CHAPTER-1

INTRODUCTION

1.1 DEFINITION

A Brick is a type of block used to build walls pavements and other elements in masonry construction.

1.2 OVERVIEW OF BRICK MAKING:

India is the second largest producer of bricks in the world producing around 240 billion bricks annually. There are around 1,400,00 brick kilns operating in India which contributes more than 10% to the total brick production of the world. Indian brick industry is mainly unorganized and non-mechanized. Expect some mechanized or semi-mechanized unites, the industry employs mainly hand-moulding methods for shaping bricks. Surface choice excavated from agriculture field and silt deposited from river and tanks are the main source of clay supply. Drying is mostly done in the open and bricks cannot be dried during the rainy season. Therefore, the industry is seasonal. It operates from 6-8 dry months of a year only (generally from November- June). More than 10 million workers are estimated to the employed with the Indian brick industry.

1.3 BRICK DEMAND IN INDIA:

The Indian economy has been growing at an average annual rate of 5-8% since 2001. From the 12^{th} 5-year plan (2012-13 to 2016-17), the target has been set to achieve an average annual growth rate of 9%. The rate of urbanization in India has been rapid with of decadal growth rate of 31.3% between 1991-2001, 31.8% between 2001-2011. The numbers of towns and cities have also increased from 3768-7951 during this period.

The growth in the economy and population coupled with urbanization has resulted in an increasing demand of residential, commercial, industrial, and public buildings as well as other physical infrastructure. Building construction in India is estimated to grow at rate of 6% per year during the period 1990-2005 and also 6.6% per year during the period 2005-2030. The building stock is expected to multiply 5times this period, resulting in a continuous increase in the demand for building materials.

1.4 **INDUSTRIAL AND ECONOMIC CONDITION:**

Cementous material, coconut coir fibre and additives (glass waste, egg shell powder, silica related waste materials) and operation (mainly the labour cost) are the most important cost components of brick production and together accounts for almost 70% of the cost of production. Management of material cost is an important consideration for brick makers. In recent years, the cost of raw materials (mainly brick earth and clay) as also increased and in certain areas of western and southern India can account for almost 25% of cost of the production.

One of the new developments of note in Indian brick sector has been the entry of the largest brick manufacturing company in the world in the India market. Wiener Berger has setup a production facility near Bengaluru. This is one of the most advanced Wiener Berger plants in the world with chamber dryer and earth tunnel kiln based on coke and LPG. The plant has a production capacity of around 6600 tons per day.

1.5 Difference Between Fired Bricks and Unfired Bricks:

FIRED BRICKS	UNFIRED BRICKS
• Fired bricks are also known as refractory brick. Fired brick is the block of ceramic material used in lining furnaces, kilns, fireboxes, fire places. • Fired brick is built primarily to with stand high temperature, but will also usually have a low thermal conductivity for greater energy efficiency. • Dimension of fired brick is 190×90×90mm • Density of fired clay bricks 2400kg/m^3	• Unfired brick is also known as earth masonry (mud brick). Unfired brick work is constructed using earth material such as some additives etc. • Unfired brick is not fired like conventional brick but the masonry unit are air dried after manufacture to reduce shrinkage and improve strength. • Dimension of unfired brick is of 190×90×90mm • Density of unfired brick 2400kg/m^3

1.6 ENVIRONMENTAL IMPORTANCE OF UNFIRED BRICK:

Environmental impact is currently a global concern that needs argent and effective measure to contain. Different sectors and activity contribute to environmental problem in many ways. In particular, the construction industry, a huge consumer of natural resources and energy, are significant impact on the environment. Since this industry is indispensable, various measure have been adopted to promote using material and construction methods with minimal impact on the environmental and people. Notably, brick is a widely used construction material, produced mostly through firing, it is an energy intensive method characterised by numerous environmental impacts. Therefore, using unfired bricks is deemed as an effective alternative solution to increase the sustainability of construction.

The firing process involved in the manufacture of bricks users mainly non-renewable fossil fuel, this results in massive emission of greenhouse gases such as Carbon dioxide, Carbon monoxide, Sulphur dioxide. With the predicted economic growth and subsequent increase in the demand for bricks, adopting sustainable construction material and process is inevitable. Such materials should be natural, sourced locally, and required minimal or no industrial processing. Generally, research has shown that using unfired brick produces 80% less carbon-dioxide than using fired bricks, and that unfired brick required minimal processing and are easily recyclable causing small environmental impact. On this account, engineers Muheise-araalia and professor Sara pavya from the university of Dublin trinity college studied the properties of unfired illitic clay brick and their protentional application in sustainable construction. Illite is the major constituent of many brick making clays all over the world. The illitic clay studied is used by brick for the production of fired brick in Ireland. The author calculated the approximate expenditure and carbon emission by the producers today, and economy that using unfired brick would implicate.

The main objective was to explore the usage of these bricks in unfired form and lower the associate environmental effect of construction. First, the author assessed the applicability of illitic clay for construction by testing its mechanical properties and comparing it with the standard values used in construction. Next, the illitic clay was mixed with sand and tested both raw and stabilized with hydrated and hydraulic limes. Several mixes were produced, their mechanical properties and performance tested and compared with those of fired.

Results showed that illitic clay can be used in earth construction unfired, and either alone or stabilized with lime. Its geotechnical properties fell within limits provided in the literature and the building standards used in construction. For all the mixes, both raw and stabilizes, the compressive strengths ranging from 2.20-4.98 N/mm^2 and the flexural strengths ranging from 0.48-1.43 N/mm^2 which also met some Europeans structural requirements.

Compared with the performance of the fired bricks, the performance of the fired bricks, the durability and strength of the unfired bricks are lower, the strength of the unfired bricks are lower, the vapor permeability was superior, and the thermal conductivity similar. Furthermore, even though stabilization enhanced the durability, it lowered water permeability and strength, and did not change much the thermal properties of the resulting unfired bricks.

In a nutshell, the authors explored the potential use of unfired illitic clay bricks in earth construction. From the results, unfired illitic clay bricks exhibit potential use in many applications as an effective alternative caused by lime stabilisation was attributed to the adsorption of calcium ions by clay material, competing for moisture and consequently undermining the lime hydration and carbonation.

Overall, the author noted that if half of the annual production of Kings court brick (approximately 15 million bricks annually) were unfired, the producers would save over 4 million euros in the carbon tax and kiln fuel in 10 years. This move could consequently half their carbon emission. Therefore, the authors noted that substituting fired with unfired bricks could sustainable construction.

1.7 CLASSIFICATION OF UNFIRED BRICKS:

Unfired clay bricks, which we can also refer to as earth materials with generally some additives. As said earlier, traditional bricks are fired in order to enhance their properties. However, unfired clay bricks are left in the air to dry to make them stronger and the bonded together with mortar and potentially finished using paint. Those earth units can be classified as traditional or modern bricks.

1.7.1 Traditional units:

Traditional clay units such as cob and mudbricks are bricks made manually without using any advanced technique. This method has been used for centuries and produces bricks with diverse dimensions. However, they all share the property of having tick walls usually above 300mm in order to cover the loss of bond strength due to mortar.

1.7.2 Modern Units:

Concerning modern sun-dried clay units, they are fabricated with precise tolerances with the help of extrusion or pressing system which leads to improving their properties, and hence their quantity. Therefore, manufacturing 100mm, modern thick sun-dried units can be considered as fact, unexpansive and environmentally friendly.

1.8 COMPRESSIVE STRENGTH:

Compressive strength is a very significant property in masonry construction, if not the most important one. When we talk about compressive strength of unfired clay bricks, we can't actually give a precise value because many parameters should be taken into consideration, namely the dimension of units' walls, the materials and percentage of water used in their manufacturing. It is commonly known that the more the percentage of water used, the lower units' strength is consequently, unfired clay bricks should be properly dried.

1.9 LOW-COST HOUSING:

In spite of various major steps taken by the governments, housing problem in rural India is becoming bad to worse due to population exploring and their low income. Various low-cost housing schemes had been floated through use of cheaper construction materials. Therefore, development of few cheaper materials has become in need of the day. This can be possible by production of new materials produced from various by-products or 'wastes into wealth'. Fly ash, a coal combustion by-product available in power plants is one such material available in plenty in our surroundings those are posing problem to the environment. Presently, these are utilised by mixing various cementitious material in production of bricks, those are substituting conventional bricks, for their cost effectiveness. But, the extreme poor people of tribal areas are deprived of using these bricks in their houses due to non-availability and financial constraints. Most of tribal houses in KBK districts of Odisha, eastern and central rural of Chhattisgarh, some parts of Jharkhand, Bihar and west Bengal are made of walls with twigs plastered with mud and Nauria tiled roofing. To bridge the gap a new product 'fly ash enriched earthen unburnt brick' has been proposed. Necessary laboratory tests for the proposed product have been carried and their suitability is presented in this paper. Poor people who can't afford for standard bricks for their houses, this can be an alternate cheaper solution for them.

CHAPTER 2

LITERATURE REVIEW

2.1 GENERAL:

Coconut fibres are agricultural waste products obtained in the processing of coconut oil and are available in large quantities in the tropical regions of the world, most especially in Africa, Asia and America. Coconut fibres are not commonly used in the construction industry but are often dumped as agricultural wastes. However, with the quest for affordable housing system for both the rural and urban population in the developing countries, various schemes focusing on cutting down conventional building material costs have been put forward.

Waste glass can be recycled as a replacement for natural aggregates and cement, therefore, reducing the amount of waste glass dumped in the landfill, and making exploration of natural aggregates unattractive and also reducing the emission of greenhouse gases in the atmosphere. Conversely, perception on using recycled waste glass for construction in that an increase in cost will be witnessed and may not be as effective as natural aggregates but with more sophisticated research this perception in declining.

Eggshell are seldom used to a stabilizing material in most part of world. However, it could be a stabilization of the construction industry. Olarewaju et al., (2011) revealed that eggshells mixed with lateritic soil can produced the low binding properties and significant to improve strength of the soil which can use as sub grade where have a good performance.

It is concluded that eggshell powders can increase the strength of the soil and it can be suitable stabilizing materials. For the investigation, resulted eggshell powders significantly increase the optimum moisture content and maximum dry density of the soil. As 8% eggshell stabilization lateritic soil processes close optimum moisture content and maximum dry density properties.

2.1.1 Influences of agro-wastes on the physico-mechanical and durability properties of unfired clay blocks (7 February 2022):

The increasing demand for construction materials along with the challenge of waste management has necessitated the development of sustainable materials utilising wastes properly. Therefore, this research examines the utilisation of various agricultural wastes, such as Eggshell Powder (ESP), Sawdust Powder (SDP) and Coconut Husk Powder (CHP), in the production of unfired clay blocks. Samples were made with various percentages of wastes: 10–50% of dry wt. of clay for ESP and 2.5–10% for SDP and CHP. In this study, the physio-mechanical and durability properties of unfired clay blocks were investigated by conducting density, linear shrinkage, capillary water absorption, flexural strength, compressive strength, ultrasonic pulse velocity test, drip test and water spray test. The tests were carried out in two phases, with the first phase including the individual integration of waste in the mixture and the second phase combining ESP (10–30%) with the optimum SDP (2.5%) and CHP (2.5%). The test results show that when the additives were used individually, the 40% ESP samples performed the best whereas for SDP and CHP 2.5% content showed better performance. Contrarily, the samples' overall characteristics deteriorated when ESP, SDP, and CHP were used together. Nevertheless, all the samples met the strength requirement of the standards and passed the durability tests. The results of this study might be useful in assessing the potential of ESP, SDP and CHP for the production of unfired clay blocks as well as finding a feasible solution to the waste management problem. water absorption ration and decreased compressive strength.

2.1.2 The potential of calcium carbide waste and termite mound soil as materials in the production of unfired clay bricks (10 January 2021):

This study investigated the physical, mechanical, thermal and microstructural properties of calcium carbide residue (CC) with chemical admixture (CA) stabilised clay bricks from termite mound clay soil (TMC). Four different mix ratios of B (TMC 70%+cement 30%+ CA 0.1); C (TMC 70%+cement 20%+ CC 10% + CA 0.1); D (TMC 70%+cement 10%+ CC 20% + CA 0.1) and E (TMC 70% + CC 30%+ CA 0.1) were produced, tested and the results compared with the control mix. Thermal conductivity, SEM, XRD and FTIR analyses were conducted to analyse the thermal, morphology and microstructural properties of the mixes. Initial rate of water absorption and water absorption after 2- and 24-hour immersion showed that mixes B and C performed better than the rest with lower values that ranged from 12.5 to 33.3%. Dry shrinkage showed a progressive decrease as the CC content was increased from 10 to 20% in mixes C and D. Wet and dry compressive strengths had optimum performance at 4.33 and 17 MPa respectively for mixes with higher content of cement. The compressive strengths of mixes B, C, D and E fulfilled the minimum criteria of some building standards in some selected developing countries. SEM, XRD and FTIR analyses established that the use of varied CC content influenced the strength behaviour when added to cement and TMC. In conclusion the study has shown that incorporation of calcium carbide (10%), cement (20%) and a chemical additive (0.1) into termite mound clay soil would help in developing improved unfired clay bricks.

2.1.3 Properties of unfired, illitic-clay bricks for sustainable construction (25 January 2021):

Illitic clays are used for brickmaking worldwide. This paper explores the feasibility of using these clays unfired, to lower the environmental impact of construction. The results suggest that illitic clay can be used unfired. The geotechnical parameters of the clay are within the limits considered suitable for earth construction, and the compressive and flexural strengths fall within recommended limits in earth standards. Masonry constructed with the unfired illitic brick, bound with a standard hydraulic-lime mortar would reach a 28-day strength of 2.45 N/mm^2 which meets structural requirements in some European masonry standards. Stabilization improved durability but lowered strength and vapour permeability, and did not significantly change thermal properties. The results suggest that both the quantity and composition of the clay fraction in an earth material determine the success of stabilization. The strength reduction caused by lime stabilization is mainly attributed to the adsorption of the Ca^{2+} by the Illite, which prevents free Ca^{2+} from taking part in the pozzolanic reaction that builds up strength. The extremely high specific surface area of the illitic clay particles (24 m^2 /g) enhanced lime adsorption consequently damaging pozzolanic reaction and strength development. If half of an annual production of 15 million brick was unfired, producers would economise over 4 million euros in kiln fuel and carbon tax in 10 years, and would approximately half their carbon emissions, lowering massively the global environmental impact of brick production.

2.1.4 Stabilised unfired clay bricks for environmental and sustainable use (April 2021):

Currently there is a growing pressure on energy efficiency for new buildings in the UK and worldwide. This has arisen partly due to the increasing awareness of the public for sustainable building construction. In addition, there is pressure on building materials manufacturers, due to new government regulations and legislations that are targeting energy usage and carbon dioxide emissions in new buildings. This paper reports on unfired clay bricks for environmental and sustainable use. Lime or Portland cement was used as an activator to an industrial by-product (Ground Granulated Blast Furnace Slag) to stabilise Lower Oxford Clay for unfired clay brick production. Portland cement was used in the formulation of the unfired clay brick test specimens predominantly as a control. Industrial scale brick specimens were produced during two separate industrial trials. The first trial was at Hanson Brick Company Ltd, Bedfordshire, UK, while the second was carried out at PD Edenhall Ltd, Bridgend, South Wales, UK. sustainability analysis results, the unfired clay material has shown energy-efficiency and suggests a formidable economical alternative to the firing of clay building components. This study is one of the earliest attempts to compare fired and unfired clay technologies, and also to combine energy use and CO_2 emission for the evaluation of unfired clay bricks relative to those bricks used in mainstream construction. This is an attempt to come up with one parameter rating. The overall results suggest that the spinoff from this technology is an invaluable resource for civil engineers and other built environment professionals who need quick access to up-to-Date and accurate information about the qualities of various building and construction materials.

2.1.5 Mechanical and physicochemical performances of reinforced unfired clay bricks with recycled Typha-fibres waste as a construction material additive (June 2021):

The aim of this study is to evaluate the suitability of recycled Typha-fibers waste as a construction material additive to unfired clay bricks. The novel approach of this paper is providing an alternative of damping Typha plants in landfills and waterways, by recycling this waste and putting them into good use as a construction material additive. Physicochemical and performance of prepared brick samples of clay plus recycled Typha-fibres waste additives, at multiple proportions (0%, 1%, 3%, 7%, 15% and 20%) by weight, are investigated according to the Moroccan testing standards in the building sector. A steady-state mixing technique with an electric stirrer, for 10 min and at 95 rpm, was adopted to ensure a homogenous distribution of the fibrous particles inside the clay matrix to produce homogenous mixtures. The used clay was found of type Illite with non-swelling characteristics and a dominant SiO_2 content, 59.6%, following X-ray diffraction and fluorescence tests. The incorporation of high Typha-fibers' waste additives produced more porous bricks; as 20% of additive content reflected the highest recorded porosity, of 14.95%, compared to reference samples, 1.14%. This prompted higher capillary water absorption coefficient with higher Typha-fibers waste proportions. A 55% increase in water absorption was observed with the incorporation of 20% additive content compared to reference samples; yet obtained capillary measurements were under the maximum permissible water absorption limit, according to Moroccan testing standards NM EN 772-11. In addition, bulk density measurements showed that prepared brick samples can be classified as lightweight structures, as their bulk density is lower than 1.75 g/cm. Produced specimens were classified as Earth Blocks Class 4 (EB4), Earth Blocks Class 3 (EB3) and Earth Blocks Class 2 (EB2) according to their recorded compressive strength. It can be deduced that higher Typha-fibres additive content produced good functioning brick samples, following Moroccan and international testing standards, with a more porous and lightweight structures, higher water absorption ratio and decreased compressive strength.

2.1.6 Recycled wastewater treatment plant sludge as a construction material additive to ecological lightweight earth bricks (June 2021):

Sludge disposal has major drawbacks on the environment when damping wastewater treatment sludge in landfills and estuaries. In addition to financial drawbacks manifested by the poor sludge management due to the lack of valorisation regulations or investments' encouragement. This paper analyses the mechanical, physicochemical, and thermal properties of earth bricks of unfired type thanks to their low energy demand and high energy savings' potential. This enables promoting a cleaner production protocol in accordance to the Moroccan testing standards in the building sector. X-ray Diffraction and Fluorescence analysis of the earth and sludge deployed reflected a dominance in Quartz (SiO_2) with a respective 59.6% and 28.37%. This affirms the high clayey composition in the used earth material. Various sludge additive percentages (0%, 1%, 3%, 7%, 15% and 20%) to earth material, by weight, are investigated. Higher sludge content in the brick samples' matrix produced more porous specimens, up to 17%, compared to control samples, of 0% additive content, with 1.04% porosity level. This resulted in higher capillary water absorption coefficient 47.15g/ (cm^2. $Min^{0.5}$) and lower compressive strength

3.95MPa compared to reference values, of 0% additive, of 25.10 g/ ($cm^2.min^{0.5}$) and 6.17MPa, respectively. In addition, bulk density analysis classified produced brick samples as lightweight construction materials, following the Moroccan testing standards. This is due to specimens' respective bulk density does not go beyond the 1.75 g/cm mark. Improvements in thermal performance were also recorded with 43% and 30% gains in thermal conductivity and specific heat capacity properties, respectively, compared to control samples. Moreover, the incorporation of sludge additive into the clayey earth matrix has shown a decrease in the mixtures' pH level. This resulted in producing more porous brick samples with improved thermal properties and lower mechanical compressive strength due to deterioration.

2.1.7 Biomass bottom ash waste and by-products of the acetylene industry as raw materials for unfired bricks (June 2021):

This research aims to study the feasibility of using wastes: biomass bottom ash resulting from the combustion process of a mix of pine-olive pruning in power generation plants, and Geosilex, a by-product obtained in the acetylene industry, as raw materials in the manufacture of unfired bricks. These materials were characterized physically, chemically and mineralogically. Different proportions of raw materials have been investigated; biomass bottom ash (100-20 wt. %) and Geosilex (0–80 wt. %). The specimens were obtained by compression at 10 MPa and cured for 28 days in water. The physical, mechanical and thermal properties of the unfired bricks have been evaluated. Optimum results have been obtained for specimens with 70–60 wt. % of biomass bottom ash and 30–40 wt. % of Geosilex, presenting the best mechanical properties, with compressive strength values of 52 MPa and thermal conductivity of 0.52–0.57 W/make, respectively. These unfired bricks presented a greater quantity of hydrated calcium silicates and hydrated 100% calcium aluminates that provide mechanical properties. This fact is due to that these specimens had the optimal amount of pozzolanic materials, $Ca(OH)_2$ present in the cementing agent Geosilex and SiO_2 and Al_2O_3, present in the ash. Recycling these raw materials in unfired bricks implies significant economic and environmental benefits owing to wastes are used as substitutes for natural raw materials.

2.1.8 Ovalbumin as natural organic binder for stabilizing unfired earth bricks: Understanding vernacular techniques to inspire modern constructions (July–August 2021):

Cement and hydrated lime are usually effective for stabilizing unfired earth but they lead to a significant CO_2 footprint. In the search for sustainable, efficient alternatives, old and vernacular techniques may provide ways of replacing such mineral binders. The example of the use of chicken egg white protein (ovalbumin) to improve earth construction materials is addressed in the present case study. It was used to stabilize two soils with different mineralogical compositions. Addition of 2 wt.% and 4 wt.% ovalbumin strongly increased both the dry and wet compressive strengths (water resistance) of the soils. For these properties, ovalbumin was a more efficient stabilizer than cement or hydrated lime. Concerning hygrothermal properties, the thermal conductivity of the soils did not change with stabilization, while the moisture buffer value decreased slightly but remained at least "good" according to the Nord test criterion. Microstructural analysis can explain the efficiency of earth stabilization using ovalbumin by the formation of a gel that fills the microcracks in the soil and strengthens it by gluing them up.

2.1.9 Synthesis and characterization of sustainable eco-friendly unburned bricks from slate tailings (September–October 2021):

The volume of tailings in the world has increased rapidly in recent years, which poses a substantial ecological threat. With the objective of reducing negative impacts on environment and reuse the abandoned slate tailings, the possibility of making eco-friendly unburned bricks by using slate tailings from Shaanxi Province of China was investigated. Raw materials included slate tailings, fly ash and cement, and bricks were produced through the process of mixing, moulding, and curing. The optimal compressive strength of the product was found at the slate tailings: fly ash: cement = 5:2:3 (wt.%) with 7-day curing at room temperature and 1-day curing in oven, and the forming water content is 15 wt.%. Under these conditions, the compressive strength and water absorption rate were 26 MPa and 14.32% respectively. Other physical properties and durability conform to the Chinese GB/T4111-2013 standard for test methods for concrete blocks and bricks and the Chinese JC/T422-2007 standard for unfired bricks made of tailings. In addition, a variety of methods were combined to explore the formation mechanism. The phase composition, chemical structure and microstructure of the brick are analysed by XRD, SEM and AFM. Finally, molecular dynamics (MD) was used to simulate main cementation component, the hydrated calcium silicate (C–S–H) gel, to advance the understanding of mechanical properties of brick at the nanoscale. The results show that the C–S–H gel formed in the curing process acted as the main adhesive component, and the slate tailings are mainly worked as aggregate skeleton to provide support strength for unburned bricks.

2.1.10 Earthen blocks with natural fibres (2021):

Earthen materials have been used for thousands of years for its easy availability and cost effectiveness. In recent times, earthen materials are gaining its momentum as the entire world understood the need of sustainability in all walks of life. It is mainly used for its sustainability and low environmental impact. To keep up with conventional building materials, fibres are incorporated into the earthen materials to enhance the performance in both strength and durability aspects. This study presents a comprehensive review of studies involving earthen blocks with natural fibres to enhance the performance of the block. Studies done with earthen blocks reinforced with ten natural fibres (viz. Date palm, jute, coconut, Hemp, Sisal, Banana, Chicken, Sugarcane bagasse, Corn, Wool fibres) were reviewed with a brief summary of physical, chemical and mechanical properties. Literature search was conducted using Google Scholar and web of science libraries. Banana fibre, date palm fibre, sugarcane, and jute fibres reinforced blocks are considerably performing better in strength, durability aspects. The adhesion property between fibre and soil are achieved by chemical treatments. Lack of treatment to fibre prior to usage in blocks was observed. Future studies can be conducted on the effect of treatment to fibres and block performance characteristics.

2.1.11 Study of the suitability of unfired clay bricks with polymeric HDPE & PET wastes additives as a construction material (January 2020):

Solid waste quantum rates are increasing as a result of the increasing consumption rate, which is a direct result of population growth, lifestyle upgrade and industrial development. In 2014, 6.852 million tons of solid waste were generated in Morocco; 10% of this portion is attributed to plastics waste. Plastics materials are widely used in every sector from packaging to construction thanks to their easy manipulation and lightweight structure. In fact, the plastics sector in Morocco has expanded to three main districts: transformation and recycling (71%), distribution (27%) and extrusion (2%). Thanks to multiple laws and decrees, the plastics usage has been rationalized in Morocco, by mainly reinforcing the recycling mentality and reinforcing the Moroccan circular economy strategy, by putting the recycled polymeric wastes into good use into certain industries, such as Construction. Using polymeric additives in the construction industry may also contribute in reducing the raw materials and energy consumption or the environmental impact, but will also contribute in developing low-cost clay-based bricks with a lightweight structure, and enhanced thermophysical properties. This study analyses the use of these polymeric waste as additives to produce lightweight clay bricks of an unfired type and analyse their mechanical properties. Another important point this study addresses is the possibility of managing unfired clay-polymer interactions without using any stabilizers, since the fiber composite structure of the polymeric additives used can, itself, provide a soil stabilization mean. Moreover, the main reason behind using stabilizers for polymer-clay bricks is to prevent clay swelling and migration. This will not be a problem since this research deals with an Illite clay type with non-swelling characteristics. And since stabilizers may be used to reinforce the polymer-clay interaction and protect the polymers from degradation, small polymeric additive sizes are studied to evaluate the coagulation and flocculation effect with a stabilizer free intercalation. Literature review shows that many researchers investigated the polymeric wastes performance as a construction material additive. discusses mixing plastic in concrete in an ecological disposal technique for plastics waste; and how PET additives can play the fine aggregation role and increase the brick's corrosion resistance. studies also demonstrated that the use of other industrial substances. For instance, HDPE granules and PET flakes can serve as coarse aggregates. Besides, polymeric waste additives have the ability to produce lighter bricks with improved thermal properties. The main constraint, however, is that the use of plastics as additives decrease the compressive strength of the produced brick. According to Ref, compressive strength decreased by almost 25% when a 15% plastics additive was used stated, however, that the use of smaller plastic granules induces a greater compressive strength. In this study an innovative samples' preparation technique known as Melt-compounding technique is introduced. This technique consists of blending clay with the polymeric additives by heat at constant stirring, in a water-free conditions, to maximize the polymerization process and reinforce the clay-polymer interactions, which is assumed to improve the mechanical performance of the prepared specimens.

2.1.12 Application of agro and non-agro waste materials for unfired earth blocks construction (10 September 2020):

The production process of conventional building materials consumes a high amount of energy which has a negative impact on the environment. The use of locally available materials and upgradation of traditional techniques can be a good option for sustainable development. Consequently, earth has attracted the attention of the researchers as a building construction material for its availability and lower environmental impact. On the other hand, in developing countries waste disposal from the agricultural and industrial sectors raises another serious concern. The scientists have introduced such waste additives into the earth matrix to improve its performance. Therefore, the present paper reviews the state-of-the-art of research on the effects of these various agro and non-agro wastes in the production of unfired earth blocks. This study is divided into three sections: The first section outlines the different types of waste materials and earth blocks considered in the selected papers. The second part deals in depth with the test results of the different properties (density, water absorption, compressive strength, flexural strength and thermal conductivity) of unfired earth blocks containing waste materials. The last section analyses and compares the results with the current earth-building construction standards. The literature survey presents that the waste materials have a clear potential to partly replace earth by complying with certain requirements. Moreover, the application of such wastes for the development of building construction materials provides a solution that decreases energy usage as well as contributes to effective waste management. Future research on establishing guidelines and standards for the development and production of these sustainable unfired earth building materials is recommended.

2.1.13 A state of the art review to enhance the industrial scale waste utilization in sustainable unfired bricks- (10 September 2020):

Manufacturing of unfired bricks, in which fines are stabilized using cementitious or chemical binders, has huge potential to incorporate various wastes as a building construction material. Although researchers have successfully attempted various wastes in unfired bricks at the laboratory scale, their industrial-scale incorporation is still limited and unexplored. From an industrial point of view, mix proportions, mixing strategies, molding methods, and curing conditions are of equal importance. However, the unavailability of comprehensive knowledge related to manufacturing aspects hampers the industrial-scale implementation of research outcomes regarding waste incorporation in unfired bricks. This study summarizes the research outcomes related to waste incorporated unfired bricks, highlighting the manufacturing aspects from the industrial point of view. In this paper, mix proportions attempted, approaches for selecting the liquid content, adopted mixing strategies, compaction parameters, and curing conditions in previous studies are discussed for various waste incorporated bricks. Studies are classified based on the binder used for stabilization, and the effects of influencing parameters on the mechanical performance of bricks are discussed in detail. Furthermore, some industrial challenges related to unfired brick production in Indian scenario are discussed. Studies related to mixture proportioning, mixing optimization and hybrid curing development for a multi-waste incorporated system are expected to be future research trend for waste stabilization in unfired bricks. The comprehensive knowledge presented here is expected to support in the selection of suitable manufacturing aspects, which in turn enhances the waste utilization in unfired bricks at an industrial scale.

2.1.14 Sustainable unfired bricks manufacturing from construction and demolition wastes-(10 April 2018):

The management of construction and demolition wastes is a huge challenge for most Governments. The greatest component of such wastes is concrete and masonry fragments or remains. Among the most common approaches to valorisation of such wastes is to convert them to recycled aggregates, however this may be hampered by low quality of some recycled aggregates compared to natural aggregates. This paper presents the results of experimental investigation where concrete and ceramic remains were used to partially substitute clay soil in producing unfired bricks. The bricks were then tested for mechanical strength, water absorption freeze-thaw resistance. Additionally, the environmental impact of the bricks was assessed based on Life Cycle Analysis (LCA). It was established that concrete waste could be used to substitute up to 50% of the clay whereas ceramic wastes could only substitute a maximum of 30% of the clay. Blended bricks made from clay and concrete waste mixes had a lower mechanical strength than those made from clay and ceramic waste. As regards water absorption, there was no marked difference between the two blends of brick however reduction in water resistance was slightly greater in bricks containing concrete waste that in those containing ceramic wastes. Also, tests showed that freeze thaw resistance was greater in bricks blended with concrete wastes than in those incorporating ceramic wastes. Life Cycle analyses demonstrated that it is the binder content in the mix that largely determines the environmental impact of the blended bricks. Lastly, it was demonstrated that the most desirable technical and environmental credentials of brick material mixes resulted from using the binder combination.

2.1.15 Estimated and real durability of unfired clay bricks: Determining factors and representativeness of the laboratory tests (2017):

This paper presents an analysis of the representativeness of the main laboratory tests and the real durability of earth-based construction materials. For this study, a natural marl soil, mixed with different percentages of silica sand, was treated with Portland cement, hydraulic lime, a mix of lime and ground granulated blast furnace slag and other binder composed of a high magnesium oxide waste mixed with ground granulated blast furnace slag. All the combinations were characterized based on the usual durability related laboratory tests as are: maximum density, unconfined compressive strength, wetting and drying, Swinburne accelerated erosion resistance, capillarity water absorption, total water absorption and freeze/thawing cycles. The results of these tests have been related to the real durability of the Samples for eighteen months of outdoor exposure. They revealed the positive effect of sand adding in the materials durability and the great result of the binder based on magnesium oxide with ground granulated blast furnace slag. It was also demonstrated the representativeness of the water absorption test as a durability indicator of earth-based construction materials

2.1.16 Unfired clay materials and construction (2016):

Strictly speaking, the use of clay soil is not nonconventional. It is only nonconventional compared or in competition with the use and application of the more energy-intensive and less environmentally friendly materials such as concrete and steel. The use of clay-based materials has a long and prehistoric background. Their association with mud huts is correct but not sufficient, and there has been serious rethinking and modernizing, such that clay-based materials can now produce aesthetically pleasant construction. Good workmanship can be achieved for both individual and large-scale housing projects using unfired clay materials, in both developed and developing countries. This chapter focuses on the use of these materials, starting from the basics – the structure of clay soils. An appreciation of clay structure and mineralogy is critical to the unlocking of some of the key steps necessary for soils' optimal performance, more especially on stabilization with either the traditional binders of lime and/or Portland cement and/or any of the emergent sustainable binders that have increasingly become available in the building and construction sectors in the past decade. With this soil science background, the chapter is aimed to capture interest among academicians, researchers, and trainers in the subject. to application, durability, and future trends with clay-based technology, the chapter also has interest with building and construction practitioners, materials manufacturers, and policy makers in both central and local government authorities. All these parties have a common interest in low-cost housing, care for the environment, and the sustainable development of community infrastructure, such as that unparalleled by the uptake of soil-based appropriate technology.

2.1.17 The development of unfired clay building material using Brick Dust Waste and Mercia mudstone clay (December 2014):

This work reports the potential of using Brick Dust Waste (BDW) as a partial substitute for clay in the development of unfired clay building materials (brick, block and mortar). BDW is a waste material from the cutting of fired clay bricks. There are various reasons necessitating the cutting of bricks -corner bricks, construction of chimneys, and other uses needing bricks of various shapes and sizes. This results in the disposal of BDW as an environmental problem of concern. In order to investigate the clay replacement potential of BDW, four types of mixes were designed at varying BDW replacement levels - 5%, 10%, 15% and 20%. Ground Granulated Blast Furnace Slag, an industrial by-product from steel manufacture was activated using quick lime and the mixture was used to stabilise Mercia mudstone clay for unfired clay production. The 56-day compressive results using cylinder test specimens showed a significant strength gain (up to 2.1 N/mm^2). Overall, the results suggest that it is possible to develop unfired clay building material using up to 20% BDW as partial substitutes for primary clay.

2.1.18 Alumina filler waste as clay replacement material for unfired brick production (19 August 2013):

This paper presents the results of an investigation for the application of alumina filler wastes and coal ash waste for unfired brick production. Mechanical test and durability assessment were carried out on unfired brick test specimens made using marl clay soil and alumina filler waste as a target material, and 70% mix of coal ash waste were used as commercials additive (Portland cement and Lime) replacement. The laboratory results demonstrate that the compressive strength resistance of the unfired bricks reduced as the clay replacement level increased. The unfired brick test specimens made with the blended mixtures containing coal ash waste and lime tended to achieve higher strength values when compared with the coal ash waste and Portland cement blends. The unfired brick test specimens were able to withstand the repeated 48-hour freezing/thawing cycles. The results obtained suggest that there is potential to manufacture unfired bricks from alumina filler waste and coal ash waste.

2.1.19 Engineering properties of unfired clay masonry bricks (14 August 2009):

The shortage of low cost and affordable housing in the UK has led to many investigations into new building masonry materials. Fired clay masonry bricks are conventionally used for mainstream masonry wall construction but suffer from the rising price of energy plus other related environmental problems such as high energy usage and carbon dioxide emission. The use of stabilised unfired clay bricks for masonry construction may solve these problems. This paper reports on the engineering properties of unfired clay bricks produced during the first industrial trial of unfired clay material development carried out at Hanson Brick Company, in Stewartby, Bedfordshire, under the Knowledge Exploitation Fund (KEF) Collaborative Industrial Research Project (CIRP) programme. The mixes were formulated using a locally available industrial by-product (Ground Granulated Blast Furnace Slag- GGBS) which is activated with an alkaline (lime or Portland cement) combined with clay soil. Portland cement was not used in the formulation of the unfired stabilised masonry bricks, except as a control, which is a significant scientific breakthrough for the building industry. Another breakthrough is the fact that only about 1.5% lime was used for GGBS activation. This level of lime is not sufficient for most road construction applications where less strength values are needed and where 3–8% lime is required for effective soil stabilisation. Hence, the final pricing of the unfired clay bricks is expected to be relatively low. The laboratory results demonstrate that the compressive strength, moisture content, rate of water absorption, percentage of void, density and durability assessment (repeated 24-hour freezing/thawing cycles) were all within the acceptable engineering standards for clay masonry units. The paper also discusses on the environmental performance of the unfired clay in comparison to the bricks, used in mainstream construction of today. The bricks produced using this technology can be used for low-medium cost housing and energy efficient masonry wall construction.

2.1.20 Compressive strength and microstructural analysis of unfired clay masonry bricks (2009):

This paper reports on the compressive strength and microstructure of unfired clay masonry bricks. Blended binders comprising of lime-activated Ground Granulated Blast

Furnace Slag (GGBS) and Portland Cement (PC)-activated GGBS were used to stabilise Lower Oxford Clay (LOC) for unfired masonry brick production. The compressive strength of the stabilised bricks incorporating lime–GGBS–LOC was higher than that of PC–GGBS–LOC. Scanning Electron Microscopy (SEM) with a Solid-state Backscattered Detector (SBD) and Energy Dispersive X-ray (EDX) analysis was employed to obtain a view of the microstructure and to conduct an analysis on the morphology and composition of the dried unfired clay brick samples, after 28 days of moist curing. The analytical results together with the physical observations have shown the formation of Calcium Silicate Hydrate (C-S-H) gel and additional pozzolanic (C-S-H) gel. The quantification of the compound content of the unfired bricks showed the presence of Calcite ($CaCO_3$), Quartz (SiO_2), Alumina (Al_2O_3) and Wollastonite ($CaSiO_8$) crystals. Traces of other crystals were also detected.

CHAPTER 3

OBJECTIVES

Utilization of waste in the production of bricks can help in conservation of natural resources like clay. Since the present scenario is damping the wastes landfill sites, it leads to cause various environment problems. The main objective of this present study is to investigate the properties of bricks produced by partial replacement of sand with coconut coir, egg shell powder and waste glass powder.

- To reduce the quantity of soil for making bricks with natural waste materials.
- To check the feasibility of coconut coir, egg shell powder and waste glass powder as a partial replacement for soil in the preparation of bricks.
- To compare the compressive strength and water absorption of soil brick admixed with additives and conventional brick.
- To produce the light weight and eco-friendly brick suitable for low-cost construction.
- To minimize the burden of agro waste (coconut coir), biodegradable (egg shell powder) and non-biodegradable waste (waste glass powder) on environmental and dumping issue.

3.1MATERIALS

3.1.1 SOIL

Laterite soils are red in colour due to little clay and more gravel of red sand-stones. Laterite soils have high clay content, which mean they have higher Caption Exchange Capacity and water-holding capacity than sandy soils. They are formed under condition of high temperature and heavy rainfall with alternate wet and dry periods.

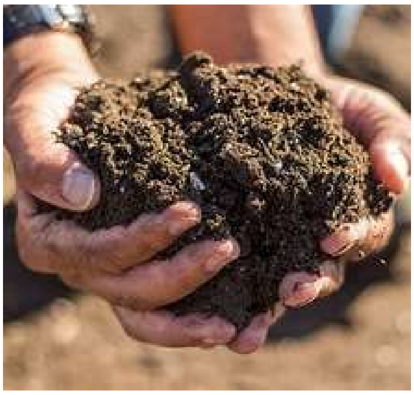

Fig. Soil

Soil is a mixture of organic matter, minerals, gases, liquids, and, organisms that together support life. Soil is a building material has good physical properties when considering energy conscious and ecological design, and also fulfills all strength. Soil is directly used to make building materials, such as cement and brick, as well as indirectly used to grow the plants used to make building materials. The soil is usually formed when rocks break up into their constituent parts. When a range of different forces act on the rocks, they break into smaller parts to form the soil. These forces also include the impact of wind, water and the reaction from salts. The formation of soil from rocks (Pedogenesis) starts with environmental weathering of the original rock. This releases nutrients which attract microbes. Their activity forms acids which further contribute to the conversion of the material. All rocks start out as igneous rock from the beginning of Earth history where molten rock cools.

3.1.2 COCONUT COIR

Fig. Coconut coir fiber

Coconut coir fibre is a natural fibre extracted Coconut from the husk of coconut. It is the fibrous material found coconut. Coconut fibre cells are narrow and hollow, between the hard, internal shell and outer coat of a with thick walls made of cellulose. Each cell is about 1 mm (0.04 in) long and 10 to 20 mm (0.0004to 0.0008 in) in diameter. Fibers are typically 10 to 30 centimetres (4 to 12 in) long. Coconut Shell is the strongest part covered in coconut fruit. Coconut shell is located in between the coconut flesh and coconut husk.

- Coconut fiber is extracted from the outer shell of a coconut.
- Coconut fibers have low thermal conductivity while being tough and stiff.
- Coconut fiber amongst all-natural fibers is the most ductile
- Coconut fibers have the capacity of taking strain 4-6 times more than that of other natural fibers.

Physical and Mechanical properties:

The physical and mechanical properties of coconut fibers are presented. The conditions specifically mentioned by the researchers are given at the end of table. Coconut fibers were investigated by many researchers for different purposes. There is a huge difference in some properties, e.g., diameter of coconut fibers is approximately same and magnitudes of tensile strength are quite different. There are variations in properties of coconut fibers, and this makes it difficult for their frequent use as construction material. The purpose of compilation of data for the properties of fibers is to get a guideline, but after compilation, a huge variation is seen. There should be some standards for such variations, just like we have standards for sand and aggregates.

Chemical Properties:

Coconut husk contain cellulose, hemi-cellulose and lignin as major composition. These compositions affect the different properties of coconut husk. The pre-treatment of husk changes the composition and ultimately changes not only its properties but also the properties of composites. Some-times it improves the behaviour of husk but sometimes its effect is not favourable.

Coconut fiber are agricultural waste products obtained in the processing of coconut oil and are available in large quantities in the tropical regions of the world, most especially in Africa, Asia and America. Coconut fiber are not commonly used in the construction industry but are often dumped as agricultural wastes. However, with the quest for affordable housing system for both the rural and urban population in the developing countries, various schemes focusing on cutting down conventional building material costs have been put forward.

3.1.3 WASTE GLASS POWDER

Fig: waste glass powder

Glass is an ideal material for recycling. The glass powder is a pozzolanic material, The glass powder is increasing the strength and durability of concrete when using suitable percentage. Glass is an inert material which could be recycled and used many times without changing its chemical property. The glass powder properties should be satisfying the cement properties. Glass is crushed into specified sizes for use as aggregate in various applications such as water filtration, grit plastering and sand replacement in concrete.

The boron glass powder and soda lime glass powder are collected from the industries. Boron glass powder are the classification of window panels and glass containers etc., and soda lime glass powders are under the classification of reagent bottles, medical devices and optical etc., Glass powder passing less than 75µm is used in the production of bricks.

3.1.4 EGG SHELL POWDER

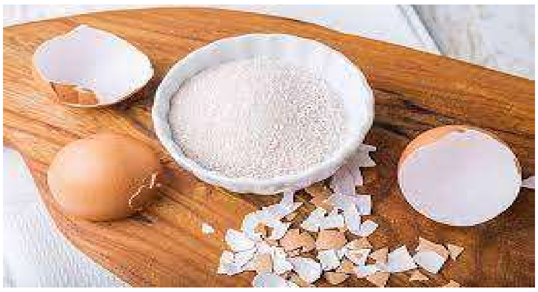

Fig. Egg Shell powder

The use of eggshell powder in concrete production reduced the cost of raw material and contributes to the construction industry. Thus, eggshells can be applicable to reduced cost of construction material and produced a new raw material for development in the construction industry. Eggshell powder is an effective calcium supplement

However, the eggshell waste powder is rich in Cao content derived from calcination of calcite ($CaCO_3$). And it is essential in a pozzolanic reaction to influence some cementitious properties in clay bricks. The result of the study showed that the powdered eggshell has substantial amount of calcium compounds (64.8%), compressive strength of the bricks increased by 31.8%, 53.7%, 60.3% and 1.6% as eggshells content were 10%, 20%, 30% and 40% respectively

CHAPTER 4

METHODOLOGY

General tests

↓

Specific gravity | Water content | Plastic limit | Liquid limit | Compaction test

↓

Casting of soil bricks
230 × 115 × 75mm as per IS 1077:1992

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Curing at room temperature

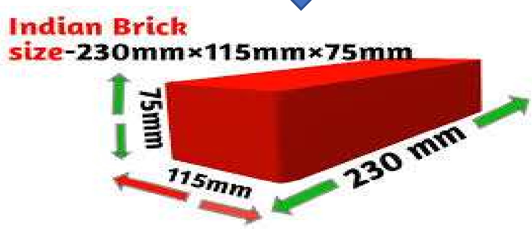
↓

Testing after curing

↓

Water absorption test | Compressibility test | Drop test | Bond test

↓



CHAPTER 5

BASIC TEST FOR TESTING SOIL

SPECIFIC GRAVITY

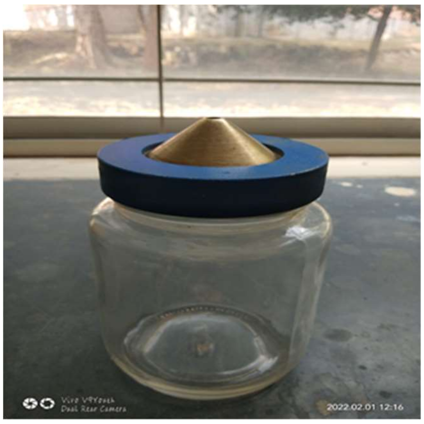


Fig: Pycnometer

Specific gravity ***G*** is the ratio of the weight of an equal volume of distilled waters at that temperature both weights taken in air.

PROCEDURE:

- Take the empty weight of the pycnometer. (W_1).
- Take sample of fine aggregate for which specific gravity has to be found out and transfer that to be the empty pycnometer and then it is weighed. (w_2)
- The flask with sample is filled with water up to a mark made on the flask and its weight is taken. (W_3)
- Then the flask is emptied and thoroughly washed. after washing the flask is filled with the water up to the mark made on the pycnometer and its weight is taken, the pycnometer should be completely dry on the outer face. (W_4)
- Calculate the specific gravity of the fine aggregate sample by formula
- Specific gravity =dry weight of aggregate/weight of equal volume of water

$$= (W_2 - W_1)/[(W_2 - W_1) - (W_3 - W_4)]$$

WATER CONTENT

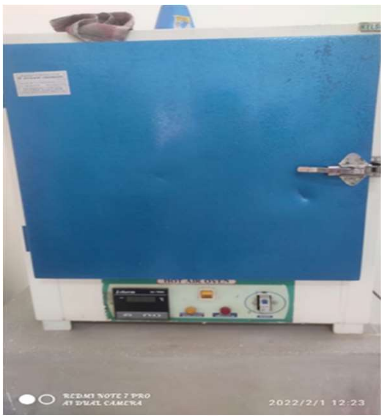


Fig: oven

The natural water content also called the natural moisture content is the ratio of the weight of water to the weight of the solids in a given mass of soil. The ratio is usually expressed as percentage.

PROCEDURE:

1] Clean the containers with lid dry it and weigh it (w_1).

2] Take a specimen of the specimen of the sample in the container and weigh with lid. (w_2).

3] Keep the container in the oven with lid removed. Dry the specimen to constant weigh maintaining the temperature between 105^0 C to 110^0 C for a period varying with the type of soil but usually 16 to 24 hours.

4] Record the final constant weigh (w_3) of the container with dried soil sample. Peat and other organic soils are to be dried at lower temperature (say 60^0) possibly for a longer period.

$$W=[(W_2-W_3)/(W_3-W_1)] \times 100$$

PLASTIC LIMIT

The plastic limit of a soil is the moisture content, expressed as a percentage of the weight of the oven-dry soil, at the boundary between the plastic and semisolid states of consistency. It is the moisture content at which a soil will just begin to crumble when rolled into a thread 3 mm in diameter using a ground glass plate or other acceptable surface.

As moisture contents increase, clay and silt soils go through four distinct states of consistence: solid, semi-solid, plastic, and liquid. Each stage exhibits significant differences in strength, consistency, and behaviour. Atterberg limit test accurately defined the boundaries between these states using moisture content at the points where the physical changes occur. The test values and derived indexes have direct applications in the foundation design of structures and in predicting the behaviour of soils infills, embankments, and pavements. The values assess shear strength, estimate permeability, forecast settlement, and identify potentially expansive soils.

PROCEDURE:

- Take about 20gm of thoroughly mixed portion of the material passing through 425-micron I.S. sieve obtained in accordance with I.S 2720 (Part1).
- Mix it thoroughly with distilled water in the evaporating dish till the soil mass becomes plastic enough be easily moulded with fingers.
- Take about 10 grams of this plastic soil mass and roll it between fingers and glass plate with just sufficient pressure to roll the mass into a threaded of uniform diameter throughout its length. The rate of rolling shall be between 60 and 90 strokes per minute.
- Continue rolling till you get a threaded of 3mm diameter.
- Kneed the soil together to a uniform mass and reroll
- Continue the process until the thread crumbles when the diameter is 3mm
- Collect the pieces of the crumbled thread in air tight container for moisture content determination.
- Repeat the test to at least 3 times and take the average of the result calculated to the nearest whole numbers.

LIQUID LIMIT

Fig. Casagrande Liquid Limit Apparatus

The liquid limit is the moisture content at which the groove, formed by a standard tool into the sample of soil taken in the standard cup, closes for 10 mm on being given 25 blows in a standard manner. At this limit the soil possess low shear strength.

PROCEDURE:

1. About 120 gm of air-dried soil from thoroughly mixed portion of material passing 425 micron I.S sieve is to be obtained.
2. Distilled water is mixed to the soil thus obtained in a mixing disc to form uniform paste. The paste shall have a consistency that would require 30 to 35 drops of cup to cause closer of standard groove for sufficient length.
3. A portion of the paste is placed in the cup of LIQUID LIMIT device and spread into portion with few strokes of spatula.
4. Trim it to a depth of 1cm at the point of maximum thickness and return excess of soil to the dish.
5. The soil in the cup shall be divided by the firm strokes of the grooving tool along the diameter through the centre line of the follower so that clean sharp groove of proper dimension is formed.
6. Lift and drop the cup by turning crank at the rate of two revolutions per second until the two halves of soil cake come in contact with each other for a length of about 1 cm by flow only.
7. The number of blows required to cause the groove close for about 1 cm shall be recorded.
8. A representative portion of soil is taken from the cup for water content determination.
9. Repeat the test with different moisture contents at least three more times for blows between 10 and 40.

PROCTOR'S COMPACTION TEST

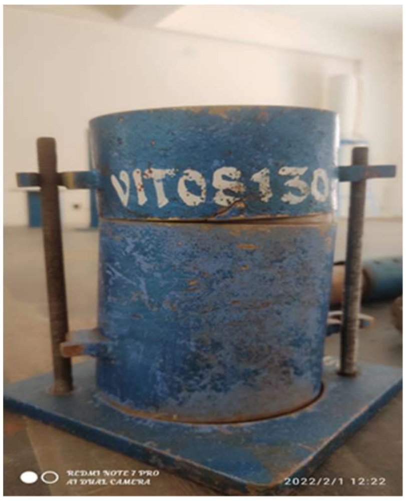


Fig. Proctor's Compaction Cylinder

Soil compaction is one of the ground improvement techniques. It is a process in which by expending compactive energy on soil, the soil grains are more closely rearranged. Compaction increases the shear strength of soil and reduces its compressibility and permeability

PROCEDURE

1. Obtain about 3 kg of soil.
2. Pass the soil through the No. 4 sieve.
3. Weight the soil mass and the mold without the collar (W_m).
4. Place the soil in the mixer and gradually add water to reach the desired moisture content (w).
5. Apply lubricant to the collar.
6. Remove the soil from the mixer and place it in the mold in 3 layers or 5 layers depending on the method utilized (Standard Proctor or Modified Proctor). For each layer, initiate the compaction process with 25 blows per layer. The drops are applied manually or mechanically at a steady rate. The soil mass should fill the mold and extend into the collar but not more than ~1 centimeter.

7. Carefully remove the collar and trim the soil that extends above the mold with a sharpened straight edge.
8. Weight the mold and the containing soil (W).
9. Extrude the soil from the mold using a metallic extruder, making sure that the extruder and the mold are in-line.
10. Measure the water content from the top, middle and bottom of the sample.
11. Place the soil again in the mixer and add water to achieve higher water content, w.

CALIFORNIA BEARING RATIO TEST:

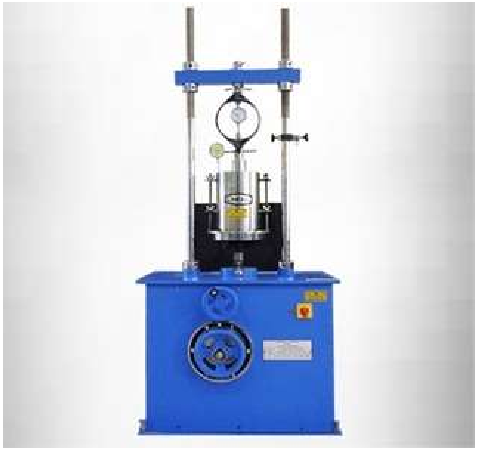


Fig. CBR Apparatus

A mould is filled with the soil specimen. It is compacted into the mould with a rammer. Then the mould is soaked in water for a certain period of time. Then a loading machine is used to apply load on a plunger. This will penetrate through the soil mould. The machine will penetrate through the soil by increasing the load gradually. There are one proving ring and one dial gauge attached to the machine. The dial gauge indicates the penetration amount. The proving ring indicates the amount of load machine is applying to the surface. For certain amounts of penetrations, corresponding load values have to be recorded. Later stress vs penetration curve is drawn.

From that curve, both for 1 in (2.54 mm) & 2 in (5.08 mm) penetration, corresponding stress value is determined. These values are used in the equation mentioned above to calculate the CBR value.

PROCEDURE

1. A 425-micron sieve is used to sieve the soil specimen. If all material passes through the sieve, we can use all of it for the test. But some of the material might be retained in the sieve. In that situation have to replace the retained amount with an equal amount of the materials which pass 425 microns in the sieve and retained 300 microns on the sieve. After sieving, make 3 sample specimens each containing 6.8 kg.
2. Specimen 1,2,3 will be compacted with about 10, 30 & 56 blows respectively. This will provide variations in the percentage of maximum dry density.
3. Sufficient amounts of water shall be mixed with specimens to maintain optimum water content.
4. The mould shall be attached to the base plate with the extension collar. Then the weight shall be measured. Then a spacer disk shall be placed into the mould with a filter paper on top of the spacer disk.
5. The mould shall be filled with soil in 3 layers. For example: for specimen 1, we have to provide 10 blows per layer with the rammer for the compaction. The water content of the material shall be determined before and after the compaction procedure.
6. Then the extension collar shall be removed and the top of the mould shall be trimmed with a straightedge to smoothen the surface.
7. The other two specimens shall be compacted following the same procedures mentioned above.
8. Remove spacer disk, base plate. then the weight of Meld plus compacted soil shall be measured.
9. Then invert the mould and soil and attach the base plate to the mould with a coarse filter paper.

DIRECT SHEAR TEST

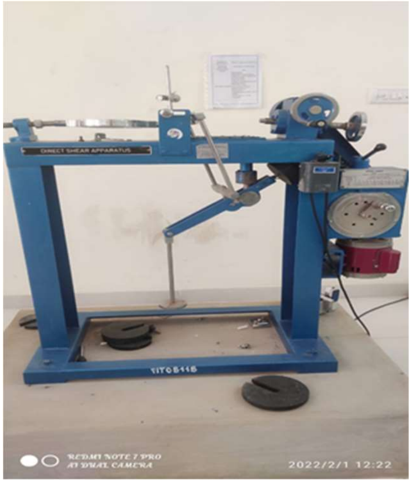


Fig: direct shear apparatus

Shear strength of a soil is its maximum resistance to shearing stresses. The shear strength is expressed as were

$$s = c' + \overline{\sigma} \tan \phi'$$

C' = Effective cohesion
$\overline{\sigma}$ = Effective stress
ϕ' = Effective angle of shearing resistance

Using direct shear test, one can find out the cohesion and angle of internal friction of soil which are useful in many engineering designs such as foundations, retaining walls, etc. This test can be performed in three different drainage conditions namely unconsolidated-undrained, consolidated-undrained and consolidated-drained conditions. In general, cohesionless soils are tested for direct shear in consolidated drained condition.

PROCEDURE:

- Measure the dimension of the shear box and calculate the area of cross section (A)
- Insert the locking keys of the shear box
- Weigh a dish containing dry cohesionless soil to be tested. Place the bottom grip plate. Place the soil in the shear box kept on a plane surface, tamp it gently and make a level surface. Keep the top grip plate. Weigh the dish again and get the weight of the soil used.

- Determine the thickness of the soil specimen including the thickness of grip plates by measuring the total height of the shear box and the height above the top grip plate. There shall be sufficient thickness of the soil sample above the potential horizontal failure plane.

- Place the loading block on the top of the grip plate

- Apply the desired normal load namely, 0.5,1.0,1.5 and 2.0 kg/cm^2, one after the other, in available machine

- Fix the dial gauges to measure the horizontal and vertical moments. Note the initial reading

- Remove the locking keys of the shear box without forgetting

- Apply the shear stress to the sample at the specified rate of shear displacement (usually 1.25mm/min for undrained quick tests). Take the reading on 2 dial gauge and proving ring at suitable intervals of shear displacement (say at every 0.2mm horizontal displacement up to about 2mm and at every 0.5mm their after) continue the test up to failure

- Repeat the above test on 3 more samples of the same soil, at the same density but with different normal loads.

- For each test, draw the shear stress v/s shear displacement graph and find the peak value $\tau_{max.}$ when there is no clear peak observed, the failure stress may be taken as that corresponding to 15% shear strain.

- Finally plot a graph between normal stress and peak value of shear stress. Thus, find the angle of internal friction.

UNCONFINED COMPRESSIVE STRENGTH

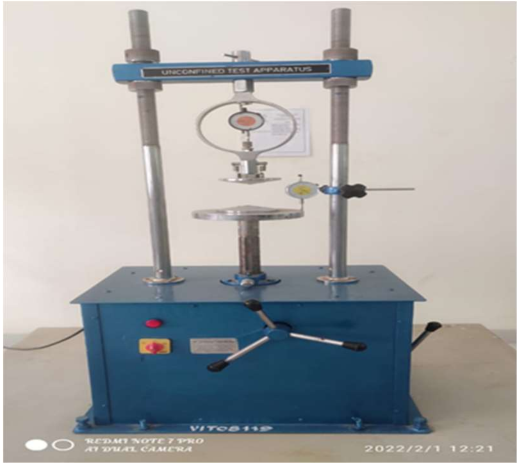


Fig: unconfined compress apparatus

PROCEDURE

- Place the sampling soil specimen at the desired water content and density in the large mould.
- Push the sampling tube into the large mould and remove the sampling tube filled with the soil. For undisturbed samples, push the sampling tube into the clay sample.
- Saturate the soil sample in the sampling tube by a suitable method.
- Coat the split mould lightly with a thin layer of grease. Weigh the mould.
- Extrude the sample out of the sampling tube into the split mould, using the sample extractor and the knife.
- Trim the two ends of the specimen in the split mould. Weigh the mould with the specimen.
- Remove the specimen from the split mould by splitting the mould into two parts.
- Measure the length and diameter of the specimen with vernier callipers.
- Place the specimen on the bottom plate of the compression machine. Adjust the upper plate to make contact with the specimen.
- Adjust the dial gauge and the proving ring gauge to zero.
- Apply the compression load to cause an axial strain at the rate of ½ to 2% per minute.

- Record the dial gauge reading, and the proving ring reading every thirty seconds up to a strain of 6%. The reading may be taken after every 60 seconds for a strain between 6%, 12% and every 2minutes or so beyond 12%.
- Continue the test until failure surfaces have clearly developed or until an axial strain of 20% is reached.
- Measure the angle between the failure surface and the horizontal, if possible.
- Take the sample from the failure zone of the specimen for the water content det

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