authors proved that a rise in the rate of substitution of granite dust led to an increase in sulphate attack. It was suggested that granite dust be treated since the authors hypothesised that a reactive ingredient in the dust would affect its durability. Additionally, the authors noted that when granite dust is used in place of natural sand in a given percentage, sorptivity and water absorption often decrease[85] [86] .

Lokeshwari and Jagdish (2016) used the building components-adobe blocks, pressed soil blocks, and concrete cubes in three distinct methods to study the granite wastes. The authors came to the conclusion that because the waste granite particle sizes were so small, they filled the block pores and provided pore refinement, which increased the compressive strength[53] .

Eliche *et al.* (2017) assessed how biomass combustion ash, such as wood and rice husk ash, affected the sustainability of clay matrix bricks. Different percentages (10–30%) of clay were replaced in the brick-making process with either wood ash or rice husk ash replacer. The bricks that met the required standard strength for clay masonry units have 10% rice husk ash and 30% wood ash[23] .

Goel and Kalamdhad (2017) revealed the results of using 520% degraded municipal solid waste (MSW) as a primary component in the burnt brick production process. Separate batches of laterite and alluvial soil were combined with the components at firing temperatures of 850^0 and 900^0 C, respectively. According to the investigations, the recommended optimum dosage is of 20% MSW[35] .

Espuelas *et al.* (2017) looked at the impacts of using industrial rejects high in magnesium oxide (MgO) as the binding ingredient for making non-fired clay bricks. Comparing the mechanical and durability qualities of the MgO-incorporated mixtures to those of the lime binder revealed similarities[24] .

Medina *et al.* (2017) suggested that granite quarry waste could be used as an environmentally friendly additional cementitious material in the future by using granite sludge to create new blended cement in place of 10% and 20% clinker. The hydroxide ion (OH-) assault, which breaks the Si-O and Al-O bonds in the granite sludge, is favoured by the pozzolanic reaction process, according to the 265 days' worth of SEM microscopy data. Additionally, it initiates the process by which calcium cations and silicon and aluminium anions combine to produce the C-S-H gels that cling to waste particle surfaces[57] .

Gao *et al.* (2017) evaluated the viability of utilising two solid wastes, such as fine granite powder from aggregate manufacturing and bottom ash from municipal solid waste incineration. The findings showed that a compressive strength of roughly 20–70 MPa can be achieved by combining granite powder up to 20% and bottom ash up to 50%. The leaching investigation verified that bottom ash and granite powder were used in accordance with Dutch laws[28] .

Sharma *et al.* (2017) stated that although it lowers the compressive and flexural strength, the addition of polished granite waste enhanced the durability attributes including water absorption, abrasion resistance, and water permeability. For pavements and non-structural uses, concrete with up to 20% natural coarse aggregate and up to 20% polished granite waste can be ideal. Replacement of 20% to 40% could also be suggested[79] .

Hongjian & Tan (2017) looked into replacing up to 60% of the glass powder in concrete with high-volume glass powder. The results showed that pozzolanic reactions were noticeable when glass powder was replaced up to 30%; however, at higher replacement levels, the performance was decreased. According to reports, during micro-structural observations, the interfacial transition zone was denser and more compact[22] .

Islam *et al.* (2017) made it clear that silica makes up the majority of the glass. Secondary calcium silicate hydrates (C-S-H) are formed by pozzolanic reactions if the waste glass was pulverised to micron size particles. The amount of waste glass injected ranged from 0 to 25%, maintaining constant water to binder (cement glass) ratio throughout all substitution levels. The findings showed that at 90 days of age, a

20% glass replacement level is the ideal threshold. According to a survey, adding glass could result in a 14% decrease in cement costs[77] .

Omran *et al.* (2017) emphasised that the primary function of the glass powder in concrete was to improve the microstructure of the material (densify), which allowed for a notable reduction in the pore system and produced improved durability attributes as the concrete aged. Over time, the glass powder combinations demonstrated improved resistance to the entry of chloride ions[64] .

Li *et al.* (2018) used various granite dust volumes and W/C ratios to examine the impact of using granite dust as a paste substitute on the durability of mortar. The authors reported that the very fine granite dust served as nuclei for the C-S-H precipitation, increasing the mortar's degree of hydration and improving its microstructure[54] .

Mashaly *et al.* (2018) concluded that the addition of granite sludge improved apparent porosity and water absorption. There were reports of improved resistance to sulphate attack, absorption, and freeze and thaw at the 20% cement substitution level with granite sludge[2] .

Munir *et al.* (2018) investigated the influence of waste marble sludge-based fired clay bricks. Authors concluded that up to 15% incorporation of waste marble powder satisfied the minimum compressive strength requirements[61] .

Murmu and Patel (2018) went over the several brick-making techniques, including moulding, pressing, fire, autoclaving, cementing, and geo-polymerization. It was made very clear that most research done on making bricks out of waste materials relies on firing to increase the bricks' strength. The energy-intensive process of burning bricks releases glasshouse gases (GHG) into the atmosphere[10] .

Ez-zaki *et al.* (2018) experimented with substituting sand with glass powder and mussel shell powder in amounts ranging from 20 to 60 percent by weight. The outcome showed that adding more glass powder-40% more than before-improves the mortar's mechanical strength and increases its resistance to chloride[26] .

Rodier and Savastano (2018) used glass waste leftover to replace up to 50% of the cement by weight in cement paste while applying fibre cement composites. At the age of 28 days, the 10% replacement of glass powder residue increased the compressive strength by 11%. It was also observed that the durability qualities are improved and sorptivity is decreased at the same replacement level[76] .

Harshini *et al.* (2019) studied the effect of silica fume (5 kg and 10 kg), plastic wastes (10 kg, 20 kg and 30 kg), BASF 1162 (0.12, 0.18, 0.68ml), Conplast SD110 and hot water on the bricks made of flyash, eco sand and cement mixture. Thus 10 kg of silica fume when added with the mixture shows enhanced properties of compressive strength, water absorption and efflorescence was nil[40] .

Hossiney *et al.* (2020) investigated the influence of Recycled Asphalt Pavement (RAP) aggregates on alkali activated paver blocks. Physical properties were investigated and results shows that workability reduces while unit weight, compressive strength and abrasion resistance of the paver block increased. Water absorption reduces with increase in RAP content. Cost of manufacturing is also reduced. Thus it could be used for pedestrian paths[42] .

Shilar *et al.* (2023) aim to create eco-friendly, high-quality geopolymer bricks for construction. The study explores using granite waste powder and iron chips to enhance sustainability and structural traits. A sodium hydroxide solution activates the bricks, tested for strength and absorption at 7 and 28 days. Findings reveal FG5 mix with 20% additives as optimal, boasting 10.1 MPa strength and 16.8 % absorption. Different mix ratios impact compressive stress. Scanning Electron Microscopy reveals surface features, while X-Ray Diffraction confirms the process of geopolymerization. Geopolymer bricks outperform burnt clay and flyash bricks structurally[81] .

Gonçalves and Balestra (2023) explores the manufacturing of modular bricks through alkali activation of clay soil, metakaolin (MK), sand or blast furnace slag (BFS) as precursors, employing NaOH solution or compound activators. Water absorption, compressive strength, thermal curing effects and various analysis microstructural analysis were conducted, along with Life Cycle Analysis (LCA). BFS-based bricks performed 22 exceptionally well, showing superior water absorption (13.4 %) and compressive strength (3.6 MPa). Microstructural analysis confirmed key formations like Zeolite, Calcite, and Hydrated Calcium Silicate. These bricks emitted 35 % less CO2 in comparison with ceramic bricks. Bricks made with metakaolin or BFS and compound activators met usage standards, suggesting a sustainable alternative by using industrial waste in place of Portland cement[36] .

Morsy *et al.* (2023) explores the application of alkali-activated concrete (AAC) in manufacturing bricks by using by products from the iron industry, such as ground granulated blast furnace slag (GGBFS) and electric arc furnace slag (EAFS). AAC bricks were manufactured to mitigate environmental impact and reduce costs. Various parameters were investigated, including compaction pressure, binder content, cement replacement ratio, sodium silicate/sodium hydroxide mass ratio, sodium hydroxide molarity, and alkaline-to-binder ratio. Results indicated that AAC bricks exhibited good compressive strength (up to 92 MPa), reduced water absorption (up to 54 %), high density (over 2.8 t/m3), and slightly increased drying shrinkage (up to 0.002 mm) compared to ordinary bricks. Notably, no efflorescence or salt signs appeared on the AAC bricks[60] .

2.5 USE OF AGRO WASTE AND RUBBER WASTE

Shu and Huang (2014) stated that there is a 45% decrease in compressive strength and a 25% fall in split tensile strength when 15% rubber chips are added in place of coarse aggregate. According to the authors, there were two main causes of the strength loss: (a) The hydrophobic nature of untreated rubber and (b) the notable small modulus (stiffness) of rubber were the causes of the weak binding between rubber and mortar. Rubber particles behave like "holes" inside the concrete because rubber is much softer than the mortar and aggregates that surround them. The overall strength of the concrete samples (or structures) was greatly decreased as a result of these holes, which produce stress concentrations during loading[82] .

Gesoglu *et al.* (2014) stated that the use of tire chips and coarse crumb rubber increased the concrete's fracture energy, whereas the use of fine crumb rubber decreased it[32] .

Aliabdo *et al.* (2015) concluded that adding rubber particles to concrete increases its ability to block out sound by 69% when fine aggregate is replaced 100% of the time. The findings showed that as the amount of rubber increased, so did the amount of water absorbed[6] .

Thomas *et al.* (2015) reported that the weight intake of sulphate attacked rubber added specimens showed an increasing trend when the rubber content gets increased[94] .

Gupta *et al.* (2015) conducted the tests to measure the impact resistance and energy absorption capacity of concrete by partially replacing waste rubber fibers by 0% to 25% in multiples of 5% and partially replacing cement by silica fume. According to the study, scrap rubber fiber has the potential to be a sustainable material with enhanced energy absorption and impact resistance[38] .

Thomas *et al.* (2016) looked at the crumb rubber waste tire rubber that was substituted with fine aggregate in increments of 2.5% from 0-20 percent. According to test results, the depth of chloride penetration at the 2.5-7.5% replacement level was either the same or less than that of the concrete mix used in the control mix[95] .

Guo *et al.* (2017) underlined that the low stiffness and surface bonding of rubber with cement are the reasons why using surface coating techniques increases the strength of concrete. Rubber-cement bonding was primarily improved by using three coating procedures (coated with ordinary cement, blended cement plus sodium silicate, and blended cement with silica fume) and two surface treatment methods (NaOH and silane coupling agent)[37] .

Bisht and Ramana (2017) affirmed that 4% is the ideal amount of crumb rubber to replace fine aggregate with. The addition of 4% and 5.5% crumb rubber to concrete instead of fine particles causes a 3.79% and 17.8% reduction in compressive strength. The density of crumb rubber concrete decreased as the percentage of replacement level increased, according to the results[19] .

Sofi (2018) conducted a critical analysis of how discarded tire rubber affected the mechanical and long-term qualities of concrete. When chipped rubber was used to replace 5–10% of the aggregate, the modulus of elasticity decreased by 17–25%; when powdered rubber was used instead, the drop was 18–36%. The higher amount of rubber substitution in the concrete reduced its tensile strength[89] .

Dobrota and Dobrata (2019) proposed a new technology of manufacture of crumb rubber by engaging ultrasonic activation. The sustainable index was three times higher than other technologies proves that the proposed method was energetically viable. With this technology, it was achievable to reduce the rubber particle size of 100-150 µm[21] .

2.6 SUMMARY OF EARLIER STUDIES

The following is shown via reviews of the literature on earlier works:

i. Industrial and agricultural wastes can be utilized as by-products and specifically as fine aggregate to reduce the weight of bricks. They can also be used as micro filler in mixtures to improve the mechanical qualities of the mixtures.

ii. Natural wastes such as the composition of limestone dust, wood sawdust, coconut fiber, durian fiber, rice and wheat husk ash, and sawdust from trees make a brick that is significantly lighter than one made of regular concrete. Even after failing loads, it does not show an abrupt, brittle fracture, and by permitting labor costs, it shows a high energy absorption capacity. Additionally, its flexural and compressive strength values meet the specifications needed for a building material to be utilized in a structural application.

iii. Additionally, a large number of industrial wastes, such as fly ash, boron waste, and blast furnace slag, were the subject of the majority of the experiments when fine aggregates for bricks or concrete blocks were substituted. The mixing of fly ash with rubber waste and agro-waste was the subject of only a relatively small number of academic reviews.

iv. A few writers have attempted to examine the effects of rubber or agro-waste on the strength and other engineering features of building blocks or concrete in previous studies. There hasn't been any attempt to use the two main waste materials simultaneously.

v. Research on the effects of combining rubber and agricultural waste with fly ash bricks in place of some of the sand and on the different engineering properties is highly promising.

2.7 RESEARCH GAP

- **Material Optimization and Composition**: Limited research has explored the optimal ratio of agro and rubber waste in light weight brick production. A systematic study of varying proportions could help in identifying the best combination for achieving maximum strength.
- **Durability Analysis**: There is a research gap in assessing the durability of lightweight bricks, particularly their resistance to weathering, water absorption, freeze-thaw cycles, and chemical exposure, which is critical part for the practical applications, remains under-explored.
- **Cost and Economic Viability**: A detailed cost analysis comparing lightweight bricks from agro and rubber waste with conventional bricks is lacking, particularly in terms of production costs, material sourcing, and market feasibility for large-scale adoption.

CHAPTER-3 OBJECTIVES AND MOTIVATIONS

3.1 GENERAL

Brick has been used by humans for construction for thousands of years. Known to have existed since 7000 BC, bricks are among the oldest known building materials. The ruins at Harappa Buhen and Mohenjo-daro provide proof of this; however all of these brick kinds are too hefty at 3.2 kg, making the structures bulkier. Many of the previous researches have been done on bricks to make them light in weight but the major issue is reported every time that due to reduction in weight, strength or load carrying capacity also reduces. Secondly, non-degradable natural or manmade wastage is coming as front issue now days which affects the environment also badly. This contribution is presenting about light weight bricks made by some non-degradable waste materials such as Agro-waste and Rubber waste, which helps to reduce the weight of the brick as well as the wastage can be used for define purpose. The very important thing is this report contributing the work in which weight of the brick has been reduced without reducing the strength of the brick. The main motive of the study is to reduce the weight and make brick as light in weight without reducing its load carrying capacity by using Agro-waste and Rubber waste. This kind of light weight brick can be available and manufacture in very low cost as it is completely made up of waste materials which are available in abundance in free of cost.

3.2 NEED FOR THE PRESENT STUDY

The various difficulties faced by the construction sector namely, high carbon emissions, non-eco-friendly construction and unsustainable development can be solved only by the utilization of less energy-intensive materials and the change in the manufacturing process of construction materials. In this regard, brick production plays a significant role where modifications can be made in the production process and also reconstitute the ingredients so that it can be made sustainable. The literature review of previous investigations reveals the following:

- Predominantly, the conventional bricks utilizing clay as the primary raw material and the production process involves firing the bricks. Cement-based bricks and blocks are also in practice. As per the literature survey, both the ways of production of bricks encompass high embodied energy and leads to massive carbon emissions.

- Due to the deficiency of natural resources for the production of conventional bricks, extensive research is underway utilizing waste materials in the motto of protection of the environment and long-term sustainability.
- It is observed from the kinds of literature that numerous investigations were carried out to standardize the brick production using potential waste materials. However, the commercial production of waste - based bricks is very much limited and for the standardization of brick manufacturing using industrial and municipal waste materials, further research and development are required.
- Fly ash-based bricks are the effective substitute to the conventional fired clay bricks. However, to cater to the country's vast brick requirements, the availability of fly ash also a point of concern; hence the alternative to the fly ash as alternate supplementary cementitious material also to be researched.
- Fine aggregate is now the natural resource that is diminishing the fastest, hence research must be done to find the best ways to replace waste products in order to preserve these resources.
- From the literature, it is well aware that the powder formed agro-waste and rubber waste has the potential to use as supplementary cementitious materials. However, the effects of both waste materials were investigated in concrete products rather than the production of bricks. Also, the possibilities of such waste materials as natural sand partial replacement material were tried extensively in various concrete products including SCC and HPC etc. rather than brick. The works of literature available to understand the effects of rubberized aggregates in the manufacturing of bricks are scarce. Thus, in this study, an attempt has been made to study the effect of powder formed agro-waste and rubber waste with partial replacement of sand in light weight fly ash bricks towards the strength, durability, structural characteristics of waste - based fly ash bricks.

3.3 AIMS AND OBJECTIVES OF STUDY

- To evaluate the performance of light weight bricks using agro waste and rubber waste.
- To study the durability of light weight bricks made by optimized mix obtained.
- To compare the optimum light weight bricks with respect to other competent options.

3.4 SCOPE OF THIS WORK

The experimental results of this work will encourage further research in the different direction for long-term performance enhancement of light-weight brick made from waste material considering the following points:

- Utilizing agro-waste and rubber waste in brick production reduces pollution, prevents waste disposal, and supports circular economy practices by transforming discarded materials into valuable, sustainable construction resources.
- Over-extraction of sand is causing environmental degradation. Replacing sand with agro-waste and rubber waste can alleviate the pressure on natural sand resources, promoting ecological balance.
- The use of readily available waste materials can lower production costs compared to traditional bricks, offering a cost-effective alternative for builders, especially in regions with abundant agro-waste and rubber waste.
- With increasing demand for sustainable materials, these innovative bricks have strong potential in the growing eco-friendly construction market, offering a competitive advantage in the industry.
- The study includes accurate physical, mechanical, and durability testing of waste-based fly-ash bricks, providing valuable insights for future research and encouraging further exploration into their long-term performance and applications.
- Cost and weight analysis, compared to market bricks, highlights variations, emphasizing the lightweight, durable, and cost-effective benefits for construction.

CHAPTER-4 MATERIALS, MIXES AND MAKING OF BRICKS

4.1 GENERAL

This chapter integuments comprehensively the detail description or exegesis of the experimental programme, which comprises the description and designation of specimens and their corresponding materials which used as well as the proposed preparation schemes by Agro-waste and Rubber waste, the initial experimental set-up and pre-instrumentation and investigation, and also complete procedure mentioned from beginning to end in given flow chart as shown in figure 4.1.

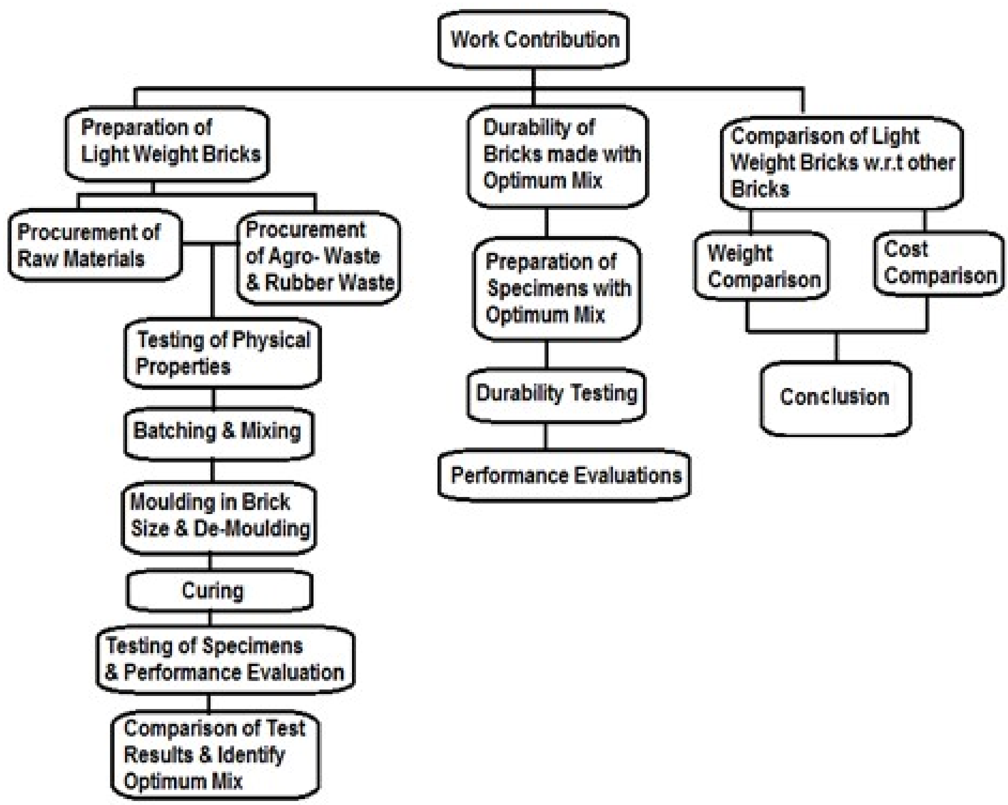


Figure 4.1 Flow Chart of Proposed Work

It also includes different attributes of materials such as binding material, Fly ash etc which found by preliminary laboratory tests such as Absorption test, soundness test, and Crushing strength test by universal testing machine, and many more, to find their behaviour w.r.t water, and also other type of testing on bricks such as efflorescence test etc comprised in this chapter. After preliminary finding on materials this chapter includes mix proportions of materials to build light eight bricks as per literature available on the same which helped to find standard proportion of materials by weight or by volume but in this investigation all materials quantities taken by as weight with standard water ratio throughout the project work. Next step is the casting of specimens which is completely depends on previous one which discussed above because through specimen design, can get actual quantity. After this soft work, many steps are there such as casting of specimens which includes process of making the specimens of required sizes, curing of specimens in dust free water for required time period so that samples can achieve maximum strength, testing on different specimens under monotonic load by universal testing machine to find their strength and other required properties are discussed in the next chapter.

However, the cautious selection of raw materials is very much critical to obtain the desired properties of the fly ash bricks. Uniform size, excellent mechanical and durable properties are essential to get good quality fly ash bricks.

The properties of various ingredients and waste materials used in this study are presented in this chapter. Also, different brick mix formulations adopted in the investigation and the making process of waste - based bricks in a factory - controlled environment are described in this chapter.

4.2 MATERIALS USED FOR THE STUDY

Many of materials which are binding material like Ordinary Portland Cement (OPC) of highest 53-grade, fly ash which is available in market as waste material of coal combustion at very low cost, Agro-waste and Rubber waste which are the type of non-degradable substances available in abundance at very low cost as these are the type of waste materials, are used in this experimental work to prepare light weight bricks, are as follows:

4.2.1 BASIC INGREDIENTS OF CONVENTIONAL FLY ASH BRICK PRODUCTION

The basic ingredients for manufacturing light weight fly-ash bricks are coal based waste fly ash, binding material means cement, fine aggregates means natural sand/stone dust and potable fresh water. Fly ash was collected from Guru Nanak Dev thermal power station, Bathinda, India which confirms to Bureau of Indian Standards means BIS:3812-2013 and ASTM C-618 class-F Pozzolan.


a) **b)**


c) **d)**

Figure 4.2 a) Cement as Binding Substitute, b) Fly ash, c) Natural Sand as Fine Aggregates, d) Fresh Water

Binding material or cement is used in present work of OPC 53-grade which is a great binder has excellent binding properties or in simple words it is a substance used in construction work which helps hardens and adheres to other materials and also binding them together. Before use of it in this work, it tested by preliminary tests, to determine important properties such as soundness, initial and final setting time, consistency etc. Which are as per Indian Standard 12269:1989.

Usage of natural sand or stone dust is optional in the fly ash brick production. In the present study, locally available natural sand was used. As per standards, sand which is used for concreting purpose is recommended for brick production. Potable drinking water was used for brick production and curing purpose. Figure 4.2 depicts an overview of the raw materials used for conventional fly ash brick production.

4.2.2 WASTE MATERIALS USED FOR THE WASTE-BASED BRICK PRODUCTION

Figure 4.3 illustrates a view of waste materials that are used as fine aggregates in fly ash bricks with some replacement in different percentages of natural sand. After detailed analysis of such different percentages, an optimized mixture is determined to make the fly ash brick more light in weight as well as considering water absorption properties and strength produced. These waste materials which are powder formed agro-waste and rubber waste as fine aggregates used with the appropriate proportions together in the mixture to get appropriate results in more accuracy.

Figure 4.3 Rubber Waste and Agro-Waste in Form of Fine Aggregates

4.3 PROPERTIES OF MATERIALS USED FOR THE STUDY

4.3.1 FLY-ASH

A finely divided pozzolanic material called fly ash interacts or communicates with calcium hydroxide, or $Ca(OH)_2$, at room temperature to create compounds with cementitious properties. The major or main source of strength for fly-ash bricks is produced by the interaction between the alumina-silicates in the fly-ash and calcium

ions when it is exposed to moisture or humidity. According to ASTM C 618 class-F pozzolan and BIS: 3812-2013 (Pulverized fuel ash-specification), the fly ash employed in this investigation was of the siliceous type.
Waste based on coal Fly-ash is a very fine gray dust that is mostly made up of glassy, spherical particles that are left over after burning coal in power plants. Because fly ash has pozzolanic properties, it combines with lime to form binding or cementitious compounds. It usually meets the criteria for being another cement-like material that is used in such an application and has a size of no more than 75-microns. Fly ash is utilized as an additional cement-like material or supplement while manufacturing cement concrete. Additional cementitious elements, when used in conjunction with binding substance, contribute to the properties of concrete that are hardened by both pozzolanic and hydraulic activity.

It was primarily made by burning bituminous coal and possesses pozzolanic qualities. Reactive calcium oxide makes up less than 10-12 percent of the bulk of this kind of fly ash. For effective brick manufacture, the National Thermal Power Corporation (NTPC) suggests employing dry fly ash from the first or second fields of electro-static precipitators. The fly ash sample from Class-F is displayed in figure 4.2b.

The fly ash's specific gravity and particle size meet the minimal requirements stated in BIS: 3812-2013, where specific gravity is the ratio of the weight in air of a given volume of a Material at a stated temperature to the weight in air of an equal volume of distilled water at a stated temperature. 50 g of sample of fly ash is taken in each 3 bottles and added with water; weight of water + bottle is taken. Then all the 3 bottles are subjected to sand bath, heating is done up to air bubbles are seen in the bottle. This is done to remove the entrapped air in the mixture; the bottle is kept for around 1 hour so that the temperature comes to 27° C. The test results came in terms of 3-different specific gravity subjected to three different samples, are 2.21, 2.30 and 2.24, respectively, and the average of these three values taken as final specific gravity for fly ash described in table 4.1.

Praburanganathan (2021) explained chemical composition of fly ash and its richness in silica and alumina which contains 58.92% and 36.52%, respectively[71] , and the rest composition is mentioned in the table 4.2.

Above mentioned tables validate the chemical properties of fly ash used in the current study with the stipulated specifications based on BIS and ASTM Standards. Fly ash fulfils the chemical specification criteria as per both the standards and well-suited for the production of bricks.

Table 4.1 Physical Properties of Fly-ash

Sr. No.	Different Properties	Values	Stipulated minimum limits as per IS 3812:2013
1.	Particle size	10 - 45 μm	45 μm
2.	Specific gravity	2.25	2-3

Table 4.2 Chemical Properties/Characteristics of Fly-ash

Sr. No.	Constituents	Chemical composition (%)
1.	SiO_2 (Silicon dioxide)	58.92
2.	Al_2O_3 (Aluminum Oxide)	36.52
3.	Fe_2O_3 (Iron Oxide)	2.3
4.	CaO (Calcium Oxide)	2.1
5.	SO_3 (Sulphur Trioxide)	0.5
6.	MgO (Magnesium Oxide)	0.89
7.	Na_2O (Sodium Oxide)	0.39

4.3.2 FINE AGGERGATES

Natural sand is the non-renewable and scarce material as on date. In general, for the production of bricks, naturally available river sand has been the choice, and it is evident, no controversy with this customized process. Aggregates are the most useful and common materials for worldwide construction which occupies most of the volume of building materials, and are a major component of composite material which deputizes as reinforcement and provide strength to composite material like to concrete, brick etc. The maximum strength of these composite materials is contingent upon the characteristics and behavior of the aggregates, including their form and the distribution of particle sizes within the wetting. In other words, aggregates play a vital role in giving concrete its strength. According to Indian Standard 2386:1963 as shown in table 4.3, a few preliminary tests were conducted to identify the many significant characteristics of aggregates. The results are displayed in figures 4.4. Less than 4.75 mm fine aggregates were used, meaning they could pass through a 4.75 mm sieve. It contributes to the production of uniformity and workability, fills up gaps in the concrete mixture, and keeps the mixture's strength intact.

Table 4.3 Different Properties of Fine-Aggregates

Property	Fine-Aggregates
Specific Gravity	2.63
Water Absorption	0.67
Fineness Modulus	3.42
Size of Aggregates (mm)	< 4.75
Bulking of Sand (%)	28
Density of Sand	1600 kg/m^3
Sieve-Analysis	Zone-III confirming to IS-383:1970

Figure 4.4 Fine Aggregates (< 4.75mm)

4.3.3 BINDING MATERIAL

Binding material or cement is used in present work of OPC 53-grade which is a great binder has excellent binding properties or in simple words it is a substance used in construction work which helps hardens and adheres to other materials and also binding them together. In fly-ash brick manufacturing process cement used to bind aggregates with all other waste materials together. When cement as binder is used with only fine-aggregate it produced mortar, or with sand and course-aggregates it produced concrete, but in this study, it used with fly ash, fine aggregates and some waste materials mentioned previously to prepare appropriate mix for the light weight brick. Before use of it in this work, it tested by preliminary tests as shown in figures 4.5 & 4.6, to determine important properties such as soundness, initial and final setting time, consistency etc. So, the different attributes of cement as per Indian Standard 12269:1989 are shown in table 4.4.

Table 4.4 Different Properties of Cement

Property	Average-value of OPC used in present investigation	Standard-value
Fineness	98.50	----
Soundness	2.9	<10
Consistency (%)	32	----
Specific Gravity	3.14	----
Initial-setting time (min.)	74	>30
Final-setting time (min.)	240	<600

Figure 4.5 Vicat Apparatus to find Consistency and Setting time of Cement

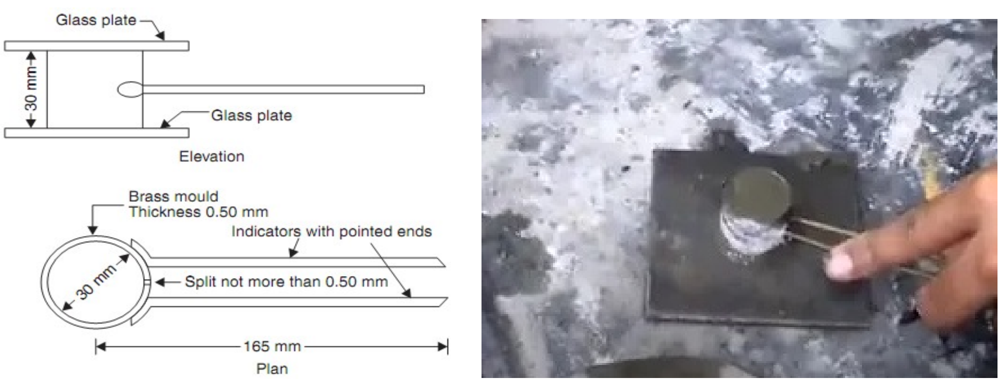


Figure 4.6 Le-Chatelier Apparatus to find Soundness of Cement

4.3.4 AGRO-WASTE

As depicted in figure 4.3, agricultural waste refers to undesired or unsalable materials resulting exclusively from agricultural activities associated with crop cultivation or animal husbandry with the ultimate goal of generating income. In this experimental project, rice husk is utilized as agro-waste to make lightweight bricks that will retain the brick's strength and can be used at a very low cost. These agro-waste are used as fine aggregates with some partial replacement of sand, so is tried to maintain the size of the particles and specific gravity near to the same with the natural sand, and the density of these agro-wastes is recorded as 643 kg/m^3 which is in between 450 - 700 kg/m^3 provided by the vendors. The crushed agro-waste used as fine aggregate replacement material in construction product has the size ranges from 0.075-4.75 mm. In the present study, the entire particles passed BIS sieve No.4 (4.75 mm), with the 20 mesh of size 0.864 mm - 1 mm was used. The specific gravity of agro-waste was 2.21 and fineness modulus was 2.75.

4.3.5 RUBBER WASTE

As seen in figure 4.3, waste rubber is one type of waste material that has been recycled and is used in a variety of fields, including energy sources, polymer composites, civil engineering, and tire manufacturing. In order to process the rubber for recycling, it must be frozen. Remember that although though this method is less popular, it is still just as successful as de-vulcanization. This method uses liquid nitrogen to freeze the rubber. After that, it is ground into granules in mills during processing. Trucks and, in the past, cars used to apply graphite powder or talcum between the tire and tube since the heat from rolling may cause the two to vulcanize otherwise. This frequently results in destructive tube removal, leaving parts of the tube lodged in the tire casing. One of the raw components for waterproof paint, waterproof sealing material, waterproof rolls, etc. is rubber powder. Rubber powder performs better when mixed with basic ingredients such as asphalt and resin. The rubber wastes are used as fine aggregates with some partial replacement of sand so is tried to maintain the size of the particles and specific gravity near to the same with the natural sand, and the density of it is recorded as 1080 kg/m^3. The crushed rubber used as fine aggregate replacement material in construction product has the size ranges from 0.075-4.75 mm. In the present study, all the rubber particles passed BIS sieve No.4 (4.75 mm), with the 20 mesh of size 0.864 mm - 1 mm was used for the study. Crushed rubber has a specific gravity of 1.09 and a fineness modulus of 2.9.

Every rubber tire is made of a mixture of rubber and fabric that is moulded to fit different car rim sizes. Chemicals are also added to rubber to extend its life and enhance its functionality. In order to improve their ability to stay on the metal rims, steel wires are also integrated into the tires, close to their inner edge. Because rubber tires are flexible, they may conform to small imperfections in the road's surface, increasing friction and improving traction. This enhances the vehicle's handling, stability, and braking performance. Rubber is not only very flexible but also quite durable; this is especially true when a tire has undergone the vulcanization process. Rubber tires are durable, able to maintain the air pressure required for efficient operation, and resistant to being punctured by items like jagged stones on the road.

4.4 BRICK MIX PROPORTIONS OF INGREDIENTS

Brick mix proportions were formulated as per National Thermal Power Corporation (NTPC) guidelines and based on the specifications reported in the available literature. As per NTPC, about 50 - 65% of fly ash, 20 - 30% of sand or stone dust, hydrated lime 8 - 12% and gypsum 3 - 5% or instead of lime and gypsum, cement can also be used with 8 – 15% as a raw material, and sufficient quantity of water to be added to make an appropriate mix. The minimum compressive strength stipulated in the BIS to qualify the bricks as a masonry unit is 3.5 - 9 N/mm^2 at the curing age of 14-days and 28 days. Numerous trials were conducted to fix a base brick mix which contains only the basic ingredients such as fly ash, cement and natural sand. With the targeted compressive strength mentioned in the code, trial specimens were cast with the varying the percentages of all the raw materials

The aim of the mix proportioning is to obtain a brick mix that fulfils the performance criteria at a lower possible cost by suitably selecting from the available constituents. Based on the targeted compressive strength, the base mix contains 60% of fly ash, 10% cement and 30% of natural sand were fixed for further investigations by incorporating various waste materials.

4.4.1 CALCULATION OF FINE AGGREGATES (INCLUDING REPLACEMENT)

Actual Weight of brick = 2.742 kg

Assumed weight = 2.900 kg (including wastage due to some reasons)

Percentage of sand used = 30% of total mix

So, Weight of sand (w) = 870 gm (without replacement)

Density of Sand = 1600 kg/m^3

Density of Rubber = 1080 kg/m^3

Density of Agro-waste = 450 - 700 kg/m^3

So, Recorded Density of Agrowaste = 643 kg/m^3

(Checked in the cube of 150mm, weight = 2.17 kg)

1. **When 20% Sand is used (means, w = 580 gm) with 10% replacement out of total 30%.**

   Weight of replacement = 870 – 580 = 290 gm

   Volume of replacement (290 gm sand) = 0.00018125 m^3 or 181.2 cm^3 or 181250 mm^3.

   Now, 5% replacement with AGW = 0.000090625 m^3 or 90.6 cm^3 or 90625 mm^3.

   So, weight of AGW = 58.27 gm

   Now, 5% replacement with RBW = 0.000090625 m^3 or 90.6 cm^3 or 90625 mm^3.

   So, weight of RBW = 97.875 gm

2. **When 19% Sand is used (means, w = 551 gm) with 11% replacement out of total 30%.**

   Weight of replacement = 870 – 551 = 319 gm

   Volume of replacement (319 gm sand) = 0.00019937 m^3 or 199.37 cm^3 or 199375 mm^3.

   a. 5% replacement with AGW = 0.000090625 m^3 or 90.6 cm^3 or 90625 mm^3.

   So, weight of AGW = 58.27 gm

   6% replacement with RBW = 0.00010875 m^3 or 108.7 cm^3 or 108750 mm^3.

   So, weight of RBW = 117.5 gm

   b. 6% replacement with AGW = 0.00010875 m^3 or 108.7 cm^3 or 108750 mm^3.

   So, weight of AGW = 69.93 gm

   5% replacement with RBW = 0.000090625 m^3 or 90.6 cm^3 or 90625 mm^3.

   So, weight of RBW = 97.875 gm

3. **When 18% Sand is used (means, w = 522 gm) with 12% replacement out of total 30%.**

Weight of replacement = 870 – 522 = 348 gm

Volume of replacement (348 gm sand) = 0.0002175 m^3 or 217.5 cm^3 or 217500 mm^3.

a. 5% replacement with AGW = 0.000090625 m^3 or 90.6 cm^3 or 90625 mm^3.

So, weight of AGW = 58.27 gm

7% replacement with RBW = 0.000126875 m^3 or 126.8 cm^3 or 126875 mm^3.

So, weight of RBW = 137.025 gm

b. 7% replacement with AGW = 0.000126875 m^3 or 126.8 cm^3 or 126875 mm^3.

So, weight of AGW = 81.5 gm

5% replacement with RBW = 0.000090625 m^3 or 90.6 cm^3 or 90625 mm^3.

So, weight of RBW = 97.875 gm

c. 6% replacement with AGW = 0.00010875 m^3 or 108.7 cm^3 or 108750 mm^3.

So, weight of AGW = 69.93 gm

6% replacement with RBW = 0.00010875 m^3 or 108.7 cm^3 or 108750 mm^3.

So, weight of RBW = 117.5 gm

4. **When 17% Sand is used (means, w = 493 gm) with 13% replacement out of total 30%.**

Weight of replacement = 870 – 493 = 377 gm

Volume of replacement (377 gm sand) = 0.000235625 m^3 or 235.6 cm^3 or 235625 mm^3.

a. 5% replacement with AGW = 0.000090625 m^3 or 90.6 cm^3 or 90625 mm^3.

So, weight of AGW = 58.27 gm

8% replacement with RBW = 0.000145 m^3 or 145 cm^3 or 145000 mm^3.

So, weight of RBW = 156.5 gm

b. 6% replacement with AGW = 0.00010875 m^3 or 108.7 cm^3 or 108750 mm^3.

So, weight of AGW = 69.93 gm

7% replacement with RBW = 0.000126875 m^3 or 126.8 cm^3 or 126875 mm^3.

So, weight of RBW = 137.025 gm

c. 7% replacement with AGW = 0.000126875 m^3 or 126.8 cm^3 or 126875 mm^3.

So, weight of AGW = 81.5 gm

6% replacement with RBW = 0.00010875 m^3 or 108.7 cm^3 or 108750 mm^3.

So, weight of RBW = 117.5 gm

d. 8% replacement with AGW = 0.000145 m^3 or 145 cm^3 or 145000 mm^3.

So, weight of AGW = 93.2 gm

5% replacement with RBW = 0.000090625 m^3 or 90.6 cm^3 or 90625 mm^3.

So, weight of RBW = 97.875 gm

5. When 16% Sand is used (means, w = 464 gm) with 14% replacement out of total 30%.

Weight of replacement = 870 – 464 = 406 gm

Volume of replacement (406 gm sand) = 0.00025375 m^3 or 253.7 cm^3 or 253750 mm^3.

a. 5% replacement with AGW = 0.000090625 m^3 or 90.6 cm^3 or 90625 mm^3.

So, weight of AGW = 58.27 gm

9% replacement with RBW = 0.000163125 m^3 or 163.1 cm^3 or 163125 mm^3.

So, weight of RBW = 176.2 gm

b. 6% replacement with AGW = 0.00010875 m^3 or 108.7 cm^3 or 108750 mm^3.

So, weight of AGW = 69.93 gm

8% replacement with RBW = 0.000145 m^3 or 145 cm^3 or 145000 mm^3.

So, weight of RBW = 156.5 gm

c. 7% replacement with AGW = 0.000126875 m^3 or 126.8 cm^3 or 126875 mm^3.

So, weight of AGW = 81.5 gm

7% replacement with RBW = 0.000126875 m^3 or 126.8 cm^3 or 126875 mm^3.

So, weight of RBW = 137.025 gm

d. 8% replacement with AGW = 0.000145 m^3 or 145 cm^3 or 145000 mm^3.

So, weight of AGW = 93.2 gm

6% replacement with RBW = 0.00010875 m^3 or 108.7 cm^3 or 108750 mm^3.

So, weight of RBW = 117.5 gm

e. 9% replacement with AGW = 0.000163125 m^3 or 163.1 cm^3 or 163125 mm^3.

So, weight of AGW = 104.9 gm

5% replacement with RBW = 0.000090625 m^3 or 90.6 cm^3 or 90625 mm^3.

So, weight of RBW = 97.875 gm

6. **When 15% Sand is used (means, w = 435 gm) with 15% replacement out of total 30%.**

Weight of replacement = 870 – 435 = 435 gm

Volume of replacement (435 gm sand) = 0.000271875 m^3 or 271.8 cm^3 or 271875 mm^3.

a. 6% replacement with AGW = 0.00010875 m^3 or 108.7 cm^3 or 108750 mm^3.

So, weight of AGW = 69.93 gm

9% replacement with RBW = 0.000163125 m^3 or 163.1 cm^3 or 163125 mm^3.

So, weight of RBW = 176.2 gm

b. 7% replacement with AGW = 0.000126875 m^3 or 126.8 cm^3 or 126875 mm^3.

So, weight of AGW = 81.5 gm

8% replacement with RBW = 0.000145 m^3 or 145 cm^3 or 145000 mm^3.

So, weight of RBW = 156.5 gm

c. 8% replacement with AGW = 0.000145 m^3 or 145 cm^3 or 145000 mm^3.

So, weight of AGW = 93.2 gm

7% replacement with RBW = 0.000126875 m^3 or 126.8 cm^3 or 126875 mm^3.

So, weight of RBW = 137.025 gm

d. 9% replacement with AGW = 0.000163125 m^3 or 163.1 cm^3 or 163125 mm^3.

So, weight of AGW = 104.9 gm

6% replacement with RBW = 0.00010875 m^3 or 108.7 cm^3 or 108750 mm^3.

So, weight of RBW = 117.5 gm

7. **When 14% Sand is used (means, w = 406 gm) with 16% replacement out of total 30%.**

Weight of replacement = 870 – 406 = 464 gm

Volume of replacement (464 gm sand) = 0.00029 m^3 or 290 cm^3 or 290000 mm^3.

a. 7% replacement with AGW = 0.000126875 m^3 or 126.8 cm^3 or 126875 mm^3.

So, weight of AGW = 81.5 gm

9% replacement with RBW = 0.000163125 m^3 or 163.1 cm^3 or 163125 mm^3.

So, weight of RBW = 176.2 gm

b. 8% replacement with AGW = 0.000145 m^3 or 145 cm^3 or 145000 mm^3.

So, weight of AGW = 93.2 gm

8% replacement with RBW = 0.000145 m^3 or 145 cm^3 or 145000 mm^3.

So, weight of RBW = 156.5 gm

c. 9% replacement with AGW = 0.000163125 m^3 or 163.1 cm^3 or 163125 mm^3.

So, weight of AGW = 104.9 gm

7% replacement with RBW = 0.000126875 m^3 or 126.8 cm^3 or 126875 mm^3.

So, weight of RBW = 137.025 gm

8. **When 13% Sand is used (means, w = 377 gm) with 17% replacement out of total 30%.**

Weight of replacement = 870 – 377 = 493 gm

Volume of replacement (348 gm sand) = 0.000308125 m^3 or 308.1 cm^3 or 308125 mm^3.

a. 8% replacement with AGW = 0.000145 m^3 or 145 cm^3 or 145000 mm^3.

So, weight of AGW = 93.2 gm

9% replacement with RBW = 0.000163125 m^3 or 163.1 cm^3 or 163125 mm^3.

So, weight of RBW = 176.2 gm

b. 9% replacement with AGW = 0.000163125 m^3 or 163.1 cm^3 or 163125 mm^3.

So, weight of AGW = 104.9 gm

8% replacement with RBW = 0.000145 m^3 or 145 cm^3 or 145000 mm^3.

So, weight of RBW = 156.5 gm

9. When 12% Sand is used (means, w = 522 gm) with 12% replacement out of total 30%.

Weight of replacement = 870 – 348 = 522 gm

Volume of replacement (522 gm sand) = 0.00032625 m^3 or 326.2 cm^3 or 326250 mm^3.

a. 9% replacement with AGW = 0.000163125 m^3 or 163.1 cm^3 or 163125 mm^3.

So, weight of AGW = 104.9 gm

9% replacement with RBW = 0.000163125 m^3 or 163.1 cm^3 or 163125 mm^3.

So, weight of RBW = 176.2 gm

So,

Quantities Required for stage 1 casting

Total Quantity of Cement required = 22.62 kg

Total Quantity of Flyash required = 135.75 kg

Total Quantity of Sand required = 37.410 kg or 37410 gm

Total Quantity of Agro-waste required = 6.114 kg or 6114 gm

Total Quantity of Rubber-waste required = 10.278 kg or 10278 gm

Using Optimum Mix (6% AGR and 5% RBW)

Quantities Required for stage 2 casting (per 15 Bricks)

Total Quantity of Cement required = 4.35 kg

Total Quantity of Flyash required = 26.1 kg

Total Quantity of Sand required = 8.265 kg or 8265 gm

Total Quantity of Agro-waste required = 1.050 kg or 1050 gm

Total Quantity of Rubber-waste required = 1.470 kg or 1470 gm

Actual Quantities Required for 1 meter cube (cu.m.)

Using Optimum Mix (6% AGR and 5% RBW)

Actual Weight of brick = 2.742 kg (Using 10% cement and 60% flyash)

Percentage of sand used = 30% of total mix

So, Weight of sand (w) = 822.6 gm (without replacement)

Density of Cement = 1440 kg/m^3

Density of Fly-ash = 1500 kg/m^3

Density of Sand = 1600 kg/m^3

Density of Rubber = 1080 kg/m^3

Density of Agro-waste = 450 - 700 kg/m^3

So, Recorded Density of Agrowaste = 643 kg/m^3

(Checked in the cube of 150mm, weight = 2.17 kg)

When 19% Sand is used (means, w = 520.98 gm) with 11% replacement out of total 30%.

Weight of replacement = 822.6 – 520.98 = 301.62 gm

Volume of replacement (301.62 gm sand) = 0.000188125 m^3 or 188.125 cm^3 or 188125 mm^3.

6% replacement with AGW = 0.0001024375 m^3 or 102.43 cm^3 or 102437 mm^3.

So, weight of AGW = 65.86 gm

5% replacement with RBW = 0.0000856875 m^3 or 85.6875 cm^3 or 856875 mm^3.

So, weight of RBW = 92.542 gm

Total Quantity of Cement required = 153.827 kg/m^3

Total Quantity of Flyash required = 923.966 kg/m^3

Total Quantity of Sand required = 293.172 kg/m^3

Total Quantity of Agro-waste required = 37.188 kg/m^3

Total Quantity of Rubber-waste required = 51.254 kg/m^3

So,

Density of light weight brick with optimum mix = 1459.407 kg/m^3

*Note: Size of the Non-Modular or Traditional Brick = 230mm * 110mm * 70mm*

Volume of one brick = 0.001771 cu.m

4.4.2 PREPARATION OF BRICK SPECIMENS

A variety of materials that are passing through a 4.75 mm sieve and retained on a 75-micron sieve, include fly ash, fine aggregates, agro waste powder, rubber waste powder, and ordinary Portland cement of grade 53, were used in this experimental work to prepare the specimen, which measures 230 mm by 110 mm by 70 mm and is displayed in figure 4.8. Pan mixer was employed for the thorough and homogenous mixing of ingredients. It is to note that the lumps if any left in the mix even of any small quantity start hydrating after the curing period gets over and cause disruption and initiate cracks to the brick structure and weaken the bricks. The lumps if any presented in the cement could be easily broken with the help of pan mixer.

Figure 4.7 a) shows the pan mixer, which is in the operation state. It was ensured that the total quantity of raw and waste materials loaded in a particular type of brick mix should not exceed the rated capacity (500 kg/batch) of the pan mixer.

The pan type mixing machine was used to mix the required amounts of the given materials in an appropriate proportion as indicated in table 4.5. The process of batching is described as "the process of measuring the materials and inosculating all the measuring material on one place in proper proportion."

Table 4.5 Proportioning of Ingredients for Light Weight Bricks

Mixes	Cement	Fly ash	Fine Aggregates		
			Sand	AGR	RBW
S20A5R5	10%	60%	20%	5%	5%
S19A5R6	10%	60%	19%		6%
S18A5R7	10%	60%	18%		7%
S17A5R8	10%	60%	17%		8%
S16A5R9	10%	60%	16%		9%
S19A6R5	10%	60%	19%	6%	5%
S18A6R6	10%	60%	18%		6%
S17A6R7	10%	60%	17%		7%
S16A6R8	10%	60%	16%		8%
S15A6R9	10%	60%	15%		9%
S18A7R5	10%	60%	18%	7%	5%
S17A7R6	10%	60%	17%		6%
S16A7R7	10%	60%	16%		7%
S15A7R8	10%	60%	15%		8%
S14A7R9	10%	60%	14%		9%
S17A8R5	10%	60%	17%	8%	5%
S16A8R6	10%	60%	16%		6%
S15A8R7	10%	60%	15%		7%
S14A8R8	10%	60%	14%		8%

S13A8R9	10%	60%	13%		9%
S16A9R5	10%	60%	16%	9%	5%
S15A9R6	10%	60%	15%		6%
S14A9R7	10%	60%	14%		7%
S13A9R8	10%	60%	13%		8%
S12A9R9	10%	60%	12%		9%

**Note: S is describing percentage of the natural sand, A is describing percentage of the agro-waste and R is describing percentage of the rubber waste in the different mixes.*

a) **b)**

Figure 4.7 a) Pan Mixer, b) Composite Mixer

The process of mixing was carried out until the basic materials were evenly mixed. After the raw ingredients had been thoroughly combined, the mixture was put into a larger pan and poured into brick moulds for mechanical and physical testing. The mixture was then adequately vibrated for a suitable amount of time to ensure that there were no voids. Before pouring concrete, the interior of the moulds was sprayed with oil to make it easier to take the samples from the moulds after a day. Three separate layers of the liquid were poured into the moulds, and a steel tamping rod was used to tamp each layer twenty-five times. Once the mixture had fully settled in the moulds after a full day, it was de-moulded and allowed to dry in a dust-free water curing tank for the necessary amount of time, following Indian Standard criteria. The entire specimen preparation process is depicted in various images 4.7–4.10.

a) **b)**

Figure 4.8 a) Required Sized Moulds, b) Filled Moulds with Mixture

Figure 4.9 De-Moulding the Specimens

As per the earlier discussion in this contribution, different light weight fly-ash bricks specimens are tested fabricated using different waste materials in the different percentage with some replacement of natural sand as shown in table 4.5 in the previous chapter. In these brick samples, the content of fly-ash and binding material means of cement was fixed as 60% and 10% respectively, but the rest 30% content covered by the fine aggregates was changed due to replacement with crushed agro-waste and rubber waste contents. Basically, natural sand as fine aggregates is varying from 12% to 20% out of total content of fine aggregates which is 30%, and corresponding waste materials are varying from 10% to 18% as shown in the table 4.5, even the size of fine aggregates is also maintain with the same size of fine aggregates so these waste materials are considered as a type of fine aggregates only in this work. There are a total of 25-different mixes depends on different proportions of fine aggregates excluding control. Each of the mix is described in terms of SAR, in which S is describing the percentage of natural sand in the mix and A is describing the percentage of the agro-waste as well as R is describing the percentage of rubber waste in the mix. Brick specimens of sizes 230 x 110 x 70 mm are prepared in the moulds and compacted properly to avoid the presence of air voids and to maintain its quality as discussed in the previous chapter. In the each mix a total of 12 samples are prepared for the testing to get appropriate results and compared with the control.

Figure 4.10 Curing of Specimens

These specimens are kept under the water after de-moulding them on 24-hours drying for the sufficient curing period to achieve its maximum strength. Bricks are mostly used to carry compressive strength in the masonry walls so considering the practical conditions, only compressive testing by UTM is used in the mechanical tests, for which two types of specimens are tested from each mix, where these specimens are defined as per the time of curing. All the specimens from each mix are tested under UTM after the curing of 14-days and 28-days in fresh water, and test results are compared in detail.

The process of manufacturing of fly ash Brick as follows:-

- This brick-making process uses the elements listed in table 4.5 in the correct amounts. These ingredients include binding material, fly ash, agro-waste, and rubber waste, which are combined to create a dry combination.
- Next, the material is thoroughly blended to create a consistent consistency.
- In order to reach a bright stage of that mix, water is then added to the aforesaid mixture for the dry mix of binding material, fly ash, fine aggregates, agro-waste, and rubber waste, as illustrated in figure 4.5.
- Once there is a greater amount of mixture, the mould transfer procedure needs to be completed.
- The experiment used moulds measuring 230 x 110 x 70 mm, which corresponds to the dimensions of conventional bricks (not modular), as illustrated in figure 4.8.
- To ensure the mixture settles in the mould, it is placed in three layers and tampered with 25 times.
- Afterwards, the mould is carefully set in a secure location to prevent it from breaking.
- To prevent any combination from sticking to the mould, grease oil is rubbed over the mould before filling it with the mixture.
- Subsequently, the mould is allowed to sit for a full day before being detached, as illustrated in figure 4.9.
- Brick placement must be done carefully to prevent breakage from pressure applied to the bricks.
- This procedure is being carried out once again for each of the 25 mixtures that are being employed in this experimental endeavor.

- After that, as seen in figure 4.10, the bricks are taken for the drying process and placed in a sink for 14 and 28 days.

- Water curing is completed after 14-days and 28-days, and the Compression Test verifies the bricks' necessary strength.

CHAPTER-5 PHYSICAL AND MECHANICAL PROPERTIES OF SPECIMENS

5.1 GENERAL

Brick masonry consists of a homogeneous assemblage of brick and mortar. The combination of these materials regulates the performance of the masonry as a structural element. However, the behaviour of masonry element depends on, the properties and the association of the integral materials as an assemblage. Hence, it is essential to consider the properties of the constituent materials, especially the brick. In this chapter, the test procedures and the results of the physical and mechanical properties of the various wastes - based fly ash bricks are presented.

The dimensions and tolerances, weight density, water absorption, hardness and compressive strength were determined. Non-destructive testing using ultrasonic pulse velocity was conducted, and the results are presented. The summary of test results of optimum brick mix identified from the investigations also offered.

This is the next stage of the experimental work after completion of preparation and curing stage of specimens. In this stage, different type of physical and mechanical testing is done in lab just to check quality of the light weight brick made by waste materials. The brief discussion about this testing is given below.

5.2 TESTS ON PHYSICAL AND MECHANICAL PROPERTIES

The physical characteristics of bricks were assessed in accordance with BIS: 12894-2002; Pulverized fuel-ash lime bricks-standard. The test procedures are outlined below.

5.2.1 DIMENSIONS AND TOLERANCE

A total of twenty bricks, according to the size and positioning of the stack were selected randomly from the developed brick samples. The bricks were arranged in a straight line upon a level surface successively in contact with each other. With the aid of a steel tape, the overall length of the assembled bricks was measured. All these dimensions were added together and the tolerance was found. Figure 5.1 shows the tolerance measurement of bricks along the different sides and the bricks tested with a length tolerance of ±4 mm, a width tolerance of ±2 mm, and a height tolerance of ±2 mm as per the BIS standards. The actual dimensional variation along any direction ranges from ±0.3 to ±1.1 mm that full-fill the acceptable tolerance limits as prescribed by the BIS.

Figure 5.1 Dimensions and Tolerance (Size of Brick is 230mm x 110mm x 70mm)

5.2.2 WEIGHT DENSITY

Brick weight density is calculated as the weight/volume ratio, expressed in kilograms per cubic meter. A set of three bricks was tested for each variation of brick mix after an adequate amount of drying time. The brick used in the weight density test measured 230 mm by 110 mm by 70 mm. The brick's volume was computed in cubic meters, or 0.001771 m^3.

According to ASTM C-67, the brick's weight must be recorded using a scale or balance of capacity that weighs no less than 3kg and has 0.5g sensitivity, as illustrated in figure 5.2.

Figure 5.2 Measuring the Weight of the Specimens

5.2.3 WATER ABSORPTION

Water absorption of brick is the percentage ratio of the change in mass to original mass. Water absorption is calculated using the below expression.

Water absorption (%) = $\frac{M2-M1}{M1} \times 100$

Where,

$M1$- weight of dry brick specimen (kg)

$M2$ - weight of saturated brick specimen (kg)

5.2.4 HARDNESS

A good brick is inherently having higher resistance to abrasion. The endurance and durability of bricks directly related to their hardness. When any sharp object scratches the surface of bricks and if there is no impression observed, then the brick is termed as hard brick. A set of three bricks in each brick mix was subjected to hardness observation using a small iron rod (4 mm diameter and 127mm (5”) length) for making an impression on the brick surface. The hardness test was conducted with reference to Sudharsan (2017) considering IS 13757:1993 [90] .

5.2.5 COMPRESSIVE STRENGTH TEST

A test of compressive strength was performed in accordance with BIS: 12894-2002. A 300T capacity Compression-Testing Machine (CTM) was used to test the bricks. The brick specimen's compressive strength test setup is depicted in figure 5.3. A constant axial stress of 14 N/mm^2/minute was applied until the sample failed.

The brick specimen's compressive strength was ascertained by applying the subsequent expression:

$$\text{Compressive strength } (N/mm^2) = \frac{Maximum\ Load\ at\ Failure\ in\ Newtons}{Average\ Area\ of\ the\ Loaded\ Bed\ Surface}$$

All that compressive strength is the highest load that is applied to the sample's cross-sectional area. The value of uni-axial compressive stress attained when a material fails totally under applied load is the ultimate compressive strength of any specimen or material. The compressive strength obtained usually experimentally by means of a compressive test under compressive load on brick specimens by universal or compressive testing machine as shown in figure 5.3. Strength is always depends on type of material used in specimen which going to test, like compressive strength of light weight fly-ash brick depends on proportions of raw materials used in it. In present study, compressive strength found on brick specimens of size 230 x 110 x 70 mm in control as well as by using crushed agro-waste and rubber waste with appropriate replacement with fine aggregates. After testing of these specimens with or without replacement, test results were comprised with each other.

Figure 5.3 Compressive Strength Test of the Specimens

5.3 RESULTS AND DISCUSSION

5.3.1 DIMENSIONS AND TOLERANCE

With the stipulated guidelines of BIS: 12894 - 2002, the dimensions and tolerances of the developed waste - based bricks of size 230 mm x110 mm x 70 mm are verified. According to the code, the total dimensions of 20 numbers of bricks along the length, width and height are given by:

- Length from 4520mm to 4680mm (4600 ± 80mm)
- Width from 2160mm to 2240mm (2200 ± 40mm)
- Height from 1360mm to 1440mm (1400 ± 40mm) (for 70mm high bricks)

The acceptable tolerances limits prescribed by BIS along the brick length as ± 4 mm and for width and height as ± 2 mm. The test results of different categories such as fly ash bricks made without using waste materials (Control), bricks made using waste materials with some replacement of natural sand (SAR) are presented in table 5.1.

Table 5.1 Test Results of Dimensions and Tolerances

S.No.	Brick Type	Measured Along	Size of Brick (mm)	Dimensions (mm)			Tolerance Limit as per Code
				Total	Average	Variation	
CONTROL BRICKS (CON)							
1	CON	Length	230	4612	230.6	+0.6	+4 or -4
		Width	110	2206	110.3	+0.3	+2 or -2
		Height	70	1412	70.6	+0.6	+2 or -2
Bricks Fabricated Using Waste Materials (AR)							
2	SAR	Length	230	4578	228.9	-1.1	+4 or -4
		Width	110	2186	109.3	-0.7	+2 or -2
		Height	70	1382	69.1	-0.9	+2 or -2

In the case of control bricks without waste material, the total dimensions along the length, height and width are satisfied with the prescribed limits. The dimensional variation along any direction ranges from ±0.3 to ±0.6 mm. The acceptable tolerance of measured dimensions along the length, ± 4 mm and for the other two dimensions of ± 2 mm per brick is satisfied.

Table 5.2 Weight Density of Brick Specimens

S. No.	Mix	Weight of Brick (kg)	Average Density (kg/m^3)
1	Control	2.742	1548.277
2	S20A5R5	2.617	1477.696
3	S19A5R6	2.596	1465.838
4	S18A5R7	2.575	1453.980
5	S17A5R8	2.543	1435.912

6	S16A5R9	2.497	1409.937
7	S19A6R5	2.578	1455.674
8	S18A6R6	2.571	1451.722
9	S17A6R7	2.544	1436.476
10	S16A6R8	2.491	1406.549
11	S15A6R9	2.46	1389.045
12	S18A7R5	2.566	1448.898
13	S17A7R6	2.532	1429.700
14	S16A7R7	2.488	1404.856
15	S15A7R8	2.459	1388.481
16	S14A7R9	2.416	1364.201
17	S17A8R5	2.527	1426.877
18	S16A8R6	2.476	1398.080
19	S15A8R7	2.445	1380.575
20	S14A8R8	2.405	1357.989
21	S13A8R9	2.397	1353.472
22	S16A9R5	2.47	1394.692

23	S15A9R6	2.44	1377.752
24	S14A9R7	2.401	1355.731
25	S13A9R8	2.385	1346.696
26	S12A9R9	2.366	1335.968

The dimensions of the waste - based bricks got altered due to the changes in the percentage of internal pores. They showed slight variations in the dimensions from the conventional fly ash bricks, however, all the waste - based bricks are fulfilled the stipulated criteria as per BIS. The dimensional variation along any direction ranges from ±0.7 to ±1.1 mm. All the developed waste - based bricks have a uniform shape, colour, sharp corners and no warping is noticed.

5.3.2 WEIGHT DENSITY OF WASTE - BASED BRICKS

The weight density assessment is an essential task in both the strength and durability aspects of a brick. A brick generally provides good strength when it holds fewer voids and porosity. If the brick contains minimum voids, the structure of bricks is of less permeable to moisture penetration and other chemical soluble elements, thereby the durability of the bricks gets enhanced. The weight density test results of control brick specimens and brick specimens fabricated using waste materials, are described in table 5.2. These test results are clearly describing that with the increase of percentage of the waste materials, density is decreasing, as in the control mix in which there was no waste material is measured as 2.742kg but after adding percentage of the waste materials there is the decrement in weight. It is only because of the natural sand as it heavier in weight as comparative weight of the agro-waste and rubber waste, which can be seen in the density of these materials as density of natural sand, agro-waste and rubber waste is 1600kg/m^3, 643kg/m^3 and 1080kg/m^3, respectively.

5.3.3 WATER ABSORPTION OF WASTE - BASED BRICKS

The real level of moistness within a brick does not only depend on the porosity of the material but also on the neighbouring air humidity and the temperature.

Comparatively, the moisture of the brick specimen in a damp environment is higher than the dry environment. Depending on the nature of the material in contact with brick, the moistness can be hugely varied. By capillary action, the moisture from the ground gets into the masonry wall if it is constructed without a damp-proof course. Similarly, dampness can be engrossed by bricks if saturated earth is in contact with the wall—both these influence the conditions of improving dampness. Since various waste materials incorporated in bricks, the inherent properties of bricks get altered and the water absorption plays a significant role to ascertain the long-term performance. The test results of control brick specimens and brick specimens fabricated using waste materials, are described in table 5.3.

Table 5.3 Test Results of Light Weight Bricks with Different Mixes

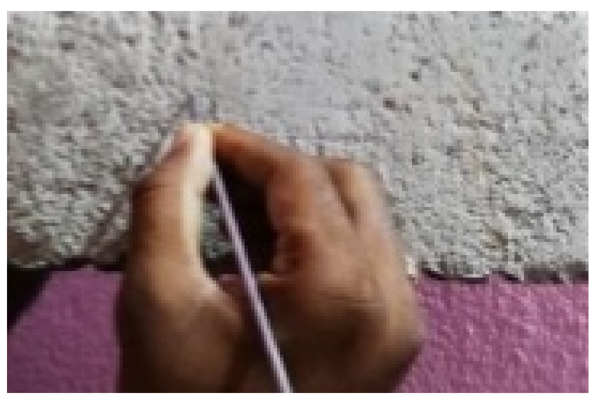
Mix	Weight of Brick (kg)	Average Comp. Strength of Brick (N/mm^2)		Water Absorption (%)	Soundness Test (Pass/Fail)	Efflolescence Test (Pass/Fail)
		14-Days	28-Days			
Control	2.742	7.23	10.65	10.9	Pass	Pass
S20A5R5	2.617	7.38	10.94	10.6	Pass	Pass
S19A5R6	2.596	7.62	11.12	10.55	Pass	Pass
S18A5R7	2.575	7.30	10.82	10.6	Pass	Pass
S17A5R8	2.543	6.91	9.69	10.4	Pass	Pass
S16A5R9	2.497	6.04	8.27	10.3	Pass	Pass
S19A6R5	2.578	7.49	11.08	10.5	Pass	Pass
S18A6R6	2.571	7.25	10.78	10.4	Pass	Pass
S17A6R7	2.544	6.85	9.7	10.5	Pass	Pass
S16A6R8	2.491	6.43	8.75	10.4	Pass	Pass

S15A6R9	2.46	5.75	7.874	10.4	Pass	Pass
S18A7R5	2.566	7.08	10.34	10.5	Pass	Pass
S17A7R6	2.532	6.80	9.605	10.3	Pass	Pass
S16A7R7	2.488	6.26	8.371	10.4	Pass	Pass
S15A7R8	2.459	5.82	7.85	10.4	Pass	Pass
S14A7R9	2.416	5.52	7.67	10.2	Pass	Pass
S17A8R5	2.527	6.64	9.56	10.4	Pass	Pass
S16A8R6	2.476	6.33	8.47	10.4	Pass	Pass
S15A8R7	2.445	5.38	7.73	10.3	Pass	Pass
S14A8R8	2.405	5.53	7.71	10.3	Pass	Pass
S13A8R9	2.397	5.11	7.24	10.1	Pass	Pass
S16A9R5	2.47	6.10	8.21	10.3	Pass	Pass
S15A9R6	2.44	5.40	7.78	10.3	Pass	Pass
S14A9R7	2.401	5.26	7.655	10.2	Pass	Pass
S13A9R8	2.385	5.10	7.22	10.0	Pass	Pass
S12A9R9	2.366	4.78	7.058	10.1	Pass	Pass

Table 5.3 presents the water absorption test results of the light weight fly-ash brick specimen fabricated using waste materials with different percentages of replacements of natural sand. In such specimens, it is described that water absorption percentage is increase due to decrease in the percentage of waste materials and the same is decreasing due to increase in the percentage of waste materials, as rubber waste does not absorb water as comparative natural sand.

The water absorption of all the developed bricks was in the ranges of 10.0% to 10.90%. The minimum water absorption was recorded in the brick mix with composition S13A9R8 which was 10.0% and the maximum water absorption was observed in the control mix which was 10.9%. Even the percentage of water absorption for the brick made using optimum mix S19A6R5 is 10.5%. With the stipulated guidelines from Indian Standard, IS 3495 (Part-2), water absorption should not be more than 15% for severe weathering conditions and 20% for moderate weathering conditions. All the developed bricks under the present study can be used for severe weathering conditions. In such specimens, it is described that water absorption percentage is increase due to decrease in the percentage of waste materials and the same is decreasing due to increase in the percentage of waste materials, as rubber waste does not absorb water as comparative natural sand.

a)



b)

Figure 5.4 a) Soundness Test, b) Hardness Observation

5.3.4 SOUNDNESS

A brick's ability to withstand unexpected contact is demonstrated by its soundness test. In this test, two bricks are randomly selected from each mix, as indicated in figure 5.4 a), and they are struck against each other. Then, there should be a distinct bell-ringing sound and no brick breaking. Then, given that the results are shown in table 5.3 in terms of pass or fail, it is considered to be a decent brick as per IS 3495 (part 2): 1992.

5.3.5 EFFLORESCENCE TEST

Soluble salts should not be present in high-quality bricks. Brick surfaces will experience efflorescence if soluble salts are present. Bricks should be dried in the shade after being submerged in water for a full day to determine if they contain soluble salts. Once it has dried, carefully inspect the brick surface. The results are shown in table 5.3 as pass or fail. If there are any white or grey deposits, they include soluble salts and are not suitable for building. The test result indicates that all the tested brick samples were not shown any white/grey patch deposits after the second evaporation. It is concluded that all the developed specimens are having good performance in regards to efflorescence. As per IS 3495 (Part-3) 1992, the efflorescence observation should be investigated after 7 days of immersion of bricks with water. The test were conducted as per BIS and found that bricks were not subjected to perceptible of any efflorescence. Therefore, the trial continued for further longer duration in case of any possible efflorescence in the later stage.

5.3.6 HARDNESS OF WASTE - BASED BRICKS

The hardness is an indication of the solidity of the brick. Based on the observation of hardness on all the developed waste - based bricks, it is concluded that the bricks have sufficient rigidity and fails to make an impression using any hard object. Figure 5.4 b) shows the hardness investigation of a brick specimen that has done considering IS 13757:1993.

5.3.7 COMPRESSIVE STRENGTH OF WASTE - BASED BRICKS

The compressive strength of bricks varied based on several parameters which include the varying proportions of fly ash, cement and particle size along with the volume of pores in the natural sand. The cement content plays a predominant role in compressive strength development. In addition to serving as a binder, cement also increases the hydration process and raises the compressive strength when it combines

with water. Pozzolanic qualities are present in Class F fly ash, which is produced when bituminous coal with CaO content less than 10% is burned.
Bhanumathidas and Kalidas (2003) suggest that based on the boiler operation, use of low-temperature fly ash produced below 900°C are suitable for the production of building bricks due to its more reactive nature in earlier days[18] . The basic principle lying in the fly ash-cement bricks are that under the tropical temperature condition, no external heat is required for the pozzolanic reaction of cement and fly ash.

Compressive strength as shown in figure 5.3 is nothing but a maximum applied load to the cross-sectional area of used sample. The value of uni-axial compressive stress attained when the material fails totally under applied force is the ultimate compressive strength of any specimen or material. The compressive strength is typically measured experimentally using a universal testing machine or compressive test under compressive stress on rectangular specimens, as seen in figure 5.3. Strength is always depends on type of material used in specimen which going to test, like compressive strength of brick depends on its quality, higher the quality strength will be high and in present study, average compressive strength found on rectangular specimens of all the groups of size 230 x 110 x 70 mm with the range of 4.78 – 7.62 N/mm^2 after 14-days of curing and 7 – 11.12 N/mm^2 after 28-days of curing where the same value for the optimum mix with 6% agro-waste and 5% rubber waste is 7.49 N/mm^2 and 11.08 N/mm^2 after 14-days and 28-days of curing, respectively, as shown in table 5.3.

Table 5.3 presents the compressive strength test results of the light weight fly-ash brick specimen fabricated using waste materials with different percentages of replacements of natural sand. In such specimens, it is described that compressive strength is increase due to decrease in the percentage of waste materials and the same is decreasing due to increase in the percentage of waste materials as agro-waste and rubber waste are more soft materials in nature as comparative natural sand which may not properly bond with the aggregates, even the overall density of the rubber is 1080 kg/m^3 which is 32.5% less compared to the same of the sand and overall density of the agro-waste is 643 kg/m^3 which is 59.81% less. This relation of the density between sand and waste materials is playing an important role for the decrement in the overall load carrying capacity of the specimens using described waste materials in more percentage, and increment in the same due to use of same waste materials in the less percentage. In this study, waste materials are replaced with the natural sand in the different percentage described in the table 4.5 having density 1600 kg/m^3 which are much heavier than rubber waste and agro-waste as described above.

5.4 OPTIMUM MIX PROPORTIONS

As per the earlier discussion in this contribution, different light weight fly-ash bricks specimens are tested fabricated using different waste materials in the different percentage with some replacement of natural sand as shown in table 4.5 in the previous chapter. In these brick samples, the content of fly-ash and binding material means of cement was fixed as 60% and 10% respectively, but the rest 30% content covered by the fine aggregates was changed due to replacement with crushed agro-waste and rubber waste contents. Basically, natural sand as fine aggregates is varying from 12% to 20% out of total content of fine aggregates which is 30%, and corresponding waste materials are varying from 10% to 18% as shown in the table 4.5, even the size of fine aggregates is also maintain with the same size of fine aggregates so these waste materials are considered as a type of fine aggregates only in this work. There are a total of 25-different mixes depends on different proportions of fine aggregates excluding control. Brick specimens of sizes 230 x 110 x 70 mm are prepared in the moulds and compacted properly to avoid the presence of air voids and to maintain its quality as discussed in the previous chapter. In the each mix a total of 12 samples are prepared for the testing to get appropriate results and compared with the control.

These specimens are kept under the water after de-moulding them on 24-hours drying for the sufficient curing period to achieve its maximum strength. Bricks are mostly used to carry compressive strength in the masonry walls so considering the practical conditions, only compressive testing by UTM is used in the mechanical tests, for which two types of specimens are tested from each mix, where these specimens are defined as per the time of curing.

All the specimens from each mix are tested under UTM after the curing of 14-days and 28-days in fresh water, and test results are compared in detail in the previous mentioned tables to recognise the optimum mix, and it is found after comparing average weight and average compressive strength of the brick specimens made by each mix, as shown in figure 5.5 and 5.6.

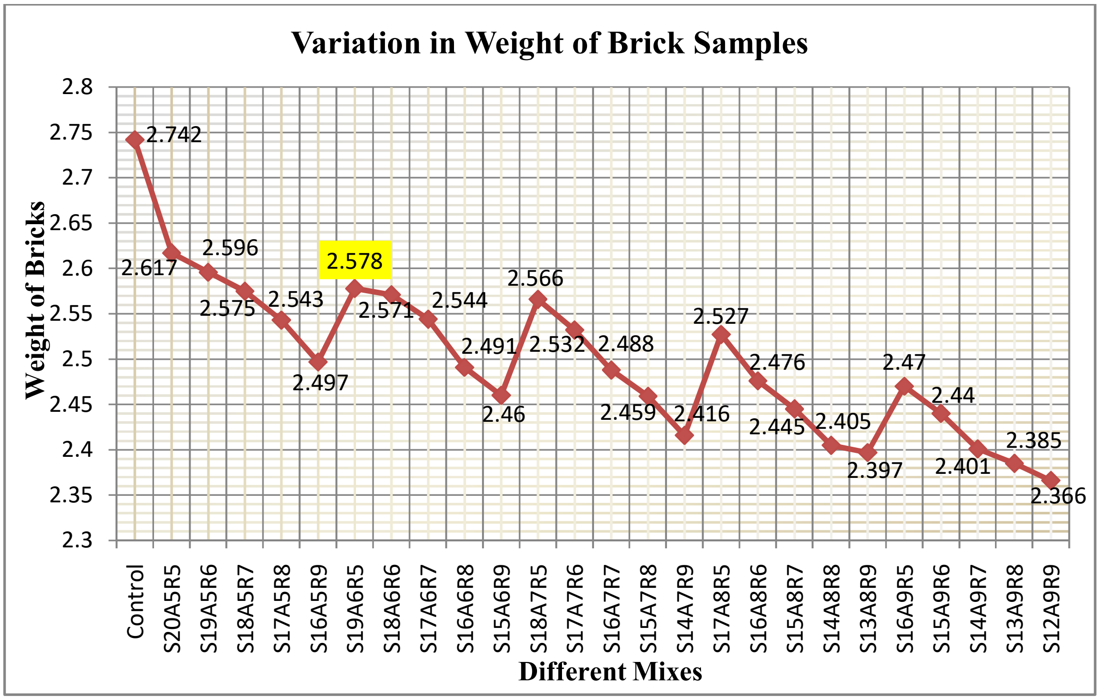


Figure 5.5 Variation in Average Weight of Brick Samples

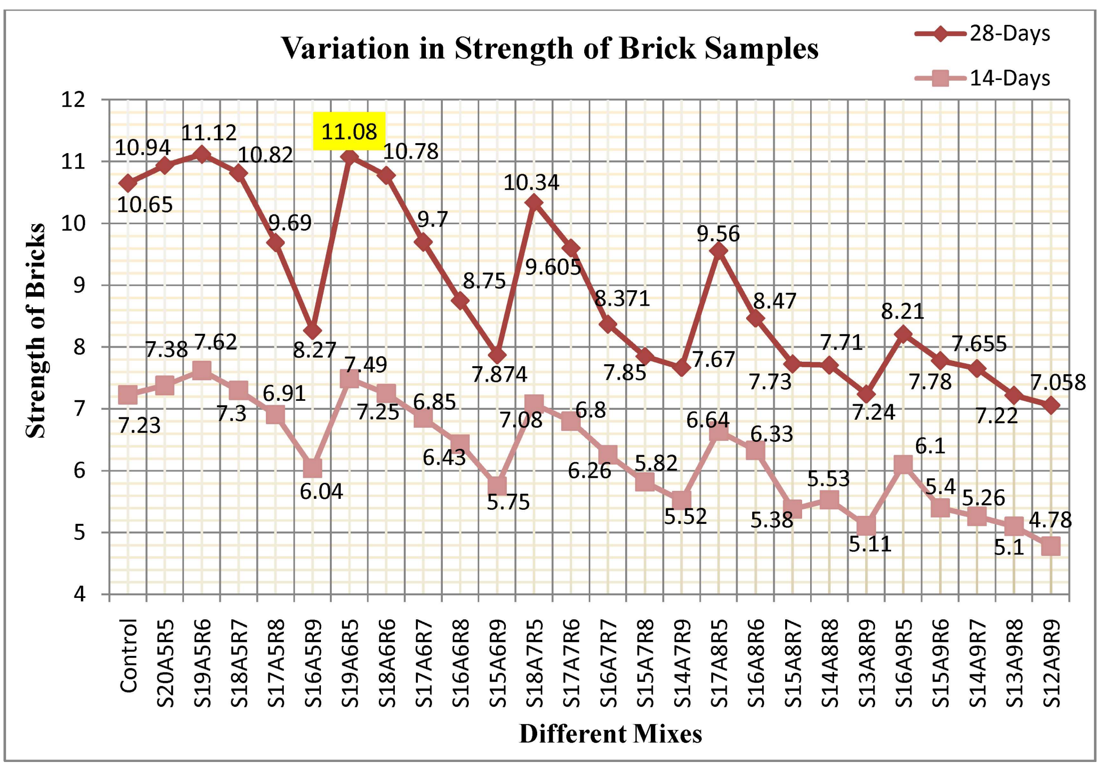


Figure 5.6 Variation in Average Compressive Strength of Brick Samples

The proportion of the optimum mix is selected out of all 25 different mixes considering brick more light in weight but without decreasing its compressive strength, and it is highlighted in the figure 5.5 and 5.6 with yellow background and the respective proportion of the mix is S19A6R5 which means the percentage of natural sand is 19% out of total of 30% fine aggregates and waste materials like agro-waste is 6% and rubber waste is 5%, where the total percentage is of fine aggregates is reaching at its appropriate limit.

It is clearly visible in the mentioned graph that with the increase in percentage of waste materials as fine aggregates, overall weight of the brick is also decreasing but at the same side average compressive strength is also decreasing, as agro-waste and rubber waste are more soft materials in nature as comparative natural sand, so the optimized mix is not only found considering only weight but average compressive strength as well so that strength cannot be decreased. Here, as per the optimized mix the average weight of the brick is decreasing by 164gm from the same of control mix as shown in the figure 5.5 and the corresponding average compressive strength of the same is 11.08N/mm^2.

CHAPTER-6 DURABILITY PROPERTIES OF OPTIMUM SPECIMENS

6.1 GENERAL

Brick is easy to maintain and user-friendly construction material that has to be durable during all phases of brick's life cycle. The longer life span and limited environmental effects make bricks, the choice of construction material even till date. Under the current study, the use of various industrial, municipal waste materials, other ingredients and changes in the production process demands to study the durability aspects in detail.

Brick-mortar bond primarily depends on the ability of the brick to absorb water and the capacity of the mortar to hold it. This water is desirable for the appropriate hydration of cement where the mortar contacts the brick. In the case of masonry units that absorb moisture from the mortar too rapidly, the mortar stiffens the bed joint quickly and there is no proper bondage for the next course of brick. In another case, if the mortar holds excessive water, the brick may float and it is tough to plumb and so, in both cases, the poor bond results. The initial rate of absorption study indicates these properties effectively. On exposure to a moist environment, either the low and higher expansion of brick depends upon the elemental composition of raw materials. Moisture penetration along cracks or pore passageways often causes the damage, but mortar expansion due to acid attack causes failure of bricks and mortar in some cases.

The diverse composition and processing of raw materials may alter the properties in the short and long run. The masonry structures are likely to exposure of environmental concern like rainfall and changes in temperature. This exposure may create a negative strain on external walls and formation of salts on the masonry surface. The destruction of masonry structures is due to readily soluble sulphuric salts in acidic and alkaline metals from brick ingredients. It links the water of crystallization and forming crystal hydrates that leads to the destruction of the masonry structure. Nevertheless, the creation of salt efflorescence on the brick masonry surface is also linked with the diffusion of salt solution in the brick.

In this chapter, the test procedures and results on durability properties of various waste-based optimum fly ash brick mix is discussed which includes the initial surface absorption test (ISAT), acid attack, weather resistance test, thawing and freezing test and the last one is rapid chloride penetration test (RCPT).

6.2 TEST REPORT ON DURABILITY PROPERTIES

GLOBAL™ TEST HOUSE PVT. LTD.

Plot No. 87/2&9, Opp. Metro Pillar No. 617, Industrial Area
Rohtak Road, Mundka, New Delhi-110041
M.: +91-9911939114, 9821975968, 9711931447
Email : info@globaltesthouse.co.in
Web.: www.globaltesthouse.co.in

KVQA

TEST-REPORT

GTHPLQR-36

Report No. GTHPL20231005/02
Date of Receipt: 10/05/2023
Date of Performance: 12-17/05/2023
Date of Issue: 18/08/2023
SRF NO: GTHPL/2023/10/05/01

Issued to:
Jimmy Gupta (PhD Scholar)
Lovely Professional University
Phagwara Punjab,

Name of Work:-Nil.
Reff No. /Letter No.:- Nil
Sample Description:-Standard Fly Ash Brick (Control)

Sample Condition:- Satisfactory

S. No.	Test	Test Method	Result
1.	ISAT (initial Surface Absorption test)	IS 2386(P-3):1963	1.0
2.	Acid Attack	IS 13630 (p-8) 2019	Passes The Test
3.	Weather Resistance Test	IS 4031 (p-3) 1988	Satisfactory
4.	Thawing and Freezing Test	IS 15658 -2021	Satisfactory
5.	RCPT Value		
1.	Total Charges passed in Coulombs	ASTM C-1202-2017	
	1.		728
	2.		685
	3.		715
	Average:		709

Chloride Ion Penetrability based on charged passed

S.N.	Charge Passed (Coulombs)	Chloride Ion Penetrability
1.	>4000	High
2.	2000-4000	Moderate
3.	1000-2000	Low
4.	100-1000	Very Low
5.	<100	Negligible

End of Report

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(1) The results listed refer only to tested samples and applicable parameters. Endorsement of product is neither inferred nor implied.
(2) Total liability of our Lab is limited to the invoiced amount.
(3) Samples will be destroyed after 15 days from the date of test certificate unless specified otherwise.
(4) This report is not to be reproduced wholly or in part and cannot be used as an evidence in the court of Law and should not be used in any advertising media without our special permission in writing
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TEST-REPORT

GTHPLQR-36
Report No. GTHPL20231005/01
Date of Receipt: 10/05/2023
Date of Performance: 12-17/05/2023
Date of Issue: 18/08/2023
SRF NO: GTHPL/2023/10/05/01

Issued to:
Jimmy Gupta (PhD Scholar)
Lovely Professional University
Phagwara Punjab,

Name of Work:-Nil.
Reff No. /Letter No.:- Nil
Sample Description:-Light Weight Fly Ash Brick (A6R5)

Sample Condition:- Satisfactory

S. No.	Test	Test Method	Result
1.	ISAT (initial Surface Absorption test)	IS 2386(P-3):1963	5.9
2.	Acid Attack	IS 13630 (p-8) 2019	Passes The Test
3.	Weather Resistance Test	IS 4031 (p-3) 1988	Satisfactory
4.	Thawing and Freezing Test	IS 15658 -2021	Satisfactory
5.	**RCPT Value**		
1.	**Total Charges passed in Coulombs**	ASTM C-1202-2017	
	1.		723
	2.		681
	3.		712
	Average:		705

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In phase -1 of this contribution, fly-ash brick specimens are prepared using different powder formed waste materials by replacing them with natural sand or fine aggregates in different percentages ranging from 10% to 18%. Each mix is studied deeply using physical as well as mechanical testing and found an optimum mix as discussed above. At the 2nd phase, bricks are prepared using optimum mix and sent to authorize lab for different durability testing using Indian Standard guidelines as described in the previous chapter. After detailed analysis of the results, such optimum brick specimens are found with their satisfactory reports as clearly mentioned in the report attached previously. By which it can be said that performance of such bricks is satisfactory, hence are safe in different weather conditions as well.

6.2.1 DISCUSSION ON DURABILITY TESTS CONDUCTED

ISAT: The ISAT (Indian Standard Absorption Test) for bricks is essential for evaluating their water absorption capacity, a critical factor influencing their strength, durability, and weather resistance. The test measures how much water a brick absorbs when submerged, providing insights into its porosity. High water absorption indicates a porous structure, making the brick weaker and more susceptible to damage over time, such as cracking or efflorescence. Conversely, bricks with low water absorption are denser, stronger, and more resistant to environmental factors like rain and humidity. In the present work, optimum mix based specimens are tested as per Indian Standard guidelines in the authorized lab under appropriate quality control, and found that the tested specimens are having low absorption indicates high-quality, stronger and durable bricks with greater resistance to weathering and moisture-related damage. As per IS2386:1963 (page-3) test results are categorized as follows:

Low Absorption (<12%): Indicates high-quality, durable bricks with greater resistance to weathering and moisture-related damage.

High Absorption (>12%): Suggests lower-quality bricks with higher porosity, prone to deterioration and weakened strength, especially in humid or rainy regions.

The ISAT ensures that bricks meet required standards for water resistance, helping to maintain the structural integrity and longevity of buildings, and the tested specimens are falling under low absorption that indicates high quality specimens.

Acid Attack: The acid attack test, specifically outlined in IS13630:2019, is designed to evaluate the durability of fly ash bricks when exposed to acidic environments, simulating conditions such as acid rain or industrial acid exposure. The test is intended to assess the resistance of fly ash bricks to acid attack, particularly focusing on their ability to withstand the effects of acidic substances like sulfuric acid (H_2SO_4). This test helps determine the durability of fly ash bricks in aggressive environments, ensuring that they are suitable for use in applications where the bricks might be exposed to acids, such as in industrial areas, coastal regions, or places with acid rain.

The permissible weight loss is typically specified in the standard and should be evaluated against the control (unexposed) samples, and if the fly ash bricks are of good quality and have sufficient resistance to acid attack, they should show minimal weight loss (typically less than 5%) and minimal reduction in compressive strength after the acid exposure and If the fly ash bricks have higher levels of weight loss or significant reduction in compressive strength, it indicates poor resistance to acid attack, and these bricks may not be suitable for use in acidic environments.

In this study, prepared specimens using optimum mix are tested as per Indian Standard guidelines in the authorized lab under appropriate quality control, and it is clearly mentioned in the report attached that specimens are passed in all the guidelines means the overall loss in weight is less than 5%.

Weather Resistance: The weather resistance of fly ash bricks is determined through a combination of tests that evaluate their ability to withstand moisture absorption, surface erosion, and dimensional changes. Proper weather resistance is critical for ensuring the durability and stability of fly ash bricks in a variety of environmental conditions; hence this test for evaluating weather resistance to the waste based specimens using optimum mix includes many points like water absorption that is below 20%, compressive strength that retains a high percentage of its initial strength after weather exposure, minimal erosion or cracks after exposure means surface durability, dimensional stability as per Indian Standard guidelines. Fly ash bricks with such results considered suitable for use in outdoor or exposed environments where weathering is a concern.

Thawing and Freezing: The IS 15658:2021 standard is the Indian Standard for "Precast Concrete Blocks for Paving" and it provides guidelines for various types of tests to determine the durability and performance of concrete and masonry materials, including fly ash bricks. Among these tests is the freeze-thaw test, which evaluates how well materials like fly ash bricks can withstand cycles of freezing and thawing, a critical factor for their use in regions with cold climates or areas subject to freeze-thaw conditions. The freeze-thaw test assesses the resistance of fly ash bricks to the damaging effects of freezing and thawing, where moisture inside the brick can freeze, expand, and potentially cause cracking or spalling. This is especially important in regions where temperatures drop below freezing, causing water trapped in the brick's pores to freeze and expand, leading to structural damage. The freeze-thaw test as per IS 15658:2021 is designed to evaluate the durability of fly ash bricks under extreme temperature fluctuations. Bricks that pass this test demonstrate their ability to withstand freezing and thawing without significant damage, ensuring their suitability for use in cold climates or areas subject to moisture cycling.

In the present study, optimum mix based specimens are used to conduct this test and study test results, and found that there are no visible cracks and spalling of the bricks after 25 freeze-thaw cycles, even the tested samples were free from the surface degradation as well. Furthermore, overall loss in weight is less than 5% and retained more than 80% of original compressive strength. By passing this test, fly ash bricks can be considered more durable for use masonry applications in regions that experience seasonal changes in temperature, preventing damage from cracking, spalling, or loss of material due to repeated freeze-thaw cycles.

RCPT: The RCPT (Rapid Chloride Permeability Test) is a test method that measures the permeability of fly ash bricks to chloride ions. The test is commonly used to assess the potential of a material to resist chloride ion penetration, which can be an indicator of the material’s durability, especially in aggressive environments such as those near marine exposure or areas where de-icing salts are used. The RCPT test measures the electrical conductivity of concrete or fly ash brick specimens when exposed to chloride ions, providing a measure of their permeability to these ions. A higher permeability indicates a greater susceptibility to corrosion from chloride ions, which can damage the material over time. The results can be classified based on the total charge passed (in Coulombs), which correlates with the material's chloride permeability.

As per ASTM C1202-2017 guidelines, specimens are considered durable for aggressive environments where chloride ions might be present when there is low permeability which is less than 1000 coulombs, and the specimens tested in present study are falling in the same category which means appropriately suitable for use in environments with frequent chloride exposure. Furthermore, the bricks may be suitable for areas with mild chloride exposure but require additional protective measures when there is moderate permeability which is between 1000 to 2000 coulombs, and fly ash bricks with high or very high permeability may be unsuitable for use in environments with frequent chloride exposure, as they are prone to rapid deterioration when the same is more than 2000 coulombs.

The RCPT (Rapid Chloride Permeability Test) as per ASTM C1202-2017 is a critical test for evaluating the chloride ion permeability of fly ash bricks, providing a measure of their long-term durability in aggressive environmental conditions. By measuring the total charge passed through the material, the test helps classify the fly ash bricks into categories based on their resistance to chloride penetration, guiding decisions on their suitability for use in various construction applications, especially those exposed to salts and moisture.

CHAPTER-7 CONCLUSION AND SUGGESTIONS

7.1 GENERAL

In the current research, detailed investigations were directed to study the performance of various industrial and municipal waste-based fly ash bricks through the evaluation of the physical, mechanical, durable and structural characteristics. The use of waste rejects in bricks can lessen the consumption of scarce resources and reduce the environment burden due to the accumulation of waste materials. Accordingly, the agro-waste in powdered form generating from agricultural industry and rubber waste in powdered form obtained from the rubber industry were partially replaced with natural sand as fine aggregates. This replacement has done in the different percentages with proper composition ranging from 10% to 18% out of total 30% of natural sand, and the prepared specimens are kept for the period of fresh water curing, 14-days and 28-days. The size of the brick is maintained as no-modular brick which is 230mm x 110mm x 70mm. The test results taken from physical and mechanical testing were studied deeply and compared with the standard fly-ash brick made with standard proportions of raw materials, and found the optimum mix considering weight and compressive strength. The final brick made using optimum mix is tested under different durability tests, and complete the weight and cost analysis and compared with other options.

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7.2 OVERVIEW ON RESEARCH FINDINGS

Dimensions and Tolerance: All the developed bricks under the current study, using described mix proportions of waste materials with replacement of natural sand full-fills the acceptable tolerance limits as prescribed by the BIS along the length as ± 4 mm, for width and height as ± 2 mm. The dimensional variation along any direction ranges from 0.3 to 1.1 mm. All the developed waste-based bricks had a uniform shape, colour, sharp corners and no warping was noticed.

Weight Density: The test results regarding overall density and weight of brick are clearly describing that with the increase of percentage of the waste materials which are agro-waste and rubber-waste in powdered form added as fine aggregates with described replacement of natural sand, density is decreasing, as in the control mix in which there was no waste material, the overall weight of brick is measured as 2.742kg but after adding percentage of the waste materials there is the decrement in weight. Overall weight of brick made using optimum mix proportions, S19A6R5, is 2.578kg which is 0.164gm or 6% less then brick made using control mix. So, it can be said that the prepared brick using such mix is light in weight. This weight reduction is only because of the replacement of natural sand as it is heavier in weight as comparative weight of the agro-waste and rubber waste, which can be seen in the density of these materials as density of natural sand, agro-waste and rubber waste is 1600kg/m^3, 643kg/m^3 and 1080kg/m^3, respectively.

Water Absorption: The water absorption of all the developed bricks was in the ranges of 10.0% to 10.90%. The minimum water absorption was recorded in the brick mix with composition S13A9R8 which was 10.0% and the maximum water absorption was observed in the control mix which was 10.9%. Even the percentage of water absorption for the brick made using optimum mix S19A6R5 is 10.5%. With the stipulated guidelines from Indian Standard, IS 3495 (Part-2), water absorption should not be more than 15% for severe weathering conditions and 20% for moderate weathering conditions. All the developed bricks under the present study can be used for severe weathering conditions. In such specimens, it is described that water absorption percentage is increase due to decrease in the percentage of waste materials and the same is decreasing due to increase in the percentage of waste materials, as rubber waste does not absorb water as comparative natural sand.

Soundness: Such fly-ash bricks using different waste materials in appropriate proportions are safe in soundness test as bricks produce bell-ringing sound without any breakage when they are struck against each other.

Hardness: The study on hardness observation has shown that the developed bricks in all the combinations reported satisfying hardness results and the produced brick displays sufficient rigidity for a scratch made using a sharp object.

Compressive Strength: In present study, average compressive strength found on rectangular specimens of all the groups of size 230 x 110 x 70 mm with the range of

4.78 – 7.62 N/mm^2 after 14-days of curing and 7 – 11.12 N/mm^2 after 28-days of curing where the same value for the optimum mix with 6% agro-waste and 5% rubber waste is 7.49 N/mm^2 and 11.08 N/mm^2 after 14-days and 28-days of curing, respectively, compared to 7.23 N/mm^2 and 10.65 N/mm^2 compressive strength after required period of curing for bricks made using control mix. In the current study, it found that there is the small change in the compressive strength of brick made using optimum mix and using control mix but found huge change in the overall weight of waste based brick as it becomes 6% lighter than the same of control brick.

Efflorescence: The test result indicates that all the tested brick samples were not shown any white/grey patch deposits after the second evaporation. It is concluded that all the developed specimens are having good performance in regards to efflorescence. As per IS 3495 (Part-3) 1992, the efflorescence observation should be investigated after 7 days of immersion of bricks with water. The test were conducted as per BIS and found that bricks were not subjected to perceptible of any efflorescence. Therefore, the trial continued for further longer duration in case of any possible efflorescence in the later stage.

Durability: In phase-1 of this contribution, fly-ash brick specimens are prepared using different powder formed waste materials by replacing them with natural sand or fine aggregates in different percentages ranging from 10% to 18%. Each mix is studied deeply using physical as well as mechanical testing and found an optimum mix as discussed above. At the 2nd phase, bricks are prepared using optimum mix and sent to authorize lab for different durability testing using Indian Standard guidelines as described in the previous chapter. After detailed analysis of the results, such optimum brick specimens are found with their satisfactory reports as clearly mentioned in the report attached (refer text in 6.2) even detailed analysis and discussion (refer text in 6.2.1) has also done in the previous chapter. By which it can be said that performance of such bricks is satisfactory, hence are safe in different weather conditions as well.

7.3 WEIGHT ANALYSIS

One of the most important objectives of the present investigation is to analysis the overall weight of the waste-based brick and to make comparison with standard fly-ash brick to understand the changes recorded. The table 7.1 is showing the detailed calculation and the respective comparison of the waste-based brick made using optimum mix with other available option. It can be seen clearly in the table 7.1 that 6% reduction in the overall weight of this brick is recorded when it compared with standard fly-ash brick, and 24.2% reduction recorded when it compared with normal red clayey brick. So, it can be said that the produced waste-based brick is much lighter than other similar options.

Table 7.1 Weight Analysis of Optimum Mix

S. No.	Particulars	Comparison of normal fly ash brick with light weight brick	Comparison of normal red clayey brick with light weight brick
1	Standard weight of 1 normal brick	2.742 kg	3.4 kg
2	Weight of light weight brick with optimum mix	2.578 kg	2.578 kg
3	Weight Reduced	164 gm (0.164 kg) per brick	822 gm (0.822 kg) per brick
4	Size of brick	230 x 110 x 70 mm	230 x 110 x 70 mm
5	Vol. of brick	0.001771 cu.m.	0.001771 cu.m.
6.	**Reduction**	**92.603 kg/m^3**	**464.144 kg/m^3**

7.4 COST/ECONOMIC ANALYSIS

One of the most important objectives of the present investigation is to understand the societal impact of using the developed different waste-based bricks by viability and economic study. There is an imperative need to produce the technologically efficient fly ash bricks without compromising the cost of production. There is a detailed comparison in terms of cost or expenditures to produce light weight fly-ash brick made using optimum mix (S19A6R5) in table 7.3 with standard fly-ash bricks made using control mix in table 7.2. Based on the economic analysis the following facts can be noted:

There is same amount of cement and fly-ash content in both type of bricks so respectively there is no change in its cost, but as there is huge change in the content of fine aggregates or natural sand so respectively some changes are noted in the price of it as cost of natural sand is decreased due to appropriate replacement with waste materials, so there is an addition of the cost of waste materials.

Table 7.2 Cost Analysis of Control Mix for 10 cubic meter

Description	Quantity	Market Price	Unit of Payment	Total Product Cost (Rs)
Cement	1.07 cum	Rs 11520 / cu.m (Rs 400 / bag)	/ cu.m	12326.40
Sand	3.07 cum	Rs 1412.6 / cu.m (Rs40/cubic feet)	/ cu.m	4336.7
Fly-ash (1cu.m = 650kg)	6.16 cum	Rs. 780 / cu.m	/ cu.m	4804.8
Total Cost of Materials				21467.9
Add 1.5% Water Charges				322.02
Add 3% Contingencies				644.04
Total cost for 10 cubic meter material				22112
Total cost for 1 cubic meter material				2211

Cost of the natural sand is Rs 4336.7 / cubic meter when it used in the control mix to full-fill the criteria of 30% fine aggregates, but using the same in optimum mix with 19% out of 30%, the cost is reduced to Rs 2588 / cubic meter due to reduction of its content, which means there is the decrement of 40% in the overall cost of sand. On the other side to full-fill the rest percentage of fine aggregates, 6% agro-waste and 5% rubber-waste is used so respective cost of the same waste materials is Rs 79.8 / cubic meter and Rs 248.3 / cubic meter that has to be added in the cost of light weight brick. Finally, overall cost of control based brick is Rs 2211 / cubic meter and the same of optimum waste-based brick is Rs 2065 / cubic meter, in which 6.6% reduction in the overall cost of waste-based brick is recorded, as shown in table 7.2 and 7.3.

Table 7.3 Cost Analysis of Optimum Mix for 10 cubic meter

Description	**Quantity**	**Market Price**	**Unit of Payment**	**Total Product Cost (Rs)**
Cement	1.07 cum	Rs 11520 / cu.m (Rs 400 / bag)	/ cu.m	12326.40
Sand	1.832 cum	Rs 1412.6 / cu.m (Rs40/cubic feet)	/ cu.m	2588
Fly-ash (1cu.m = 650kg)	6.16 cum	Rs. 780 / cu.m	/ cu.m	4804.8
Agro-Waste	11.4 kg	Rs 7 / kg	/ kg	79.8
Rubber-Waste	19.1 kg	Rs 13 / kg	/ kg	248.3
Total Cost of Materials				20047.3
Add 1.5% Water Charges				300.71
Add 3% Contingencies				601.42
Total cost for 10 cubic meter material				20650
Total cost for 1 cubic meter material				2065

7.5 CONCLUSION OF THE STUDY

The following are the valid conclusions obtained after results from the experimentation, and analysis of the results thereof:

- The optimum mix of the waste materials and the natural sand that is S19A6R5 is found with fix proportions of fly ash and cement considering self weight and compressive strength factors for which the overall density of the optimum waste based brick is 6% less from the same of control mix specimen. So, it can be said that the prepared waste based brick using such mix is light in weight.
- It is found that water absorption percentage increases due to decrease in the percentage of waste materials and the same decreases due to increase in the percentage of waste materials as the minimum and maximum water

absorption is 10.0% and 10.9% for the mix S13A9R8 and control mix, respectively, and the same for optimum mix is 10.5%. Even as per IS 3495 (Part-2), developed bricks can be used for severe weathering conditions as well because water absorption limit is 15% for severe and 20% for moderate weathering conditions.

- The average compressive strength for the specimens' prepared using optimum mix is 7.49 N/mm^2 and 11.08 N/mm^2 after 14-days and 28-days of curing, respectively, and when it is compared to the same of control mix it found that there is the overall increment of approx 3.6% and 4% in the average compressive strength after 14-days and 28-days of curing, respectively.
- The durability test results describe clearly that performance of prepared light weight bricks using optimum mix is satisfactory, hence it is safe in different weather conditions as well as discussed in detail in 6.2 and 6.2.1.
- As per the detailed calculation done in table 7.1, it is concluded that there is the 6% and 24.2% reduction in the overall weight of the waste based brick using optimum mix compared to standard fly-ash brick and normal red clayey brick, respectively, hence, prepared brick can be said as light weight brick.
- When considering the economic factor of the brick, it is concluded that the overall cost of waste-based brick prepared using optimum mix is Rs 2065 / cubic meter, in which 6.6% reduction is recorded when it compared to the standard fly ash brick prepared using control mix.

Based on the current study and its outcomes, it is concluded that the development of waste-based fly-ash bricks using optimum mix is meaningfully appropriate and relevant for the upliftment of economically weaker sections of the society. The current study is also effectively useful for humanity and small-scale brick manufacturers for their stringent economic needs and enhanced technical benefits without compromising its compressive load carrying capacity, even sustainability and eco-friendly issues.

7.6 SUGGESTIONS FOR FUTURE WORK

- The current investigation focused on studying the effects of industrial and agro waste materials such as rubber-waste powder and agro-waste powder. Research can be extended to the thermal properties of various waste-based bricks can be investigated.
- The percentage of fly ash can also be varied, and the waste materials are replaced with differing rates of substitution can be tried in future.
- The cyclic load condition can be applied for the masonry, and the seismic characteristics such as energy absorption, ductility characteristics, stiffness and stiffness degradation can be determined.
- The behaviour of masonry element with different types of cement mortar grades may be investigated in the future.
- Dynamic analysis can be done and the behaviour of various waste-based masonry units can be determined with various scale reduced models of a masonry building.
- Masonry prisms and wall elements can be constructed with different aspect ratio and diverse masonry bonds such as English bond, and the Flemish bond can be tried.
- The micro-structural study can be further extended.
- Life cycle assessment can be done in future investigations.

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APPENDIX I

Certificate No. 245220

LOVELY PROFESSIONAL UNIVERSITY

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Certificate of Participation

Presented to **Mr. Jimmy Gupta** of **Lovely Professional University** in recognition of his/her participation in **"International Conference on Innovation and Intellectual Property Rights"** held on **18-19th April, 2022** organized by Division of Research and Development, Lovely Professional University, Punjab.

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Place: Phagwara (Punjab), India

Prepared by
(Administrative Officer-Records)

Convener
Dr. Runjhun Tondon
(IAIPR 2022)

Dr. Chander Prakash
CD, Division of Research and Development

CERTIFICATE

OF PRESENTATION

3rd International Conference on Advances in Science, Engineering & Management (ICASEM-2022)

18th - 19th November 2022 | Hyderabad, Telangana, India

Certificate No: IFERP20221118_10132

This is to Certify that **Jimmy Gupta** of **Lovely Professional University** presented his/her research paper titled *"Performance of Light Weight Bricks Fabricated Using Different Waste Materials"*

in the "3rd International Conference on Advances in Science, Engineering & Management (ICASEM-2022)" Organized By Lords Institute of Engineering and Technology (Autonomous), Hyderabad, In Association with Institute For Engineering Research and Publication (IFERP) held on 18th - 19th November 2022 at Hyderabad, Telangana, India.

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PERFORMANCE OF FLYASH BRICKS FABRICATED USING WASTE MATERIALS

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Highlights-

- The performance of bricks constructed using industrial wastes is investigated and the outcomes are discussed in this paper.
- In this study, bricks were produced using an innovative self-compacting technique.

Abstract-

Waste-industrial by product from the thermal electrical/power plants known as fly-ash, that is used as a type of raw material to make bricks. In order to lessen the strain on an exhaustible re-source that jeopardises the sustainability of the surrounding environment, bricks made by fly-ash are suggested as an alternative to traditional burnt-clay bricks. However, fly-ash is a substance with its own set of issues. Additionally, excessive strain on one material may eventually impact demand, which could have an impact on the construction sector. In order to counter this possibility, a number of environmentally friendly industrial waste materials are selected to partially replace fly-ash in fly-ash bricks, including bottom ash (BA), granite powder (GP),

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Utilization of Waste Materials in Construction Brick

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Abstract— Due to the qualities of brick, it is one of the most important and frequently used masonry units which are used in construction as a building material. Numerous attempts and efforts have been made to include wastes such as wood sawdust, rubber, processed waste tea, limestone dust, polystyrene, sludge, and fly ash into the brick manufacturing process. Recycling such trash into materials of construction is a feasible solution to the environmental crisis or pollution related issues. This contribution mentions the recycling of a variety of trash into light weight fly ash bricks. A variety of effectively materials have been explored which can be recycled very easily, as well as effects of these wastage on the physical and mechanical attributes of bricks are studied. The majority of bricks made of various types of waste materials have demonstrated beneficial impacts on the qualities of light weight fly ash bricks.

Index Terms*—Light weight fly ash bricks, Compressive strength, Building materials, Waste recycling, Waste management.*

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Introduction

Construction brick is one of the world's earliest constructed construction materials. Hand-moulded and sun-dried clay bricks dating from 14,000 BC have been discovered in Egypt's lowest strata of Nile deposits. Clay which is a type of fine grained soil was also the primary raw material and important ingredient in ancient Mesopotamia, and the majority of buildings at the period were constructed entirely of clay bricks. Bricks were first used in the ancient area of Ur or modern Iraq, which was constructed using bricks made up of mud around 4,000 BC, and the early walls of Jericho approximately 8,000 BC. The understanding of preserving clay bricks through firing dates all the way back to 5,000 BC. Burned bricks were further developed in response to archaeological evidence unearthed in starting of early civilisations such as the Tigris, Indus, and Euphrates that employed both type of unfired and fired bricks. The Romans made use of burnt bricks and were instrumental in the introduction of burnt bricks and widespread use in England. However, after the Romans left to the Britain, the brick manufacturing technique faded and was restored later by Flemish brick producers (Y. Abali, 2007). Brick development continued in the majority of the world's counties, and bricks were sent in the shipment to Australia, with an experienced brick builder and brick moulds. Construction bricks have been adopted for building purposes by the majority of societies throughout history due to their superior physical and engineering properties.

Brick is amongst the most challenging masonry units to work with. It offers the broadest selection of products, with an infinite variety of textures, colours and patterns. The industry produced/manufactured 300 million construction bricks in 1996 in Victoria, accounting for approximately 54% of the capacity of the available facilities. Japan, New Zealand, the Middle East, and other Asian countries were among the export markets. This equates to 130 million dollar annual revenue. Brick is a strong material with good load carrying capacity that has evolved and improved with time, even it maintains a good level of economic and technological competitiveness with some other structure and field systems. Apart from fine grained soil or clay, the primary raw material or ingredient for bricks is shale, and soft slate, which are often extracted from different open pits, resulting in disruption of vegetation and drainage even wildlife habitat as well. The composition of the clays used to make bricks varies considerably and is determined by the soil's origin (A.Abdul Kadir, 2008a & b).

These kinds of bricks are extremely durable required less maintenance and also are fire resistant. Bricks' primary characteristics that distinguish them as a good material for construction of buildings are load carrying capacity or