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**ANALYSIS OF MECHANICAL PROPERTIES
OF CELLULAR LIGHTWEIGHT CONCRETE
CONTAINING BAGASSE ASH**

A Thesis in stream of Construction Technology and Management

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A Thesis

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ABSTRACT

The cellular lightweight concrete (CLC) or sometimes might often called that foamed concrete is either a cement paste or mortar, classified as lightweight concrete, in which air voids are entrapped in mortar by suitable foaming agent. This research study various mechanical properties of compressive strength, dry density and water absorption of cellular lightweight concrete (CLC), which made from ordinary portland cement, sand, bagasse ash and foaming agent admixture. Bagasse ash use to replace cement in different proportions from 5 to 30 percent by volume of cement. Optimum replacement percentage is determined using cement-sand mortar then applies in CLC. Optimum bagasse ash present is a percentage which gives same or higher performance compare with CLC without bagasse ash. Different mix of CLC with constant water to binder ratio of 0.5, 1.5% foaming admixture and target density of 1600 kg/m^3 were tested. 10% replacement of cement with bagasse ash slightly increases compressive strength and dry density, while 15% replacement of cement gives almost same strength with the control mix. The study result shows that replacing cement with bagasse ash up to 15% improves mechanical properties of CLC such as compressive strength, dry density, water absorption and plastic shrinkage.

Key Words: Cellular Lightweight Concrete, Bagasse Ash, Foaming Agent Admixture, Mechanical Properties

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LIST OF ABBREVIATIONS

ACI	American concrete Institute
ASTM	American Society for Testing and Materials International
BA	Bagasse Ash
CLC	Cellular Lightweight Concrete
CLCB	Cellular Lightweight Concrete Block
CLCBA	Cellular Lightweight Concrete Contains Bagasse Ash
ES	Ethiopian Standard
FA	Foaming Agent
HCB	Hallow Concrete Block
LWC	Lightweight Concrete
OPC	Ordinary Portland cement
W/C	Water to Cement Ratio
W/B	Water to Binder Ratio

CHAPTER ONE

INTRODUCTION

1.1. Background

Cellular Concrete was first developed in Stockholm, Sweden in the early 1900's. The original material was known as "gas concrete" to be used in producing heat-insulated building materials. This led to the development of related lightweight concrete which are now known as cellular concrete, foamed concrete, aerated concrete and autoclaved cellular concrete [1].

After the Second World War, this technology quickly spread to different parts of the world, mostly Europe and the Soviet Union. A detailed study concerning the composition, physical properties and production of foamed concrete was first carried out in the 1950s and 60s. Following this research, new admixtures were developed in the late 1970s and early 80s, which led to the commercial use of foamed concrete in construction projects. The applications were for floor, roof and wall units. Having low compression strengths, it limited this product to fills and insulation only [2].

Foamed concrete, also called cellular light weight concrete is produced by the mixing of Portland cement, sand including or alone fly ash, water and preformed stable foam (or Foaming Admixture). The foam is produced with the help of a foam generator by using foaming agent. The air content is typically between 30 to 80 percent of the total volume. The bubbles vary in size from around 0.1 to 1.5 mm in diameter [3].

The role of foaming agents in cellular concrete is to create small and enclosed air bubbles by reducing the surface tension of a solution and increasing the stability of air bubbles. Foamed concrete differentiates from (a) gas or aerated concrete, where the bubbles are chemically formed through the reaction of aluminium powder with calcium hydroxide and other alkalis released by cement hydration and (b) air entrained concrete, which has a much lower volume of entrained air is used in concrete for durability. Presently, cellular concrete is used for sound and heat insulation, building blocks and panels, fire protection wall, energy absorbing pads in roads, road sub-base, structural fill, foundations, geotechnical and mine fill applications [4].

In present days; Ethiopia has lots of building projects, so finding alternative construction material is one of the solutions to construct economical and sustainable buildings. This study

deals with the possibility of producing cellular light weight concrete by partially replacing cement with locally available pozzolanic material (Bagasse ash) instead of fly ash and checking its mechanical properties as alternative wall making material.

1.2. Definitions

Concrete

According to PCA (design and control concrete mixture book), Concrete is defined as a mixture of two components: aggregates and paste. The paste, comprised of Portland cement and water, binds the aggregates (usually sand and gravel or crushed stone) into a rock like mass as the paste hardens because of the chemical reaction of the cement and water

Hydraulic Cement

Is a blending material that sets and hardens by chemical reaction with water and capable of doing so underwater. For example Portland cement and slag cement are hydraulic cements.

Aggregate

According to ACI terminology, aggregate is a granular material, such as sand, gravel, crushed stone, crushed hydraulic cement concrete, or iron blast-furnace slag, used with a cementing medium to produce either concrete or mortar.

Lightweight concrete

Lightweight concrete is a concrete that has a density lower than that of conventional concrete. The density may range from 300 kg/m³ to 2000 kg/m³ compared to normal concrete that has a density around 2300kg/m³ to 2400kg/m³ [5].

Cellular lightweight concrete

The cellular lightweight concrete (CLC) or sometimes might often call that foamed concrete is either a cement paste or mortar, classified as lightweight concrete, in which air voids are entrapped in mortar by suitable foaming agent. Cellular light weight concrete is produced by the mixing of Portland cement, sand including or alone fly ash, water and suitable foaming agent [6]. Foam concrete is produced either by pre-foaming method or mixed foaming method.

Foaming agent

Foaming agent is a material that facilitates formation of foam. The role of foaming agents in cellular concrete is to create small and enclosed air bubbles by reducing the surface tension of a solution and increasing the stability of air bubbles. Typically, surfactant or synthetic and protein foaming agents are used in cellular concrete [7]. Both types of agents reduce the surface tension of the solution, which facilitates the formation of stable air bubbles.

Sugarcane Bagasse Ash

Sugarcane bagasse ash is combustion by product of sugar cane bagasse in sugar mill industries [8]. Because of its good pozzolanic performance, bagasse ash has been suggested as an excellent alternative cementitious material in several previous research studies. Disposal of bagasse ash is a critical issue for sugar industries because of environmental constraints and land requirement [9].

1.3. Statement of the problem

In most of building constructions has been used Hollow Concrete Block as a partition material. The current HCB (Hollow concrete block) has some drawbacks in quality, performance and suitability [10]. A quality can be a material quality, production quality and quality of produced block. The quality of mentioned subjects directly related with the class of the block. As any partition material, HCB should fulfil basic performance criteria's such as strength, sound insulation, heat insulation, fire resistance and weather resistance. Suitability of HCB directly related with construction time, cost, versatile usage, availability and workability.

In recent years, construction material producers are introducing Gypsum board, Magnesium board, Hydra foam blocks and Agro stone. The acceptance and usage of those materials are not usual due to their performance, familiarity and availability. To come up with the above mentioned problems, the sector need a material which achieves basic standard requirements and performance criteria's without high increment of cost. In this paper, cellular lightweight concrete has been introduced as alternative wall making material by using locally available raw materials such as cement, sand and bagasse ash. And it will be tested to check basic mechanical properties, and also cost efficiency.

To achieve the above building requirements, cellular light weight concrete is an alternative option due to its properties of light weight, good thermal insulation characteristics and also can be formed as blocks and precast panels. In the past studies, using cast insitu or precast CLC (cellular lightweight concrete) minimize construction time and also machinery and workmanship cost [5]. Bagasse ash is waste product from sugar factories which has pozzolanic characteristics. In addition of the above advantages, partially replacing cement with bagasse ash in CLC production also used for sustainable waste disposal management.

1.4. Research Motivation and Objectives

Ethiopia has a vast construction activity that needs versatile concrete technology and alternative construction materials. Motivation of this thesis is to develop a new economical multipurpose lightweight concrete that can use as alternative solution and easily adapt to the construction industry. Considering the above motivation, cellular lightweight concrete is propose as alternative material due to its performance, different application area and easy adaptation.

In many countries, researchers use fly ash as a supplementary Cementous material in cellular lightweight concrete (CLC) to enhance fresh and long term concrete properties. In this study, instead of using fly ash; locally available sugarcane bagasse ash used to produce CLC and its mechanical properties are analyse. Beside above reasons, utilization of sugarcane bagasse ash for production of CLC will support for eco-friendly and proper waste disposal.

The purpose of this work is to evaluate the mechanical properties of cellular lightweight concrete containing bagasse ash as alternative wall making material. It consist cement, sand, bagasse ash and up to 35% of air voids.

General objective

- The purpose of this research is to produce economical and multipurpose cellular lightweight concrete by using cement, sand and bagasse ash; mean while improving the mechanical properties.

Specific objective

- Analyse mechanical properties of cellular lightweight concrete containing locally available bagasse ash as partial replacement of cement to achieve better mechanical properties.

- The experimental study aim to determine optimum foaming agent (air entrained admixture), bagasse ash replacement dosage to produce CLC concrete that satisfy existing wall making material requirements.

CHAPTER TWO

LITERATURE REVIEW

2.1. Lightweight Concrete

Lightweight concrete is a concrete that has a density lower than that of conventional concrete. The density may range from 300 kg/m^3 to 2000 kg/m^3 compared to normal concrete that has a density around 2300 kg/m^3 to 2400 kg/m^3 [5].

It was first introduced by the Romans in the second century where ‘The Pantheon’ has been constructed using pumice, the most common type of aggregate used in that particular year [2]. From there on, the use of lightweight concrete has been widely spread across other countries such as USA, United Kingdom and Sweden [6].

The specific gravity of concrete can be lowered either by using porous lightweight aggregates instead of ordinary ones, or introducing air into the mortar, or removing the fine fractions of aggregate and compacting concrete only partially. In all cases, the main goal is to introduce voids into the aggregate and the mortar or between mortar and aggregate. A combination of these methods can also be made in order to reduce further the weight of concrete. The use of lightweight aggregates is by far the simplest and most commonly used method of making a lightweight concrete [7].

Due to material variability and formulation from place to place, the classification of lightweight concrete is currently based on its density. This is because in most cases the strength and the density of concrete are directly related [5]. According to ACI 213R-18 classifies lightweight concrete according to its density and applications as shown below [12]:

Low density concrete: This lightweight concrete has a density ranging from 300 kg/m^3 – 1000 kg/m^3 . It is used as a non-load-bearing part of a building, such as insulation and partitions. The strength of this concrete is less than 7 MPa, and the aggregates most commonly used are vermiculite and perlite.

Medium density concrete: has a density around 1000 kg/m^3 to 1600 kg/m^3 . The major aggregates used in this type of concrete are pumice and scoria. This type of concrete is generally a cementitious product which can be used as a load-bearing material. The minimum strength of this type of concrete is around 17 MPa.

Moderate density concrete: has a density interval between 1600 kg/m^3 to 2200 kg/m^3 can also be referred to as structural lightweight concrete and is used for load-bearing structures. Aggregates used in this type of concrete are mainly pulverized fuel ash, expanded slag and shale.

2.2. Advantages and Disadvantages of Lightweight Concrete (LWC)

Compared to traditional concrete, lightweight concrete provides several benefits which can be divided into three perspectives: [5]

1. Engineering

Reduction of Dead Load: The mass per unit strength is lower in lightweight concrete. This offers significant advantages in reducing the self-weight of concrete structures such as high-rise buildings.

Seismic / Earthquake reaction: Lightweight concrete is better at absorbing shock reactions compared to ordinary concrete. Lightweight concrete can easily absorb impact loads without damaging the concrete.

Insulation: Based on the experiment done by Abrams (1979) and Neville (1981) on thermal conductivity of concrete showed that lightweight concrete has lower thermal conductivity than ordinary concrete. Therefore, it can be assumed that the fire resistance of lightweight concrete is better and hence the insulation properties are greatly enhanced. This is due to the porous nature of the concrete and the reduction of the spalling effect due to expansion of entrapped water [13].

Sound absorption: John (1997) suggested that the transmission of noise is inversely related to the air interface of concrete. In addition, as lightweight concrete is energy absorbent in nature, more sound will be absorbed by the material [4].

Flexibility and ease: John (1997) found that lightweight concrete can be modified without difficulty. Ordinary tools can be utilized for alteration without the need of pre-drilling.

Lightweight concrete also provides a number of choices in in-situ casting as well as factory manufacture as it is light and can be handled easily.

2. Economic

Time-saving: Since less mass is involved in construction compared to ordinary concrete, construction time can be reduced. Building components such as floors, walls, ceilings and roofs with lightweight properties can be transported and handled much more easily.

Cost-saving: Due to its lightness, lightweight concrete can easily reduce the cost of transportation, labour and handling.

3. Environmental

Whilst lightweight concrete was originally developed to replace normal concrete, it can also be customized to replace timber in residential construction. Thus, deforestation can be greatly reduced. Moreover, the prospective ingredients for lightweight concretes are mostly derived from industrial waste, such as fly ash. This will assist in converting the waste into greener products. Also, the fact that lightweight concrete is lighter than traditional concrete helps to save some CO₂ emissions due to less energy consumption, especially during transportation of the materials [4].

Apart from its advantages, lightweight concretes have also several disadvantages as listed below: [11]

1. The production cost per unit for LWC is higher than other ordinary concrete due to high electricity and manpower consumptions.
2. The production process of lightweight concrete needs considerably more attention than that of traditional concrete.
3. It is not as strong as conventional concrete.
4. Very few contractors who are familiar with autoclaved aerated concrete and cellular concrete.
5. Construction with autoclaved aerated concrete need special permission because of chemical usage and production area.

However, in many ways the advantages of lightweight concrete overshadow its disadvantages. In recent years, architects and builders worldwide have followed the trend of using lightweight concrete as building material. Scientists and engineers have also been researching

lightweight concrete for applications such as prestressed concrete, wall cladding for tall buildings and for roof structures [11].

2.3. Cellular Lightweight Concrete

The cellular lightweight concrete (CLC) or sometimes might often call that foamed concrete is either a cement paste or mortar, classified as lightweight concrete, in which air voids are entrapped in mortar by suitable foaming agent. Cellular light weight concrete is produced by the mixing of Portland cement, sand including or alone fly ash, water and suitable foaming agent [8].

It possesses high flowability, low self-weight, minimal consumption of aggregate, controlled low strength and excellent thermal insulation properties. By proper control in dosage of foam, a wide range of densities ($1600\text{--}400\text{ kg/m}^3$) of foamed concrete can be obtained for application to structural, partition, insulation and filling grades [14].

Ground Fly ash and ground granulated blast furnace slag have been used in the range of 30–70% and 10–50%, respectively as cement replacement to reduce the cost, enhance consistence of mix and to reduce heat of hydration while contributing towards long term strength [14].

The entrapment of air to create air voids has been normally obtained by introducing protein-based or synthetic-based foaming agents, generating voids created by the mechanical or chemical reaction of the components. Cellular concrete can have between 10% to 70% air voids, which results in a material that is lightweight but may compromise the compressive strength and durability properties, hindering its structural implementation and broader usage [4].

2.3.1. Composition of cellular concrete

Cellular light weight concrete (Foamed Concrete) is produced by the mixing of Portland cement, sand, including or alone fly ash, water and preformed stable foam (or using foaming admixture). The air content is typically between 10 to 80 percent of the total volume [3].

Foam concrete is produced either by pre-foaming method or mixed foaming method. Pre-foaming method comprises of producing base mix and stable preformed aqueous foam separately and then thoroughly blending foam into the base mix. In mixed foaming, the surface active agent is mixed along with base mix ingredients and during the process of mixing; foam is produced resulting in cellular structure in concrete [14]. The foam must be

firm and stable so that it resists the pressure of the mortar until the cement takes its initial set and a strong skeleton of concrete is built up around the void filled with air [16].

The role of foaming agents in cellular concrete is to create small and enclosed air bubbles by reducing the surface tension of a solution and increasing the stability of air bubbles. Foamed concrete differentiates from (a) gas or aerated concrete, where the bubbles are chemically formed through the reaction of aluminium powder with calcium hydroxide and other alkalis released by cement hydration and (b) air entrained concrete, which has a much lower volume of entrained air is used in concrete for durability [4].

Typically, surfactant or synthetic and protein foaming agents are used in cellular concrete [9]. Synthetic foaming agents are an amphiprotic substance that are strongly hydrophilic and easily dissolve in water yielding air bubbles. However, when introducing synthetic agents into concrete, which is a complex chemical environment, the compatibility of surfactant and cement particles is critical to effectively entrain the desired air content and concrete microstructure [9]. The air entraining mechanism of protein-forming agents differs from that of the synthetic agent. The former creates air bubbles as a result of the degradation of proteins. As the peptide linkage of large protein molecules breaks, more hydrophobic small molecules are formed. This process not only reduces the surface tension of the solution and creates an interface for air bubbles, but the hydrogen bonds between molecular groups help develop stable air bubbles. The effectiveness of protein-foaming agent is influenced by temperature and PH [17].

2.3.2. Cellular concrete properties

❖ Consistency and stability

Similar to self-consolidating concrete, cellular concrete is designed to achieve a desired flowability and compatibility which are partly influenced by the water content, and the amount of foam used [14]. A relatively stiff concrete mix may result in the collapse of the air bubbles, whereas a higher consistency mix or a slurry-type material may not be capable of holding the bubbles, which can result in segregation. Therefore, the density ratio (i.e., the ratio of the density at fresh state and at hardened state) should be close to 1:1 to achieve the stability [4].

The consistency reduces with an increase in volume of foam in the mix, which may reduce self-weight and greater cohesion resulting from higher air content and whereas adhesion between the bubbles and solid particles in the mix increases the stiffness of the mix. The

stability of foam concrete is the consistency at which the density ratio is nearly one (the measured fresh density/design density), without any segregation and bleeding. This ratio is higher than unity at both lower and higher consistencies due to either stiffer mix or segregation [14].

❖ **Compressive strength and density**

Research done by Kearsley and Wainwright [18] showed that compressive strength is a function of dry density and decreases sharply with a decrease in density. However, Wee T.[19] examined the relation between air content, compressive strength and density, and revealed that density decreases without a substantial loss in compressive strength due to increasing the air content. Increasing the air content does not increase the size of the void but increases the number of voids per unit volume.

Above two experiment works proposed that further increasing the air above the optimum value leads merging of air bubbles and increase the size of void, which in turn reduces the strength. They also found that the inclusion of air voids in foamed concrete has a greater effect on compressive strength than on elastic modulus.

For dry density of foam concrete between 500 and 1000 kg/m³, the compressive strength decreases with an increase in void diameter. For densities higher than 1000 kg/m³, as the air-voids are far apart to have an influence on the compressive strength, the composition of the paste determines the compressive strength [20].

It has been reported that small changes in the water–cement ratio does not affect the strength of foam concrete as in the case of normal weight concrete. Opposite of the trend usually noted for conventional concrete/mortar; foam concrete mixes with high w/c ratio (within the consistency and stability limit) increase in water–cement ratio increase the strength. It has been concluded by Tam et al. that the strength of moist-cured foam concrete depends on water–cement ratio and air–cement ratio. On other hand, the combined effect should be considered when volumetric composition of air-voids approaches that of water voids [14].

The hydration reaction of foam concrete influenced by more parameters than normal concrete. Due to the relatively high volume of air in cellular concrete, the heat of hydration cannot dissipate easily, creating high temperature inside the concrete. This effect is inversely proportional to the density. Further research is required to examine if currently used hydration

models are applicable to cellular concrete, owing to their unique thermal characteristics and density, which may have a significant effect on hydration processes [21].

❖ **Flexural and tensile strengths**

The ratio of flexural strength to compressive strength of cellular concrete is in the range of 0.25–0.35. Splitting tensile strengths of foam concrete are lower than those of equivalent normal weight and lightweight aggregate concrete with higher values observed for mixes with sand than those with fly ash. This increase is attributed to the improved shear capacity between sand particle and the paste phase [22]. Use of Polypropylene fibers has been reported to enhance the performance with respect to tensile and flexural strength of foam concrete, provided it is not affecting fresh concrete behaviour and self-compaction [23].

❖ **Modulus of elasticity**

The static modulus of elasticity of foam concrete is reported to be significantly lower than that of normal weight and lightweight concrete, with values typically varying from 1.0 to 8.0 kN/mm², for dry densities between 500 and 1500 kg/m³, respectively [22].

The E values of normal weight concrete exhibited values up to four times larger than that of equivalent strength foam concrete. Foam concrete with fly ash as fine aggregate is reported to exhibit lower E-value than that of foam concrete with sand. This variation is attributed to the high amount of fine aggregate in sand mix compared to fly ash mix, which contains entirely paste with no aggregate [14].

❖ **Drying shrinkage**

Foam concrete possesses high drying shrinkage due to the absence of aggregates, i.e., up to 10 times greater than those observed on normal weight concrete. In a comparative study on the shrinkage behaviour with sand and fly ash as filler, foam concrete with sand exhibited smaller drying shrinkage which is attributed to the higher shrinkage restraining capacity of sand as compared to fly ash particles [22].

❖ **Air void distribution**

From past studies, Foam concrete with narrower air-void distributions shows higher strength. The use of fly ash as filler helps in achieving more uniform distribution of air-voids by providing uniform coating on each bubble and there by prevents merging of bubbles. In addition to the air-void size and its distribution, the compressive strength of foam concrete is

also be influenced by the void/paste ratio, spacing of air-voids, number (frequency) of air-voids. Because of the uniform shape (characterized by shape factor) of air-voids, its influence on strength is negligible [20].

2.3.3. Functional properties

❖ Thermal insulation

Due to its cellular structure (pore structure) foam concrete has excellent thermal insulating properties [14]. The thermal conductivity of foam concrete of density 1000 kg/m^3 is reported to be one-sixth the value of typical cement–sand mortar. A study on the performance of foam concrete to enhance the thermal performance of low rise building has shown that the foam concrete ground supported slab foundation is possessing better thermal insulation and lower sorptivity properties while producing at its factory strength [24].

❖ Acoustical properties

Cellular concrete does not possess unique or significant sound insulation characteristics. Foamed concrete is stated to be less effective than dense concrete in resisting the transmission of air-borne sound because the Transmission Loss (TL) of air-borne sound is dependent on mass law, which is a product of frequency and surface density of the component. While dense concrete tends to deflect sound, foam concrete absorbs it, and hence the foam concrete has higher sound absorption capacity [25]. The sound insulation of foam concrete may be higher than lightweight concrete with less density and produced by lighter aggregates.

❖ Fire resistance

At high temperature the heat transfer through porous materials is influenced by radiation, which is an inverse function of the number of air–solid interfaces traversed. Hence along with its lower thermal conductivity and diffusivity, the foam concrete may result in better fire resistance properties [2]. Fire resistance is enhanced as the density is reduced. At high temperatures, the heat transfer through porous materials is influenced by radiation, which is an inverse function of the number of air–solid interfaces traversed. Hence, along with its lower thermal conductivity and diffusivity, foam concrete may result in better fire resistance. For lower densities of foam concrete, the proportional strength loss at high temperature exposure is less than that of normal concrete [4].

2.3.4. Application of cellular lightweight concrete

Foamed concrete may be produced by mixing the above mentioned ingredients in ready mix plant or ordinary concrete mixer. Foamed concrete is self-compacting concrete requires no compaction, and will flow readily from a pump outlet to fill mould, form, restricted and irregular cavities. It can be pumped successfully over significant height and distances. The 28 days strength and dry density of the material vary according to its composition, largely its air voids content, but usually they range from 1.0 to 25.00 N/mm² and 400 to 1800 kg/m³ [3]. The plastic density of the material is about 150 to 200 kg/m³ higher than its dry density.

Presently, cellular concrete is used for sound and heat insulation, building blocks and panels, fire protection wall, energy absorbing pads in roads, road sub-base, structural fill, foundations, geotechnical and mine fill applications [4]. Some of the application areas are listed below [3]:

1. Foamed light weight concrete in the form of bricks, blocks or poured in-situ is used for thermal insulation over flat roofs or for cold storage walls or as non-load bearing walls in RCC/Steel framed buildings or for load bearing walls for low-rise buildings.
2. Fire rating of foamed concrete is far superior to that of brick work or dense concrete.
3. Bulk filling, using relatively low strength material, for redundant sewerage pipes, wells, disused cellars and basements, storage tanks, tunnels and subways etc.
4. Infill to the spandrel walls of arch bridges.
5. Backfill to retaining walls and bridge abutment.
6. Stabilizing soil, for example in the construction of embankment slopes.
7. Grouting for tunnel work.

2.4. Pozzolanic Supplementary Cementitious Materials

A pozzolan is a siliceous or alumina siliceous material that, in finely divided form and in the presence of moisture, chemically reacts with the calcium hydroxide released by the hydration of Portland cement to form calcium silicate hydrate and other cementitious compounds. Natural pozzolans, fly ash and slags has pozzolanic character and categorized as supplementary cementitious materials or mineral admixtures [26].

Supplementary cementitious materials are added to concrete as part of the total cementitious system. They may be used in addition to or as a partial replacement of Portland cement or

blended cement in concrete, depending on the properties of the materials and the desired effect on concrete.

Supplementary cementitious materials are used to improve a particular concrete property, such as resistance to alkali-aggregate reactivity. The optimum amount to use should be established by testing to determine (1) whether the material is indeed improving the property, and (2) the correct dosage rate, as an overdose or under dose can be harmful or not achieve the desired effect. Supplementary cementitious materials also react differently with different cements [27].

2.4.1. Properties of pozzolanic supplementary cementitious materials

❖ Chemical Properties

According to ASTM C618 [28], Fly ash and natural pozzolans shall conform to the requirements as to chemical composition prescribed in Table 1.

This standard classifies those materials in three different classes;

Class N—Raw or calcined natural pozzolans that includes some diatomaceous earths; opaline cherts and shales; tuffs and volcanic ashes or pumice, calcined or uncalcined.

Class F—Fly ash normally produced from burning anthracite or bituminous coal that meets the applicable requirements for this class as given herein. This class fly ash has pozzolanic properties.

Class C—Fly ash normally produced from lignite or subbituminous coal that meets the applicable requirements for this class as given herein. This class of fly ash, in addition to having pozzolanic properties, also has some cementitious properties.

Table 1: Mineral Admixture Chemical Properties

Chemicals Composition	Mineral Admixture Class		
	N	F	C
Silicon dioxide (SiO ₂) plus Aluminium oxide (Al ₂ O ₃) plus Iron oxide (Fe ₂ O ₃), min %	70	70	50
Sulphur trioxide (SO ₃), max, %	4	5	5
Moisture content, max, %	3	3	3
Loss on ignition, max, %	10	6	6

This specification covers coal fly ash and raw or calcined natural pozzolan for use as a mineral admixture in concrete where cementitious or pozzolanic action, or both, is desired, or

where other properties normally attributed to finely divided mineral admixtures may be desired, or where both objectives are to be achieved.

Physical Properties

According to ASTM C 618, Fly ash and natural pozzolans shall conform to the physical requirements prescribed in Table 2.

Table 2: Mineral Admixture Physical Requirements [28]

Physical Properties	Mineral Admixture Class		
	N	F	C
Fineness:			
Amount retained when wet-sieved on 45 µm (No. 325) sieve, max, %	34	34	34
Strength activity index:			
With portland cement, at 7 days, min, percent of control	75	75	75
With portland cement, at 28 days, min, percent of control	75	75	75
Water requirement, max, percent of control	115	105	105
Soundness:			
Autoclave expansion or contraction, max, %	0.8	0.8	0.8
Uniformity requirements:			
The density and fineness of individual samples shall not vary from the average established by the ten preceding tests, or by all preceding tests if the number is less than ten, by more than: Density, max variation from average, %	5	5	5
Percent retained on 45-µm (No. 325), max variation, percentage points from average	5	5	5

Fly ash, the most widely used supplementary cementitious material in concrete, is a by-product of the combustion of pulverized coal in electric power generating plants. Upon ignition in the furnace, most of the volatile matter and carbon in the coal are burned off. During combustion, the coal’s mineral impurities (such as clay, feldspar, quartz, and shale) fuse in suspension and are carried away from the combustion chamber by the exhaust gases. In the process, the fused material cools and solidifies into spherical glassy particles called fly ash [27].

Sugarcane bagasse ash is obtained as a by-product from cogeneration combustion boilers in sugar industries. The sugarcane bagasse consists of approximately 50% of cellulose, 25% of hemicellulose and 25% of lignin. Each ton of sugarcane generates approximately 26% of bagasse (at a moisture content of 50%) and 0.62% of residual ash. The residue after

combustion presents a chemical composition dominated by silicon dioxide (SiO_2). This chemical composition of bagasse ash has advantage using as supplementary cementitious material. [29]

To use bagasse ash as a supplementary Cementous material instead of fly ash; at least some basic pozzolanic parameters should be fulfilled. From the study done by Gritsada Sua-iam and Natt Makul on bagasse ash as high amount cement replacement on self-compacting concrete [30] and another study done by Nambiar and Ramamurthy on fineness of filler type on compressive strength of foamed concrete made with cement–fly ash mix; a typical chemical comparison on fly ash an bagasse ash is shown in table below [31].

Table 3: A typical chemical composition of type 1 Portland cement, typical class F fly ash (ASTM 618) and bagasse ash (From Wenji sugar factory).

	Type 1 Portland cement (OPC)	Fly Ash(FA)	Bagasse ash (BA)
Chemical composition (% by mass)			
Silicon dioxide (SiO_2)	16.39	63.6	66.92
Aluminum oxide (Al_2O_3)	3.85	28.19	7.06
Ferric oxide (Fe_2O_3)	3.48	2.99	6.12
Magnesium oxide (MgO)	0.64	0.54	1.96
Calcium oxide (CaO)	68.48	1.54	3.61
Sodium oxide (Na_2O)	0.06	0.05	4.28
Potassium oxide (K_2O)	0.52	0.003	4.92
sulphur oxide (SO_3)	4	0.26	0.25
$\text{SiO}_2 + \text{Al}_2\text{O}_3 + \text{Fe}_2\text{O}_3$	23.73	94.78	80.1
Physical properties			
Loss on Ignition (% by mass)	1.7	0.85	15.34
Specific gravity	3.2	2.09	2.2
Specific surface area (cm^2/g)	610	251	274

2.4.2. Integration of Fly ash in Foam Concrete

A study done by Nambiar and Ramamurthy on fineness of filler type on compressive strength of foamed concrete made with cement–fly ash mix, uniform distribution of air voids can be achieved by inclusion of fly ash than fine sand [12]. Meanwhile high volume utilization of fly ash as filler (fine aggregate) instead of sand become possible thus is providing a means of economic and safe disposal of this waste product. The pore system in cement based material is conventionally classified as gel pores, capillary pores, macro pores due to deliberately

entrained air, and macro pore due to less compaction. The gel pores not influence the strength of concrete through its porosity, although these pores are directly related to creep and shrinkage. Fly ash being finer, helps in uniform distribution of air voids by providing a well and uniform coating on each bubbles and preventing it from merging and overlapping [12].

Another study done by Khamphoo and Theerawat on the effects of fly ash as partial replacement of cement and assess its properties. CLC made from Pre-formed foam, cement and fly ash was tested for mechanical properties of compressive strength, water absorption and porosity. Uses of fly ash replace cement in the proportions 10, 20 and 30 percent by weight of binder. Constant water to binder ratio of 0.5 and unit weight of 800 kg/m³ compared compressive strength at curing age 3, 14, 28 and 60 days. The study result that replacing cement with fly ash gives high strength on the early stage. The study concludes that for a given density, an increase in fly ash content of the mix results in increased strength. And also Replacing cement with high fly ash not affects the compressive strength in early age. Replacing cement with high fly ash affects the pore size decrease and cause compressive strength increased [8].

2.4.3. Integration of Bagasse ash in concrete

Previous studies have reported that the use of sugarcane bagasse ash as supplementary cementitious material in the concrete can improve its properties. The utilization of bagasse ash has been constrained because of inadequate understanding of the material and lack of suitable processing methodology for use in a large scale [32]. No significant study was done on utilization of bagasse ash as a supplementary Cementitious material for cellular lightweight concrete.

Ganesan k. investigated the utilization of bagasse ash as pozzolanic material in concrete. In this study raw bagasse ash was directly burnt to 650 °C for one hour and ground to 5.4 micron mean grain size. The performance of bagasse ash as mineral admixture was evaluated in concrete and results suggested that concrete with up to 20% bagasse ash replacement had better performance than control concrete [33].

Pozzolanic activity effect of burning of sugarcane bagasse ash was studied; the results of the study showed that the maximum reactivity of bagasse ash was found in the sample that was burnt at around 500°C. Method of grinding and fineness also affect pozzolanic characteristics; pozzolanic activity was found to increase with fineness; the study concluded that grinding to values of D80 (80% passing size) below 60 micron and Blaine fineness above 300m²/kg

resulted in products that could be classified as pozzolanic material as per ASTM C 618-12A [34].

R.Srinivasan and K.Sathiya has studied the effect of sugar-cane bagasse ash (SCBA) in concrete by partial replacement of cement at the ratio of 0%, 5%, 10%, 15% and 25% by weight. The experimental study examined the compressive strength, split tensile strength, flexural strength, young's modulus and density of concrete. The results showed that the bagasse ash in blended concrete had significantly higher compressive strength, tensile strength, and flexural strength compare to that of the concrete without SCBA. It is found that the cement could be advantageously replaced with bagasse ash up to maximum limit of 10%. Therefore it is possible to use sugarcane bagasse ash as cement replacement material to improve quality and reduce the cost of construction materials such as mortar, concrete pavers, concrete roof tiles and soil cement interlocking block [35].

2.5. Properties of Cellular Lightweight Concrete Containing Bagasse ash

Most of the researchers focused on studying foamed concrete properties by replacing cement with fly ash. Very limited number of researches has done on bagasse ash as cement replacement material.

Patchara and Somchai studied effects of Bagasse Ash as Fine Aggregate in Non-Autoclave Cellular Concrete. This research focuses on evaluating the feasibility of utilizing bagasse ash as a fine aggregate in non-autoclave cellular concrete. The original bagasse ash (BG) from the Thai sugar industry was used to replace river sand (SA) at 0%, 20%, 30% and 40% by volume. All mixes were controlled flow between $45 \pm 5\%$ and used foam content (FV) at 50% by volume of mixture. Compressive strength, density, water absorption, and drying shrinkage were determined. The results revealed that the compressive strength, density, and drying shrinkage decreased with increasing of BG content, while the water absorption slightly increased as compared to the control cellular concrete. The optimum replacement level of BG to SA was 20% by volume which it gave the compressive strength, density, and water absorption of 3.37 MPa, $1,000 \text{ kg/cm}^3$ and 25%, respectively. From the experimental results, it can be concluded that the Bagasse ash could be used as a fine aggregate in the cellular concrete [36].

Another study done by Gritsada Sua-iam and Natt Makul, examined the effect of adding limestone powder to self-compacting concrete mixtures in which large amounts of bagasse

ash were employed as a fine aggregate replacement. The unit weight of the SCC decreased with increasing BA content and increased with increasing LS content, allowing a type of lightweight SCC to be obtained. The resulting concrete structure had a decreased weight and low long-term maintenance costs. Incorporation of suitable levels of BA and LS improved the early-stage compressive strength development, due to filling effects and pozzolanic reactions. The volumetric percentage replacement of 20% limestone powder in fine aggregate incorporating 20% bagasse ash effectively enhanced the workability and hardened properties of self-compacting concrete [30].

The optimum amounts of supplementary cementing materials used with portland cement or blended cement are determined by testing, by the relative cost and availability of the materials, and by the specified properties of the concrete [27]. To replace fly ash with bagasse ash in production of CLC, it's mandatory to conduct tests and check concrete parameters.

2.6. Summary of Literature Review

After reviewing past researches and literatures, here shown below a list of summarized points:

- Cellular lightweight concrete or Foamed concrete is a mixture of cement, sand, and water and with or without supplementary cementitious materials such as fly ash and slag.
- Cellular lightweight concrete technology becomes well developed since 50 years but become highly popular due to its multipurpose application and high amount of waste materials utilization.
- Optimum amounts of supplementary cementitious materials used are determined by testing, product availability, relative material cost and specific concrete properties.
- In many countries, fly ash is used as cement replacement material up to 50% in production of foamed concrete to increase concrete performance and reduce cost.
- In some past researches, bagasse ash is also used to replace cement and sand; and the optimum value varies from 10% to 30% based on the concrete type and properties.

Gap Identified between Ethiopian Construction Practice and literature review

- Currently available wall making materials have some performance problems due to material quality, poor quality control and technology drawbacks.
- Cellular lightweight concrete (CLC) has not been used in the construction industry.

- As an advanced lightweight concrete technology, adopting and producing of CLC by using locally available materials may bring an alternative solution for the construction.
- Sugarcane bagasse ash is a by-product of sugar factories and has pozzolanic characteristics. Due to its availability and low cost, bagasse ash can be used instead of fly ash to produce CLC.

Leads and methodology

- Based on literature review and current construction practice, CLC can be alternative solution for wall construction and also for other application areas.
- Laboratory testing shall be conducted to check mechanical properties of CLC that produced by bagasse ash.
- The feasibility of using CLC shall be checked by cost comparison with HCB that dominantly used for construction of walls.

CHAPTER THREE

MATERIALS AND METHODS

3.1. Materials

3.1.1. Cement

Ordinary Portland cement type I (OPC from Dangote Cement factory) used in this study had the physical properties and chemical compositions as shown in Tables 4 and 5, respectively.

3.1.2. Bagasse ash

Bagasse ash from wenji sugar factory has collected to use as supplementary cementitious product and prepare by sieving with 300 micron sieve size (No 50) and assign as SBA. It was a burned at temperature of 500 °c. Bagasse ash chemical analysis done by Geological survey of Ethiopia. The result shows that the summation of SiO_2 , Al_2O_3 and Fe_2O_3 is 80 which is greater than a minimum requirement of 70 in ASTM C 618, class F fly ash.

According to ASTM C 618, pozzolanic material such as fly ash and raw natural pozzolan shall have a maximum present retained of 34 % on Sieve No 325 (45 micron). Whereas bagasse ash used in this experiment have 20 % retained on this specific sieve. Bagasse ash used in this experiment is prepared by sieving on No 50 sieve without grinding and preparation, this is to use bagasse ash without any additional preparation cost. For more information refer Appendix I on laboratory result.

The physical properties and chemical composition of BA is also listed in Tables 4 and 5, respectively.

Table 4: Physical properties of materials

Materials	Specific gravity	Passing on a sieve No. 50 (%)
Ordinary Portland cement (OPC)	3.15	100
Original bagasse ash	1.96	12.9
Sieved bagasse ash	2.2	100

Table 5: Chemical compositions OPC (Dangote cement) and bagasse ash [from wenji factory]

Investigated Chemicals	Chemical Compositions (%)	
	Ordinary Portland cement (OPC)	Bagasse ash (BA)
Silicon dioxide, SiO ₂	22.82	66.92
Aluminum oxide, Al ₂ O ₃	5.41	7.06
Iron oxide, Fe ₂ O ₃	3.37	6.12
Calcium oxide, CaO	66.32	3.60
Magnesium oxide, MgO	1.46	1.96
Sodium oxide, Na ₂ O	-	4.28
Potassium oxide, K ₂ O	-	4.92
Sulfur trioxide, SO ₃	2.16	0.25
Loss on ignition, LOI	-	19.6
SiO ₂ + Al ₂ O ₃ + Fe ₂ O ₃	31.6	80.1

Bagasse ash doesn't have a standard to use as cement replacement material. It's not logical to compare with fly ash and other pozzolanic materials. Some of the chemical and physical properties of bagasse ash used for this experiment comply with the properties of fly ash for cement replacement that written on ASTM C618. The possibility of using bagasse ash for cement replacement in cellular concrete shall be proved by experimental work.

3.1.3. Fine Aggregate

Local river sand, with a fineness modulus of 3.04 was used as a fine aggregate. Specific gravity and water absorption tests were conducted according ASTM C 128. The fine aggregate had specific gravities of 2.60, and water absorptions of 1.83%. Fine aggregate passing sieve size 4.75mm used in this experimental study.

3.1.4. Foaming Agent

The research used SikaLightcrete®-02 foaming agent produced in Egypt. This is a surface active agent foaming product for lightweight, pumped or poured concrete used in structures to

improve acoustics and thermal insulation and, for low strength concrete fillings. Due to its stabilizing components, SikaLightcrete®-02 produces very high, stable air content during the work and pumping time. The specific gravity is 1kg/Li same as water.

SikaLightcrete®-02 is added to the gauging water or added simultaneously together with the gauging water into the concrete mixer. Recommended dosage of the product is 0.5 - 2.0% by weight of cement for lightweight concrete with sand and lightweight aggregates. Trial mixes was conducted to determine the correct dosage. At least additional mixing time of at least two minutes per m³ of concrete must be observed.

All laboratory test results of Bagasse ash and sand summarized in Appendix I.

3.2. Experimental Method

To understand different properties of cellular lightweight concrete (CLC) and what is required to produce such type of concrete will be made possible by referring different literature written on properties of concrete specifically on CLC.

The major steps to be followed while conducting the research will be:

- Specify the properties of materials which are necessary to produce CLC concrete,
- Purchasing the necessary materials; fine aggregate, cement, bagasse ash and foaming agent.
- Preparing the materials as per the specifications in ACI standards (Including availability and Literature review).
- Conducting characterizing tests on the fine aggregate, Bagasse Ash and cement
- Preparation of CLC mix designs
- Conducting test on CLC and analysis of test results; in particular compressive strength, density and water absorption.
- Analyze and compare with ASTM standard for lightweight concrete

Both review of written literature and laboratory experimental studies guide to study effect of bagasse ash content on the properties like density, flow behavior, strength, shrinkage and water absorption of cellular lightweight concrete. Based on literature review different percentages of bagasse ash from 0% to 40% used and above tests conducted to verify it's

applicability for wall making construction material. Foaming agent is a basic ingredient to CLC to form air bubbles inside the concrete and make the concrete lightweight. Suitability of both foaming agent and bagasse ash (cement replacement material) check according to ASTM C 796-97 and ASTM C 618. CLC produce in this study intend to use for building partition and fill applications. So cellular concrete with minimum target compressive strength of 5MPa and density of 1200kg/m³ is design to use both structural and non-structural elements.

To have a clear understanding on mechanical behavior of Cellular lightweight concrete containing bagasse ash, three different experimental steps are conducted:

A. Mechanical Properties of Mortar Matrix containing Bagasse Ash

This experiment intended to see the characteristics of mortar by replacing cement with bagasse ash (with 5, 10, 20 and 30 percentage by volume of cement). The mix design is adopt from ACI523.1R 86 (Guide for cast-in place cellular concrete) by removing air formed by foaming agent from the batch volume. In this part of the study, optimum bagasse ash content for mortar is determine by comparing compressive strength and density of five different mixes.

B. Mechanical Properties of Mortar Matrix containing foaming agent (CLC without bagasse ash)

This study is to analyze the properties of mortar containing foaming agent that entrain air up to 35% (with 1, 1.5,2 and 2.5 percent by weight of cement). The mix design is adopt from ACI523.1R 86 (Guide for cast-in place cellular concrete). In this part of the study, optimum foaming agent percentage which entrains high air content without significant reduction of density is select for the next experiment.

C. Mechanical properties of CLC concrete containing Bagasse Ash

Based on the above studies, cellular light weight concrete mix with optimum bagasse ash content and optimum foaming agent is study in this part. Due to uncertainties of combined effect of bagasse ash and foaming agent rather than single material effect in past studies; optimum content and nearest values are taken for this experiment. And also because of high density (>800kg/m³) and foaming agent type (low air entraining capacity < 35%), above two studies deviates from ACI 523 (Guideline based on preformed foam, for CLC with density below or equal to 800kg/m³). To have economical and suitable mix design, it's better to formulate new mix design based on our density requirement, material type and cement

consumption. This new mix will be tested to check whether it satisfy the ASTM standard or not.

3.3. Mix proportions

Standard concrete mixing equipment is normally not acceptable for low-density cellular concrete mixtures because the action of the mixer does not combine the ingredients with the correct speed and mixing action. A high-speed paddle mixer is preferable because it properly combines the ingredients and blends the preformed foam rapidly and efficiently to produce a uniformly consistent low-density cellular concrete mixture. Other mixers and processes that produce uniform mixtures include high-shear mixers [37].

First it is important to know the minimum cement content in the mortar mix that can achieve good stability (compatibility and consistency). For this trial mix, w/c ratio of 0.5 and cement content varies from 250-350 kg. Assume that the dry density of 1100kg/m³ same as class A HCB (Ethiopia Standard). Mix ratio is done according to ACI 523 1R-86 (adopted from ASTM C 567) method of calculating approximate oven dry density when the batch quantity, moisture content of aggregates, and the batch volume the concrete is known.

$$O_c = (w_{da} + 1.2w_{ct}) / S \dots\dots\dots \text{Equation 1}$$

- Where,
- O_c = Approximate oven dry density (kg/m³)
 - w_{da} = weight of dry aggregate in the batch
 - w_{ct} = weight of cement in the batch
 - S = Batch volume
 - $1.2w_{ct}$ = weight of cement plus weight of water for hydration
(consider water for hydration to be 20% of weight of cement)

And the air content in the mix determine using Equation 2:

$$\text{Air content before pumping} = 100 [1 - (D_w / D_{th})] \dots\dots\dots \text{Equation 2}$$

Whereas Theoretical density is determined using Equation 3.

$$(D_{th}) = (W_c + W_s + W_f) / [(W_w / 1000) + (W_c / SGC * 1000) + (W_f / 1000)] \dots\dots\dots \text{Equation 3}$$

- Where,
- D_w = Wet Density
 - D_{th} = Theoretical density

Analysis of Mechanical Properties of Cellular Lightweight Concrete Containing Bagasse Ash

A mix with a Good compatibility (high density) without collapse of air bubbles (without high decrease of air content) is chosen as good optimum mix. And a CLC mix with this ratio change to mortar mix by replace air volume with other mix ingredients to analyse effect of bagasse ash on strength and foaming agent (volume increment) on pure mortar matrix.

Table 6: Trial mix to study foaming agent characteristics

Cement content	Sand	Water	Foaming agent (%)	w/c	Wet Density	Theoretical density	Air content (%)	Avg.com. Strength MPa (14 days)
350	680	175	1%	0.5	1672	2179.9	23.29	6.38
350	680	175	1.5%	0.5	1535.19	2179.9	29.57	6.25
350	680	175	2.0%	0.5	1459	2179.9	33.07	6.02

Table 7: Trial mix to determine effective optimum cement content

Cement content	Sand	Water	Foaming agent (%)	w/c	Wet Density	Theoretical density	Air content (%)	Avg.com. Strength MPa (14 days)
350	680	175	2.0%	0.5	1459	2179.9	33.07	6.02
300	740	150	2.0%	0.5	1577	2213	29	6.9
250	800	125	2.0%	0.5	1401	2275.2	37.92	2.44

Based on above trial mixes, the percentage of foaming agent with high air entrainment and good strength selected as a base mix for next experiments. 2% of foaming agent attains maximum air content and cement with 300kg gives a better strength and density due to compactability, it considered as good mix ratio. Because of maximum foaming agent air entrainment of 35%, the concrete mix can't reach 1m^3 and deviates from ACI 523. So it's important to adjust material quantity to get CLC mortar mix of 1m^3 include air entrained.

Both increasing cement and sand has a result of high air entrainment and low strength. Only increase the sand content lowers the strength. By assuming air content of 29%, dry density of 1360, w/c ratio of 0.55, and for 1m^3 mix cement increase from 300 to 330 and sand increase from 740 to 1000. This mix changed to normal mortar mix to investigate effect of bagasse ash and foaming agent. All below experiments accordingly adjust to study volume change and other mechanical properties.

According to the above experimental program different mix proportion are used and tested to check the mechanical behaviour:

A. Mix proportion 1: Sieved bagasse ash is use to replace OPC at 5%, 10%, 20% and 30% by volume of binder. The binder content and water to binder (W/B) ratio of all of concrete mixtures were kept constants at 466 kg/m³ and 0.55, respectively. The mix proportions of all concrete samples are presented in Table 8.

Table 8: Concrete mix proportions to determine optimum bagasse ash replacement percentage.

Mix	Mortar Mix Proportion (kg/m ³)				
	Cement	Sand	Bagasse Ash (By volume)	Water	Air
CBA0	466.5	1409.5	0	256.5	4%
CBA5	443	1409.5	16.3	256.5	4%
CBA10	420	1409.5	32.5	256.5	4%
CBA20	373	1409.5	65	256.5	4%
CBA30	326	1409	98	257	4%

B. Mix proportion 2: Based on the product specification of Foaming Agent (Sika Lightcrete 02) the percentage of foaming agent from 1-2.5% by weight of cement are use in this experiment. The effect of foaming agent or air entrainment in mortar mix is analysing by keep other parameters constant. Acoording to ASTM C 796, foaming agent solution will be considered as part of total mixing water. W/C ratio of 0.55 used in all mix proportions and keep all parameters constant except the foaming agent. The optimum percentage determined based on strength and density of the mix. The mix proportion for this study shown in below table below:

Table 9: Concrete mix proportions to determine effective foaming agent percentage.

Mix	Mortar Mix Proportion (kg/m ³)			
	Cement	Sand	Water	Foaming Agent
CFA0	466	1409	257	0
CFA1	466	1409	252.34	4.66
CFA1.5	466	1409	250.01	6.99
CFA2	466	1409	347.68	9.32
CFA2.5	466	1409	245.35	11.65

C. Mix proportion3: From the above two experiments, optimum bagasse ash content and % of foaming agent (% range without affecting target strength) will selected for this experiment. Mechanical properties CLC concrete containing bagasse ash investigates on this section of the experiment.

3.4. Laboratory Tests

To understand the physical properties of CLC the following laboratory tests shall be conducted.

3.4.1. (As-cast) Wet density

The as-cast density at the point of placement should be determined by calculating the density of samples using a container of known volume and empty weight, as prescribed in applicable sections of ASTM C 796. Monitoring the as-cast density of the cellular concrete is an important job-site quality-assurance tool for controlling the uniformity and density of the mixture at the point of placement.

3.4.2. Air content or Volume change

Air content of fresh concrete mix is calculated based on experimental density of the freshly mixed concrete at the mixer, and theoretical density (calculated based on absolute volume). Full steps are prescribed on ASTM C 796. To know the exact quantity of wet mix, volume increment (volume change) is measure by calculating the volume difference between control mix and Foam concrete mix.

3.4.3. Compressive strength

The relationship between compressive strength and as-cast density is an important indicator of the quality of cellular concrete. The compressive strength of cellular concrete should be evaluated in accordance with ASTM C 796 and C 495. Compressive strength specimens should not be oven-dried. When it is necessary to determine oven-dry density, it is necessary to make companion specimens for this test in addition to those specimens for compressive strength testing.

3.4.4. Oven dry density and water absorption

When the oven-dry unit weight is desired, mold two companion specimens for this purpose at the same time as the compressive strength specimens. Cure the companion specimens the same as the compressive strength specimens, except dry the companion specimens at the age of 28 days in an oven at 230 ± 18°F (110 °C) and weigh at 24-h intervals until the loss in weight does not exceed 1 % in a 24-h period. Determine the weight and dimensions of the oven-dry specimens and calculate the weight per cubic meter from the average data obtained. (Ref: ASTM C 495)

Find the average weight of water absorbed by the cylinders by subtracting the average dry weight of cylinders from the average wet weight of cylinders. Record to the nearest 0.1 lb (or 0.05 kg). Find the average volume of water absorbed by dividing the average weight of water absorbed by the density of water in lb/ft³ (kg/m³). Determine the water absorption using the following Equation 4:

Absorption, % by volume = $V_w/V_c * 100$ Equation 5

Where VW is volume of water absorbed in 24 hr and VC is volume of test specimen

3.4.5. Plastic Shrinkage

A linear shrinkage for mortar mixture is conduct according to ASTM C531-00 with slight modification. The linear shrinkage measured the change in length that occurs after the material is rigid enough and strong enough to move the studs. In this study, the linear shrinkage measures at 24 hr after casting by direct taping of concrete samples and calculate the percentage shrinkage. This method used for research purposes to provide information on linear changes takes place in test materials.

CHAPTER FOUR

TEST RESULTS AND DISCUSSION

4.1. Effect of Replacing Cement with Bagasse Ash in Mortar

By using mix proportion from section 3.3, effect of cement replacement with bagasse ash analyse on this section the research. Bagasse ash replace with 5%, 10%, 20% and 30% by volume of cement to maintain same volumetric mix batch. All mix proportion has same quantity of sand and water as control parameter and Water to binder ratio of 0.55. To have same comparative base study, a cylinder with 100m*200mm dimensions use in all mix designs, and compressive strength and density has determined. Summary of mix proportion and test results are shown in table below.

Table 10: Mix proportion and effect of bagasse ash replacement on mortar mix

Description	Mix Proportion (Kg/m ³)				
	BA 0%	BA 5%	BA 10%	BA 20%	BA 30%
Cement	466.5	443	420	337	326
Sand	1409.5	1409.5	1409.5	1409.5	1409.5
Water	256.5	256.5	256.5	256.5	256.5
BA (By Volume)	0	16.3	32.5	65	98
Density (kg/m ³)	2127.60	2138.05	2130.09	2101.59	2102.33
Average Compressive strength (MPa)	11.28	12.14	11.66	9.14	6.12

The chart shown below summarizes the effect of bagasse ash on compressive strength and density of mortar mixture.

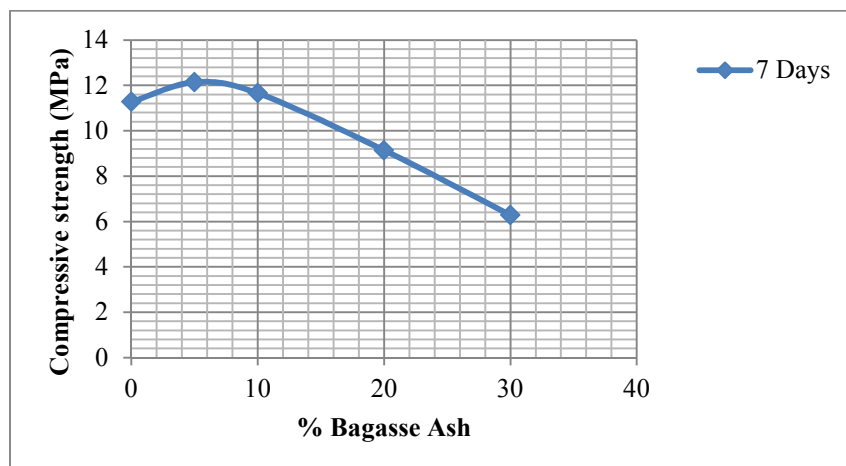


Figure 1: Effect of bagasse ash on compressive strength and density.

The compressive strength of mortar mixture increase with increasing the percentage of bagasse ash until bagasse ash reaches 6% by volume of cement. The compressive strength start decreasing when the bagasse quantity increased more than 6%, but still higher than the strength of normal mortar mix up to 12% replacement. When bagasse ash replacement is higher than 12%, the mix has lower strength than normal mix. In this thesis, bagasse ash used as a cement replacement material to minimize the cost of the mixture without affecting the strength, so it feasible to take max bagasse ash replacement which has same strength with the normal mix. In this case we take 10% bagasse ash percentage as an optimum value which attends higher strength than the normal mortar mixture.

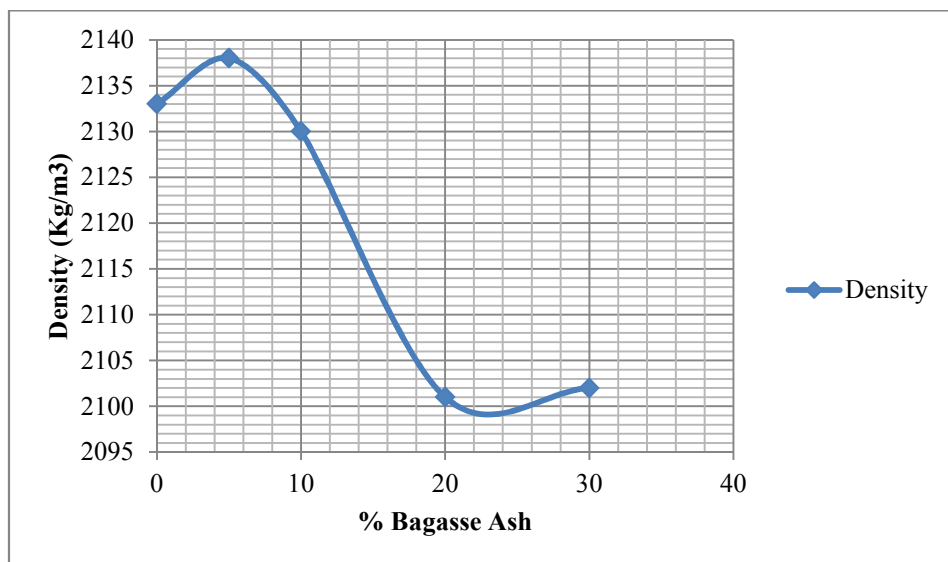


Figure 2: Effect of bagasse ash on density.

The same as compressive strength, density of mortar increase with bagasse ash percentage until it reaches 5% and start decreasing. The density increase due to bagasse ash filler property which fills small pores and achieves good compactability. After 5%, the mass of mixture become low due to low specific gravity of bagasse ash than cement, in another term the filling property of bagasse ash dominated with specific gravity. At 10% replacement of bagasse ash the mortar has less density than the control mix; the lighter the mixture will be an advantage as far as the strength is not affected.

To summarize, 10% bagasse ash replacement by volume of cement will give a higher strength and lower density than the control mix without bagasse ash. The lower density is due to low density of bagasse ash compared with cement. The lighter the Weight of the mixture has lesser dead load on the building which decreases the cost of large foundation.

4.2. Effect of Foaming Agent Dosage in Mortar Mix

In this section of the research; the effect of foaming agent dosage on mechanical properties of mortar mixture by keeping other parameters constant has analysed. Sika lightcrete-02 foaming agent is use to form stable air bubbles in the mortar mix; it can entrain air up to 35% of the total mix. Mortar mix with foaming agent percentage of 1, 1.5, 2 and 2.5has tested to study its influence on mechanical characteristics. According to ASTM C 796-97 the foaming mixture added will consider as a part of mixing water. Mix proportion and physical properties of each mix such as Wet density, compressive strength, and dry density are summarized in table below.

Table 11: Mix Proportions and effect of foaming agent on mortar

Description	Mix Proportions (kg/m ³)				
	FA 0%	FA 1%	FA 1.5%	FA 2%	FA 2.5%
Cement	466.5	466.5	466.5	466.5	466.5
Sand	1409.5	1409.5	1409.5	1409.5	1409.5
Water	256.5	251.83	249.51	247.17	244.83
Foaming agent	0	4.66	6.99	9.33	11.66
Wet Density	2116.30	1824.76	1822.25	1681.02	1803.32
Volume Increment	0	20.76	23.07	30.77	19.23
Compressive strength(14 days)	11.14	8.05	7.06	4.32	5.55
Dry Density	1905	1624	1614	1488	1578
Wet density/dry density		1.1236	1.1290	1.1297	1.142

From the above test result, compressive strength and density of cellular concrete decrease inversely with foaming agent percentage. When the foaming agent dosage reach 2.5 %, the function of forming stable air bubbles decrease and the concrete strength start increasing. Foaming agent percentage of 1.5% gives more stable mix without significant change in strength compared with 2% and 2.5%. The figure shown below describes effect of foaming agent on density and compressive strength of cellular concrete.

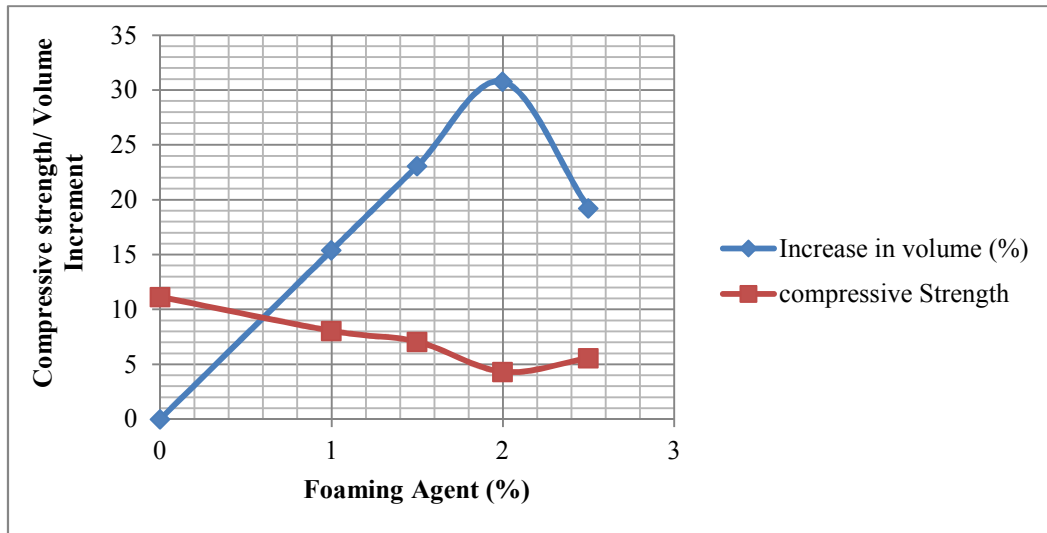


Figure 3: Effect of foaming agent on compressive strength and volume increment

From the above figure, decrease in strength directly related with increased volume, in other terms increasing foaming agent percentage decrease the mortar strength due to air entrainment properties while increasing the volume. The mortar mix increases its volume without significant or dramatic change of strength indicted as a stable mix. From literatures, stable mix is a mix which a ratio of wet density to dry density near to one (a mix without bleeding or segregation). In this experiment and density ratio a mortar mix with 1.5% and 2% is choose as stable. Above 2% the mix become unstable due to a collapse of air bubbles, which decrease the air volume and increase compressive strength. The density of CLC mix decrease with increase dosage of foaming agent or with increase air volume. The chart below shows density characteristics versus foaming agent percentage.

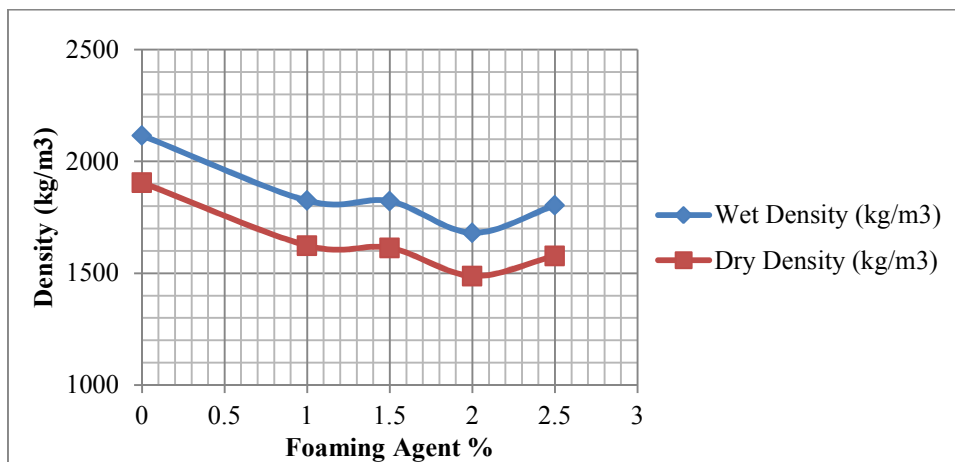


Figure 4: Foaming agent dosage versus density relations

Both wet and dry density of CLC decrease with increase in dosage of foaming agent in the mix until it reaches 2%. If the foaming agent increase above 2%, the mix become unstable with bleeding and segregation, meanwhile increase the density due to collapse of unstable air bubbles inside the mix. 1% and 1.5% of foaming agent almost have the same effect on the mix density, but 1.5% mix has high air content with good compact ability. In almost in all mortar mixes the density mix difference of 200kg/m³ is realized between wet and dry density. Whereas compressive strength of CLC mix directly proportional with density. From this experiment wet density can use as an indicator for checking achievement of other parameters such as dry density and compressive strength. The chart below shows relation between wet density, dry density and compressive strength.

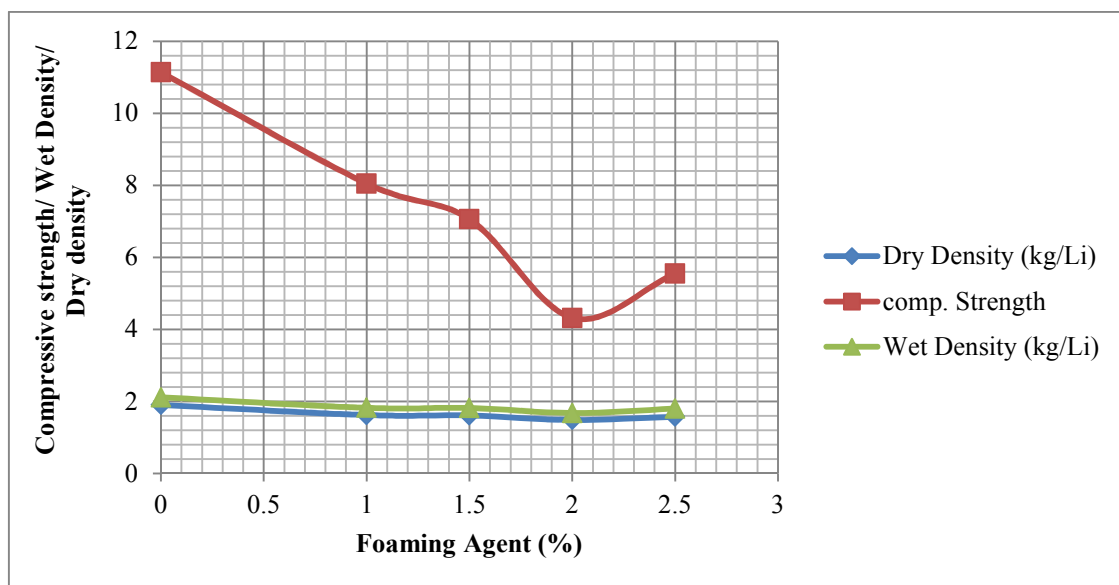


Figure 5: Relationship between wet density, dry density and compressive strength of CLC

4.3. Influence of Bagasse Ash on Mechanical Properties of Cellular Lightweight Concrete

Both above two experiments can be used as a baseline mix to choose appropriate parameters of basic ingredient and target properties. From the first experiment on bagasse ash, bagasse ash content of 10% chooses as optimum value for mortar mix with W/C ratio of 0.55. From the second experiment of foaming agent effect on mortar mix, 1.5% foaming agent dosage has achieve high strength with volume increment of 23%.

All above mortar mixes has a problem of bleeding in initial setting time due to high water content and fluidity (see a picture below) which trigger high plastic shrinkage. To avoid such problems, a lower W/C ratio of 0.5 can be used without affecting the workability of the mix.



Figure 6: Bleeding of mortar during measurement of wet density and its effect on plastic shrinkage.

During trial mix to study bagasse characteristics with W/C ratio of 0.55(Ref: Table Fig 1), at 10% and 14% bagasse ash percentage gives almost same 14 day strength value. So it's feasible to test both 10 % and 15% of bagasse ash replacement to visualize its maximum effect on CLC. The control mix (CLC 1.5%) without bagasse ash used for comparison. From an experiment done on foaming agent effect on mortar shows that 1.5% foaming agent achieve 7 Mpa compressive strength which satisfy a strength class of currently used HCB block. Therefore, 1.5% foaming agent dosage is used in this section of the experiment. The volume increment of mortar due to addition of foaming agent measured by pouring same mass of each mixture into volumetric glass cylinder and measures the change in volume. Table 12 shows a CLC mix proportion to analyse the effect of bagasse ash on mechanical properties of cellular concrete.

Table 12: CLC mix proportion containing bagasse ash

Description	Mix Proportions (kg/m ³)			
	Pure Mortar	CLC 1.5%	CLCBA 10%	CLCBA 15%
Cement	471	330	297	280.5
Sand	1807	1265	1265	1265
Water	229	160.05	160.5	160.05
Bagasse Ash (10%)	-	-	23.04	34.57
Foaming agent	-	4.95	4.95	4.95
From the trial mixes, Expected min air entrain (%)	4	23	23	23

First check foaming agent air entrain capacity by determine the exact volume increment between pure mortar and other mixes. Table below shows volume expansion of each mix compared with pure mortar using laboratory glass cylinder:

Table 13: CLC Air volume calculation

Mix	Volume	Total Mass	Volume change (%)
CLC 1.5%	600ml	1.768	
CLCBA 10%	765ml	1.768	27.5
CLCBA 15%	768ml	1.768	28

All CLC mixes satisfy the minimum requirement of air entrainment or volume change. This result also checked using theoretical density method (ASTM C796) and all mixes have 25% air entrained. After checking the air volume, every mix tested according with ASTM C 495 and ASTM C 796. Test result for mechanical properties such as compressive strength, density, water absorption and plastic shrinkage discuss in below:

4.3.1. Wet density

Wet density of cellular concrete is an important parameter to control field density; it can be easily measured by using known volume steel container and balance. Before casting the CLC, wet density mixture should be determined by calculating the density of samples using a container of known volume. Summary of test result shown in table below:

Table 14: Wet density of CLC containing Bagasse ash

CLC with 1.5% Foaming Agent			
MIX	CLC	CLCBA 10%	CLCBA 15%
Wet density (kg/m ³)	1712.71	1700.92	1695.13
Theoretical density (kg/m ³)	2286.42	2272.75	2267.03
Air content (%) (ASTM C 796)	25.09	25.16	25.23

The increasing a percentage of bagasse ash from 0-15% decrease wet density and theoretical density. This due to a lower density of Bagasse ash compared with cement that makes CLC lighter than the standard one. Below chart shows density and bagasse ash percentage relationship. From the chart wet density of any mix contain bagasse ash can be estimated.

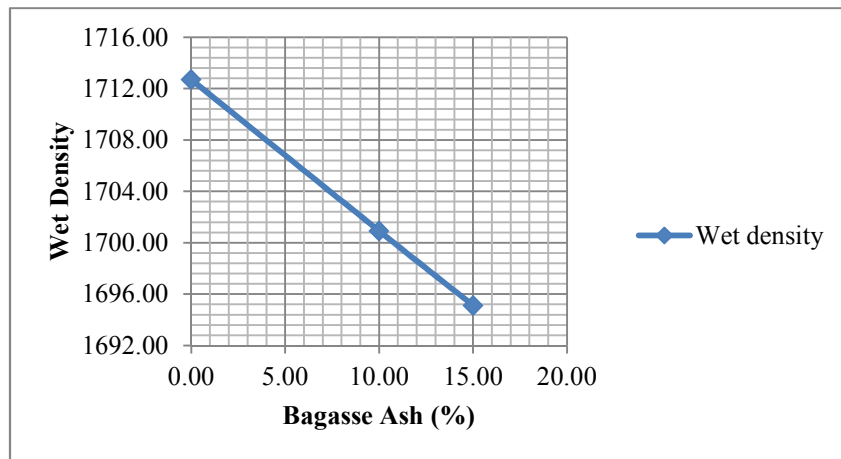


Figure 7: CLC Wet Density and bagasse ash replacement

4.3.2. Compressive Strength

Bagasse ash has a filler and extra micro silica which react with cement calcium oxide to form C-S-H gel. Both properties increase a compressive strength, but in this section of the experiment we select a bagasse ash of 10% and 15% to achieve same strength with a control mix and decrease the total cost of a concrete. The compressive strength of cellular concrete should be evaluated in accordance with ASTM C 796 and C 495. Table below shows the compressive strength of CLC with bagasse ash replacement percentage.

Table 15: Influence of bagasse ash on compressive strength of CLC

CLC with 1.5% Foaming Agent			
MIX	CLC	CLCBA 10%	CLCBA 15%
Avg 28 days compressive strength (Mpa)	6.92	6.95	6.79

This result proves that by replacing 10% to 15% of cement by bagasse ash gives almost equal compressive strength. High consumption of cement in CLC production is the main factor for high cost compare with other materials, therefore bagasse ash replacement minimize material cost of cement the cost by 10-15%.

4.3.3. Oven dry Density and water absorption

Oven dry density and water absorption are the basic parameters for evaluating the characteristics of light weight concrete.

Oven dry density can be determined by dry the companion specimens at the age of 28 days in an oven at 230 6 18°F (110 °C) and weigh at 24-h intervals until the loss in weight does not

exceed 1 % in a 24-h period. Determine the weight and dimensions of the oven-dry specimens and calculate the weight per cubic meter from the average data obtained. (Ref: ASTM C 495)

Find the average weight of water absorbed by the cylinders by subtracting the average dry weight of cylinders from the average wet weight of cylinders. Record to the nearest 0.1 lb (or 0.05 kg). Find the average volume of water absorbed by dividing the average weight of water absorbed by the density of water in lb/ft³ (kg/m³). Dry density and water absorptions for specimens containing bagasse ash summarized in table below.

Table 16: Oven dry density and water absorption of CLC containing bagasse ash

CLC with 1.5% Foaming Agent			
MIX	CLC	CLCBA 10%	CLCBA 15%
Oven Dry Density (kg/m ³)	1538.7	1541.13	1535.6
Water Absorption (%)	13.22	12.90	12.71

Oven dry density of CLC containing 10% bagasse ash is higher than the control mix. Whereas CLC has 15% bagasse ash has lower dry density. This shows that the density of CLC governed by a filler property of bagasse ash until it reach 10% and above 10% it dominated by the density of bagasse ash. From above test results, Oven dry density and compressive strength of cellular lightweight concrete are directly proportional. On the other hand, water absorption of CLC decrease with increasing of bagasse ash content because of its filler characteristics. CLCBA 10% and CLCBA 15% mixes only have slight decrease of water absorption compared to the control mix. An oven dry density and water absorption property with increase of bagasse ash content is shown in figure below.

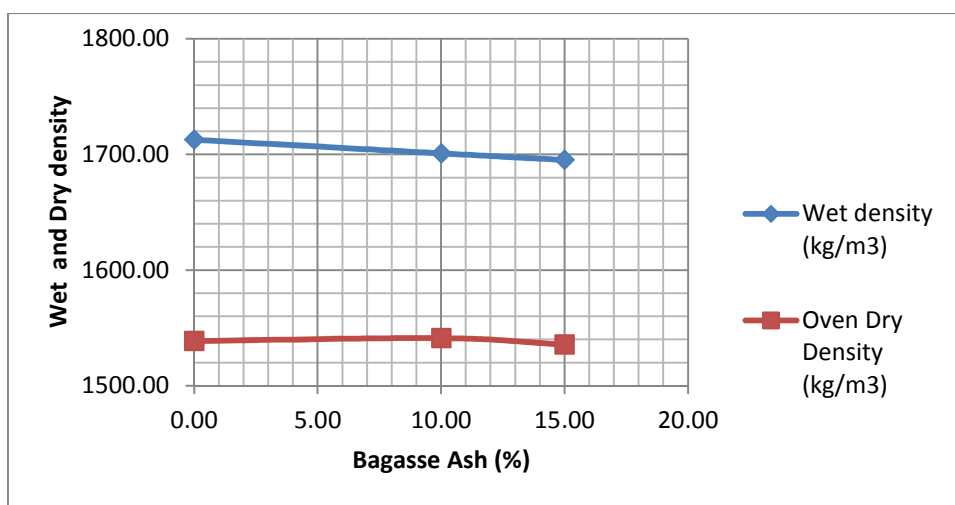


Figure 8: Comparison between wet and dry density of CLC containing bagasse ash

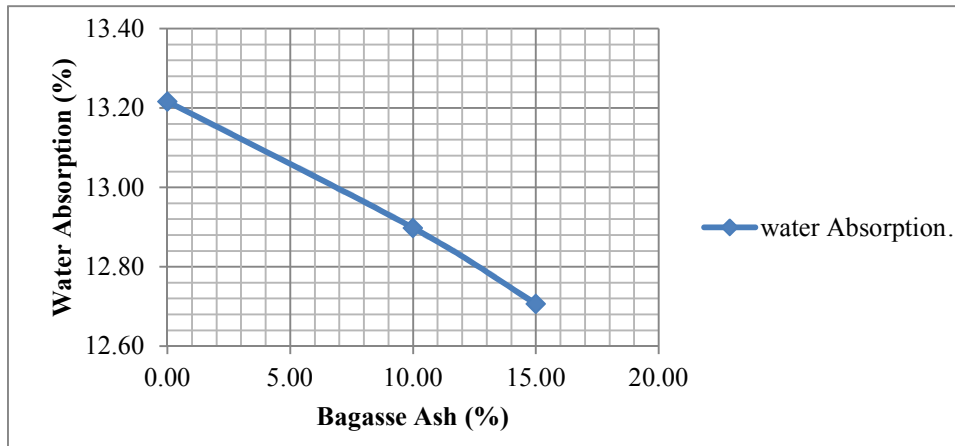


Figure 9: Water absorption of CLC containing bagasse ash

Replacement of cement by 10-15% bagasse ash in CLC slightly decreases density and water absorption of the mix.

4.3.4. Plastic Shrinkage

A linear plastic shrinkage for mortar mixture is conducted according to ASTM C531-00 with slight modification. In this study, the linear shrinkage measures at 24 hr after casting by direct taping of concrete samples and calculate the percentage shrinkage. This method used for research purposes to provide information on linear changes that take place in test materials. Plastic shrinkage of each mix summarized in table below.

Table 17: Plastic shrinkage of CLC containing bagasse ash

CLC with 1.5% Foaming Agent			
MIX	CLC	CLCBA 10%	CLCBA 15%
Plastic shrinkage (%)	0.8572869	0.1001001	0
Wet/Dry density ratio (stability parameter)	1.11	1.10	1.10

Plastic shrinkage of the mix highly decreases with replacement of cement with bagasse ash. Due to high fineness of bagasse ash particles, it coats the air bubbles and forms stable air inside mortar, which decreases collision of small air bubbles to form big ones and increases the stability of the mixture. Those factors also increase the stability of the mix without bleeding and segregation.

CHAPTER FIVE

ECONOMIC ANALYSIS of USING CLC BLOCKS

5.1. Correlation between cylindrical and block strength

To compare a material cost of CLC blocks with currently used HCB blocks, first the comparison should be in similar criteria such as block compressive strength, total mix cost. Therefore cylindrical strength from this research shall be converted to block strength. The conversion is based on a research done by C.S.BARBOSA and J.B. HANAI on relationship between compressive strength cylindrical concrete (100mm*200mm) and HCB (14*19*39) [38]. This research has done on concrete cylinder and blocks that shall be changed to mortar strength. Figure 11 shows the relationship between cylindrical and blocks strength. To do such comparison, the equivalent concrete compressive strength of CLC (mortar mixture) shall be determined.

Research done by Weigler and Karl (1972), cited by Chen et al. (1999) by comparing the strength developments in mortar and lightweight aggregate (LWA) concretes [39], and noticed the existence of dividing strength in LWA concretes. They explained the dividing strength as the change of stress distribution between the mortar and the lightweight coarse aggregate during the strength development of LWA concretes. According to their concept, the relationship between the strengths of concrete and mortar can be described in three ranges (Fig. 10). The condition in the first range is similar to that of normal aggregate concrete in which the E value of Normal aggregate concrete (NCA) is higher than that of mortar and the mortar governs the compressive strength that implies the mortar strength is equal to concrete strength in low strength concretes.

In the second stage, at high strength, as the E value of coarse aggregate (E_A) is lower than that of mortar (E_m), concrete strength is restrained by the strength of coarse aggregate. Because two distinct tendencies of concrete strength are depicted in relation to mortar strength, it is implied that a change in stress distribution occurs. The equivalent concrete compressive strength of CLC mortar mixture correlated from the graph below [39]:

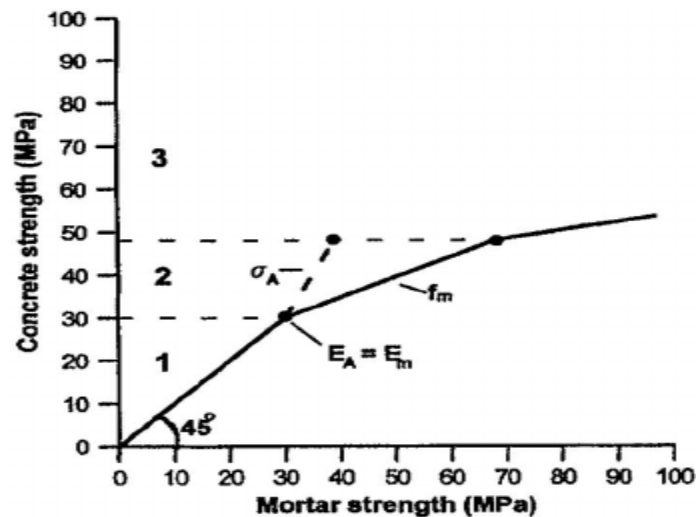


Figure 10: Relationship between concrete strength and mortar strength (reprinted from Cement and Concrete Composites , vol. 21, H.J. Chen, T. Yen, T.P. Lia, and Y.L. Huang, “ Determination of the Dividing Strength and Its Relation to the Concrete Strength in Lightweight Aggregate Concrete, ” pp. 29 – 37, 1999, with permission from Elsevier)

Based on the above figure, the compressive strength of cement mortar is equal to concrete until it reaches 30Mpa because mortar governs compressive strength . Therefore, cement composite of CLC concrete produced in this research has 1:1 strength ratio with concrete which implies the research on cylindrical versus block strength can be directly used without any conversation factor.

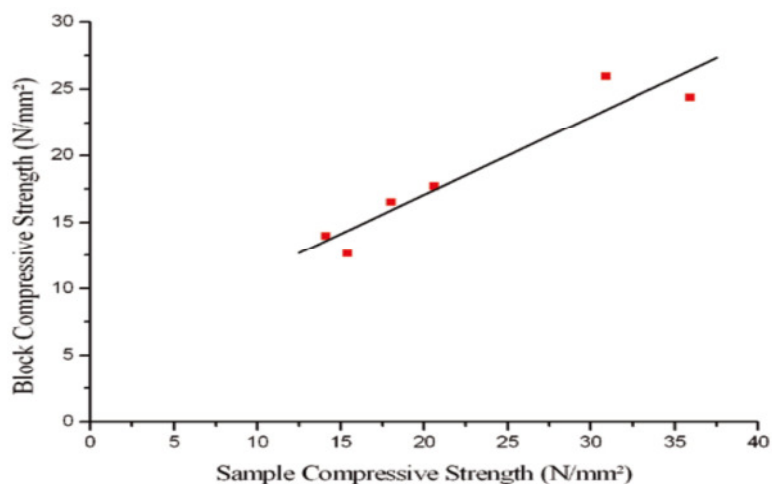


Figure 11: Relationship between cylindrical and block strength by C.S.BARBOSA and J.B. HANAI

The equation below interpreted the above graph by assuming linear data distribution. Strength below 10 MPa determine by interpolating values of the graph.

$$f_b = 0.72f_c + 3.3 \dots \dots \dots \text{Equation 6}$$

Based on the above equation, cellular lightweight concrete with 15% bagasse ash replacement has a cylindrical and block strength of 6.79 Mpa and 8 Mpa respectively. This satisfies a minimum safety factor of 40% field uncertainty. Cellular lightweight concrete block with 15% bagasse ash has a higher compressive strength than Class A HCB (Average compressive strength of 5 Mpa).

To conclude, a Cost CLC block containing 15% bagasse ash can be compared with class A HCB (Ethiopian standard).

5.2. Cost comparison between CLC block and HCB (Hallow Concrete Block)

The feasibility of using CLC blocks is evaluated by material and production cost reduction. Material Cost comparison between class A HCB and CLC is summarized in table below. Mix proportion of HCB block adopted from one of the biggest manufacturer which produce class A, B and C class blocks.

Both HCB and CLCB mix proportions are at SSD condition and has 100 kg cement. Mix design of CLCB with 15% bagasse ash replacement and HCB class A are selected for comparison. The table on the next page is a summary of cost analysis of each mix and material cost.

Table 18: Cost comparison between HCB and CLCB

Description	HCB			CLCB		
	Mix proportion at SSD condition (m ³)	unit price/m ³	cost in (Birr)	Mix proportion at SSD condition (m ³)	unit price/m ³	cost in (Birr)
Cement (100kg)	0.03	7250.00	230.16	0.032	7250.00	230.16
Aggregate O1	0.32	268.00	85.76			0.00
Sand	0.16	480.00	76.80	0.180	480.00	86.40
Pumice	0.08	85.00	6.80			0.00
Bagasse Ash				0.006	1000.00	5.60
water	0.03	0.60	0.02	0.057	0.60	0.03
Foaming Agent				0.002	23000.00	39.10
Entrained air (%)				0.082		
Total volume yield	0.59			0.358		
Total material cost (Birr)			399.53			361.29
No of block per 100kg cement (15*20*40)	50.00		50.00	75.00		75.00
Cost per block			7.99			4.82
Min Compressive strength	4.50			5.00		

The material cost of CLCB is lower than that of HCB. Cost per block of CLCB is 40% lower than HCB. Another advantage of CLC is no need for compaction whereas HCB need high electricity for vibration and compaction. CLC can be precast or cast in place based on the project requirement while HCB can be used as precast block.

CHAPTER SIX

CONCLUSION AND RECOMMENDATION

6.1. Conclusion

In this research, significant past research works were reviewed on cellular lightweight concrete (CLC), and new mix proportions were designed based on literature review and trial mixes. Laboratory tests were conducted to analyse mechanical properties of CLC. In past practices, fly ash was used as cement replacement material in CLC, whereas in this experiment bagasse ash from Wenji sugar factory is used as partial cement replacement material.

All the above works are done to check a suitability, property and feasibility of CLC containing bagasse ash. From laboratory tests conducted by using bagasse ash as a cement replacement material, the following conclusions are forwarded:

1. 1.5% bwc of a particular foaming agent admixture were used and achieved a stable mix without bleeding and segregation.
2. Bagasse ash can be used as cement replacement material up to 15% by volume of cement in CLC without decreasing of the mechanical properties (compressive strength and density).
3. 10% replacement of cement with bagasse ash slightly improves mechanical properties of CLC such as compressive strength and dry density.
4. Addition of bagasse ash in CLC significantly reduces a plastic shrinkage and water absorption which are the main parameters of mortar mixture.
5. Replacement of bagasse ash in CLC reduces the cost of cement by 10%. Total material cost of blocks produced by CLC is less than that of HCB. Which implies using CLC for production of hollow blocks is feasible in both performance and cost.

6.2. Recommendations

Cellular lightweight concrete is a versatile material which can apply in different building and other construction activities. The production of CLC can easily adopt in current construction sectors without high increment of production cost and need of big equipment. Further investigations are recommended in the following points:

- Cellular lightweight concrete were produced by adding a foaming agent admixture during concrete mixing. Detail study on the performance of CLC using pre-formed foam shall be explored.
- Effect of bagasse ash on micro structure of foam concrete shall be investigated.
- Full economical study including machinery cost and initial investments shall be investigated.

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APPENDIXES

Appendix I- Laboratory Test Results

Appendix I-A Materials Laboratory Test Results

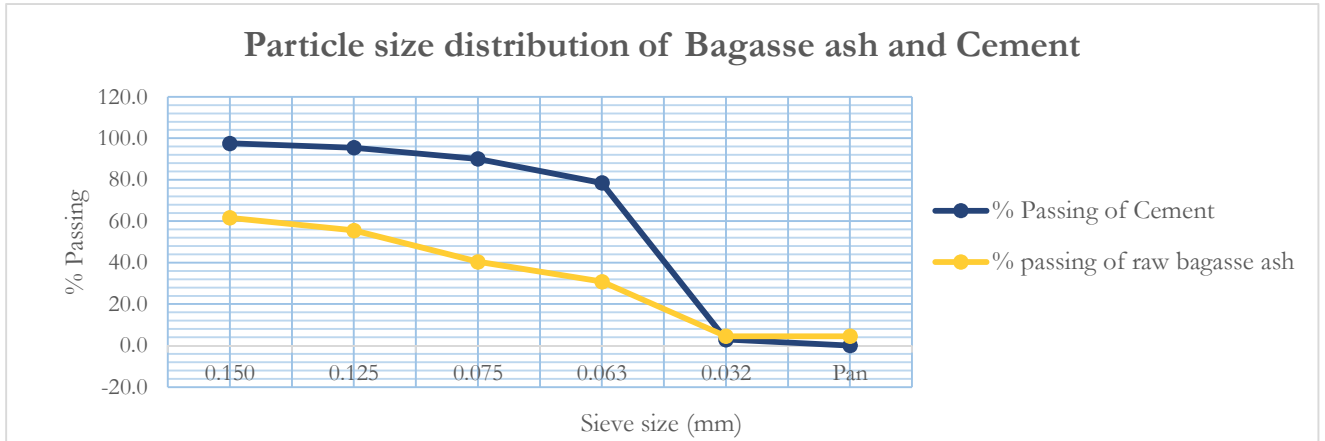
Specific gravity of bagasse ash

Bagass Ash Specific gravity		
Formula	Description	Gram
A	mass of water+ bottle	126
B	mass of sample	20
C	mass of boottle+ sample	49
D	mass of boottle+ sample +water	137
V=D-A	volume (ml)	9
SG= B/E	Specific gravity (kg/Li)	2.22

Particle of cement and bagasse ash (pass 300 micro sieve)

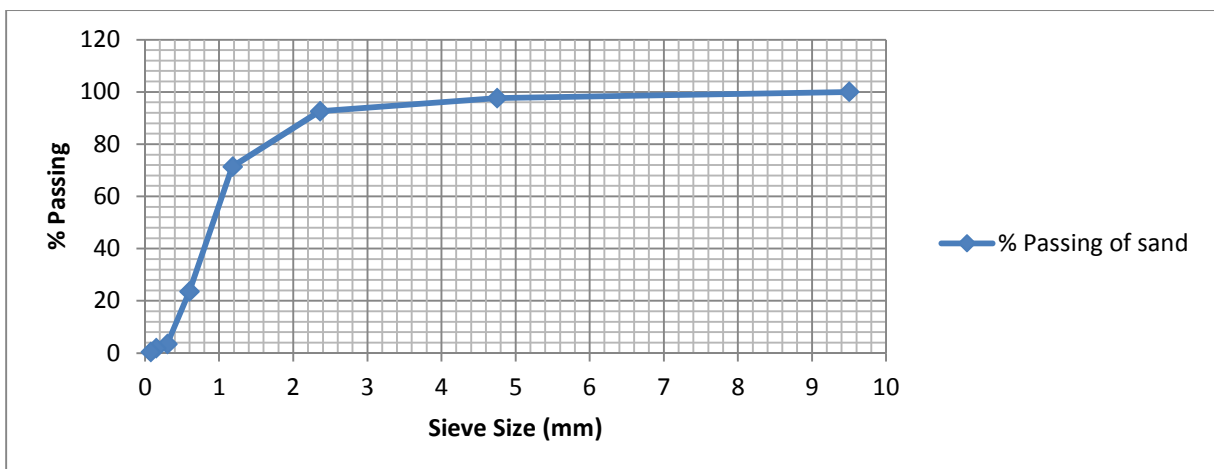
Description	Dangote cement (Specific gravity =3.15 kg/Li)						
Weight of sample	242						
Sieve Size	Seive No.	Seive +Cement (gm)	Weight of seive (gm)	Weight Retained (gm)	Percent Retained (%)	Cumulative percent retain	% pass
0.150 mm	#3/8	276	270	6.0	2.5	2.5	97.5
0.125 mm	#4	452	447	5.0	2.1	4.5	95.5
0.075 mm	#8	269	256	13.0	5.4	9.9	90.1
0.063 mm	#16	285	257	28.0	11.6	21.5	78.5
0.032 mm	#30	631	448	183.0	75.6	97.1	2.9
Pan	#50	250	243	7.0	2.9	100.0	0.0
Total Sum				242.0	100.00		

Description	Baggase ash from Wonji Sugar Factory (pass 300 micron sieve)					
Weight of sample	145					
Sieve Size (mm)	Seive + Baggase ash (gm)	Weight of seive (gm)	Weight Retained (gm)	Percent Retained (%)	Cumulative percent retain (%)	% pass
0.150	304	270	34.0	23.4	23.4	76.6
0.125	459	447	12.0	8.3	31.7	68.3
0.075	282	256	26.0	17.9	49.7	50.3
0.063	274	257	17.0	11.7	61.4	38.6
0.032	497	448	49.0	33.8	95.2	4.8
Pan	245	243	2.0	1.4	96.6	3.4
Total sum			140	96.55		



Gradation and specific gravity sand

Sand Gradation						
sieve size (mm)	Mass Retained	% Retained	cumulative % retained	% Passing	cumulative Retained	Fineness Modulus (FM)
9.5	0	0	0	100	0	
4.75	12	2.4	2.4	97.6	2.4	
2.36	25	5	7.4	92.6	7.4	5
1.18	106	21.2	28.6	71.4	28.6	28.6
0.6	239	47.8	76.4	23.6	76.4	76.4
0.3	101	20.2	96.6	3.4	96.6	96.6
0.15	8	1.6	98.2	1.8	98.2	98.2
0.075	7	1.4	99.6	0.4	99.6	
Pan	2	0.4	100	0	100	
Total Mass	500 gm	100				304.8
					FM	3.048



Analysis of Mechanical Properties of Cellular Lightweight Concrete Containing Bagasse Ash

Chemical composition of bagasse ash (From Geological survey of Ethiopia)

Geological Survey of Ethiopia, Geochemical Laboratory Directorate
 Geochemical Laboratory Complete Silicate Analysis Report Format
 Form G0004

FILE ID : 7173/16 ppt
 Originator: Mihret Geremew(AAIT)
 Date Submitted: 08/10/2016


Element to be determined Major Oxides & Minor Oxides

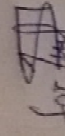
Sample type: Powder
 Preparation : 200 MESH
 Number of Sample: 1
 Analytical Method: LIBO2 FUSION , HFAttack, GRAVIMETRIC, COLORIMETRIC and AAS

Analytical Results in PERCENT

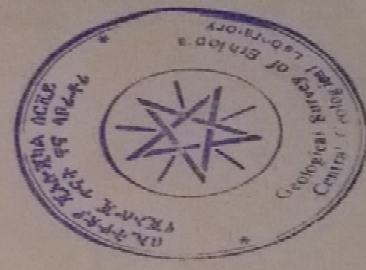
FIELD NO	Lab No	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	CaO	MgO	Na ₂ O	K ₂ O	MnO	P ₂ O ₅	TiO ₂	H ₂ O	LOI	503
M.G.1	7173/16	66.92	7.06	6.12	3.60	1.96	4.28	4.92	0.2	0.02	0.05	0.01	3.65	0.25

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QUALITY CONTROL

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DATE REPORTED
 08-30-2016



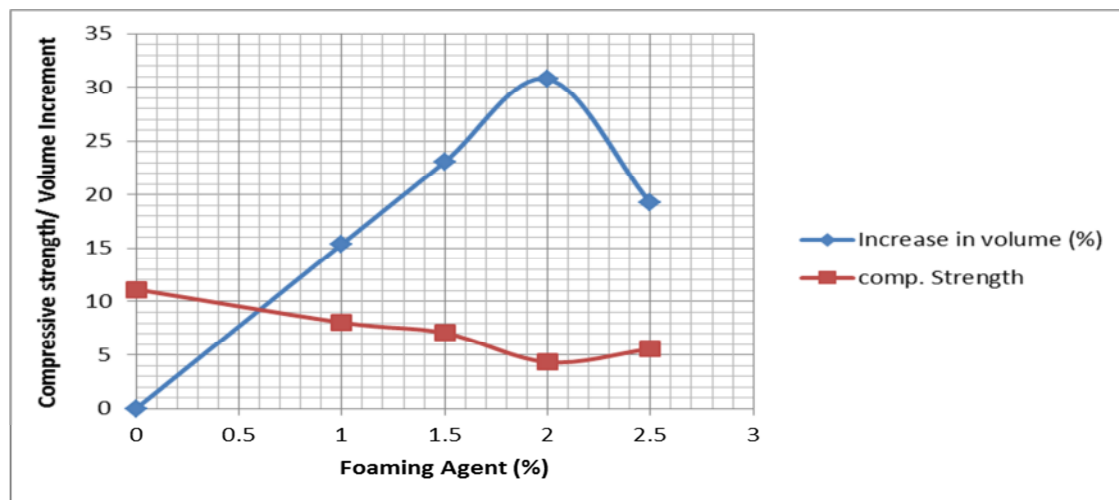
Appendix I-B Laboratory Test Results for Mortar

Effect of foaming agent dosage on mechanical properties of Mortar

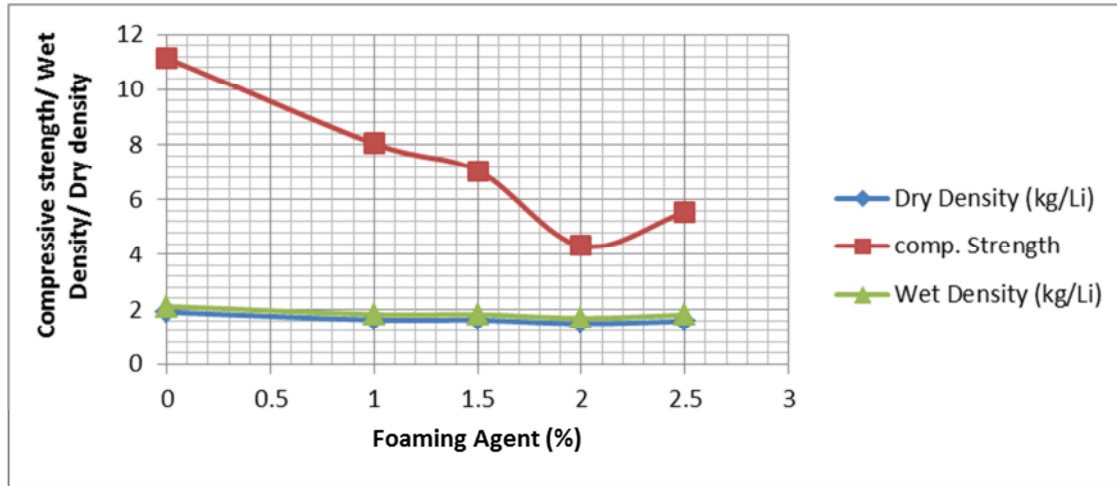
Foaming agent effect on compressive strength/ density/ volume change					
FA%	0	1	1.5	2	2.5
Wet Density (kg/m ³)	2116.306	1824.768	1822.257	1681.028	1803.323
Increase in volume (%)	0	15.38462	23.07692	30.76923	19.23077
comp. Strength	11.14	8.05	7.06	4.32	5.55
Dry Density (kg/Li)	1.905	1.624	1.614	1.488	1.578
Dry Density (kg/m ³)	1905	1624	1614	1488	1578
Stability (wet/dry density)		1.123626	1.129031	1.129723	1.14279
Wet Density (kg/Li)	2.116306	1.824768	1.822257	1.681028	1.803323

Compressive strength versus foaming agent Percentage

Average dry mass /comp strength			14 day compressive strength							
FA%	0		1		1.5		2		2.5	
sample No	Dry mass	Com .stg	Dry mass	comp .stg	Dry mass	comp .stg	Dry mass	comp .stg	Dry mass	comp. stg
1	2995.0	11.8	2552.0	8.7	2530.0	7.1	2330.0	4.1	2473.0	5.7
2	3003.0	12.7	2557.0	7.4	2544.0	6.3	2336.0	4.3	2482.0	5.6
3	2981.0	10.9	2538.0	8.9	2550.0	7.1	2343.0	4.8	2480.0	5.4
4	2988.0	9.1	2552.0	7.3	2531.0	7.8	2336.0	4.1		
Average	2991.8	11.1	2549.8	8.1	2538.8	7.1	2336.3	4.3	2478.3	5.6
volume (m ³)	0.0016									
Dry Density	1905.6		1624.0		1617.0		1488.1		1578.6	



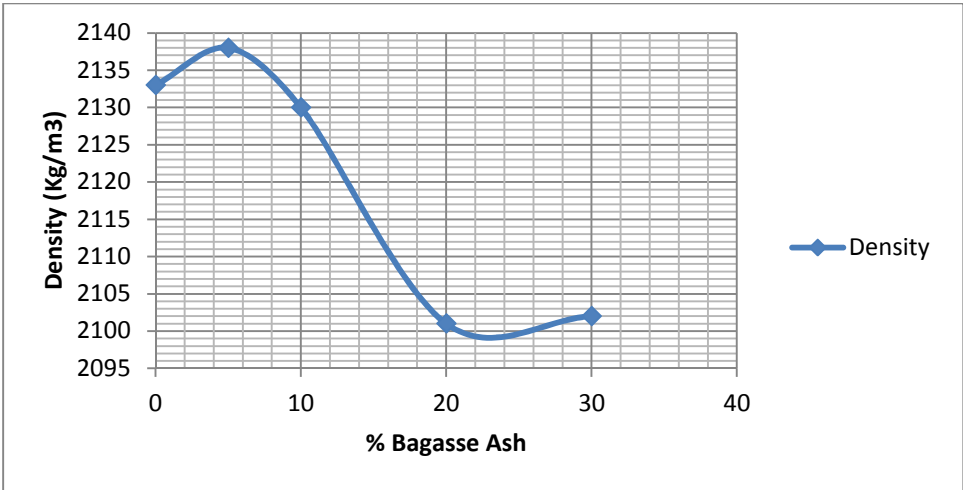
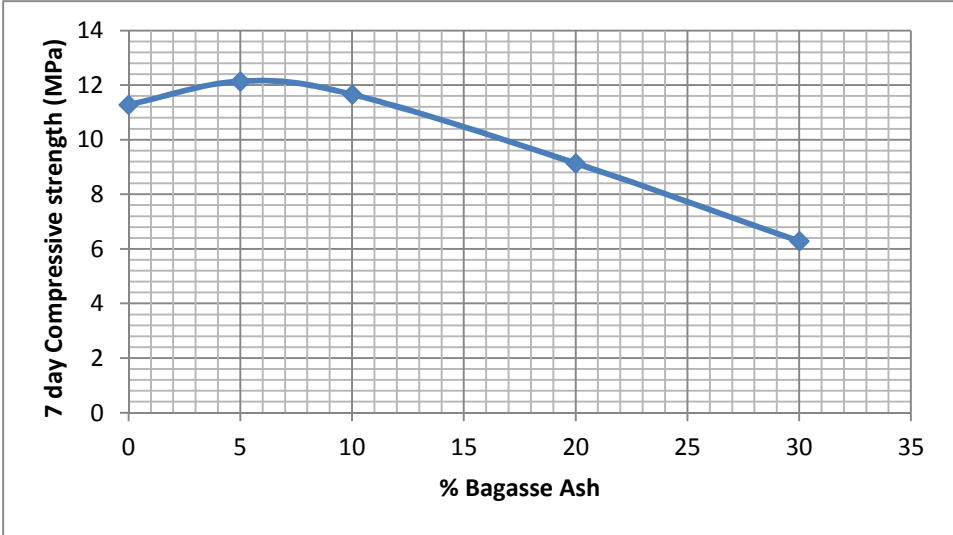
Analysis of Mechanical Properties of Cellular Lightweight Concrete Containing Bagasse Ash



Effect of Bagasse ash replacement on mortar

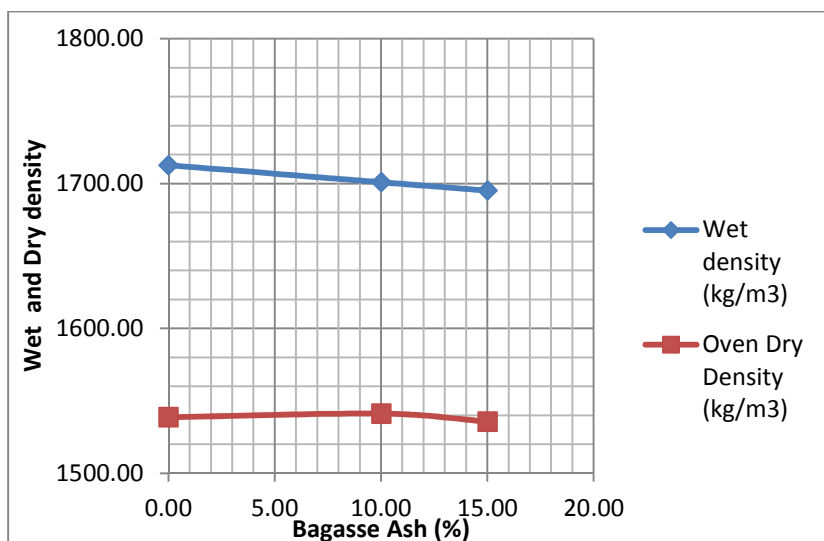
Bagasse Ash effect on comp.strength/ density					
BA%	0	5	10	20	30
Density (kg/m ³)	2133	2138	2130	2101	2102
7 Day compressive strength (MPa)	11.28	12.14	11.66	9.14	6.28

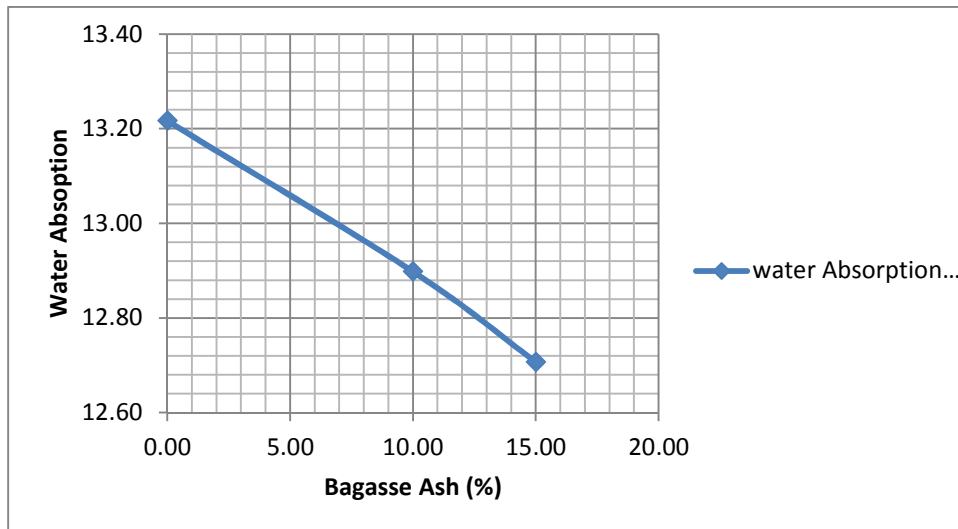
Average mass /comp strength			7 days							
BA% by volume	0		5		10		20		30	
sample No	Mass (gm)	comp. strg (MPa)	Mass (gm)	comp. strg (MPa)	Mass (gm)	comp. strg (MPa)	Mass (gm)	comp. strg (MPa)	Mass (gm)	comp. strg (MPa)
1		10.23	3360	11.41	3358		3303	8.39	3324	6.31
2	3354	11.54	3354	12.44	3344	12.04	3313	9.05	3288	6.01
3	3323	12.36	3346		3335	12.32	3296		3290	6.53
4	3344	11	3367	12.57	3340	10.62	3286	9.98		
Average	3340.3	11.28	3356.7	12.1	3344.2	11.6	3299.5	9.14	3300.6	6.28
volume	0.00157									
Density	2127.601		2138.057		2130.096		2101.592		2102.335	



Appendix I-C Laboratory Test Results for Cellular Lightweight Concrete

MIX (kg/m3)	0% BA	10% BA	15 % BA
cement	330	297	280.5
sand	1265	1265	1265
water	160.05	160.5	160.05
BA		23.04	34.57
FA	4.95	4.95	4.95
Water to binder ratio	0.5	0.5	0.5
Wet density	1712.71	1700.92	1695.13
Theoretical density	2286.4213	2272.7484	2267.027585
Theoretical Air	25.092107	25.160216	25.22675899
Dry density	1538.7	1541.13	1535.6
Wet to dry density ratio	1.11	1.10	1.10
wet mass	2721.5	2740	2743
28 day mass	2514	2537.5	2543.5
Absorbed volume of water	0.0002075	0.0002025	0.0001995
Volume of concrete	0.00157	0.00157	0.00157
water absorption	13.216561	12.898089	12.70700637
Avg 28 days compressive strength	6.92	6.95	6.79
Initial height	200	200	200
24 hr height	198.3	199.8	200
Plastic shrinkage (%)	0.8572869	0.1001001	0





Appendix II- photographs



Picture 1: sampling of bagasse ash from that disposed from wenji sugar factory mill



Picture 2: High speed shear mixing of CLC



Picture 3: Formation of air bubbles inside the mortar



Picture 4: Wet density determination using known container volume



Picture 5: cylindrical cubes contains bagasse ash