STRENGTH CHARACTERISTICS OF FLYASH-CEMENT STABILIZED COMPRESSED EARTHEN BLOCKS

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The author wants to dedicate this work in the memory of her late father.

ABSTRACT

Manufacturing Fired Clay Bricks (FCB) contributes to pollution and leads to loss of fertile soil. To save valuable natural resources, reduce pollution and increase energy efficiency, environment friendly Compressed Stabilized Earth Block (CSEB) can serve as a suitable alternative solution to FCB. This study aims at investigating the effect of flyash and cement as stabilizers on the strength characteristics of CSEB and its cost effectiveness.

Five soil samples were collected from different locations of Narsinghdi, Bhola and Barishal districts. Suitable soil for the production of CSEBs was selected from these collected samples. This investigation has been carried out with different combinations of soil-fly ash-cement mixes with varying level of compaction, cement percentage and water content. Fly ash content of 5%, 10%, 15%, 20% were used along with 5%, 7% and 10% cement content. Meanwhile water content was varied using 10%, 15%, 20% and 25% by weight of each sample. The soil mixtures were poured into steel moulds and compacted to produce cubic samples measuring 5cm × 5cm × 5cm.

The effect of the stabilizers on the compressive strength and water absorption capacity of the prepared CSEBs were observed and determined after 7, 14 and 28 days of curing. The maximum compressive strength of CSEB was obtained as 2.63 MPa consisting of 80% soil, 10% fly ash, 10% cement by weight and 20% of mixing water content by total weight of mixture. To understand microstructural behavior of these blocks, Scanning Electron Microscopy (SEM) tests were performed, it was found that size of voids decreases with an increase in fly ash content. The combined effect of flyash and cement contributed to good bonding and increased compactness which has been well interpreted in the images received. A comparative cost study was carried out between fly ash stabilized CSEBs and conventional fire burnt bricks, it has been found that fly ash block of equivalent brick size costs much less than FCBs available in Bangladesh. Meanwhile using the combination that attributed the highest strength of these CSEBs, unfired bricks measuring 25 cm × 12 cm × 7 cm (approximately) were made using the specifications of Bangladesh Standards and Testing Institution (BSTI), these bricks when experimented exhibited similar results of compressive strength like the flyash-cement stabilized blocks which makes both these suitable as construction materials in non-load bearing walls upon fulfilling specific building code requirements.

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ACRONYMS

AVEI	Auroville Earth Institute
CSEB	Compressed Stabilized Earth Block
CGI	Corrugated Iron Sheet
CEB	Compressed Earth Block
FCB	Fired Clay Brick
GHG	Green House Gas
SB	Stabilized Block
USB	Unstabilized Block

Chapter 1

INTRODUCTION

1.1 General

Raw earth was one of the first, oldest and most traditional building materials to be used by man and it has a heritage dating back over at least 10,000 years (Islam, 2010; Hossain, 2015). From the civilization of Mesopotamia dated 6000 years back the use of earth as a building material is very evident (Deboucha and Hasim, 2011). Still today 50% of the population in developing countries, including the majority of rural population and at least 20% of the urban and suburban population, live in earthen dwellings (Houben and Guillaud, 2005).Sustainability of such earthen houses gained the attention of developed countries in the past 40 years (Islam et al., 2006; Islam, 2010). However, this interest is not growing in developing countries like Bangladesh. As a low-income country, the common people of Bangladesh can only dream of building a decent shelter for themselves at a low cost. Therefore, a need arises to find a feasible building material which is not only locally obtainable and economical, but is also a way towards sustainable development.

Abundant use of Fired Clay Brick (FCB) is observed both in the urban, semi-urban and rural areas of Bangladesh. This culture leads to deforestation and generation of humongous amount of greenhouse gases. If earthen blocks can be prepared with as much strength and durability as that of fired bricks it might be a suitable alternative solution to fired brick and can save both money and environment. Since, Bangladesh has only limited natural sources of stones and construction of infrastructure and buildings often depends on the supply of locally produced bricks. The construction sector has been growing at a rate of 8.1% to 8.9% a year during the last decade, with concomitant growth in demand for bricks (IIDFCL, 2009). As a result, fire burnt brick is the most common and popular construction material in our country. But burning of fuel for firing of bricks results in emissions of gaseous pollutants and ash into the environment. It is estimated that around 15 billion bricks are produced annually in Bangladesh from around 5,000 brick kilns (Hossain, 2008). On average, a traditional brick kiln burns 70 percent coal and 30 percent firewood. It needs around 25 tons of coal or 42 tons or 3,500 cubic feet of woods to burn one lakh bricks. Brick kilns are puffing away 240 lakh trees per year which has led to deforestation. Studies show that the current deforestation rate in South Asia is 0.6 percent, whereas it is 3.3 percent in Bangladesh. Studies have also shown that brick kilns have produced 12.99

million tons CO_2 in the year 2012 by burning bricks and which is increasing every year (Imran and Baten, 2014).

Bangladesh lies in a seismic vulnerable zone. Recent seismic activities indicate Bangladesh is at high seismic risk. The July 27, 2003 Barkal earthquake left around 150 houses destroyed and 500 families homeless (Islam and Kanungo, 2007). Obviously, this is due to the lack of seismic deficiency of traditionally constructed earthen houses. Seismic deficiencies of earthen structures are primarily due to brittleness and low tensile strength of the block as well as poor bonding between block and mortar. Hence, to improve seismic performance, it is necessary to improve block properties (i.e., strength, ductility and toughness).

Besides fly ash, an industrial by product of coal combustion of thermal power plants became an environmental issue because of its improper disposal. In Bangladesh 2.41 % of the total energy is produced from coal based thermal power plants which are now the major source for production of fly ash. In 2015, fly ash production of Bangladesh were at 52000 metric tons per annum, which is expected to soar to 377000 metric tons per annum by the end of year 2018 (Islam et al., 2015). Disposal system of this wastes is not abiding by any law and practically the produced fly ash is transported and disposed into some dry embankments. Present problem with fly ash lies in the fact that not only does its disposal requires large quantities of land, water, and energy, its fine particles, if not managed well, by virtue of their weightlessness, can become airborne. When not properly disposed, fly ash is known to pollute air and water, and stands for the cause of respiratory diseases when inhaled.

Earthen buildings have the benefit that they can be built from on-site materials rather than materials with high carbon footprints (Holliday et al., 2016). However, there are few undesirable properties such as loss of strength when saturated with water, erosion due to wind or driving rain and poor dimensional stability (Islam and Haque, 2009; Islam and Iwashita, 2010). Durability and strength are also major problems.

Considerable research has been made in the modern times to make earth as a sustainable construction material. This has led to the development of technology using earth in the form of rammed earth and unfired bricks popularly known as Compressed Stabilized Earth Block (CSEB). For six decades remarkable initiatives have been made to make unfired stabilized bricks (Jagadish et al., 2011; Deboucha and Hasim, 2011). This is achieved by proper grading of soil mix, proper compaction and stabilization using admixtures, which results in increased density, reduced water absorption, increased frost resistance and mainly increased the compressive strength of masonry blocks (Nagaraj et al., 2014).

Bangladesh needs an alternative building material to Fired Clay Bricks(FCB),Corrugated Iron Sheet (CI), concrete, wood, bamboo, etc. that is both cost effective and environment friendly. CSEB can be a good alternative. Not only CSEBs are 25-30% cheaper than FCB, but also produce 70% less CO_2 emissions per m^2 wall that of FCB. In addition, there is no deforestation for firewood, neither any top soil depletion. For the production of CSEB, mainly subsoil is needed and abundant supply of riverbed sand available in Bangladesh can be utilized. Extraction of river bed sand can aid in navigability by removing excess sand from the river beds by dredging. This extracted sand can serve as an excellent raw material for manufacturing CSEB. Moreover, hollow-interlocking CSEBs allow for horizontal and vertical reinforcement for earthquake resistant construction. For constructing affordable, safe and eco-friendly housing, CSEB is a strong alternative in Bangladesh.

In this research, attempts have been made particularly to determine the strength characteristics of earthen blocks made with river bed sand and fly ash.

1.2 Background

The oldest structure with adobes and sundried blocks were built in Egypt in 1300 BC, the vault of Ramasseum. Man has been building structures with earth more than 10000 years ago which becomes evident from the building remnants obtained in the Harappa, Mohenjo-Daro and Jericho (Jagadish, 2012). Since the early 1950's considerable attention has been made to develop low-cost housing for low income population by researching building materials and techniques that are locally available. In this sequence Compressed Stabilized Earth Block has been developed.

The choice of sustainable construction materials and design for low cost housing can be helpful not only to address social and economic issues but also environmental issues such as reduction of Green House gases (GHG) emissions. Soil blocks possess long lasting and less environmental impact. For this reason, in most parts of the world use of earth as a building material can be noticed. Therefore, it demands research and continuous investment in appropriate technologies that ensures low cost construction materials and minimizes environmental impact (UN-HABITAT, 2009).

The pre-condition of low cost house construction is affordable and available raw materials. Earth is perhaps the most accessible and economical natural material used for building blocks (Chan, 2009). Soil blocks are attractive materials because they are inexpensive to produce (Islam and Yaacob, 2011). The block made out of soil for building materials have existed in many countries for a very long time (Binici et al., 2005). Earth has the advantages of being recycled and hence soil blocks can be easily turned into earth without pollution to the environment and can be reused (Rigassi, 1985). Furthermore, the energy required for for producing soil block is relatively low as compared to burnt bricks (Al-Sakkaf, 2009). Moreover, it has the advantages of being used for a variety of building components such as walls, roofs and floors. Overall, it can be used as low-cost housing for its abundant availability and inexpensiveness in most countries (Morris and Booyesen, 2005).

Another severe problem of earthen building is its vulnerability to earthquake loading. Various researches have been carried out around the world to alleviate these problems. One such form of earthen building material is Compressed Earthen Block (CEB). When stabilizers such as fly ash, cement are added in certain proportions to form CEB, then it is called Compressed Stabilized Earthen Block, CSEB (Mesbah et al., 2004; Marin et al., 2010; Ming, 2011). The numbers of factors influencing the properties of such blocks are many. Not only the stabilizers but also the clay content has significant effect on strength and erosion properties of CEB/CSEB. Due to affordability, local availability and ease of construction, earth blocks have huge potential as a low-cost building construction material in Bangladesh.

Fired Clay Bricks (FCB) has been the chief building material for housing construction in Bangladesh. It is regarded as a massive source of Greenhouse gas (Rahman et al., 2016; Riza et al., 2010; Morel et al., 2001). Moreover, a huge amount of agricultural top soil is used yearly to produce FCB. Hence, in a country like Bangladesh to find a low-cost, eco-friendly and sustainable building material is of paramount importance. Compressed Stabilized Earth Block (CSEB) made with various additives is a potential alternative to FCB. Main factors affecting the CSEB's strength are stabilizer content and types of soil. Addition of stabilizer with soil for making CSEB plays an important role to develop bonding between soil stabilizer mixes and thus enhances its strength and durability (Riza et al., 2011 and Anifowose, 2010). Therefore, CSEB has a great potential as a building material.

This study focuses on to develop low cost light weight environment friendly compressed stabilized earth block (CSEB). Fly ash is used as a stabilizer in this study. Different percentages of cement and with varying combinations of soil and fly ash are used for the production of CSEB specimens.

1.3 Objectives

The main objectives of this research work are as follows:

1) To find the suitability of riverbed sand for preparing compressed stabilized earthen blocks.
2) To determine the strength of flyash-cement stabilized block specimens and compare its strength with that of conventional bricks available in Bangladesh.
3) To develop a guideline for making flyash and cement compressed earthen blocks.

1.4 Methodology

In order to achieve the objectives as mentioned, the following methodologies was adopted:

1) Five soil samples were used for this study. One of the soil samples was collected from Amanatgong khal and another one from Dadpur Ferry Ghat Mehendiganj under Barishal district of Bangladesh. From the remaining soil samples, one soil sample is collected from Roktinodi, Durlabhpur of Shibganj upazila under Chapai Nawabganj district, one from Rahmatkhali khal of Laxmipur-Bhola ferry route and other one is collected from Meghna river. All the five collected samples were river dredged sample. Laboratory tests such as specific gravity, grain size analysis, and Atterberg limit tests were conducted to determine the characteristics of the collected soil samples. Fly ash and cement was used with the selected soil to stabilize the earthen blocks.
2) Compressive strength test was conducted on cubic specimen of 5cm long, 5 cm wide and 5 cm deep to determine the compressive strength of stabilized soil block.
3) Compressive strength test was also conducted on unstabilized soil blocks to the compressive strength of unstabilized block and comparing with stabilized block strength. Thus, determining how stabilizer effect the compressive strength of blocks.

4) Absorption test was also conducted on both stabilized and unstabilized CSEB block to determine the absorption capacity of prepared CSEB specimens.
5) The microstructural composition of the blocks was observed and compared using Scanning Electron Microscopy (SEM).
6) Using the guidelines of Bangladesh Standards and Testing Institution (BSTI) standard unfired brick samples 25 cm long, 12 wide and 7 cm deep were made and their respective strength after 28 days of curing was determined and compared with that of conventional bricks available in Bangladesh.

1.5 Thesis Layout

The complete research work for achieving the stated objectives is divided into several chapters so that it becomes easier to understand the chronological development of the work. The contents of each chapter are briefly described below:

Chapter One is an introduction of this study that includes the problem statement, background and objectives of this study along with the methodology to achieve the stated objectives.

Chapter Two presents the literature review which includes history, the techniques of earth construction, stabilization techniques of earth blocks. This chapter also discusses the earthen house construction scenario in the world and earthen house practice in Bangladesh. Here, the aspects of CSEB in Bangladesh the energy required and pollution emission are briefly described here. The advantages and disadvantages of earthen house are also narrated in this chapter. Finally, review of the past researchers is presented.

Chapter Three describes the collected soil samples location. The selection of soil and stabilizing material are also narrated in this chapter. The total compositions of CSEB specimens at different combinations are presented here. Research methodology and experimental programs are also discussed in this chapter.

Chapter Four presents the index properties of collected soil samples. The results from the compressive strength, absorption capacity, scanning electron microscopy tests are also presented here. The results of the test parameters are discussed with the help of figures, graphs and charts.

Finally, in Chapter Five, the main conclusions drawn from the study are pointed out. In addition to that, some suggestion for future work are also provided.

Chapter 2

LITERATURE REVIEW

2.1 Introduction

Earth has been used as a building material in many developing and developed countries for centuries but the modern construction technologies and materials have declined its popularity to a great extent. The introduction of building materials such as burnt bricks, steel, cement etc. have caused low interest on soil as building material. This has led to not only the increased cost of housing but also the environmental impact due to its manufacturing process and energy consumption.

The use of earthen house has been reduced due to its vulnerability to moisture, drought and earthquake. Additionally, UN-HABITAT estimates that 3 billion people lack decent housing. With a continually growing global population, this Fig. is likely only to rise. In Uganda, for example, demand exists for 1.6 million new homes each year; this is met by a supply of a mere 100,000.

Building new homes on such a scale requires large amounts of construction materials. Traditional building methods such as fired masonry or concrete are environmentally damaging on many fronts, deforestation occurs to provide firewood, concrete involves large amounts of embodied energy etc. (The Good Earth Trust, 2008).

In contrast to modern technologies and traditional fired masonry, building with unfired mud or clay bricks reduces the cost of construction and the environmental impact. Most importantly it also promotes local business and employment. As a potential construction material, it seems to tick all the sustainability boxes and has great potential in the developing world.

Considering these facts, this chapter provides a summary of relevant research of Compressed Stabilized Earth Block (CSEB) to provide a satisfactory background of subsequent discussion. It also presents a brief discussion of the global and local earthen house construction scenario. It also shows present state of problems like brick kilns pollution scenario, fly ash production and dumping scenario etc. in Bangladesh. In this chapter, an attempt has been made to present a selective overall summary of research into the characteristics of CSEB and potential of CSEB as a building material.

2.2 Techniques for Earthen House Construction

Earth based construction and building have existed for thousands of years and are still practiced today. The twelve main construction technique using soil as building material has been shown in Fig. 2.1. Among them most extensive and popularly used techniques are cob, adobe, wattle and daube method, rammed earth and compressed earth. These techniques are briefly described below.

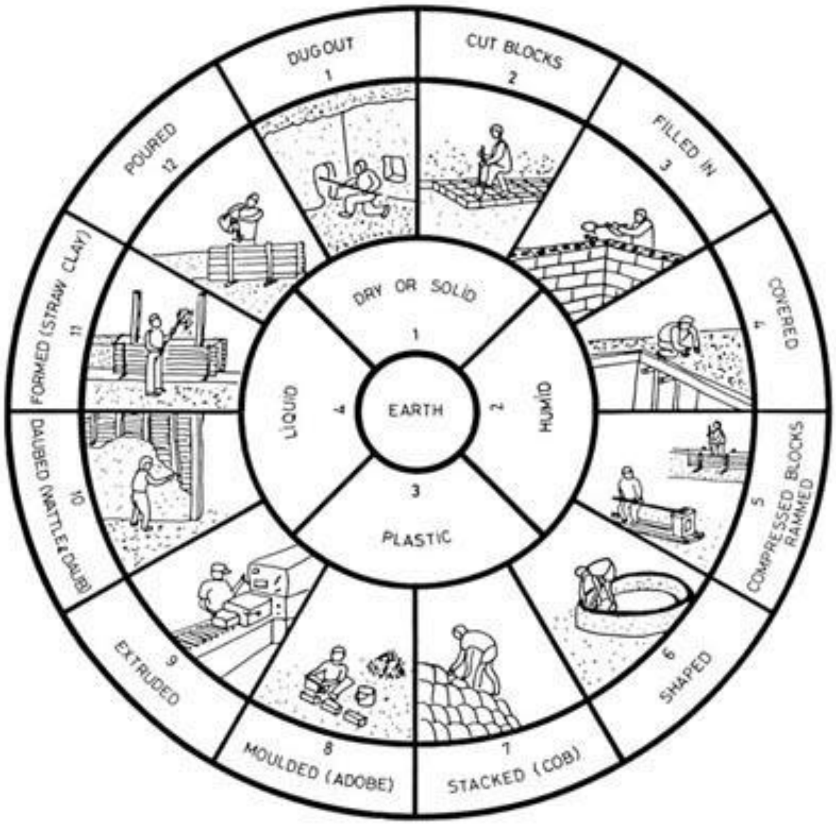


Fig. 2.1: 12 principal earth construction technique (Auroville Earth Institute, 2018)

2.2.1 Cob

Cob is one of the ancient earth construction technique. The oldest cob house still standing is 10000 years old. Cob is mixture of sandy-sub soil, clay and fibrous organic material (typically straw). It is mixed by crushing the particles together by either jumping on it or using the head of a digger. The procedure involves stacking earth balls on top of one another and lightly compact them with hand or feet to form a monolithic wall (Houben and Guillaud, 1994). Historically, cob have been mixed by farm's animal who walk up and down on the sand, clay and straw. The sandy sub-soil must be sharp and ideally, contain angular stones and gravel which will make it stronger. About 75% of cob is made up of this sandy aggregate.

Fig. 2.2: Cob structure (Kim-Carberry, 2011)

2.2.2 Wattle and daub

Wattle and daub is an earth construction technique that consists of wooden strips woven together called wattle which is covered with a mixture of soil and straw called daub. An extremely earth is used which is mixed with a straw or other vegetable fibers to prevent shrinkage cracks upon drying (Houben and Guillaud, 1994).

Fig. 2.3: Wattle and daub structure (Caisaem Taipa, 2018)

2.2.3 Adobe

An adobe is a composite material made of earth mixed with water and natural fibers. The soil composition typically contains sand, silt and clay. Water is added to the mixture until it attains plastic condition. Then it is molded into bricks and allowing the brick to dry evenly, thereby preventing cracking due to uneven shrinkage rates.

Fig. 2.4: Adobe Brick (unconventional travel.com, 2018)

2.2.4 Rammed earth

Rammed earth walls are constructed by ramming a mixture of selected aggregates including gravel, sand, silt and a small amount of clay, into place between flat panels called formwork. Traditional technology repeatedly rammed the end of a wooden pole into the earth mixture to compress it.

Fig. 2.5: Rammed earth (Gowda, 2016)

In modern times, rebars are also used with rammed earth.It is one of the earth construction techniques that creates dynamic compacting soil in temporary forms to make a monolithic wall (Hall and Djerbib, 2004).

2.2.5 Compressed earth block

Compressed earth block (CEB) is a construction technique in which soil is stabilized by adding admixtures and earth block is made by mechanically or manually pressing the soil particles into a mold.

The reason for compacting soil in a mold is to improve the engineering properties of the material (Rigassi, 1985). The CEBs are made in small sizes and installed onto the wall by hand with mortar which is spread very thinly between the blocks for bonding.

(a)

(b)

(c)

Fig. 2.6: Compressed earth blocks of different shapes and sizes

2.3 Methods and Techniques of Stabilization

There are several ways of stabilizing earth. According to Houben and Guillaud (1994), there are four main methods of stabilizing earth blocks. They are:

(i) Stabilization by reinforcement
(ii) Stabilization by water-proofing
(iii) Stabilization by cement
(iv) Stabilization by treatment with chemicals

Again, according to Rigassi (1985), there are six categories of stabilizing soil for construction purpose.

Table 2.1: Stabilization techniques (Rigassi, 1985)

Purpose/Techniques	Explanation of Technique
Density	This is done by creating a dense environment by reducing block pores and capillary channels under application of force (Compression)
Cementation	Cementitious materials are used to bind and improve the engineering properties of soil. Some of the materials used are lime, Portland cement, glues and resins
Reinforcing	Fibrous materials such as fibers from organic origins (agricultural waste), animal origin (wool or hair) and synthetic origin (polythene) are used with a view to improving the properties of soil
Bonding	It involves the use of chemicals such as acids, flocculants, lime, polymers etc. to stabilize the soil
Water-proofing	In this technique, materials such as bitumen and bentonite are added that expand and seal off access pore of the soil to stabilize it
Water-dispersal	This is done by modifying the water in the soil to improve the properties of the soil. It uses chemicals such as resins, calcium chloride and acids to eliminate the absorption of water

Every soil is not suitable for earthen construction. So, some stabilizers must be used for making earth block. Then the stabilized earth block may be used for building a sustainable house. According to original soil quality, materials like gravel or sand can be added for easy improvement of soil properties.

According to the technique used, the improvement of soils will vary. Auroville Earth institute has recommended some general guidelines for soil stabilization to make CSEB as shown in Table 2.2 and Table 2.3.

Table 2.2: Composition of good soil for CSEB according to Auroville Earth Institute

Type of stabilization	Gravel (%)	Sand (%)	Silt (%)	Clay (%)	Requirements
Cement Stabilized block	15	50	20	15	When the soil is more sandy than clayey
Lime Stabilized block	15	30	20	35	When the soil is more clayey than sandy

Table 2.3: Average stabilizer proportion according to Auroville Earth Institute

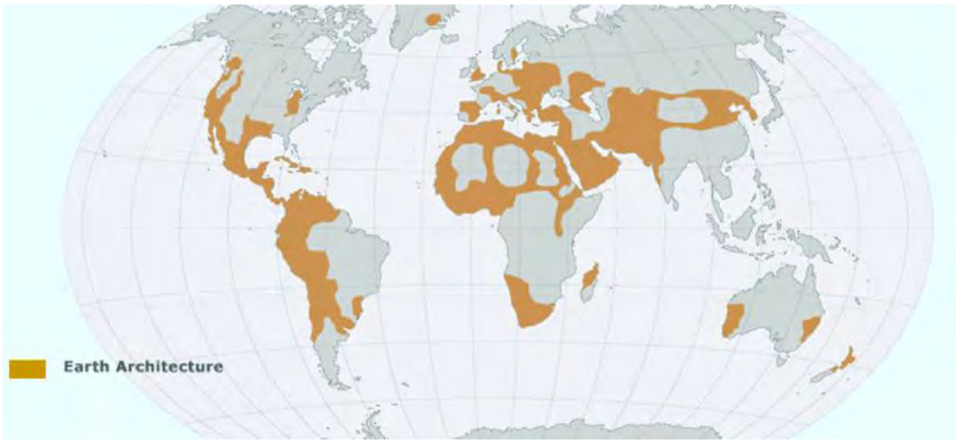
Stabilizer	Minimum	Average	Maximum	Comment
Cement Stabilization	3%	5%	No technical maximum	Low percentages of the stabilizers are considered from the view point of cost effectiveness
Lime Stabilization	2%	6%	10%	Low percentages of the stabilizers are considered from the view point of cost effectiveness

Table 2.4: Suitable ranges of soil composition for making CSEB (Ahmed, 2010)

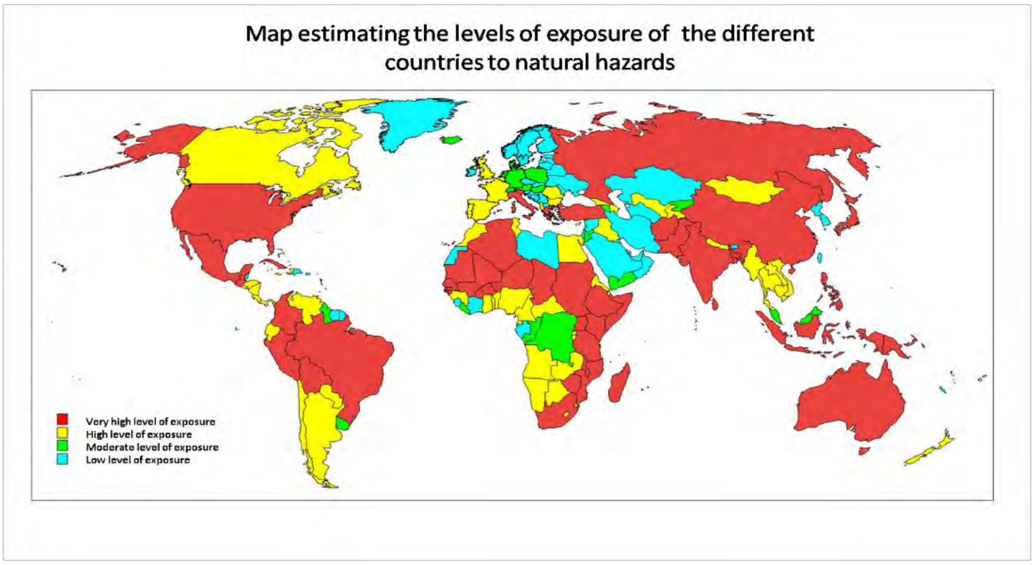
Soil type	Range (%)
Clay	15-40
Silt	25-40
Sand	40-70
Gravel	0-40

2.4 Global Scenario of Earthen House Construction

The use of earthen house is very common in some of the world's most hazard-prone regions, such as Latin America, Africa, the Indian subcontinent and other parts of Asia, the Middle East, and southern Europe (Fig. 2.7a) It has been observed that in Peru 60% of homes are built of adobe or rammed earth. In Kigali, the capital of Ruwanda, 38% of housing is built in unbaked earth. Earth architecture have also deep roots in the Middle East: In Iran, the heart of ancient Persia; Iraq, cradle of the Sumerian civilization; Afghanistan, North and South Yemen. The techniques of the barrel vault and dome were perfected in Iran, as the ancient centers of bam, Yazd, Seojan and tabriz bear witness.



(a)



(b)

Fig. 2.7: Maps of: (a) distribution of global earthen architecture and (b) hazardous areas

World's oldest earthen building still standing is about 3,300 years old. The Ramassem, made of adobes, was built around 1,300 BC in the old city of Thebes. It is on the left shore of the Nile, opposite Luxor. In Indian sub-continent, the oldest earthen building is Tabo Monastery, in Spiti valley - Himachal Pradesh. It was also built with adobe and has withstood Himalayan winters since 996 AD. But from the end of the 19th century, the skills of earthen builders have been progressively lost. The current world owes a lot to the Egyptian architect Hassan Fathy, for the renaissance from the middle of the 20th century of earthen architecture. It is evaluated that about 1.7 billion people of the world's population live in earthen houses (Auroville earth institute, 2018).

2.5 Present Scenario of Earthen House Construction in Bangladesh

Earthen house construction practice is more than 200 years old in Bangladesh. In Bangladesh, the mud house is one of the traditional housing types that are used by poor families mainly in rural areas as well as in outskirts of small cities. This building type is typically one or two stories and preferably used for single-family housing. Some greater districts of Bangladesh: Rajshahi, Potuakhali, Khulna, Dinajpur, Bogra and Chittagong are the areas where mud house system is widely practiced. It is more predominant in less flood -prone areas, i.e. in the highlands or in mountainous regions. Building materials irrespective of location, housing, in general is classified by type of materials used for construction. Houses are classified into categories as described in Table 2.5.

Table 2.5: Dwellings by structural types in Bangladesh, 2001 (BBS, 2008)

Structure	Total (%)	Urban (%)	Rural (%)
Jhupri (made of jute sticks, tree leaves, jute sacks etc)	8.8	7.6	9.2
Kutcha (made of mud brick, bamboo, sun-grass, wood and occasionally corrugated iron sheets as roofs)	74.4	47.7	82.3
Semi-Pucca (walls are made partially of bricks, floors are cemented and roofs of corrugated iron sheets)	10.1	23.1	6.3
Pucca (walls of bricks and roofs of concrete)	6.7	21.7	2.2
Total	100	100	100

Rural house construction and distribution pattern of housing in a certain region develops according to the need of the inhabitants under a set of geographic control and changes with the evolution of the human needs at the different stages of the socio-economic and cultural development. Main load bearing system consists of mud walls of 1.5 to 3.0 feet thickness, which carry the roof load. Clay tiles, thatch or CI sheets are used as roofing materials. The application of these materials depends on their local availability and the ability of the house owners.

Chowdhury (1995) reported the presence of earthen houses as high as 50 to 60% in Rajshahi and surrounding districts, based on the data of 1981 census. Some greater districts of northern areas and hilly areas of south-east part of Bangladesh have wide practice of earthen house construction. Due to availability of other manufactured building products and change into the outlook of people, earth construction practice reduces day by day.

At present, 18% of the total houses of Bangladesh are made of earth (GOB, 2008). Thatch or bamboo and CI sheet wall houses are in practice here parallel to earth wall houses. Thatch or CI sheet houses have got certain problems but earthen house possesses manifold advantages, although, it has got some inherent weaknesses like: wash ability of outer walls, foundation and plinth, vulnerability against earthquake loading.

If these weaknesses can be solved easily and cheaply then it might attract the people of developing countries to live in. It describes earthen house construction practice and its present status and future prospect.

In Bangladesh, various building materials are used for construction. Mud, bamboo, CGI sheet, bricks are widely used in rural areas.

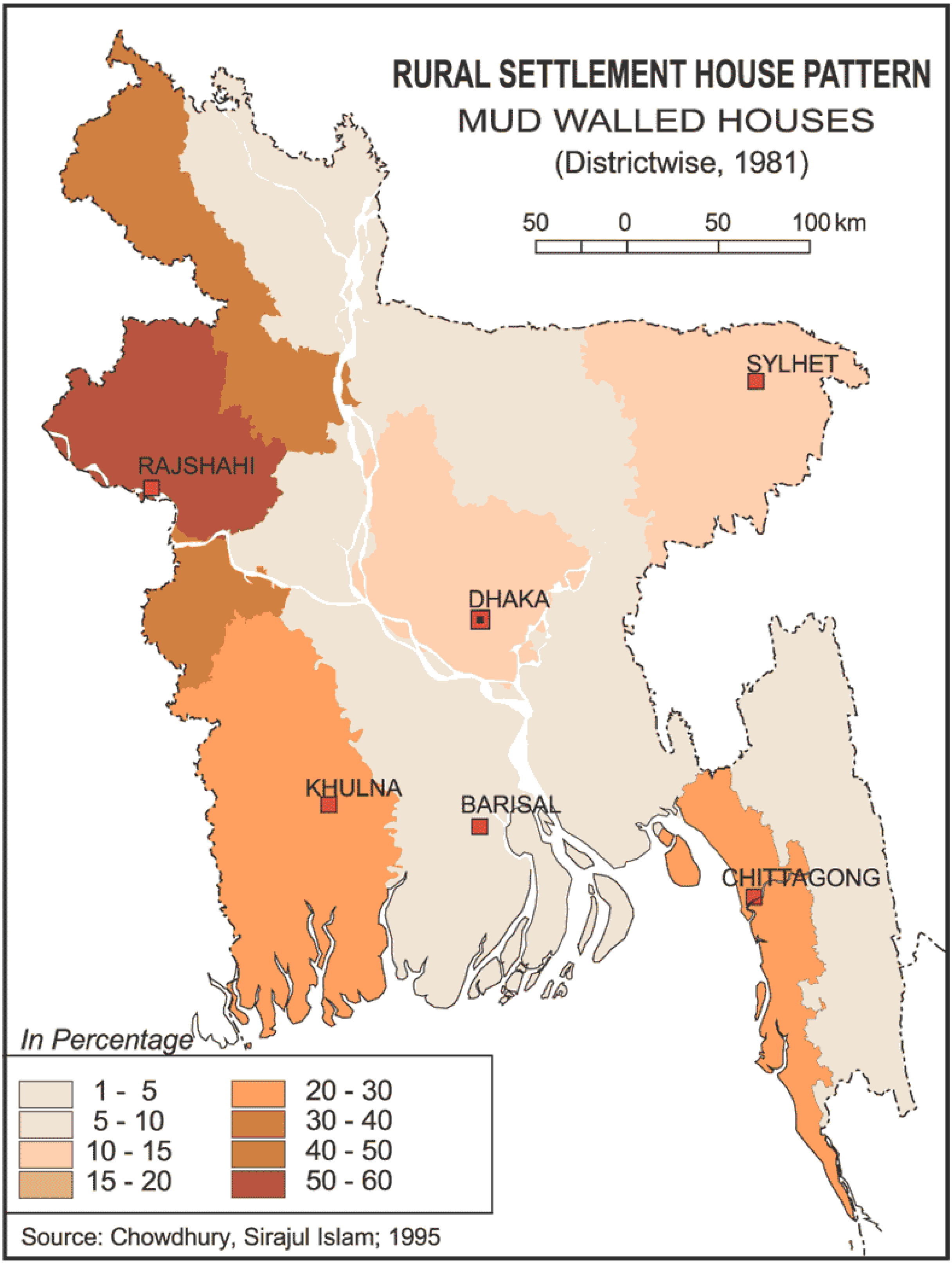


Fig. 2.8: Earthen house distribution in Bangladesh (Chowdhury, 1995)

2.6 Brick Kilns Pollution Scenario in Bangladesh

Brick kilns are a major source of air pollution throughout Bangladesh. Brick making is one of the largest GHG emissions source in Bangladesh, with large CO_2 emissions from the combustion of coal and wood.

Bangladesh has only limited natural sources of stones and construction of infrastructure and buildings often depends on the supply of locally produced bricks. The construction sector has been growing at a rate of 8.1% to 8.9% a year during the last decade, with concomitant growth in demand for bricks (IIDFCL, 2009). It is estimated that around 15 billion bricks are produced annually in Bangladesh from around 5,000 brick kilns (Hossain, 2008).

Fig. 2.9: Pollution by brick kilns in Bangladesh (Dhaka Tribune, 9th November 2017)

Among the brick kilns, 75% are Fixed Chimney Kilns (FCK), while around 16% are still Bulls Trench Kilns (BTK), which are highly polluting. The rest (only 9%) are Zigzag and Hoffman Kilns (ZK and HK), which are better in their emissions performance. Almost all the brick kilns use coal as the primary fuel, although unofficial estimates mention that around 25% of the fuel used in 2007 was still wood.

According to HBRI (2017) report, Bangladesh produces 25 billion bricks every year. To meet this demand this demand requires excavating 60 million tonnes of topsoil, causing dust pollution and degrading the ground. Brick kilns also consume 5 million tonnes of coal and 3 million tonnes of wood annually, in the process emitting 15 million tonnes of carbon into the air.

2.7 Fly Ash Production Scenario in Bangladesh

Coal has a large share of contribution towards worldwide electric power production. In recent years, coal consumption in power production sector has increased in a significant rate. In year 2011, 29.9% of the world's electricity was generated from coal powered plant and this rate is expected to be increased at about 46% at the end of year 2030 (Yao Z. T., 2014).

As a result, coal combustion waste, a part of which is basically fly ash is expected to grow in a colossal quantity which is hazardous in nature and its disposal method has become a great concern.

In Bangladesh, 2.41 % of the total energy is produced from coal powered thermal power plants which are now the major source for production of fly ash. Till 2015, fly ash production of in Bangladesh was at 52000 metric tons per annum, which is expected to soar to 377000 metric tons per annum by the end of year 2018.

Disposal system of this wastes is not abiding by any law and practically the produced fly ash is transported and disposed into some dry embankments. Present problem with fly ash lies in the fact that not only does its disposal requires large quantities of land, water, and energy, its fine particles, if not managed well, by virtue of their weightlessness, can become airborne. When not properly disposed, fly ash is known to pollute air and water, and stands for the cause of respiratory diseases when inhaled.

Considering present scenario, Bangladesh should comply with the world's trend of recycling this waste (fly ash). A viable option for the bulk utilization of fly-ash could be in the production of CSEBs containing fly ash as a major ingredient. If possible two gigantic problems, reduction of using clay as for brick manufacturing and healthy disposal of fly ash, can be solved at a time.

2.8 Problems of Earthen Houses

Although earthen house possesses many fold advantages, it has got some inherent weaknesses. The main weaknesses of earthen houses are described briefly in the next sections:

2.8.1 Shrinkage problem

Drying shrinkage cracks are developed on the surface of earthen houses as natural wetting and drying continues. Degree of shrinkage mainly depends on soil composition. The shrinkage cracks, thus formed, weaken the joints between block and mortar.

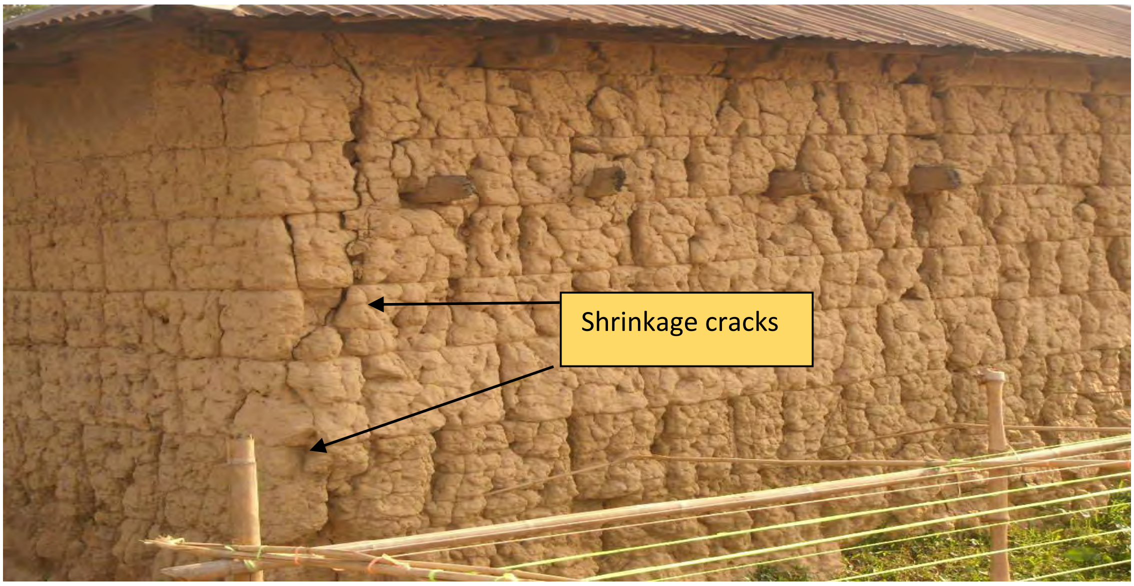


Fig. 2.10: Shrinkage crack on earthen walls

2.8.2 Moisture problem

Earthen walls and foundations absorb moisture when comes in contact with water. Due to absorption of water the soil particles lose bonding strength and starts washing away.

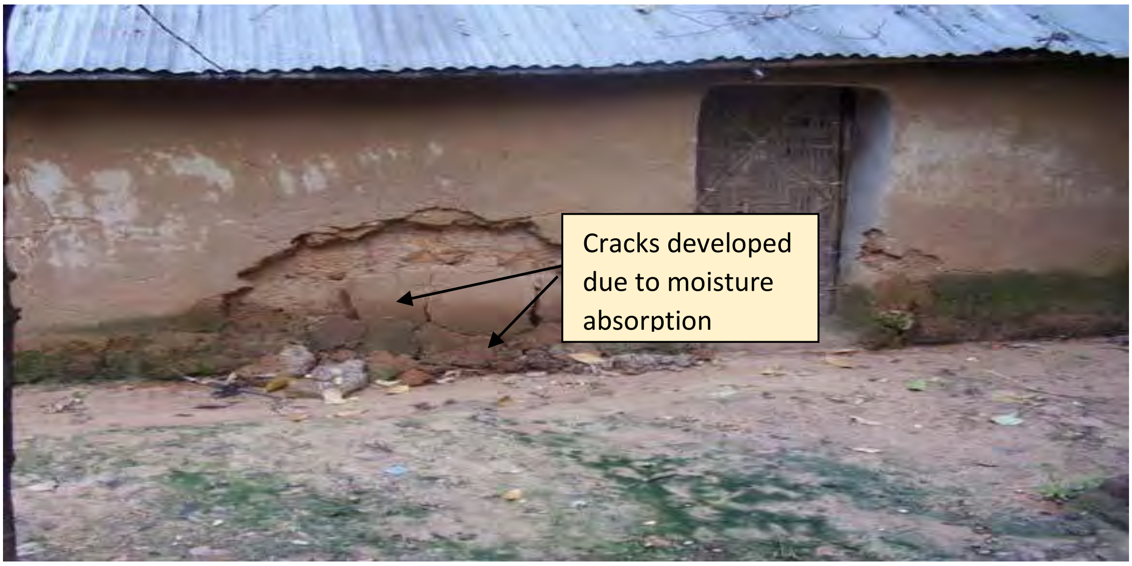


Fig. 2.11: Damage of wall due to moisture absorption

2.8.3 Earthquake problem

Seismic behavior of earthen buildings is commonly characterized by a sudden and drastic failure. From historical earthquake events, it is estimated that the collapse of earthen structures is mainly due to the following reasons:

(i) Earth is a brittle material and practically possesses no tensile strength.

(ii) Poor construction practices often decrease the bond between earthen block and mortar. Mortar becomes totally or partially disintegrated after a few cycle of tremor due to earthquake.

(iii) They are massive and heavy. Thus, they attract high levels of seismic forces. Besides, the architectural concepts of the past have changed and at present the typical thickness of earthen walls have been greatly reduced to make them externally similar to the brick masonry. These factors together with lack of maintenance make the earthen house vulnerable to earthquake forces.

The following typical modes of damages are identified by the observed earthquake damage patterns-

(i) Cracks between walls and floors.
(ii) Cracks at the corners and at wall intersections.
(iii) Out-of-plane collapse of perimeter walls.
(iv) Diagonal cracks in structural walls.
(v) Partial disintegration or collapse of structural walls.

Typical seismic action modes of failure are shown schematically in Fig. 2.5. The schematic diagram shows that typical vertical cracks in the upper portion of walls occur due to out of plane bending of the walls and the diagonal cracks in the wall between window or door opening occur due to in plane bending of the walls.

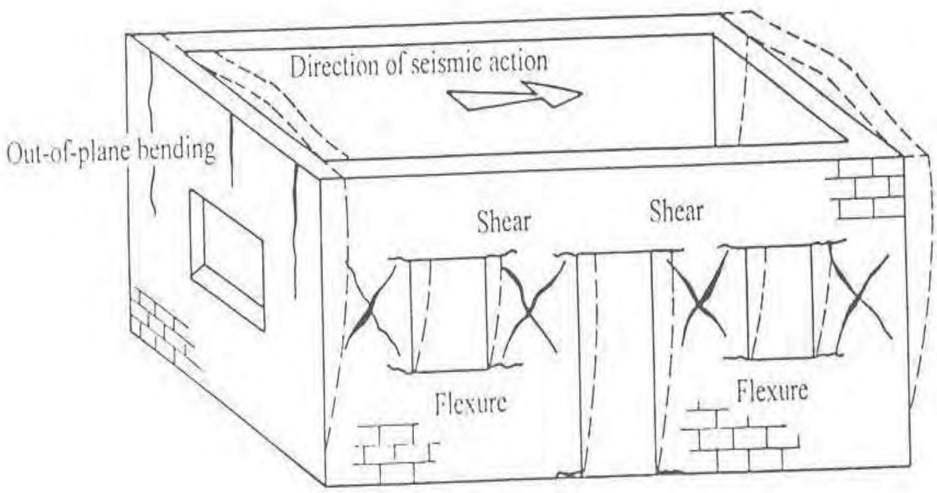


Fig. 2.12: Schematic of failure pattern due to seismic action (Tomazevic, 2006)

2.9 Advantages and Disadvantages of Compressed Earth Block Technology

There are many advantages of the CSEB system. On-site materials can be used, which reduces cost, minimizes shipping costs for materials, and increases efficiency and sustainability. The wait-time required to obtain materials is minimal, because after the blocks are pressed, materials are available very soon after a short drying period. The uniformity of the blocks simplifies construction, and minimizes or eliminates the need for mortar, thus reducing both the labor and materials costs. The blocks are strong, stable, water-resistant and long-lasting. Some of the advantages of CSEB are briefly described below:

(i) Suitable soils are often available at or near the construction site. Distance from a source supply gives CSEB an advantage.
(ii) CSEB can be manufactured to a predictable size and has true flat sides and 90-degree angle edges. This makes design and costing easier.
(iii) Presses allow blocks to be consistently made of uniform size.
(iv) Non-toxic: materials are completely natural and non-toxic.
(v) CSEBs are virtually sound resistant, an important feature in high-density neighborhoods, residential areas adjacent to industrial zones
(vi) CSEBs are fire resistant, earthen walls do not burn.

(vii) Insects are discouraged because the walls are solid and very dense, and have no food value.

Tradition wall construction using soil as building material directly, without burning, in any of the forms has certain disadvantages as mentioned. The performance of this wall is not very satisfactory. CSEB as a building material has several disadvantages. Some of these are:

(i) Proper soil identification is required or unavailability of soil.
(ii) Wide spans, high and long building are difficult to construct.
(iii) Low technical performance compared to concrete.
(iv) Under stabilization resulting in low quality product.
(v) Low social acceptance due to counter examples by unskilled people or bad soil or equipment.

The shrinkage and/or cracking is another disadvantage of CSEB technology. Understanding the behavior is crucially important. In addition, uncertainty exists regarding soil behavior when exposed to moisture and extreme temperatures throughout its lifetime. This is complicated by the fact that the moisture content of even a cured earthen block fluctuates with ambient condition.

However, burnt brick wall consumes significant amounts of fuel energy. Since the country is facing an energy crisis, alternatives to wood such as coal, are not cheap either and in any case, are desperately needed for other purposes such as cooking. Therefore, there is an alternative way of using soil as wall construction.

2.10 Review of Past Researches of CSEB

Although most of the people of Bangladesh live in non-engineered houses (81% of the total population), very few researches have been conducted to improve the rural houses of Bangladesh. But significant researches have been conducted on CSEB all over the world. A brief review of some of the past researches are given below:

Apers (1983) stated that CSBs are produced by compressing a damp mix of soil and cement in a press mould. After de-moulding, the green blocks are not used immediately but are first allowed to cure. This is because the strength of a block, just as in the case of concrete blocks, increases with age.

Houben and Guillaud (1994) concluded that ordinary Portland cement is an important ingredient and variable in a CSB. Without its inclusion, compressed blocks would be no different from common sun-dried 33 mud blocks and would simply disintegrate on contact with water or when subjected to moderate impact loads. Compared with concrete products, where 12-18% by weight of cement is used, only about half of that amount (5-8% by weight), is required in stabilized blocks (ILO, 1987, Webb and Lockwood, 1987).

Lal (1995) compared the major advantage of the stabilized earth block vs the burnt brick (another common construction material used in Africa). It saves significant energy of around 70% and such blocks are cheaper by 20 to 40% compared to burnt bricks. CSEB are also a fraction of the price of concrete blocks and timber.

Adam and Agib (2001) have stated that the basic function of cementation is to make the soil water-resistant by reducing swelling and increasing its compressive strength. With respect to the general processes of cementation, penetration and binding mentioned above, many factors must be considered. Processes may also vary between different types of soils. Cement is considered a good stabilizer for granular soils but unsatisfactory for clays. Generally, cement can be used with any soil type but with clays it is uneconomical because more cement is required. The range of cement content needed for good stabilization is between 3% and 18% by weight according to soil type.

Arumala and Gondal (2007) stated that CSEB is a safe alternative to masonry and if installed correctly can offer a durable sustainable home that is affordable to unprivileged people and showed that compressed earth blocks are resistant to sound transmission, fire, insect damage and durable if properly protected. Little energy is needed for their production compared to other wall systems and soil is an environmentally friendly material.

Kundoo (2008) illustrated additional advantages of building with clay or mud materials that are related to the dimensions of Social Sustainability. Some of these advantages are worker health and safety; impacts on local communities, quality of life; and benefits to disadvantaged groups. Besides giving unskilled labor ample opportunities to find work, while also providing jobs to the local potter whose lively hood is threatened by the plastics and metal industries that are replacing the products that potters used to provide. These benefits are: (1) Generating employment, (2) Local 36 materials replacing building materials from industries, (3) House as a generator of building materials, rather than a consumer, (4) Environmental Implications and Sustainability.

Zami and Lee (2008) stated that the flexibility and simplicity in technology incorporated in CSEB affords adaptability and easy transfer of knowledge between different stakeholders in the building industry, where individuals and communities, as a whole, can easily participate in building their own homes in an affordable way. The greatest advantage of CSEB is the simplicity of producing these blocks.

Nahar (2018) made CSEB, where sand, cement, jute and lime were used as stabilizer with the selected regional soil (red clay). The compressive strength of CSEB was found to be between 0.89 and 6.07 MPa consisting of 3-9% cement, 20-60% coarse sand and 50-60% fine sand by weight.

However, significant researches are conducted in several parts of the world. In order to counteract the disadvantages of earthen house and to improve the quality, to minimize pollution, various researches have been carried out at various places. Despite the global nature of these problem, researches took places in few parts of the world. Those researchers have found some solution to improve the quality of CSEB.

2.11 Application of Fly-ash in brick manufacturing

From time to time practices have been involved for management of fly ash and conversion of this ash into bricks is one of them. Fly ash brick (FAB) are specifically masonry units which are used as building material. These bricks are made up of Class C fly ash and water, compressed at high temperature and pressure and toughened with an air entrainment agent. Due to the presence of high concentration of calcium oxide in class C fly ash, the brick can be described as "self-cementing" because when it is mixed with lime it combines to form cementitious compounds.

The manufacturing of fly ash bricks is quite easy and it is said to save energy because the process involves very little consumption of energy. This also reduces mercury pollution and costs 20% less than traditional clay brick manufacturing system. Raw material required for production are fly ash, gypsum, alum and stone crushing dust. For manufacturing of fly ash bricks, these raw materials have to be mixed as per the ratio specified by the individual industrial establishments. Most of the machine manufacturers suggest the following two mixing ratios which are Normal Mixing ratio and Profitable mixing ratio.

The composition of raw materials in the normal mixing ratio is fly ash 62%, sand 25%, lime 8% and gypsum 5% while in case of profitable mixing ratio this ratio becomes 20%, 60%, 15% and 5%, respectively. Fly ash manufacturers use profitable mixing ratio to survive in the market if they are facing low availability of fly ash. If a manufacturer is using the profitable mixing ratio for the production of fly ash then at the same he should maintain the quality too. For the production of fly ash bricks firstly fly ash, gypsum, sand and hydrated limes are fed into a pan mixer manually where water is added in the required proportion for intimate mixing.

The proportion of the raw material is generally in the ratio depending upon its quality and availability. Once raw materials are mixed, the mixture is shifted to the hydraulic Brick Making machines. The bricks are carried on wooden pellets to the open area where they are dried and water cured for 14 days. The bricks are tested and sorted before

2.11.1 Types of Fly-ash Bricks

Fly ash bricks are generally classified into four major groups:Clay Fly ash Bricks, Fly ash Sand Lime Bricks, Cold Bonded Lightweight Fly ash Bricks and Flux Bonded Fly ash Bricks Blocks and Tiles.

2.11.2 Fly ash bricks versus normal clay bricks

The application of Fly ash bricks in various construction projects leading over traditional normal clay bricks due to its unique properties.

Table 2.6: A comparative study of fly ash bricks and normal clay bricks (Wealthy waste)

Properties	Normal Clay Brick	Fly ash brick
Color	Varying color as per soil	Uniform pleasing color like cement
Shape and size	Uneven shape as hand made	Uniform in shape
Density	Lightly bonded	Dense composition
Finishing	Plastering required	No plastering required
Weight	Heavier in weight	Lighter in weight
Compressive strength	35 kg/cm^2	100 kg/cm^2
Porosity	More porous	Less porous
Thermal conductivity	1.25 – 1.35 W/m^2 ºC	0.90-1.05 W/m^2 ºC
Water Absorption	20-25 %	6-12 %

2.11.3 Advantages of fly ash bricks

Appearance

The bricks have the appearance which is very pleasant like cement; Due to smoothness and finish on their surface they require no plastering for building work. These are compact, uniformly shaped and free from visible cracks. They are lighter in weight than ordinary clay bricks and are less porous. The color of these bricks can be altered by the addition of admixtures during the process of brick making. The size of these bricks can vary but they are generally available in the same sizes of the normal clay bricks.

Structural capability

These bricks do not cause any extra load on design of structures due to its comparable density and thus provide better resistance for earthquakes and other natural calamities. Compressive strength of fly ash sand lime bricks is around 9 N/mm^2 (as against 3.5 N/mm^2 for handmade clay bricks).

The bricks possess high compressive strength which eliminates breakages/wastages during transport and handling. When a structure is formed using fly ash bricks the possibility of cracking of plaster is reduced due to lower thickness of joints and plaster and basic material of the bricks, which is more compatible with cement mortar.

Thermal properties

These bricks have got thermal conductivity around 0.90-1.05 $W/m^2\,^{o}C$ (20-30% less than those of concrete blocks). These bricks do not absorb heat; they reflect heat and gives maximum light reflection which causes less heating of huge structures.

Sound insulation

It provides an acceptable degree of sound insulation. The sound produced at one side of a wall made using fly ash bricks do not let the sound waves pass easily to the other side of the wall due to its compactness. Hence they may be considered for the abatement of the noise pollution.

Fire and vermin resistance

Fly ash bricks have a good fire rating due to the absence of fire catching materials. It has no problems of vermin attacks or infestation.

Durability and moisture resistance

Fly ash blocks are highly durable. When their joints are properly joined, the bricks are ready to be directly painted with the paints available in the market or with the cement paint without plaster. The bricks, usually, are rectangular faced having sharp corners, solid, compact and uniformly shaped. The bricks are said to absorb the moisture approximately 6-12% than that of 20-25% for handmade clay bricks thus they help reducing dampness of the walls.

Toxicity and breathability

There are no positive evidences and studies that suggest about toxic fume emissions or the indoor air quality of structures built with fly ash bricks. Although scientists in some part of world have claimed about the radioactive emissions by these blocks.

Fly ash as a raw material is very fine so care has to be taken while its handling and transport to avoid any kind of air pollution in the view of occupational safety. Once it is flue, it can remain airborne for long periods of time, causing serious health problems relating to the respiratory system. But block manufactured from fly ash has no such problems.

Sustainability

We can conclude that fly ash is a cocktail of unhealthy and hazardous elements like silica, mercury, iron oxides, calcium, aluminum, magnesium, arsenic and cadmium. It poses serious environment and health hazards for a large population who live in the nearby area of the plants. But the brick is better off, during the process of brick making the toxins associated with fly ash gets changed into a non-toxic product.

The mixing of with lime at ordinary temperature leads to the hydration of calcium silicate and formation of a dense composite inert block. Thus it has the potential of being a good building material. In India about 100 million tons of fly ash is produced annually by the numerous thermal power plants, which could cause serious contamination of land, groundwater and air but due to practice of fly ash bricks now it is safe and sound.

Build ability, availability and cost

The compressive strength of fly ash blocks is so high that it eliminates breakages/wastage during handling and gives a neat finish, with lower thickness of joints and plaster. The construction technique does not change in the case of fly ash bricks and remains as same as in the case of regular bricks which ensures easy change of material.

Masons do not require additional training while construction. Though these bricks are abundantly and widely available closer to thermal power plants all over the country for obvious reasons, finding dealers in all major cities and towns would not be a problem.

Applicability

The blocks are easily available in several load bearing grades which are suitable for use in various construction practices

a) Load bearing external walls, in low and medium size structures.
b) Non-load bearing internal walls in low and medium size structures.
c) Non-load bearing internal or external walls in high-rise buildings.

Fig. 2.13: Residential building constructed with fly-ash bricks in India

2.12 Benefits of promoting Flyash Technology in Bangladesh

Flyash production process contributes to a host of environmental and social benefits. On the environmental aspect, Flyash brick units do contribute in many ways such as:

(i) Conservation of top soil.

(ii) Utilisation of industrial by-products, otherwise would have caused pollution. This includes an effective way of managing flyash generated from coal based power plants.

(iii) Conservation of Fossil fuel.

(iv) Avoidance of local pollution on account of elimination of the sintering process.

(v) Abatement of Green House Gas (GHG) emissions. Local communities: reduced negative environmental and health impacts on account of better workplace environment. Round the year livelihood and reduced drudgery.

(vi) The global community: Reduction in GHG emissions and contribution for our fight against climate change.

(vii) Local Government: better waste management and overcoming pressing local environmental issues by promoting the concept of circular economy.

(viii) Industrial sector: production of better quality bricks with reduced resource input as well as reduced cost of waste disposal.

2.13 Codes for CSEBs

There are specific codes that determines the applicability of CSEBs to perform as construction material where suitable. The following table highlights the minimum compressive strength of CSEBs for India, Bahrain and Mexico.

Table 2.7: Minimum compressive strength of CSEBs for India, Mexico and Bahrain.

Country	Code	Minimum Compressive Strength	Applicability
India	IS :1725-1982	1.96 MPa	Non load bearing walls
Bahrain	Building Code v1.0	7.5 MPa	Non load bearing work
Mexico	New Mexico Earthen Building Code	2.07 MPa	Non load bearing wall, insulating walls

2.14 Summary

The techniques of earthen house construction, methods and techniques of stabilization, global scenario of earthen house construction, earthen house construction scenario in Bangladesh and researches related to it, brick kilns pollution scenario, problems of earthen house, attributes of CSEB and review of past researches on CSEB are discussed in this chapter. This can be summarized in the following:

(i) Earth based construction and building have existed for thousands of years and are still practiced today. There are twelve main construction techniques using soil as building material. Among them popularly used techniques are cob, adobe, wattle and daube method, rammed earth and compressed earth. These popularly used methods are briefly described in this chapter.

(ii) For the production of CSEBs certain stabilizers and stabilizing techniques are used with soil. Because all stabilizing techniques and stabilizers are not suitable for all type of soil. Different stabilizing techniques and some guidelines from past researches regarding stabilizers and soil composition are discussed here.

(iii) The global earthen house construction scenario and earthen house construction scenario in Bangladesh are briefly discussed in this chapter.

(iv) Brick kilns are a major source of air pollution throughout Bangladesh. Brick kilns emit largest amount of Green House Gases. This chapter presents a summary of the brick kilns pollution scenario in Bangladesh.

(v) Introduction to Compressed Stabilized Earth Block (CSEB), advantages and disadvantages of CSEB and review of past researches related to CSEB are discussed in this chapter.

(vi) Fly an industrial by product of coal combustion thermal power plants has become as a hazardous material due its improper disposal. It has become an environmental issue. This chapter briefly describes fly ash production scenario in Bangladesh and its hazardous impact on environment, advantages and application of flyash bricks, benefits of promoting flyash technology in Bangladesh.

Chapter 3

EXPERIMENTAL PROGRAM

3.1 General

Soil samples were collected from five different location for experimental program. Among the collected soil samples, one soil sample is selected was selected for making Compressed Stabilized Earth Block (CSEB). With the selected soil sample fly ash and cement were used for preparing CSEBs. CSEB specimens were prepared using the soil samples collected from Meghna river. A total of 15 types of combinations were used to produce CSEB. Uniaxial compressive strength test was conducted on cubic specimen to know the CSEB block strength characteristics. The same test was performed on unstabilized specimen to know the strength characteristics of unstabilized block. In addition to this, water absorption capacity test was also conducted on both stabilized and unstabilized blocks. This chapter describes the collection and selection process of soil. Properties of selected stabilizing material are described. CSEB specimen preparation, experimental set-up and the test parameters are also described.

3.2 Collection of soil Sample

Soil samples were collected from different places of 4 different districts of Bangladesh. The location of collected soil samples are mentioned in Table 3.1 and Fig. 3.1.

Table 3.1: Locations of collected soil sample

Soil Sample Location	Soil Designation	Latitude and Longitude
Meghna River, Narsinghdi	SM	23°39’20”N 90°39’11”
Roktinodi, lawarghor, Durlavpur, Barishal	SRLD	-
Rahmatkhalikhal, Laxmipur-Bhola Ferry Route	SRHLV	22°56’09”N 90°48’59”
Dadpur, Mehendiganj, Barishal	SDMB	22°48’05”N 90°31’32”
Amanatganjkhal, Barishal.	SAB	22°42’42”N 90°22’32”

Amanatganjkhal, Barishal.

Patarhat Launch Terminal, Dadpur, Mehendiganj, Barishal

Rahmatkhalikhal, Laxmipur-Bhola Ferry Route

Meghna River, Narsinghdi

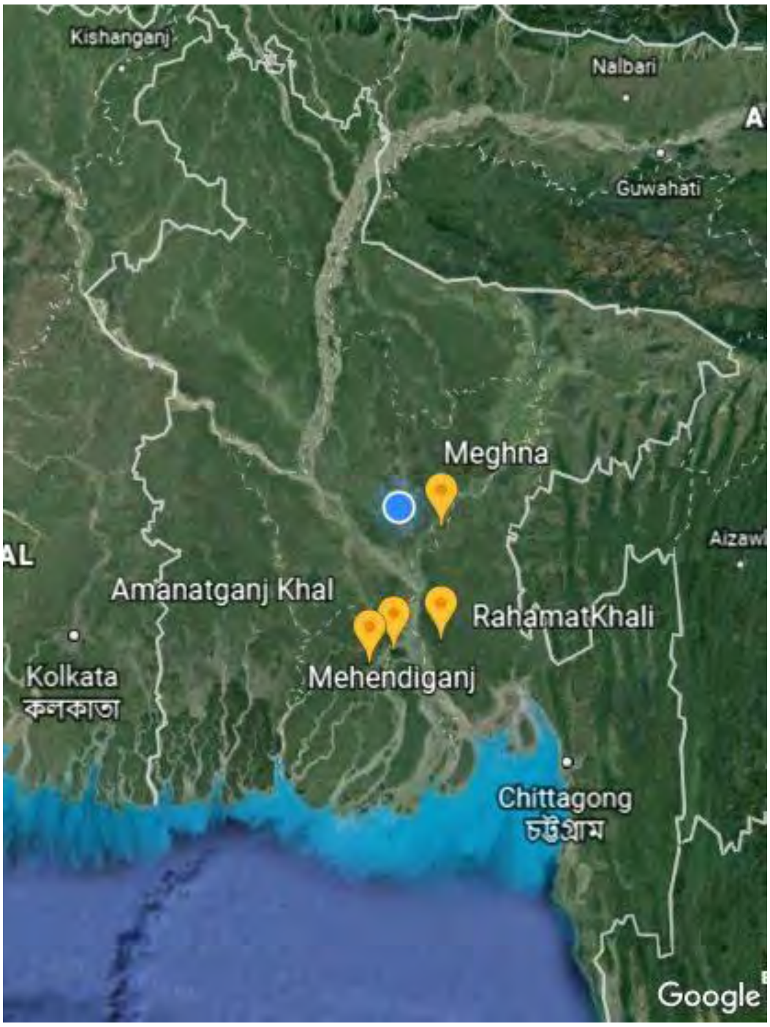


Fig. 3.1: Location of collected soil samples

3.3 Laboratory tests on soils

The soils used for making the blocks were evaluated first by performing some tests for the purpose of classifying and identifying the types of soils. The tests were conducted as per described in ASTM. The list of experiments and no of tests for soil identification are presented in table Table 3.2.

Table 3.2: Test conducted for soil identification

Name of the test	ASTM standard	Parameters to be determined from test
Grain size Distribution	ASTM C136	Grain size distribution curve
Specific gravity	ASTM D854	Specific gravity
Atterberg limits	ASTM D4318	Liquid limit and Plastic limit

3.4 Selection of soil

Soil is an earth concrete. Soil contains gravel, sand, silt and clay as binder. Clay is the cement of the earth but they are not stable under water. CSEBs are made from soil that is 15-40% non-expansive clay, 25-40% silt powder, and 40-70% sharp sand to small gravel content. Soil moisture content ranges from 4-12% by weight.

Clay with a plasticity index (PI) of up to 25 or 30 would be acceptable for most applications. The Plasticity Index of the mixed soil (clay, silt and sand/gravel combined) should not exceed 12 to 15. A good soil for CSEB is sandier than clayey or silty. The soil must not contain organic materials and top soil.

As can be seen, the proportions of each type of material can vary considerably depending on the qualities of each, which differ quite widely, particularly for clays. Knowing the proportions of each, as shown on a particle size distribution curve, is an important indicator but is rarely enough for soil selection purposes. The suitable ranges are shown in Table 3.3.

Table 3.3: Soil suitable range for CSEB (Auroville Earth Institute, India)

Type of Stabilization	Gravel (%)	Sand (%)	Silt (%)	Clay (%)
cement stabilization	15	50	15	20
lime stabilization	15	30	20	35

3.5 Soil Classification

Every soil is not suitable for making CSEB. It is essential to ensure the properties of soil samples before using it for CSEB preparation. The soil sample is generally characterized using the particle size distribution analysis. The particle size analysis gives information about the soil ability to pack into a dense structure and the quantity of fines present. Soil must be classified in order to rationalize and optimize the exploration of knowledge of their properties (Houben and Guillaud, 2005).

3.6 CSEB Preparation

CSEBs are prepared using soil sample collected from Meghna River. The procedure for preparation of CSEBs are described here in a nutshell.

3.6.1 Preparation of soil

Soil preparation operations play a crucial part in the ultimate quality of the blocks. These operations can sometimes make it possible to use soils which are unusable in their natural state because it modifies the grain size distribution of soil.

First the collected soil samples were oven dried for 24 hours. Then, the oven-dried soil sample was pulverized. The main objective here was to either break up lumps which are held together by clay (crushing) or to fragment stones and gravel (grinding).

After pulverization the soil sample was screened. This is done to remove foreign particles like glass shreds, grass, stones and the particles which are too coarse. In this study the soil was allowed to pass through #4 sieves. After pulverization, the soil which passes the #4 sieve was used for the production CSEBs.

3.6.2 Determination of moisture content

After soil was prepared for the CSEB production, the optimum amount of water measured out for preparing the CSEB specimens. But it is difficult to calculate beforehand the precise volume of water which will be needed to reach the optimum moisture content for compaction, as this will depends on the natural moisture content of the various materials (soil, sand, etc.) which varies greatly.

So, it is necessary to determine the optimum quantity of water by using simple tests and by experience. In this study, oven dried sample was used and trialed with several percentage of water content. From the trial water content, the optimum mixing water content is selected (by observing both strength and workability variation).

3.6.3 CSEB specimen preparation

After completion of soil sample preparation and measuring out the optimum amount of mixing water, the soil sample was thoroughly mixed with the stabilizers with a trowel inside a pan .This mixture is then mixed with water until it was plastic enough to mold.

Prepared mix was filled in the mold in two layers and certain blows/layer of manual press was applied by using a tamping rod having a dimension of 2.5 cm × 2.5 cm × 15 cm. The drop height of the tamping rod was about 5 cm. For determination of the compressive strength and absorption capacity, 5cm × 5cm × 5cm blocks were prepared.

The mold with the specimen was kept for 24 hours. After 24 hours the bolts were disjointed and the blocks were removed from the mold and carefully placed in open air for curing. After pulling out specimen from the mold, they were placed on a tray for sun drying in open air. In drying process, water was allowed to evaporate and the clay fraction to shrink.

To prevent shrinkage occurring too quickly, water is sprinkled over the drying surface. Sun drying was carried out for 28 days. In this study compressive strength test was conducted after 28 days of drying.

(a)

(b)

(c)

(d)

e)

(f)

Fig. 3.2: (a) Freshly collected soil sample (b) oven dried soil sample (c) manual pressing of block (d) freshly molded block (e) curing of blocks (f) blocks after curing

3.6.4 Proportion of soil-fly ash-cement-water mix

CSEB specimens were prepared having a dimension of 5 cm x 5 cm x 5 cm. for crushing strength test and absorption test. Detailed test program for crushing strength test and absorption test are presented in table 3.4, 3.5 and 3.6.

Table 3.4: Different percentages of cement used for stabilization

Cement (%)	Composition Percentages		Water (%)
	Soil	Fly ash	
5	80	10	20
7	80	10	20
10	80	10	20

Table 3.5: Different percentages of water content used for stabilization

Water (%)	Composition Percentages		
	Soil	Fly Ash	Cement
10	80	10	10
15	80	10	10
20	80	10	10
25	80	10	10

Table 3.6: Different number of blows used for CSEB preparation

No. of Blows	Composition Percentages			Water (%)
	Soil	Fly Ash	Cement	
16	80	10	10	20
32	80	10	10	20
50	80	10	10	20

3.6.5 Definition of prepared CSEB specimen

For easy identification of CSEB specimens a system was followed which has been explained in Fig. 3.3 and Table 3.7.

It is essential for further understanding and interpretation of this study. This system carries the percentages of soil, fly ash, cement and water of individual block specimens prepared for crushing strength test and absorption test.

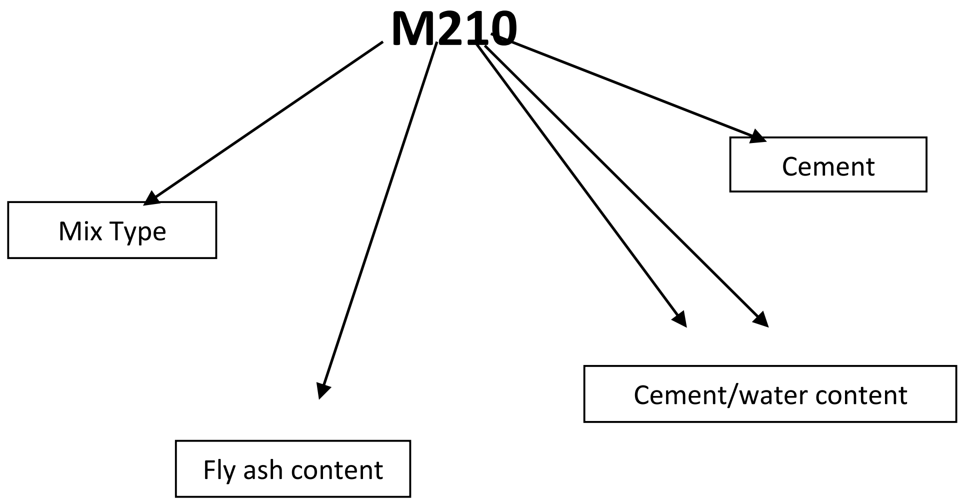


Fig. 3.3: A system to identity CSEB specimen

Table 3.7: Explanation for identification of CSEB specimen

Ingredients	Specimen Designation	Ingredients percentages			Water	Pressing
		Sand	Cement	Fly ash		
Fly ash content	M1	70	10	20	20	32
	M2	75	10	15	20	32
	M3	80	10	10	20	32
	M4	85	10	5	20	32
	M5	90	10	0	20	32
Water content	M325	80	10	10	25	32
	M320	80	10	10	20	32
	M315	80	10	10	15	32
	M310	80	10	10	10	32
Pressing	M316	80	10	10	20	16
	M332	80	10	10	20	32
	M350	80	10	10	20	50
Cement content	M35C	80	5	15	20	32
	M37C	80	7	13	20	32
	M310C	80	10	10	20	32

3.7 Compressive strength test of the cubic samples

An unconfined compressive strength machine of capacity 26.7 kN was used to measure the compressive strength of the CSEBs according to ASTM D143 in the Geotechnical Laboratory of Civil Engineering Department of BUET.

The samples were placed between two 3 mm thick circular cast iron plates were used at the top and bottom to ensure uniform surface loading. To measure the block's axial strain, a strain gauge was used. The stress vs. strain curve for each block was prepared and from the curve maximum strength of the block and failure strain was determined.

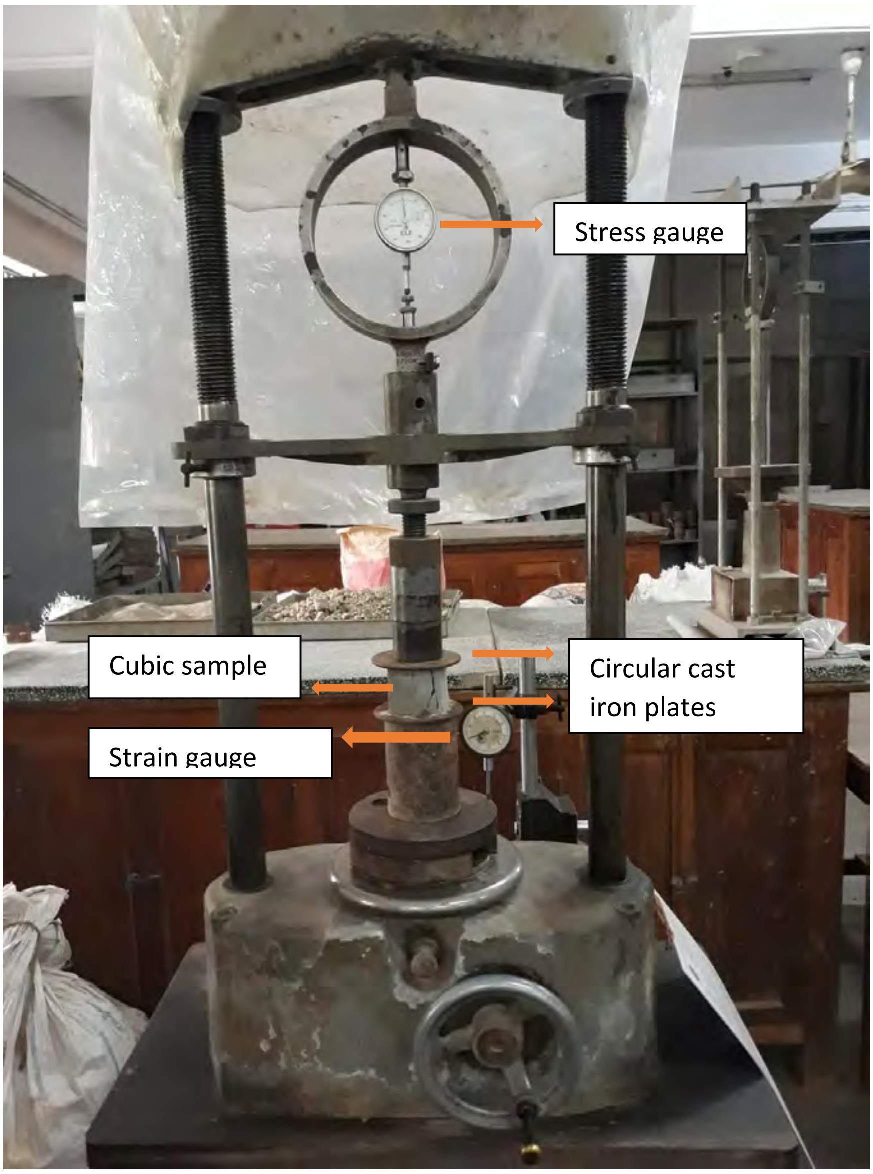


Fig. 3.4: Compressive strength testing machine

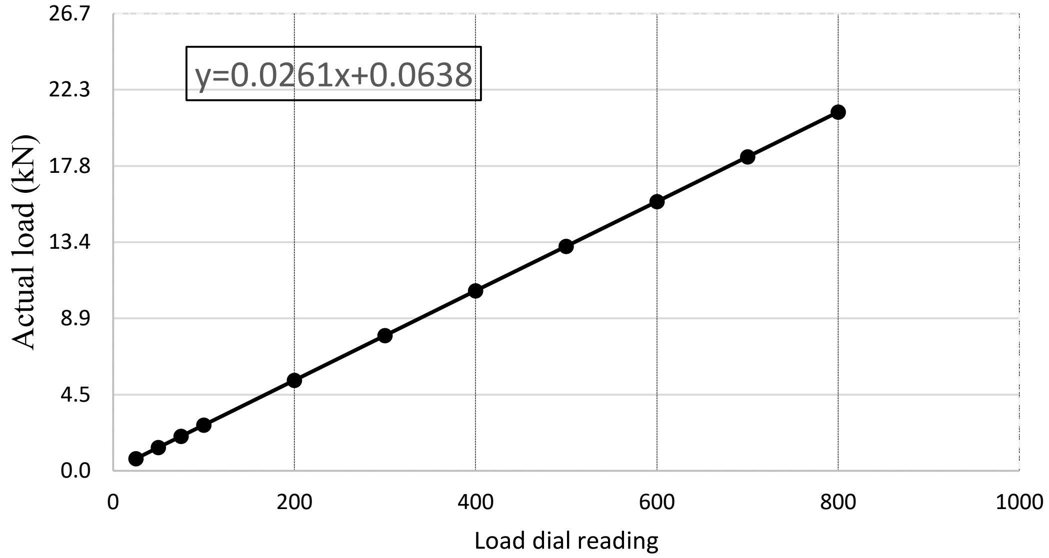


Fig. 3.5: Calibration chart for testing machine used for compressive strength test.

3.8 Absorption Test

Some specimen was selected for the water absorption capacity test according to ASTM C830. The water absorption Capacity test was conducted on 28 days CSEB specimens. The selected specimens was first oven dried for 24hours. Then the mass of the CSEB specimens was taken. After that, they were under water at fully submerged condition for 24hours. After 24hours of immersion under water, the mass of the specimens again taken. Water absorption capacity of the blocks is calculated by using the following equation,

$A(\%) = (W_w - W_d)*100/W_d$……………………………………………..(3.1)

Where,

W_w = Mass of the wet block after 24hrs immersion under water

W_d = Mass of the oven dry block

(a)

(b)

(c)

Fig. 3.6: (a) weighing of dry block (b) 24 hours immersion under water (c) surface drying of soaked block

3.9 Scanning Electron Microscopy (SEM)

A scanning electron microscope (SEM) is a type of electron microscope that produces images of a sample by scanning the surface with a focused beam of electrons. The electrons interact with atoms in the sample, producing various signals that contain information about the surface topography and composition of the sample. The electron beam is scanned and the position of the beam is combined with the detected signal to produce an image. SEM testing was used to look at the microstructure at each of the samples.

The testing procedures were performed per standard procedures at Glass and Ceramic Engineering Department, BUET. SEM imaging is a relatively quick way to investigate the microstructure of a soil sample. To obtain such an image, the samples were prepared. Five different cubic samples containing 0%, 5%, 10%, 15 %, 20% Fly ash were taken and oven dried for 24 hours. A small portion measuring 2 cubic inches was dismantled from each sample to form five specimens and mounted onto a stud and placed in the chamber of a machine with SEM capabilities. The technician can maneuver the observation lens and focus in on different areas as needed. A variety of images can be produced under different magnifications. In learning the microstructural composition of the sample, one can compare the properties with those of known specimens. In order to analyze the microstructure of the sample using SEM technology, JEOL JSM 7600F Scanning Electron Microscope was required .The most important equipment was the SEM equipment itself; however, care was needed to be taken to adequately prepare the sample for imaging.

Fig. 3.7: JEOL JSM 7600F Scanning Electron Microscope

3.10 Standard Brick

Bangladesh Standards and Testing Institution (BSTI) suggests that the standard size of a brick is 10 inch long, 5 inch wide and 3 inch deep. (Fig. 3.8). Unfortunately, some brick kilns in Bangladesh manufacture bricks measuring 9 inch by 4.5 inch by 2.8 inch, which is 23 cm by 11 cm by 7 cm (approximately).

In this investigation, the soil mixture exhibiting maximum compressive block strength 2.63 MPa was poured into a wooden mould measuring 25 cm by 12 cm by 7 cm. The mixture was compacted using same number of blows in each layer to maintain consistency with the way the blocks were made.

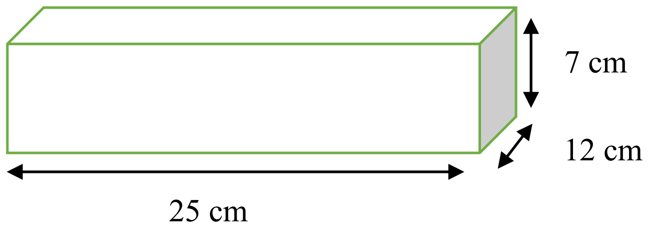


Fig. 3.8: A schematic diagram of standard brick

3.10.1 Sample preparation for brick production

Prepared mix containing 80% sand, 10% fly ash, 10% cement and 20 % mixing water content by weight was filled into a wooden mold (measuring 30 cm x13 cm x 7 cm) in two layers and certain blows/layer of manual press was applied by using a tamping rod having a dimension of 2.5 cm × 2.5 cm × 15 cm.

The drop height of the tamping rod was about 50cm. For compressive strength 25 inch x12 cm x7 cm brick samples were prepared. The mold along with the specimen was kept for 24 hours. After 24 hours the bolts were disjointed and the blocks were removed from the mold and carefully placed in open air for curing.

After pulling out specimen from the mold, they were placed on a tray for sun drying in open air. In drying process, water was allowed to evaporate and the clay fraction to shrink. To prevent shrinkage occurring too quickly, water is sprinkled over the drying surface. Sun drying was carried out for 28 days.

In this study compressive strength test was conducted after 28 days of drying. The process mentioned above replicated exactly the same detailed procedure for block preparation. The only difference here is that scale factor is increased in the ratio 3:1.The sample mix constituted the combination that exhibited highest strength among the block samples.

(a) (b)

(c) (d)

(e)

Fig. 3.9: (a) Wooden mould (b) Sample mixture (c) Pouring the mixture into mould and tamping with rod (d) Brick samples sun dried for 28 days (e) Brick after curing

3.11 Compressive Strength Test of unburnt bricks

Due to limited capacity of the compressive strength machine in the Geotechnical Laboratory, the compressive strength test of the prepared bricks was conducted using Macklow-Smith Ltd. Machine in the Concrete and Materials Laboratory of Civil Engineering Department, BUET. The maximum capacity of this machine is 700 kN. Each sample of brick measured approximately 2 kg were placed within wooden plates measuring 40 cm long, 25 cm wide and 0.8 cm deep, both at top and bottom to apply uniform loading.

Fig. 3.10: Compressive strength testing machine for bricks

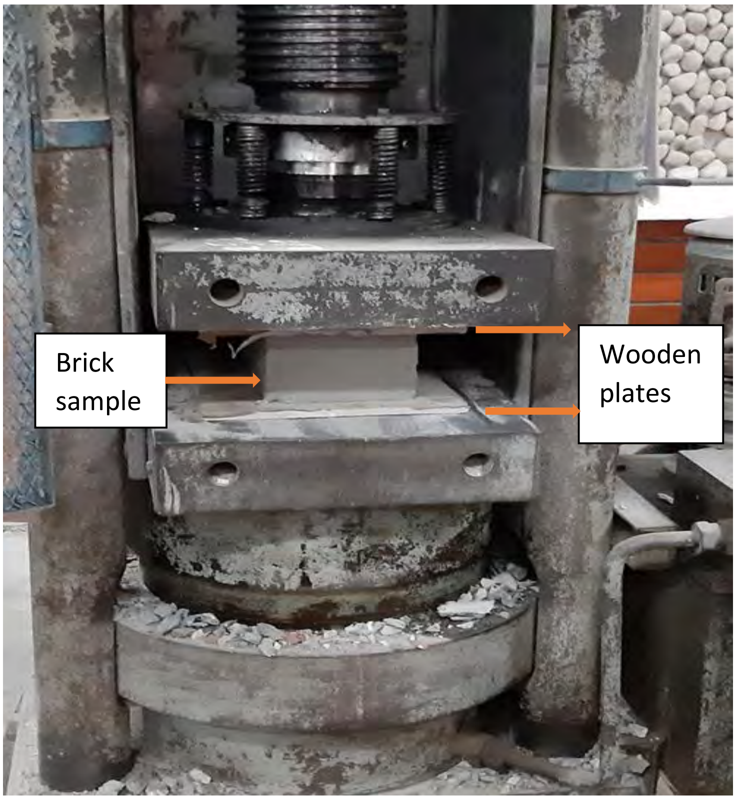


Fig. 3.11: Arrangement of brick sample inside Macklow-Smith Ltd. machine

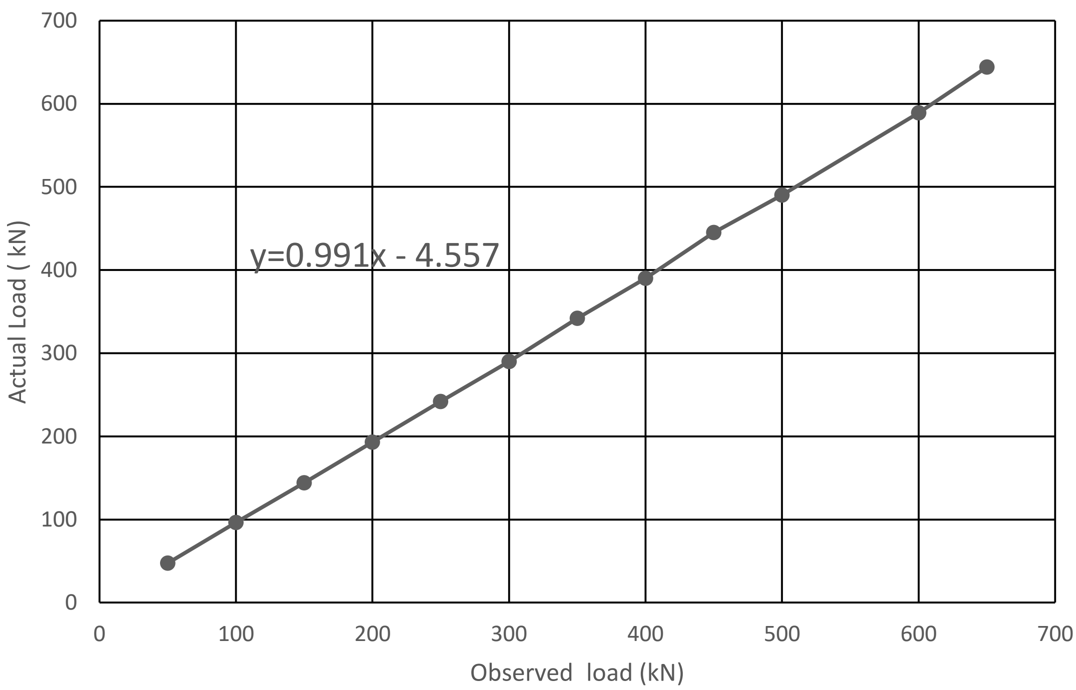


Fig. 3.12: Calibration chart for testing machine used for compressive strength test for bricks

3.12 Test Plan

First soil index properties were determined to classify the soil. Compressive strength test, water absorption capacity test, Scanning Electron Microscopy were performed on CSEB specimens prepared from selected soil after curing. Following the guidelines of BSTI, brick samples were made and their compressive strength were determined.

Chapter 4
RESULTS AND DISCUSSIONS

4.1 General

The main purpose of this research is to investigate the effectiveness of fly ash and cement with soil at different proportions to construct sustainable, environment friendly CSEBs that can be used for building construction. The obtained compressive strength for different proportions of fly ash, cement and soil has been described in this chapter. Beside this, absorption capacity of the CSEBs are also discussed here. Soil identification test was conducted to identify the suitable soil for preparation of CSEBs. This chapter discusses the soil index properties, soil compressive strength and absorption capacity of the prepared CSEB specimens at different combinations.

Photographs of relevant test specimens have been presented here. The compressive strength of prepared CSEB specimens has been discussed with respective curves and charts. The CSEB specimen compressive strength has been compared with various percentage of fly ash and cement content with respective graphs and charts. These graphs and charts will clearly show the ranges of crushing strength for different percentages of fly ash and cement content.

4.2 Index properties of Collected Soil Sample

For this study five soil samples were used. The grain size distribution curve of collected soil samples which were used for production of CSEBs have been presented in Fig. 4.1. The grain size distribution curve of fly is presented in Fig. 4.2.

The physical properties such as specific gravity, grain size distribution, Atterberg limits of the collected soil samples have been presented in Table 4.1. In Fig. 4.1, grain size distribution of collected soil sample has been shown. The soil sample (SM) collected from Meghna river consists of 75.6% sand and 24.4% silt as shown in Table 4.1. Compressive strength test and absorption test were conducted upon the block specimens made with SM soil to know the compressive strength and absorption capacity of prepared specimen.

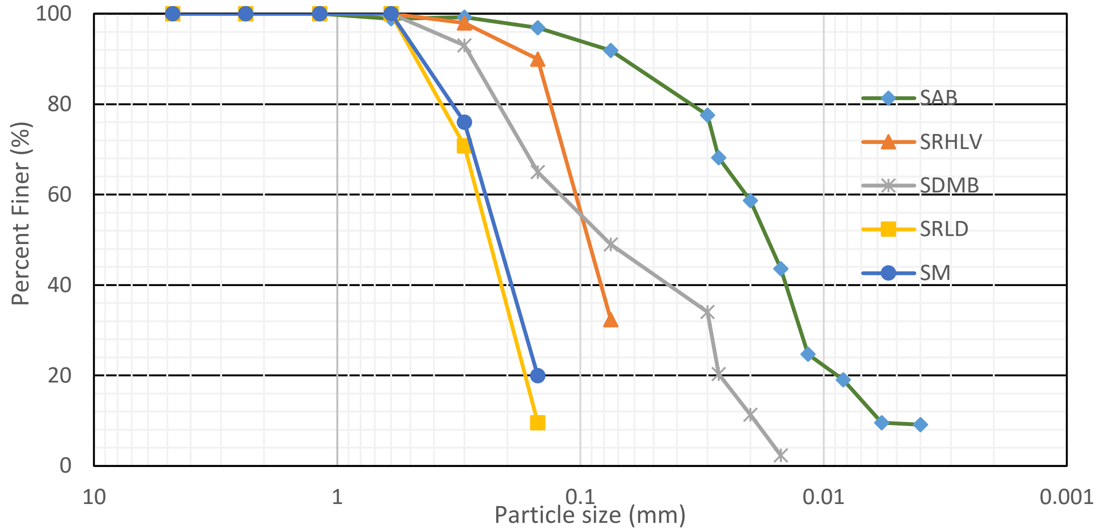


Fig. 4.1: Grain size distribution curve of collected soil samples

Table 4.1: Index properties and grain size distribution of collected soil sample

Soil Designation	Specific Gravity	Fineness Modulus	Sand (%)	Silt (%)	Clay (%)
SM	2.70	1.06	75.6	24.4	-
SRLD	2.73	1.21	79.7	20.3	-
SRHLV	2.72	0.69	71.2	20.8	-
SDMB	2.74	0.65	42.3	57.7	-
SAB	2.70	0.64	8.1	86.9	5

4.3 Properties of Fly Ash and Cement

Fly ash used in this study for stabilization is Class F fly ash. To know the index properties of fly ash grain size distribution test and Atterberg limits test were conducted on the fly ash. The results of these tests have been presented in Fig. 4.3 and Table 4.2.

From Table 4.2, it is seen that fly used for stabilization of CSEB consists of 100% of silt and it has also no plasticity index. During Atterberg limits test of fly ash it is observed that for relatively lower water content the groove could not be prepared. And for relatively higher water content after 2-3 blows water was coming out at the surface and groove got closed .From these observations, it is decided that fly ash has no plasticity.

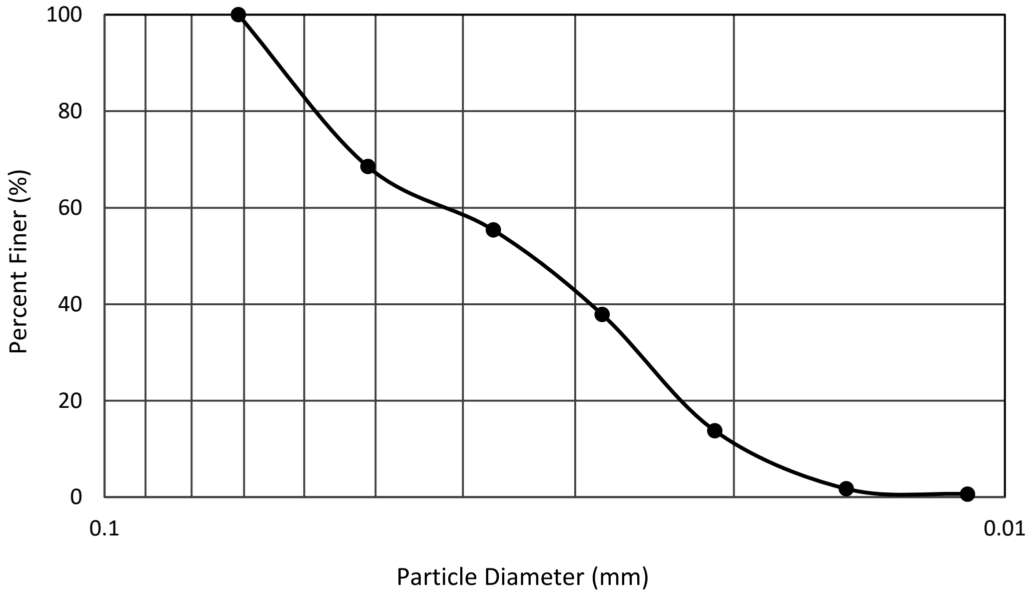


Fig. 4.2: Grain size distribution of fly ash

Table 4.2: Index properties and grain size distribution of fly ash

Sample Designation	Specific gravity	Plasticity Index	Sand (%)	Silt (%)	Clay (%)
Fly Ash	2.25	-	-	100	-

In this investigation, Ordinary Portland Cement (OPC) was used instead of Portland Pozzolana Cement (PPC). In OPC the hydration reaction produces free lime which reacts with the additional fly-ash to form secondary CHS-gel hence the strength of brick increases.

But in case of PPC the fly ash is initially present in the cement and the free lime is reacts with that fly ash to produce CHS gel and the additional fly ash that we have added remains unreacted hence causing reduction of strength.

Specification and Composition of the OPC used: BDS EN 197-1:2003 and ASTM C-150, Type – I. It contains 95 % clinker and 5% gypsum.

4.4 Properties of Prepared CSEB Specimens

Compressive strength test was performed on the CSEB specimens prepared with SM (denotes soil collected from Meghna River soil to compare the strength characteristics of prepared of CSEB blocks.

The typical stress strain relationships for different proportions of soil, cement and fly ash has been presented in Fig. 4.3. Description of the specimen groups, compressive strength and failure strain has been shown in the following table.

Table 4.3: Compressive strength and failure strain of CSEB specimens in various combinations.

Variable in specimen groups	Content (%)	Specimen Designation	Compressive Strength (MPa)	Failure Strain (%)
Cement Content (%)	5	M35C	0.47	3
	7	M37C	0.28	2
	10	M310C	2.56	12
Water Content (%)	10	M310	1.41	3.5
	15	M315	1.52	2.5
	20	M320	2.57	4.5
	25	M325	2.47	3.0
Pressing (no. of blows per layer)	16	M316	1.95	3.0
	32	M332	2.63	3.5
	50	M350	1.88	2.5
Fly ash content (%)	20	M1	2.14	7.5
	15	M2	1.79	10.5
	10	M3	2.57	12.0
	5	M4	1.50	2.5
	0	M0	1.16	3.0

4.5 Variation of compressive strength with water content

In Fig. 4.3, the variation of compressive strength of specimen prepared with 10%, 15%, 20% and 25% water content has been presented, it is seen that the compressive strength increases from 1.41 MPa to 2.57 MPa with the increase of water content from 10% to 20%. After that the compressive strength decreases with the additional of water after 20%. From these observations, it seems that 20% water content is the optimum water content for CSEB specimen.

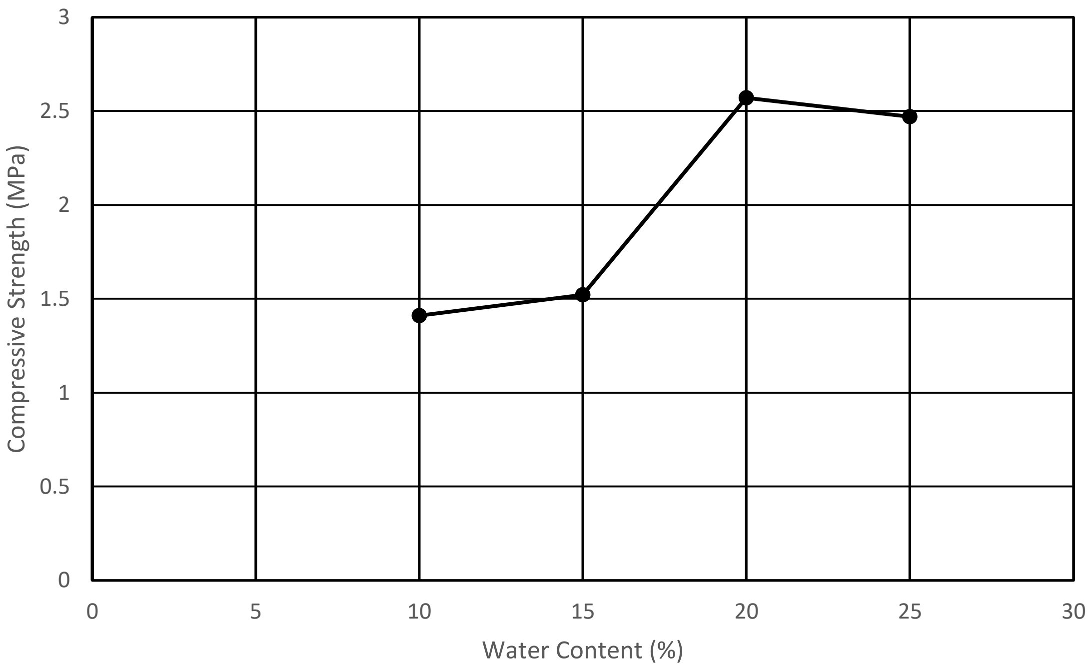


Fig. 4.3: Compressive strength vs water content

4.6 Variation of Density and Compressive Strength with pressing

In Fig. 4.4, the wet density and dry density of CSEB prepared CSEB specimen have been plotted against pressing (no. of blows per layer). From the Fig. 4.4 it is seen that both the dry density and moist density of the prepared CSEB specimens increase with increased amount of pressing. Dry density of the specimen increases from 1.526 gm/cc to 1.793 gm/cc with the increase of pressing from 16 blows per layer to 50 blows per layer. Similarly, for moist density increases from 1.678 gm/cc to 1.945 gm/cc. In Fig. 4.5, the compressive strength of CSEB specimens prepared with 16, 32 and 50 blows per layer of pressing has been plotted. In Fig. 4.6 it is seen that the compressive strength increases from 1.93 MPa to 2.63 MPa with the increase of pressing from 16 to 32 blows per layer. After that the compressive strength decreases with the additional of pressing after 32 blows per layer. So, 32 blows per layer of pressing is the optimum amount of press for CSEB specimen.

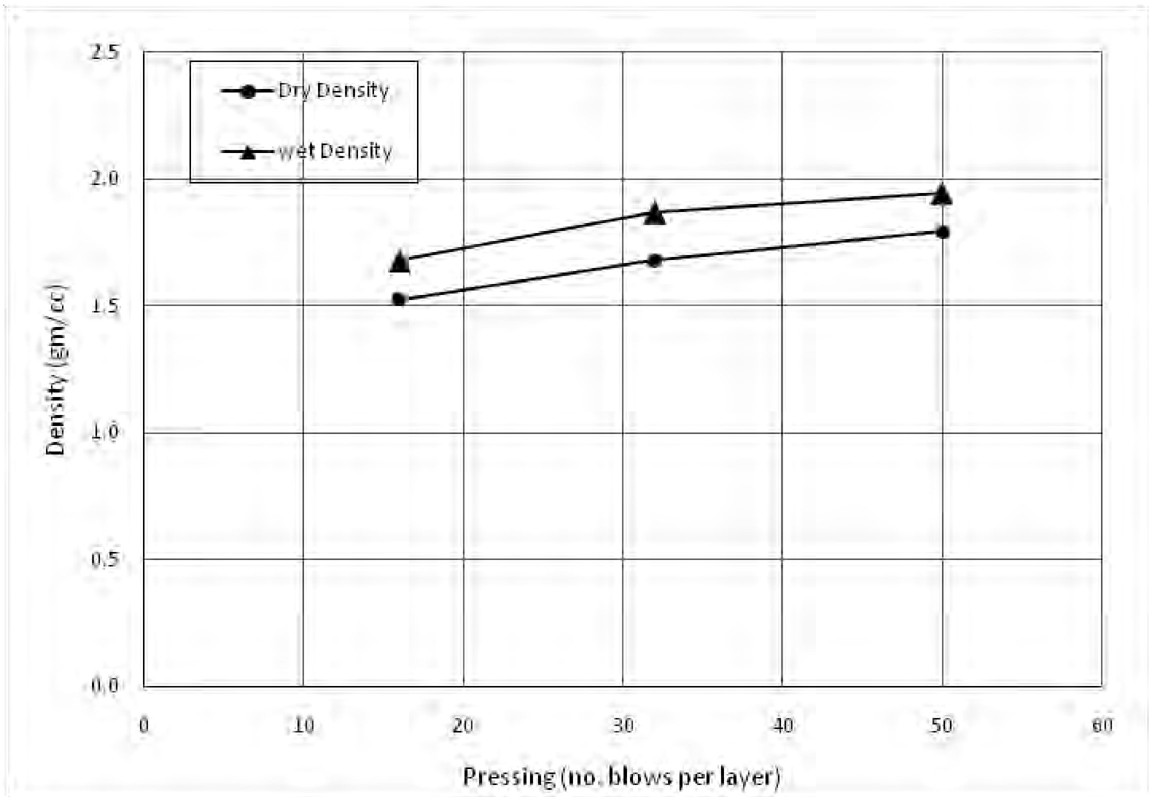


Fig. 4.4: Variation of density with pressing (no. blows per layer)

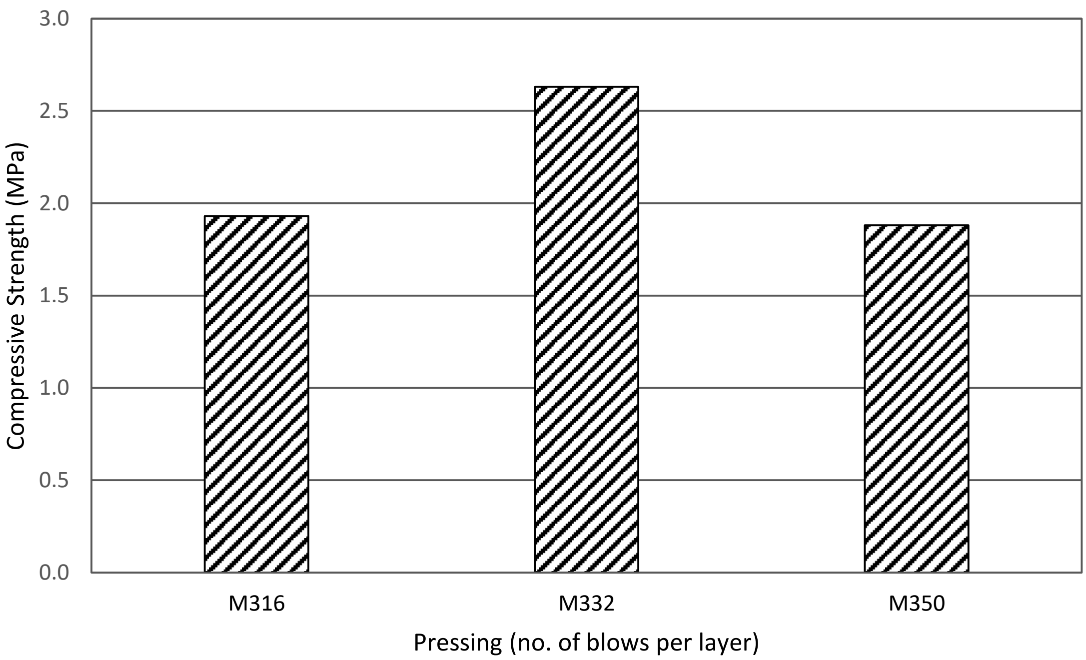


Fig. 4.5: Compressive strength vs pressing (no. of blows per layer)

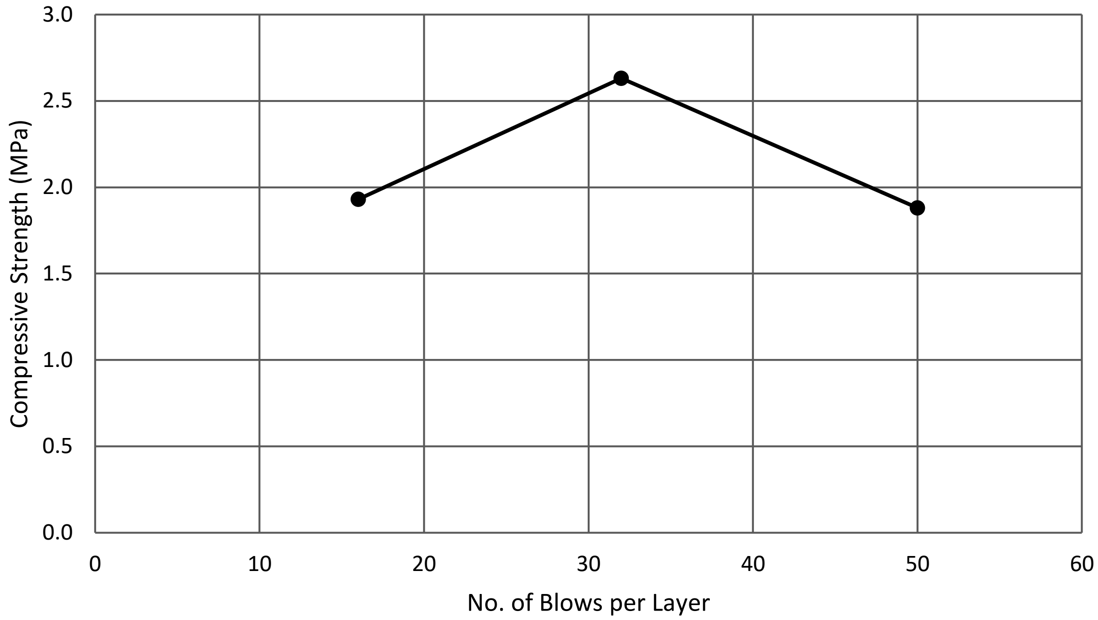


Fig. 4.6: Variation of compressive strength with no. of blows per layer

4.7 Variation of Compressive Strength with Cement Content

In Fig. 4.7, the 7 days compressive strength of CSEB specimens prepared with 5%, 7% and 10% cement content has been plotted and in Fig. 4.8, the 28 days compressive strength of CSEB specimens prepared with 5%, 7% and 10% cement content has been plotted. The variation of 7 days and 28 days compressive strength of specimen prepared with 5%, 7% and 10% cement content has been presented.

From Fig. 4.8 it is seen that the 7 days compressive strength decreases from 0.39 MPa to 0.29 MPa with the increase of cement content from 5% to 7%. After that the compressive strength increases with the increase of cement content percentage. Also, it is seen that 28 days compressive strength decreases from 0.5 MPa to 0.3 MPa, which gradually increases to 2.62 MPa.

But more than 10% cement content is not used because according to “Standard Norms and Specification for CSEB Blocks” (CSEB Green Buildings in Nepal, 2012) use of cement more than 10% is not cost effective. So, 10% cement content is the optimum cement content for CSEB specimen.

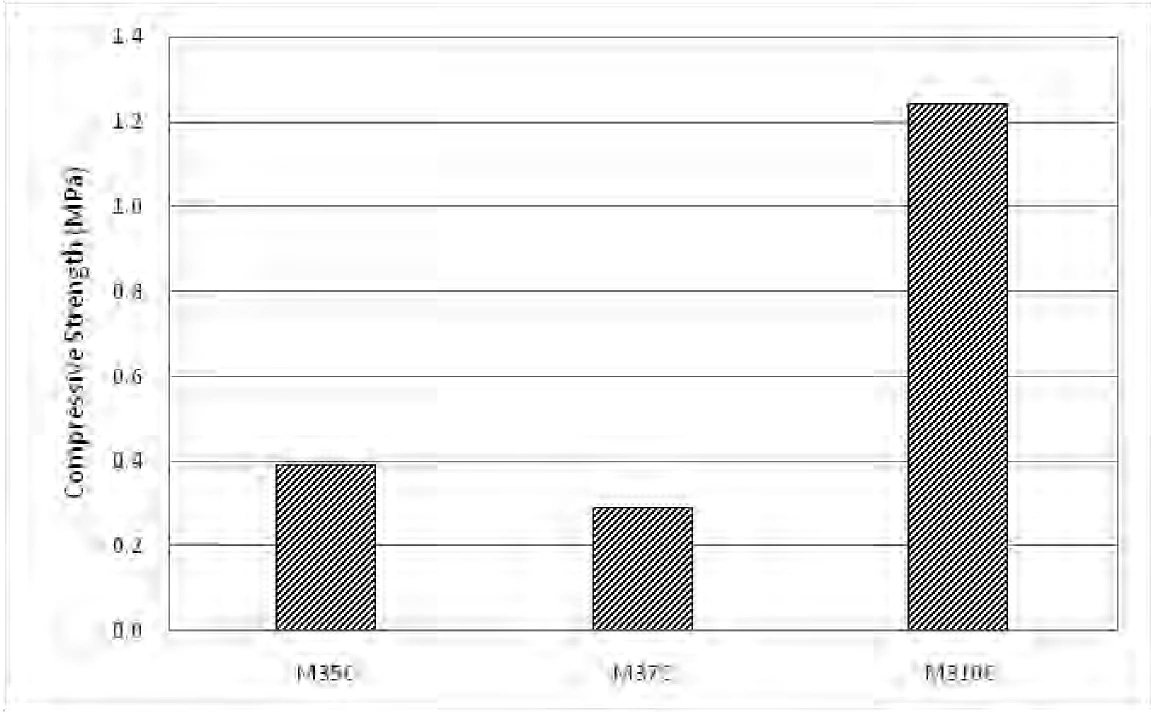


Fig. 4.7: 7 days Compressive Strength vs Cement Content

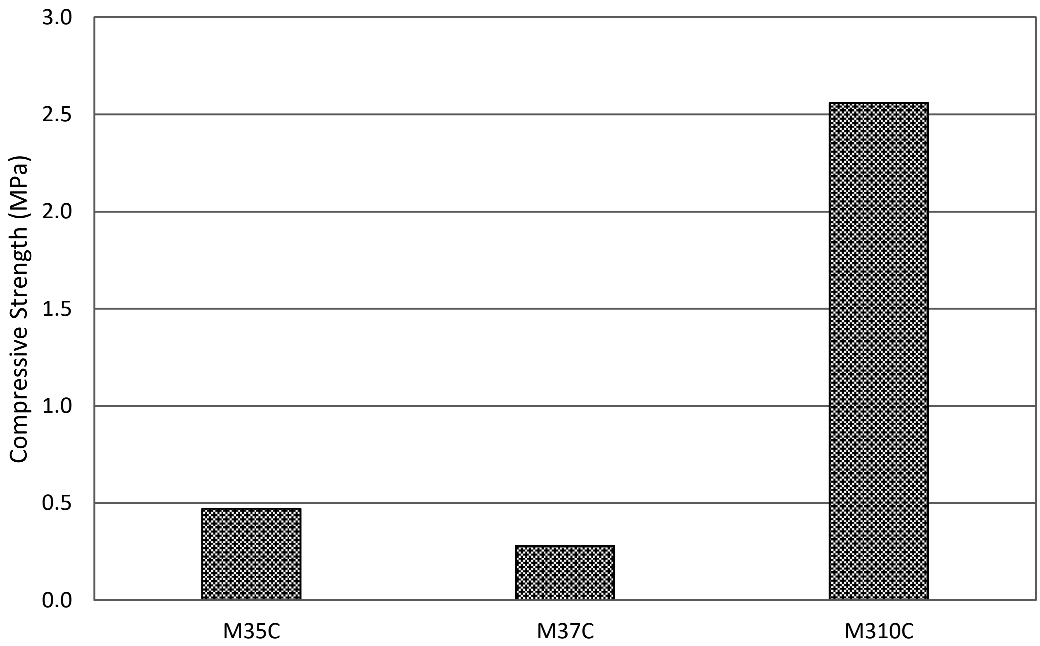


Fig. 4.8: 28 days Compressive Strength vs Cement Content

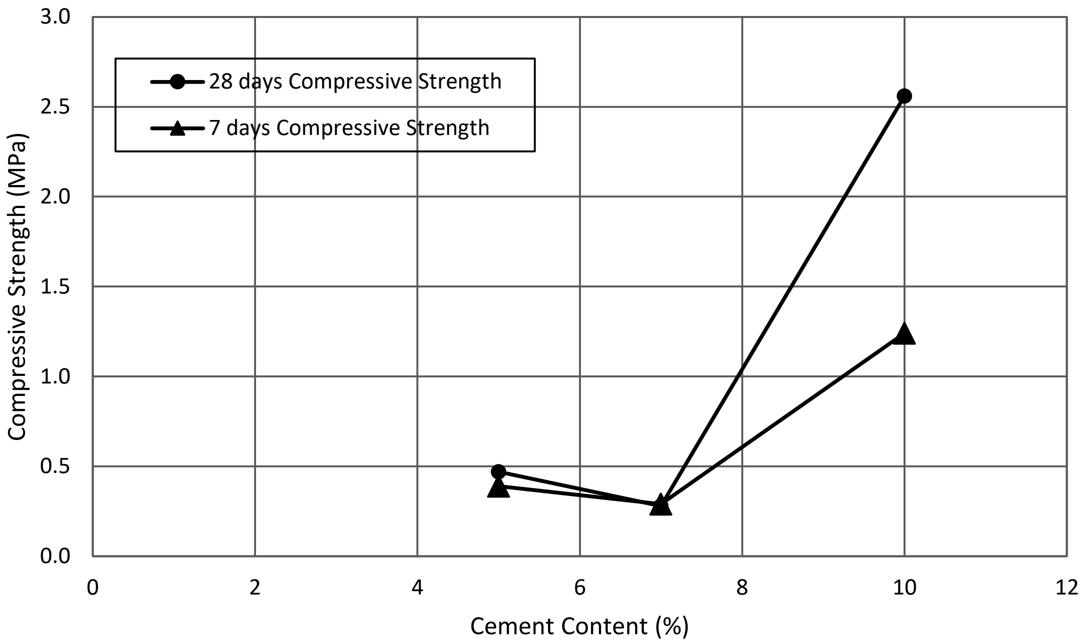


Fig. 4.9: Variation of compressive strength with cement content.

4.8 Variation of Compressive Strength with Fly ash content

In Fig. 4.10, 4.11 and 4.12, after an interval of 7 days, 28 days and 60 days, compressive strength of CSEB specimens prepared with 0%, 5%, 10%, 15% and 20% of fly ash content has been plotted respectively.

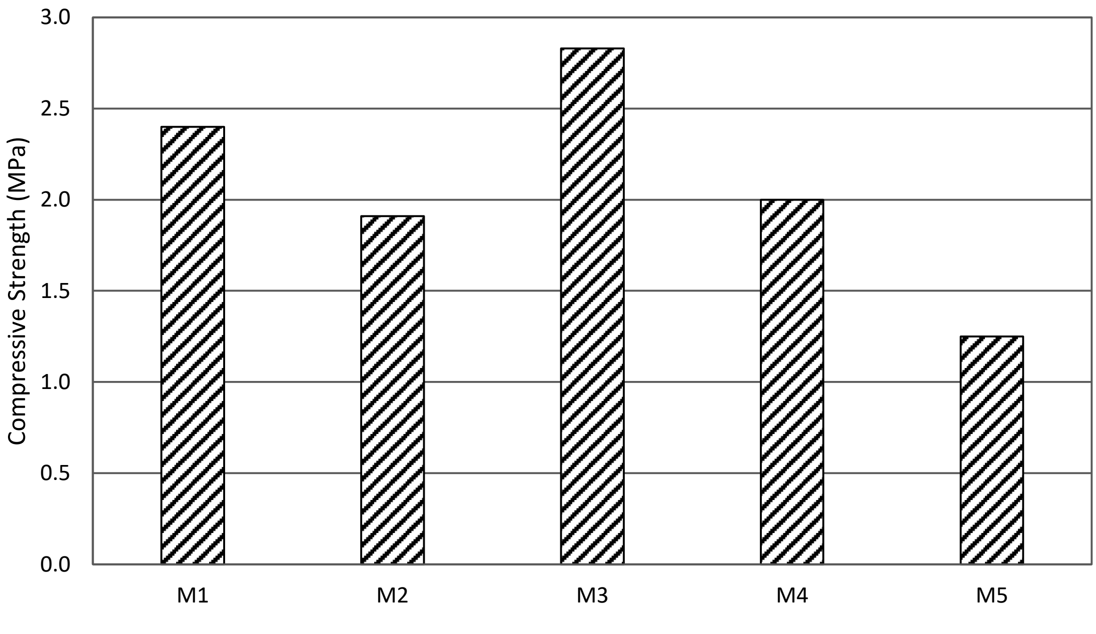


Fig. 4.10: 7 days Compressive Strength vs fly ash Content

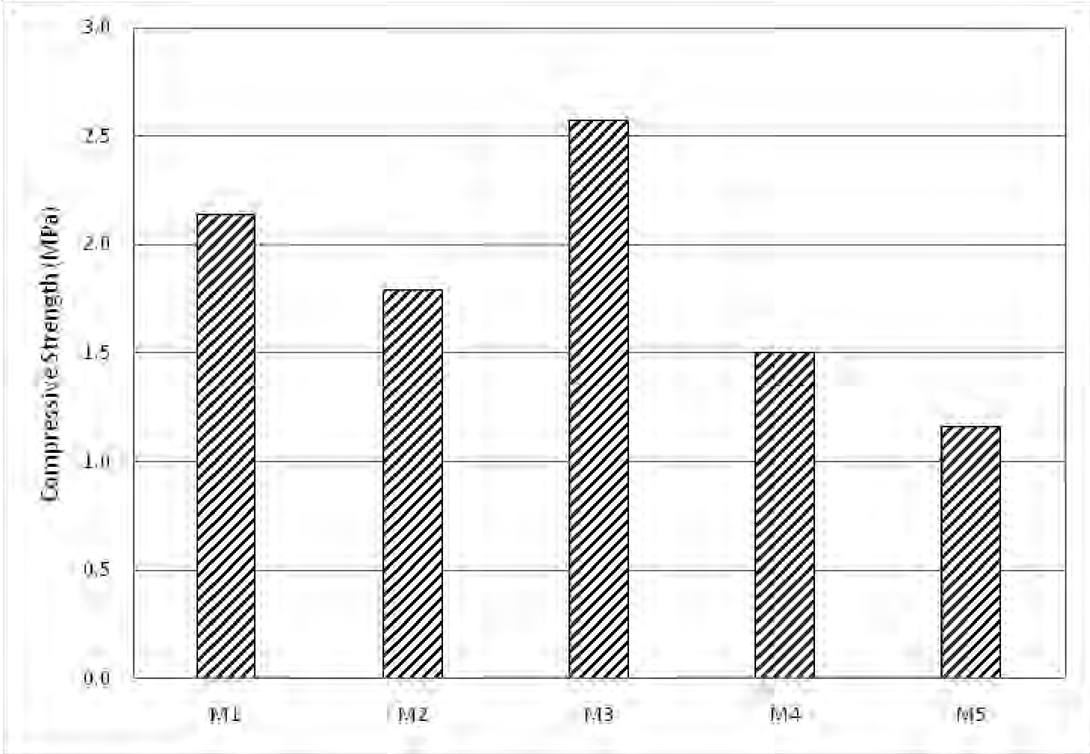


Fig. 4.11: 28 days Compressive Strength vs fly ash Content

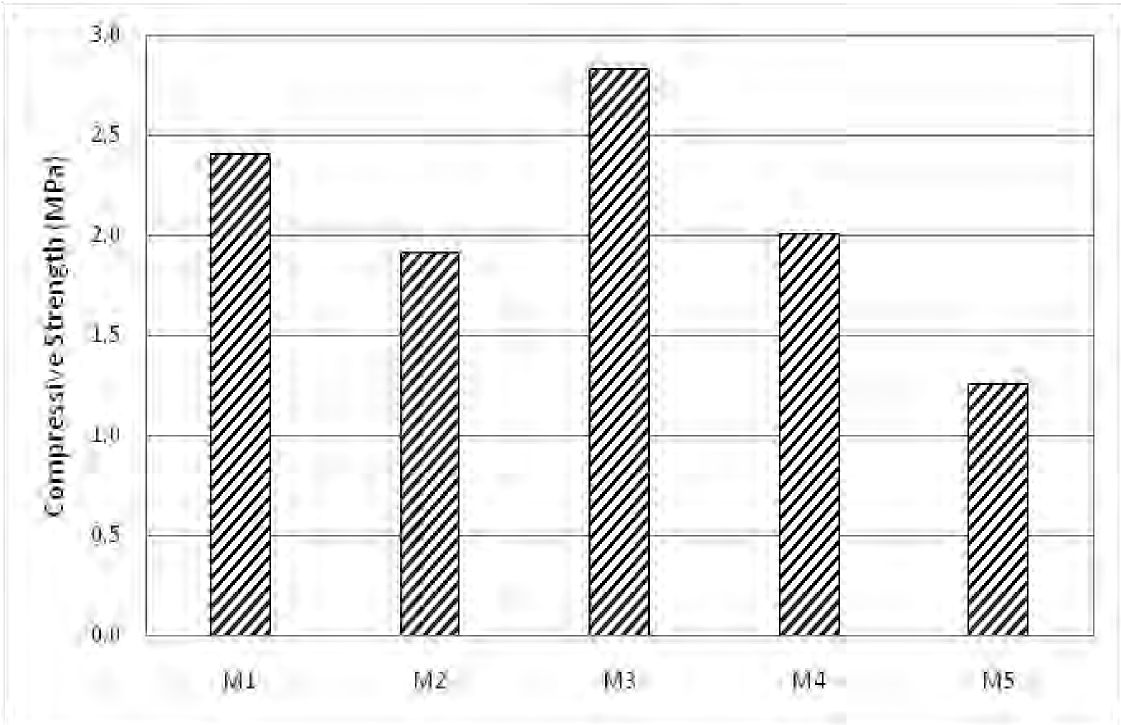
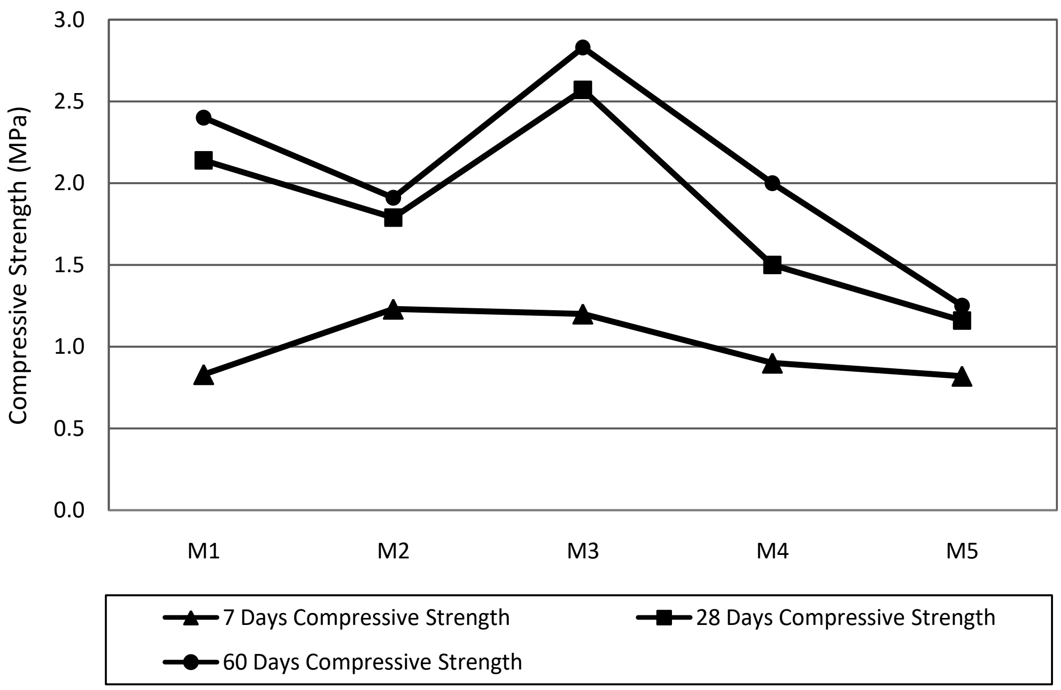


Fig. 4.12: 60 days Compressive Strength vs. fly ash Content

From Fig. 4.13, it is seen that the 7 days compressive strength increase from 0.82 MPa to 1.23 MPa with the decrease of fly ash content from 20% to 15%. After that the compressive strength decreases with further decrease of fly ash content. For 28 days, it is seen that compressive strength decreases from 2.14 MPa to 1.79 MPa with the decrease of fly ash content from 20% to 15%. Then it increases up to 2.57 MPa with the decrease of fly ash to 10%. Then compressive strength again decreases with further decrease of fly ash content. It is also observed that, 60 days compressive strength decreases from 2.40 MPa to 1.91 MPa with the decrease of fly ash content from 20% to 15%. Then it increases up to 2.83 MPa with the decrease of fly ash to 10%. Then compressive strength again decreases with further decrease of fly ash content. So, 10% fly ash content is the optimum amount of fly ash content for CSEB specimens.



Key:

M0 (0% fly ash + 10% cement + 90% sand); M1 (20% fly ash + 10% cement + 70% sand)

M2 (15% fly ash + 10% cement + 75% sand);M3 (10% fly ash + 10% cement + 80% sand)

M4 (5% fly ash + 10% cement + 85% sand)

Fig. 4.13: Variation of compressive strength with fly ash content.

4.9 Water Absorption properties of Prepared CSEB

In Fig. 4.14 and 4.15, the absorption capacity of CSEB specimens prepared with 10%, 15%, 20% and 25% mixing water content has been plotted. It is seen that the absorption capacity decreases from 21.7% to 15.08% with the increase of water content from 10% to 20%. After that the absorption capacity increases with additional water after 20%. From this, it seems that at 20% mixing water content is water absorption capacity is minimum.

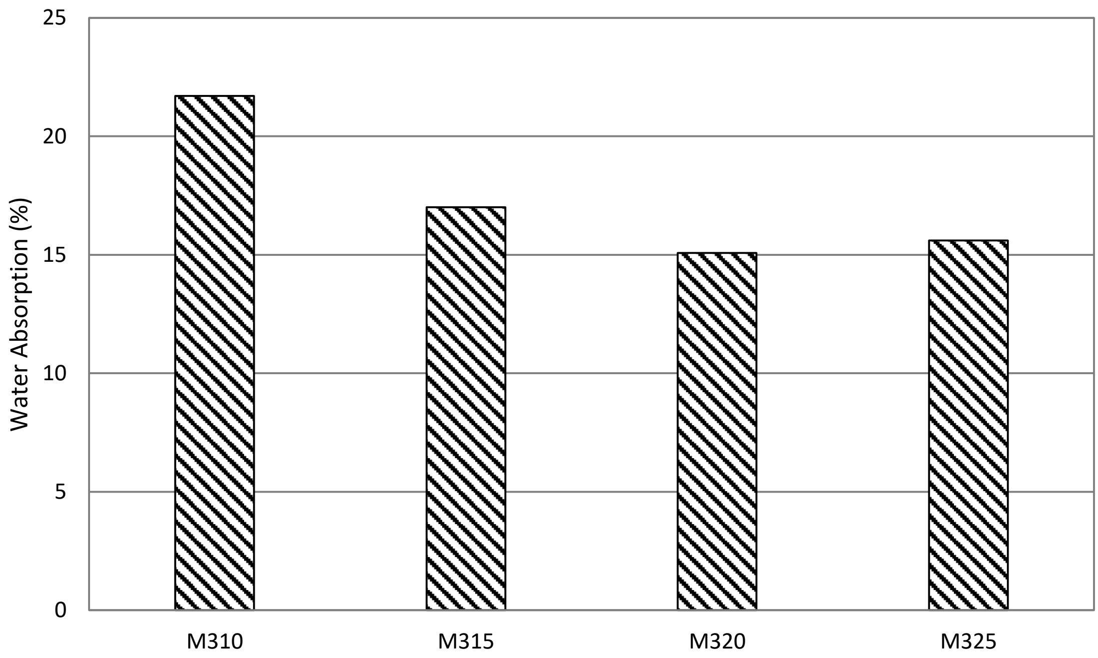


Fig. 4.14: Water absorption capacity vs mixing water content

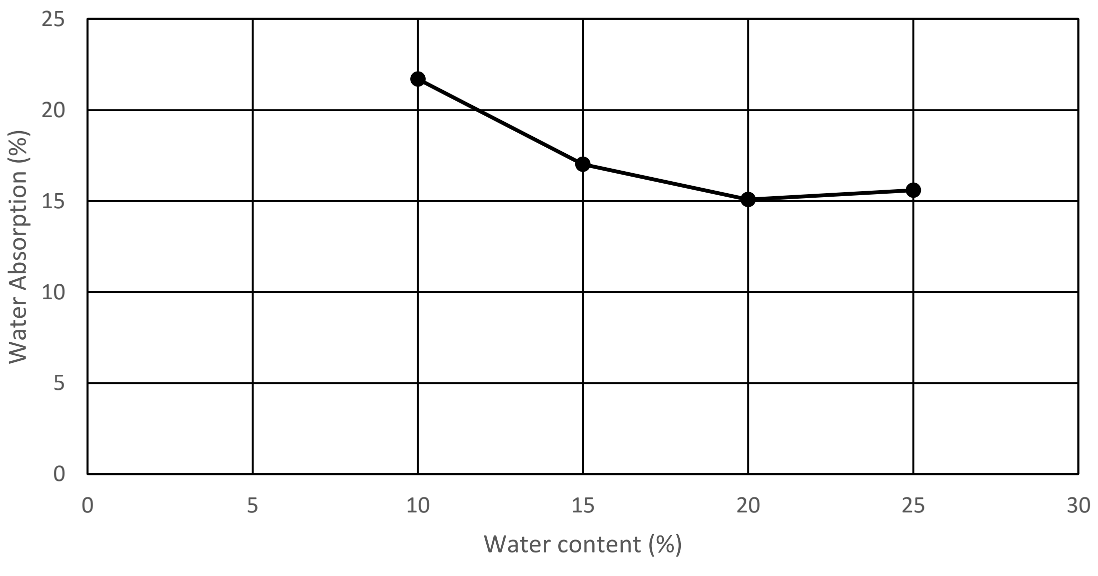


Fig. 4.15: Variation of absorption capacity with mixing water content

In Fig. 4.16 and 4.17, the water absorption capacity of CSEB specimens prepared with 16, 32 and 50 blows per layer of pressing has been plotted. From Fig. 4.17, it is seen that the water absorption capacity decreases from 14.72% to 12.05% with the increase of pressing from 16 to 50 blows per layer. This is because the density increases with addition pressing, as a result pore space in the specimen decreases. So, water absorption capacity of CSEB specimen decreases with increase amount pressing.

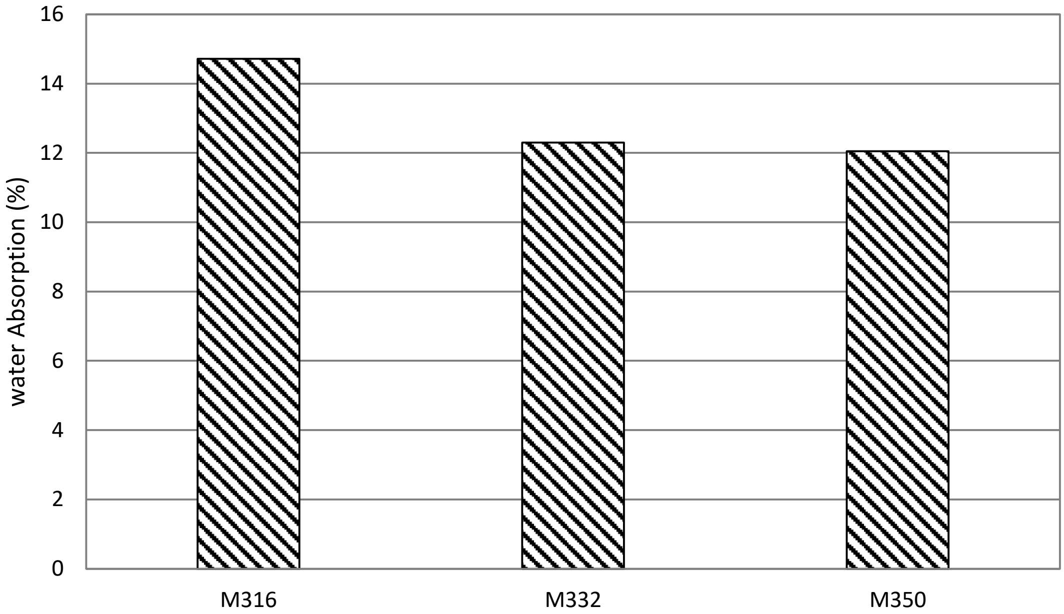


Fig. 4.16: Water absorption capacity vs pressing (no. of blows per layer)

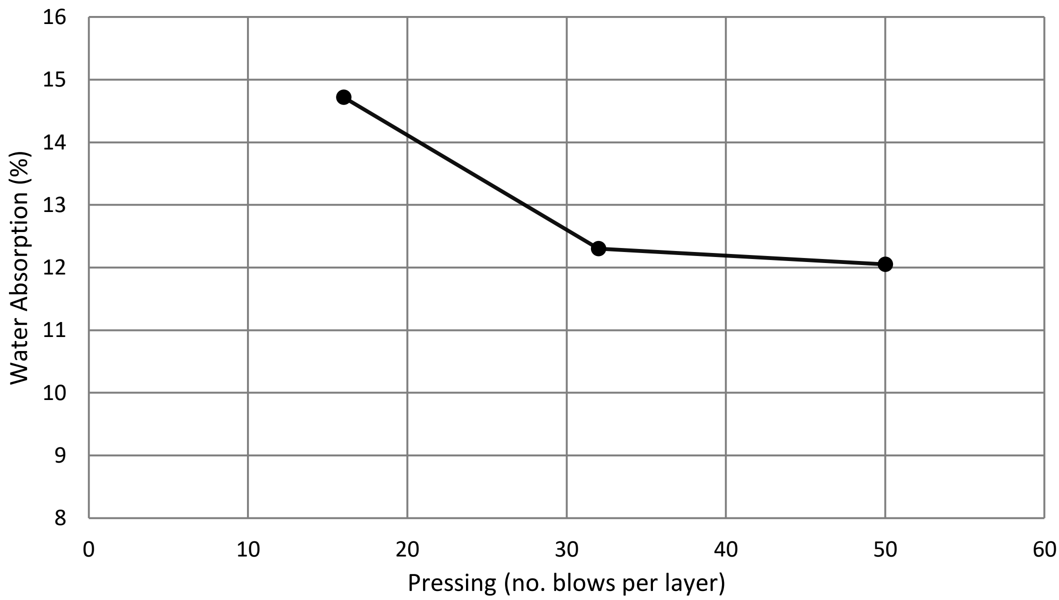


Fig. 4.17: Variation of absorption capacity with pressing (no. of blows per layer)

In Fig. 4.18 and 4.19, the absorption capacity of CSEB specimens prepared with 5%, 7% and 10% cement content has been plotted. It is seen that the absorption capacity increases from 16.26% to 17.48% with the increase of water content from 5% to 7%. After that the absorption capacity decreases with additional cement after 7%. From this, it seems that, at 10% cement content is water absorption capacity is minimum.

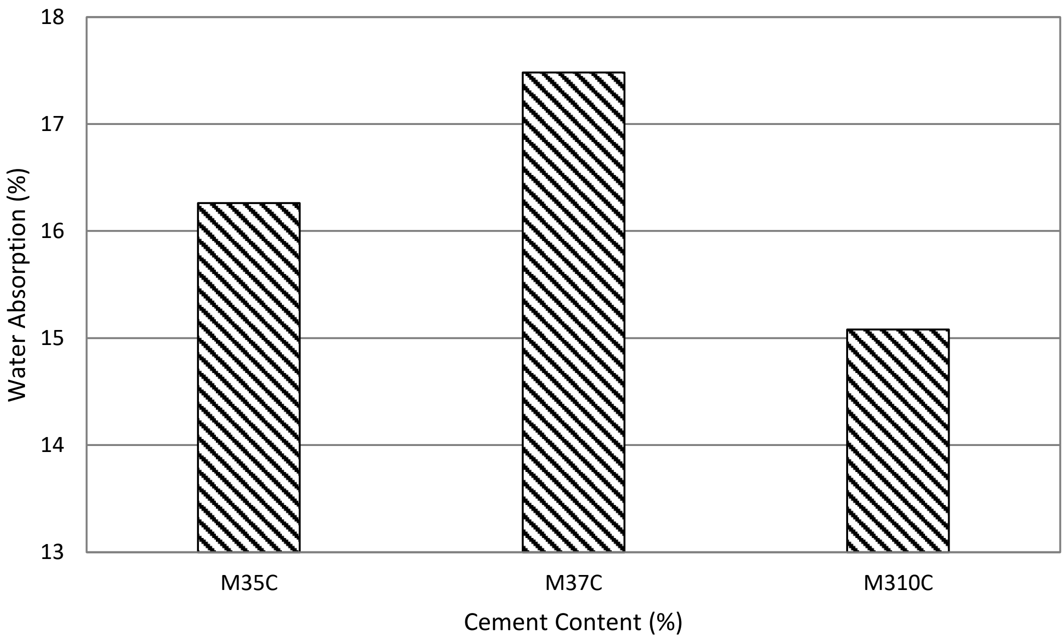


Fig. 4.18: Water absorption capacity vs cement content

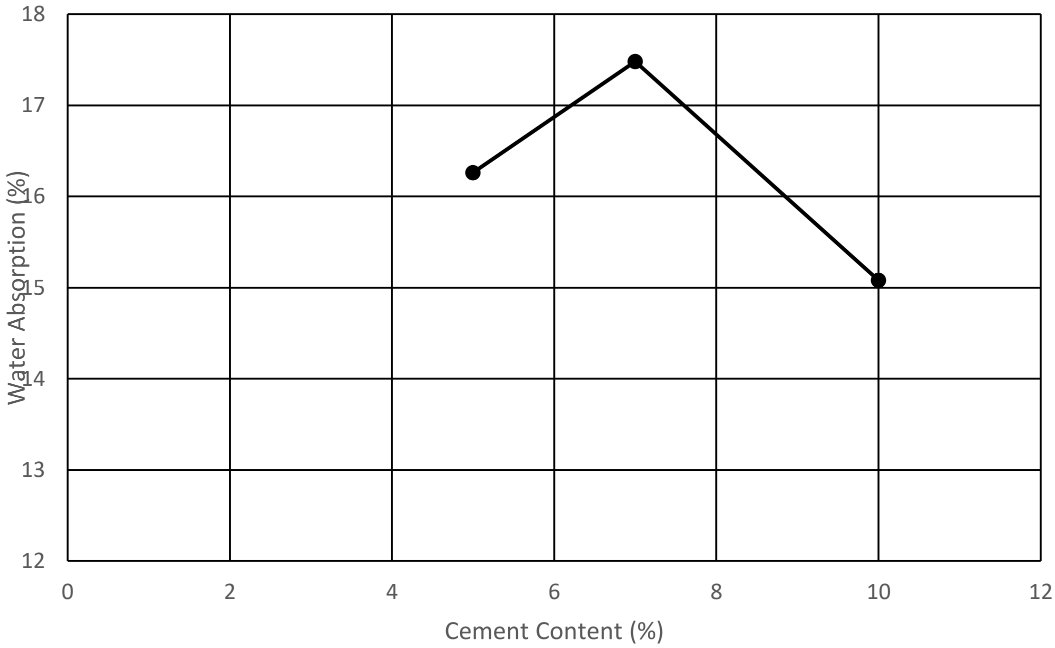
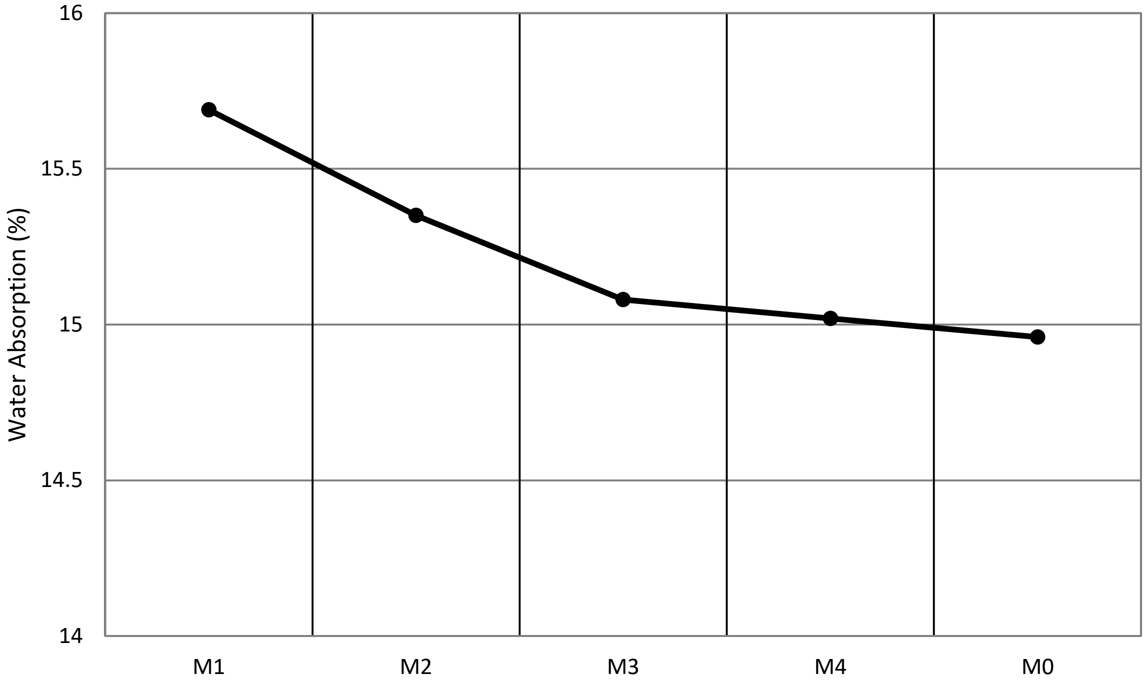


Fig. 4.19: Variation of absorption capacity with cement content

In Fig. 4.20, water absorption capacity of CSEB specimens prepared with 0%, 5%, 10%, 15% and 20% of fly ash content has been plotted. It is seen that the water absorption capacity decreases from 15.69% to 14.96% with the decrease of fly ash content from 20% to 0%. So, the lower the fly ash content the lower the water absorption capacity.



Key:

M0 (0% fly ash + 10% cement + 90% sand); M1 (20% fly ash + 10% cement + 70% sand)

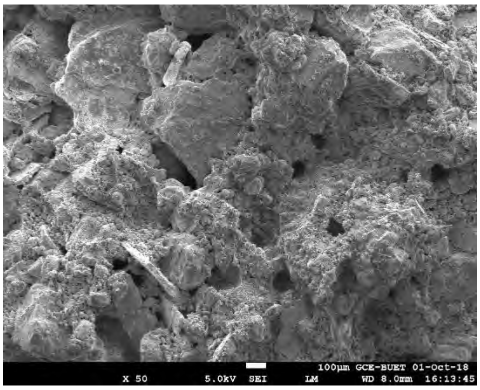
M2 (15% fly ash + 10% cement + 75% sand);M3 (10% fly ash + 10% cement + 80% sand)

M4 (5% fly ash + 10% cement + 85% sand)

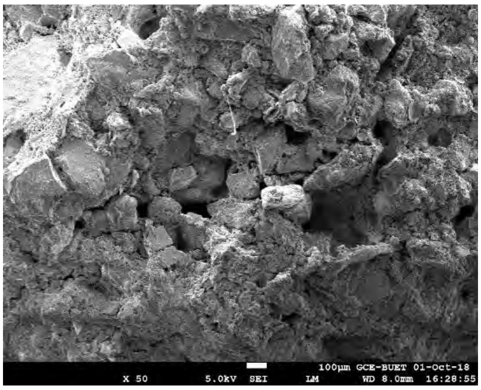
Fig. 4.20: Variation of absorption capacity with fly ash content

4.10 Scanning Electron Microscopy Test Results

Fig. 4.21 compares the images received by performing SEM on the five different block samples. As Fly-ash content is gradually increasing the size of the void is diminishing. Therefore the porosity of the blocks will decline if fly-ash percentage is increased.



(a)



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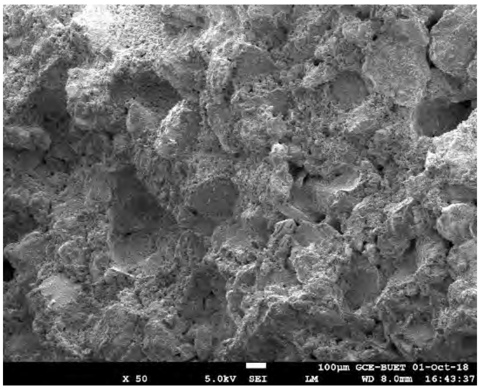
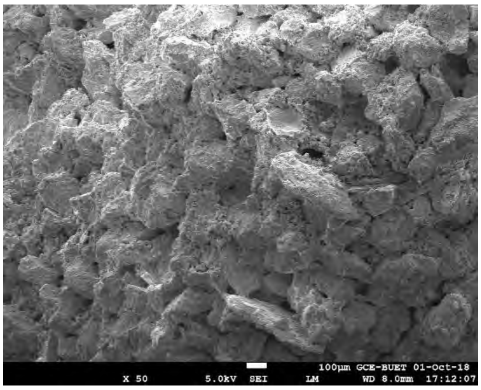
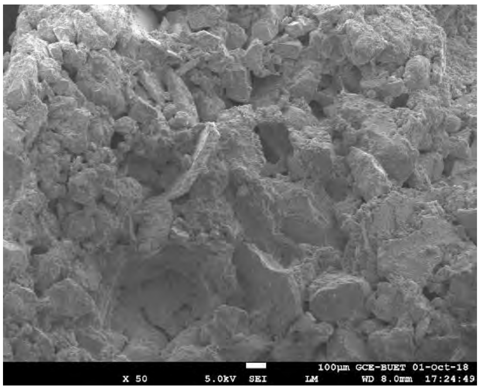


(c)



(d)



(e)

Fig. 4.21: SEM images (50 x magnification) :(a) 20% flyash, (b) 15% flyash, (c) 10% flyash, (d) 5% flyash and (e) 0% flyash (control)

4.11 Cost Effectiveness of CSEB over Flyash Bricks

In Table 4.4, production cost of each block of prepared CSEB has been shown. Production cost of each fly ash block equivalent to brick size is also presented. From the table 4.5 it is seen that the cost of production of fly ash block equivalent to brick size cost BDT. 5.5-6.25.

In Table 4.6, a comparison among different types of bricks and fly ash blocks have been presented.

Table 4.4: Raw material cost (Survey from local market, 2018)

Raw materials	Cost/ kg (BDT)
Fly ash	1.23
Soil	0.50
Cement	6.50
Water	0.175/gallon

Table 4.5: Production cost of fly ash stabilized CSEB blocks

Sample Designation	Cost of fly ash used in 3 blocks (BDT.)	Cost of cement used in 3 blocks (BDT.)	Cost of water used in 3 blocks (BDT.)	Cost of each 5 cm cubic block (BDT.)	Cost of each fly ash block equivalent to brick size (BDT.)
M1	0.2640	0.65	0.011	0.425	6.24
M2	0.1848	0.65	0.011	0.407	5.98
M3	0.1232	0.65	0.011	0.395	5.80
M4	0.0616	0.65	0.011	0.383	5.63
M5	0	0.65	0.011	0.370	5.44

Table 4.6: Cost comparison between different types of bricks

Types of bricks	Cost of bricks (BDT.)
S-grade bricks	7.5-8.0
A-grade bricks	6.5-7.0
Machine made bricks	10-11
Fly ash stabilized bricks	5.50-6.25

4.12 Compressive Strength of Bricks

After curing the brick samples the compressive strength was determined, which is presented in Fig.4.22.. The samples were grouped in pairs, the first two were cured for a week, the next two for 14 days and the last samples 5 and 6 were cured for a total 28 days. From Fig. 4.22, it can be seen that the strength of bricks is gradually increasing with curing period. The optimum strength of bricks was recorded 2.63 MPa. It has been observed that the optimum brick strength is approximately equal to the optimum strength of blocks.

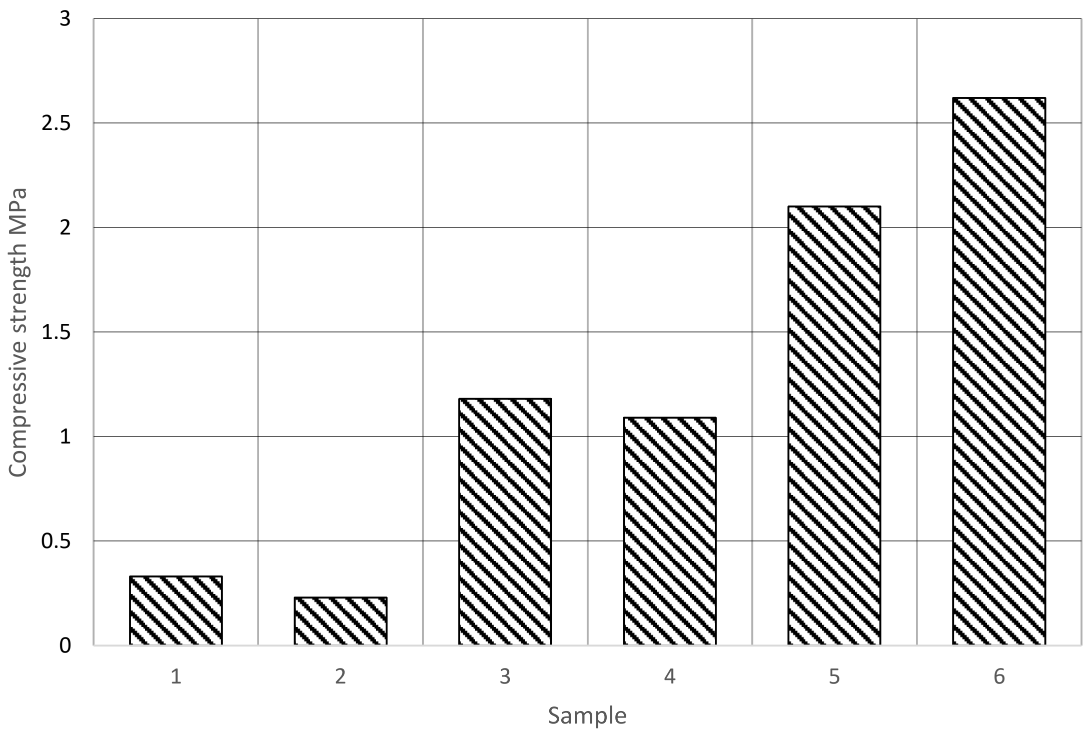


Fig. 4.22: Strength of unburnt bricks after 7, 14 and 28 days.

4.13 Comparison of strength received with a similar research

The compressive strength of the CSEBs in this investigation varied between 0.28 MPa to 2.63 MPa. The maximum compressive strength 2.63 MPa was obtained using 10% fly ash, 10% cement, 20 % water and 80 % sand. To understand its applicability as a building material, a comparison is done with a similar research.

Nahar (2018), concluded that compressive strength of CSEB was found to be between 0.89 and 6.07 MPa consisting of 3-9% cement, 20-60% coarse sand and 50-60% fine sand by weight. The results obtained from their study stated that such blocks may be useful in reducing the consumption of fired brick used as non-load bearing building block in construction sector of Bangladesh.

Based on the results obtained by Nahar (2018) and comparing the strength with this study, both the stabilized blocks and bricks can also be utilized as a construction material in non-load bearing walls.

4.14 Summary

Laboratory test on soil was conducted to determine the soil properties. Compressive strength test on the prepared CSEBs was conducted to determine the compressive strength of prepared CSEBs. Compressive strength test was conducted on total 15 types CSEB specimens. The comparison of different combinations of CSEB specimens have been discussed with relevant graphs, charts and tables. Water absorption capacity of some prepared CSEB specimens are also determined after 24 hours immersion under water. Finally, comparison of compressive strength and water absorption capacity of CSEB specimens have been presented with relevant figures. These can be summarized as follows:

(i) Laboratory test results on the collected soil samples are compared and from that suitable, soil from the collected soil sample, for preparing CSEB are determined.

(ii) Compressive test result conducted on 15 different types of CSEB specimens of different combination was compared. From the comparative study the optimum mixing water content, pressing and combination for preparing CSEBS are determined. From the compressive strength result, maximum compressive strength of CSEB specimen found was 2.63 MPa.

(iii) Absorption test was also conducted on the prepared CSEB specimens. From the result obtained from absorption test it has been found that with the increase of fly ash content water absorption capacity of CSEB specimen has increased.

(iv) Images taken after Scanning Electron Microscopy investigations were compared with each other. It was found that size of the void decreases with increase of flyash content. This shows flyash works well in establishing good bonding indicating an increase in strength.

(v) Cost of production of each combination is determined. Cost of each type of block equivalent to brick size is also determined. Then it is compared with production cost of S-grade, A-grade and machine made brick and it has been found that production cost of fly ash stabilized CSEB is less than these bricks.

(vi) Moreover, the block samples exhibiting highest strength so far were replicated to form bricks using bigger mould following BSTI specifications and their compressive strength were observed and compared with curing period.

Chapter 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusion

The main findings of this study are as follows:

(i) Five river bed sand samples were collected and soil from Meghna river fulfilled the required criteria and was used as a raw material for the production of CSEBs.

(ii) The compressive strength of the CSEBs varied between 0.28 MPa to 2.63 MPa. The maximum compressive strength 2.63 MPa was obtained using 10% fly ash, 10% cement, 20 % water and 80 % sand.

(iii) The strength of the fly-ash and cement stabilized block was compared with various codes to check its performance and suitability as a construction material. According to the code IS :1725-1982 and New Mexico Earthen Building Code, these flyash-cement stabilized blocks exhibiting strength beyond 1.95 MPa fulfills the code requirement and holds the capacity to perform as a construction material in non-load bearing walls, rural houses ,one-story building, low rise buildings.

(iv) From the compressive strength test of unburnt bricks measuring 25 cm × 12cm × 7 cm, following BSTI specifications, it was seen that the highest strength i.e. 2.62 MPa was received after curing for 28 days. These bricks constituted the percentages of the CSEB exhibiting highest compressive strength of 2.63 MPa. The narrow differences between the compressive strength of the blocks and bricks received indicates the bricks can also be utilized as a construction material in non-load bearing walls.

(v) From the absorption capacity results, it has been found that the water absorption decreases with the increase of fly ash content. This indicates there is sufficient strength to inhibit porosity which works well in exhibiting strength in the blocks In spite of the fact that the minimum water absorption capacity of CSEBs should be than 12%, the test results indicated the capacity exceeded 15 %.The poor quality of fly ash and humid weather conditions might have contributed to an increment in absorption capacity.

(vi) From the images of scanning electron microscopy tests, it was found that size of voids decreases with an increase of fly ash content. The combined effect of fly ash and cement contributed to good bonding and increased compactness which has been well interpreted in the images received.

(vii) From the cost analysis of CSEB blocks, it has been found that fly ash block of equivalent brick size costs BDT. 5.5-6.25 and its cost is about 1.3 times, 1.2 times and 1.8 times cheaper than S-grade, A-grade and machine-made brick respectively. Manufacturing the CSEBs on a larger scale will definitely shrink the cost of production and help these compete well in the market as a cost effective material.

5.2 Recommendations for Future Study

The main objective of this research was to determine the strength characteristics of CSEB. Moreover, opportunities for future researchers are numerous. The following studies can be conducted in future:

(i) In this research, the soils were collected from five specific sites only. Soil from other parts of Bangladesh are not investigated for the suitable soil for CSEB.

(ii) Because of use of poor quality of fly ash, the targeted strength of fly ash stabilized bricks that usually varies within 10-12 MPa could not be achieved. Class C can be used instead of Class F fly ash in this investigation.

(iii) Due to limitation of scope, analysis of dynamic property was not carried out. Dynamic test like Shaking Table test can be conducted.

(iv) In this study CSEBs are compacted by manual pressing. Compaction with mechanical pressing for example by using 'Auram Earth Block press' can be conducted.

(v) Because of the limitation of scope, analysis of lateral loading property of the fly ash stabilized CSEB block was not carried out.

(vi) Despite the possibilities and advantages offered by stabilized earth materials, building with earth is still not in the common practice. Either people don't want to acknowledge the advantage of this material or they do not want to take the burden to organize the block production on their site and manage everything themselves. So public awareness can be risen by letting them know about CSEB.

Thus, it is suggested for future study to work on these areas in future in order to address all the problems finding out probable solutions to overcome the drawbacks. Finally, it is expected that the present study will be useful to all those dealing with civil engineering projects and research work on building materials that were once considered as waste, ways to utilize river bed sand effectively. The research will also be useful to those who are involved in the development of low cost and eco-friendly house construction and implement the same in the context of the present scenario of our country.

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APPENDIX-A

LABORATORY TEST RESULTS

Atterberg limit test

Soil sample No.:

Table A.1: Liquid limit

No. of Blows	Container No.	Wt. of Container (gm)	Wt. of container + Wet Soil (gm)	Wt. of container + Dry Soil (gm)	Wt. of water (gm)	Wt. of Dry Soil (gm)	Water content (%)	Liquid limit (%)
16	716	7.2	19.1	15.9	3.2	8.7	36.78	34.3
20	3	7.3	18.7	15.7	3.0	8.4	35.71	
26	505	6.6	17.2	14.5	2.7	7.9	34.18	
29	880	10.5	28.1	23.8	4.3	13.3	32.33	
36	2012	9.8	25.2	21.5	3.7	11.7	31.62	

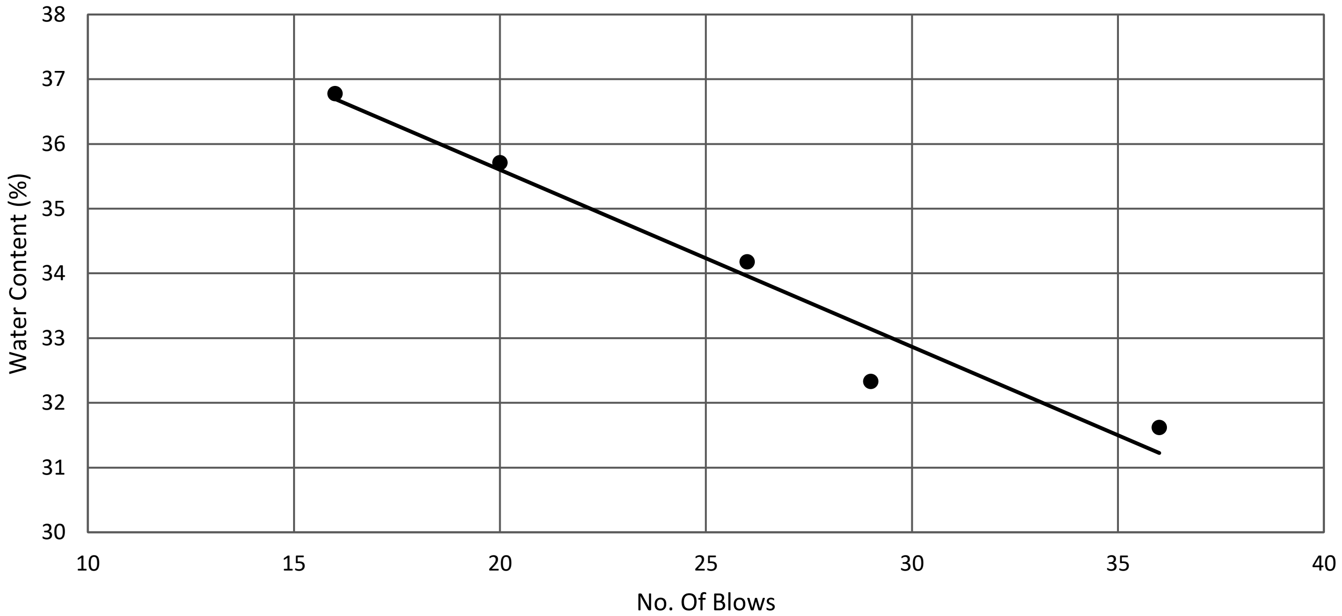

Fig. A.1: Water content vs no. of blows

Table A.2: Plastic limit

Container no.	Wt. of Container (gm)	Wt. of Container + Wet Soil (gm)	Wt. of Container + Dry Soil (gm)	Wt. of water, Ww (gm)	Wt. of Dry soil, Ws (gm)	Water Content, w (%)	Plastic limit (%)
114	6.7	11.1	10.4	0.7	3.7	18.92	19.3
875	7.2	10.3	9.8	0.5	2.6	19.23	
2155	10.2	13.8	13.2	0.6	3.0	20.00	

Table A.3: Shrinkage limit

Dish no.	Wt. of Dish (gm)	Wt. of Dish + Wet Soil (gm)	Wt. of Dish + Dry Soil (gm)	Wt. of Dry soil, Ws (gm)	Wt. of Displaced mercury (gm)	Volume of displaced mercury, V (cm^3)	Shrinkage limit (%)
8	30.7	60.4	53.0	22.3	196.3	14.49	28

Table A.4: Summary of Atterberg limit test

Liquid Limit (%)	Plastic Limit (%)	Shrinkage Limit (%)	Plasticity Index
34.3	19.3	28	15

Crushing Strength Test

Sample designation: **M310**

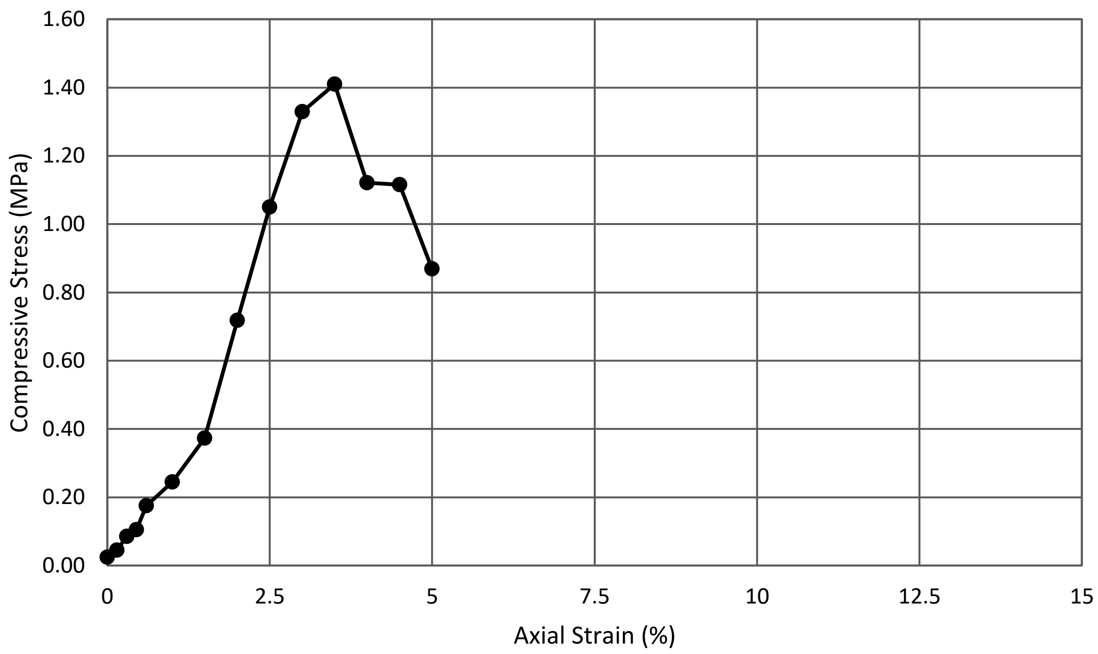

Fig. A.2: Compressive Stress vs. Axial Strain (10% water)

Sample designation: **M315**

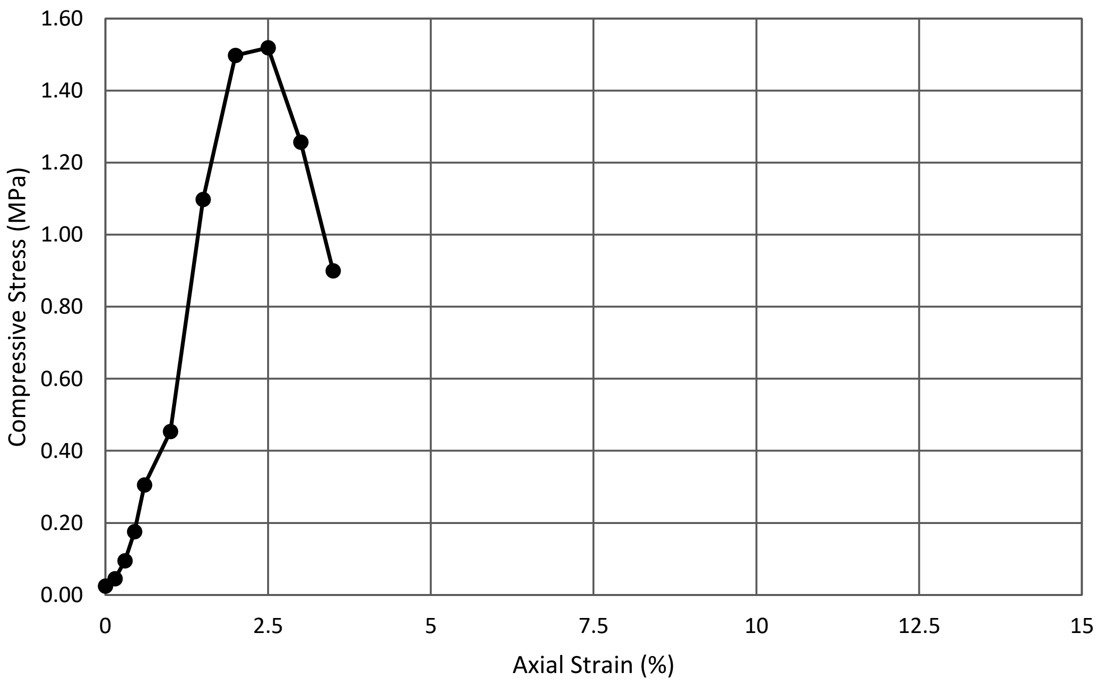

Fig. A.3: Compressive Stress vs. Axial Strain (15% water)

Sample designation: **M320**

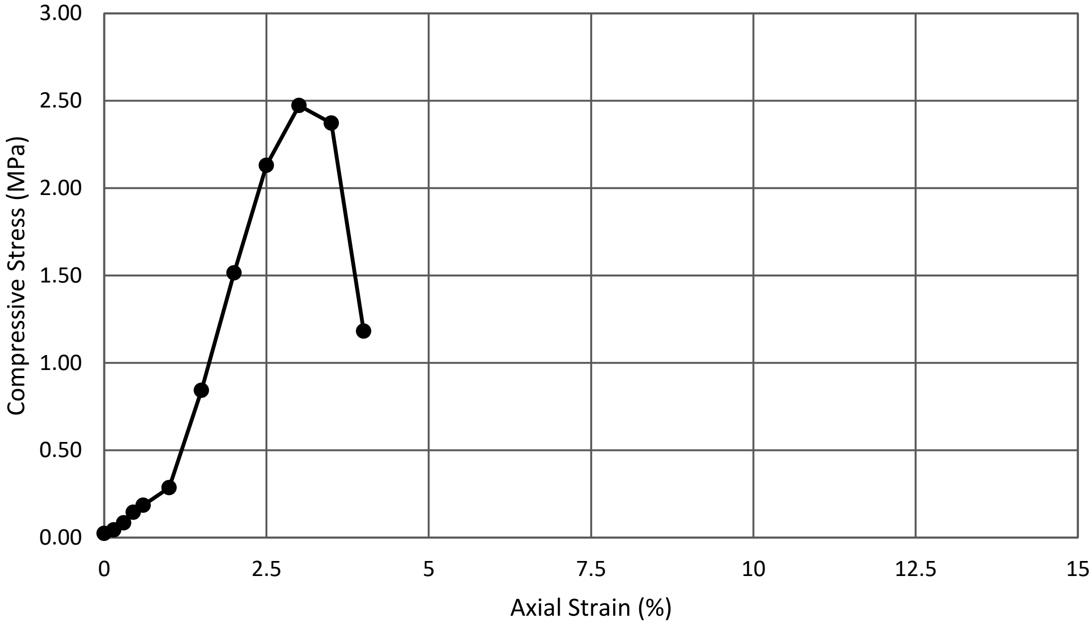

Fig. A.4: Compressive Stress vs. Axial Strain (20% water)

Sample designation: **M325**

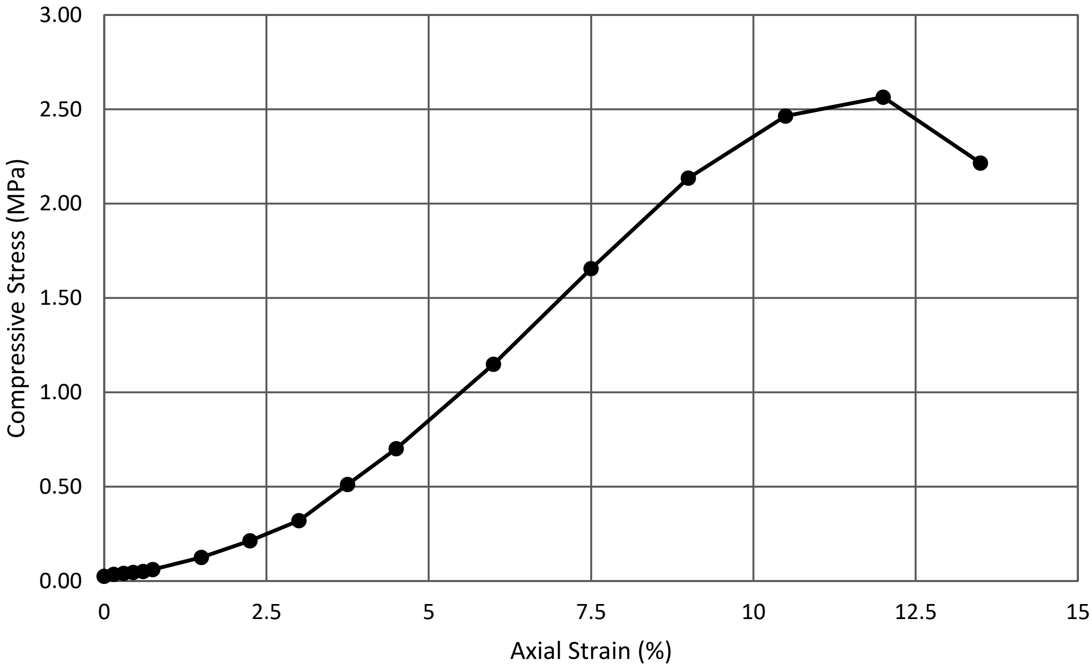

Fig. A.5: Compressive Stress vs. Axial Strain (25% water)

Sample designation: **M316**

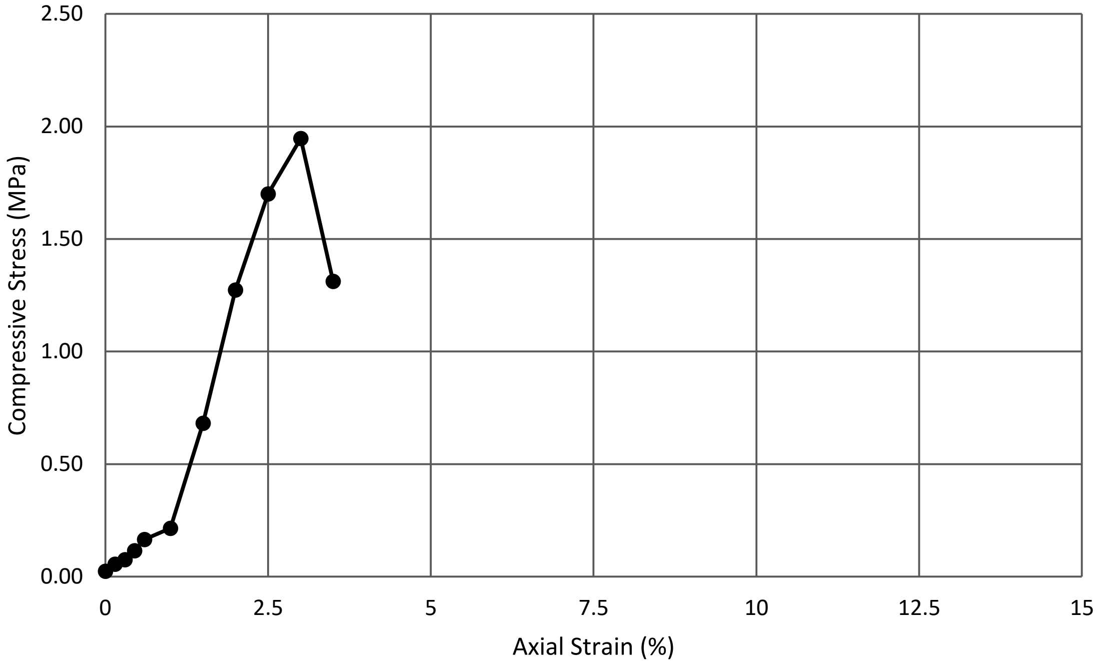

Fig. A.6: Compressive Stress vs. Axial Strain (16 blows per layer)

Sample designation: **M332**

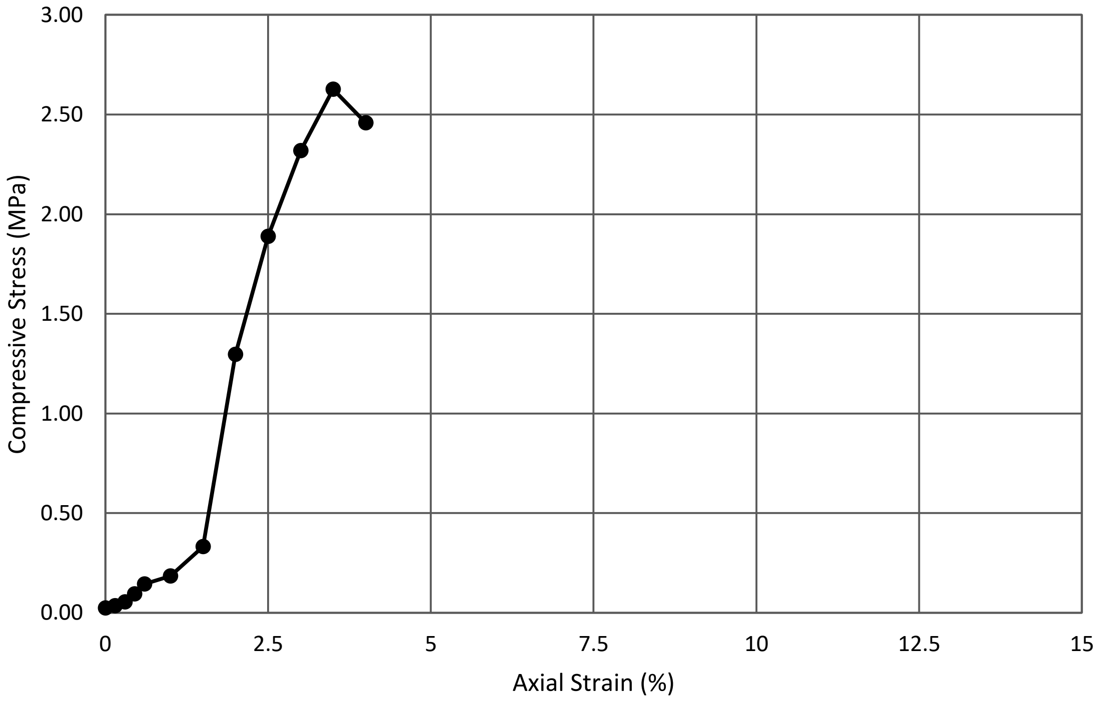

Fig. A.7: Compressive Stress vs. Axial Strain (32 blows per layer)

Sample designation: **M350**

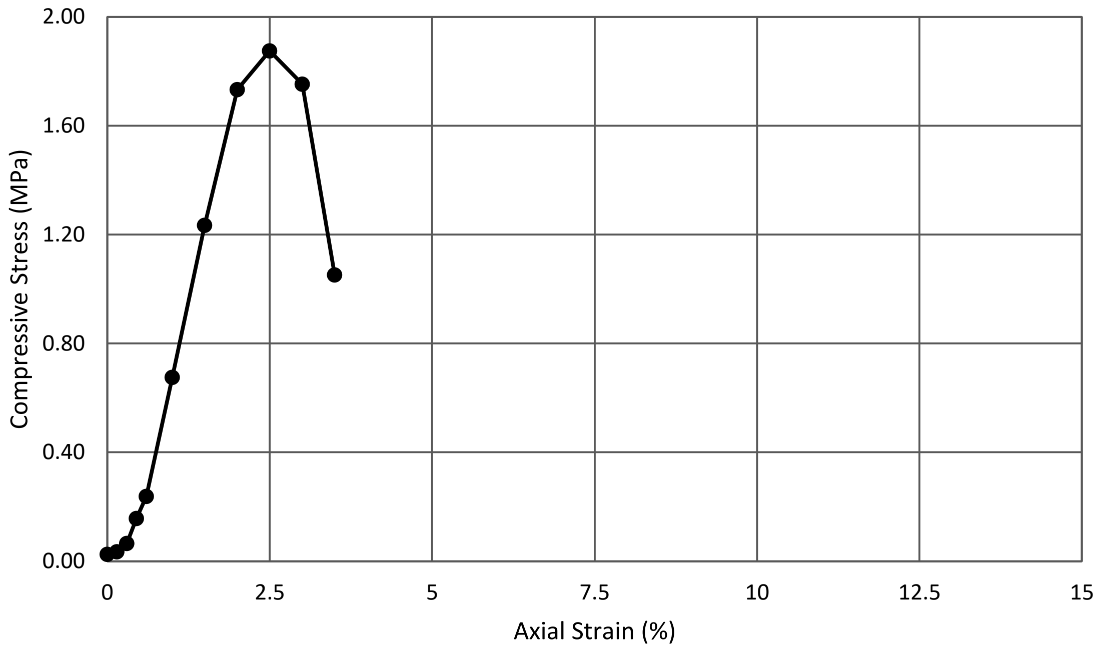

Fig. A.8: Compressive Stress vs. Axial Strain (50 blows per layer)

Sample designation: **M35C**

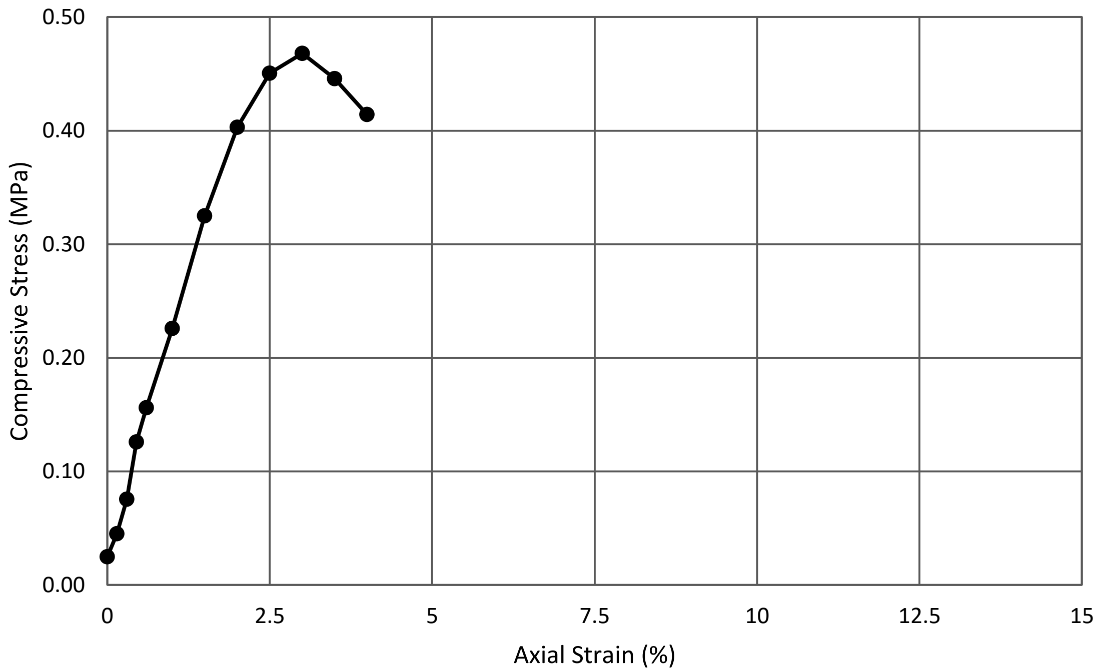

Fig. A.9: Compressive Stress vs. Axial Strain (5% cement content)

Sample designation: **M37C**

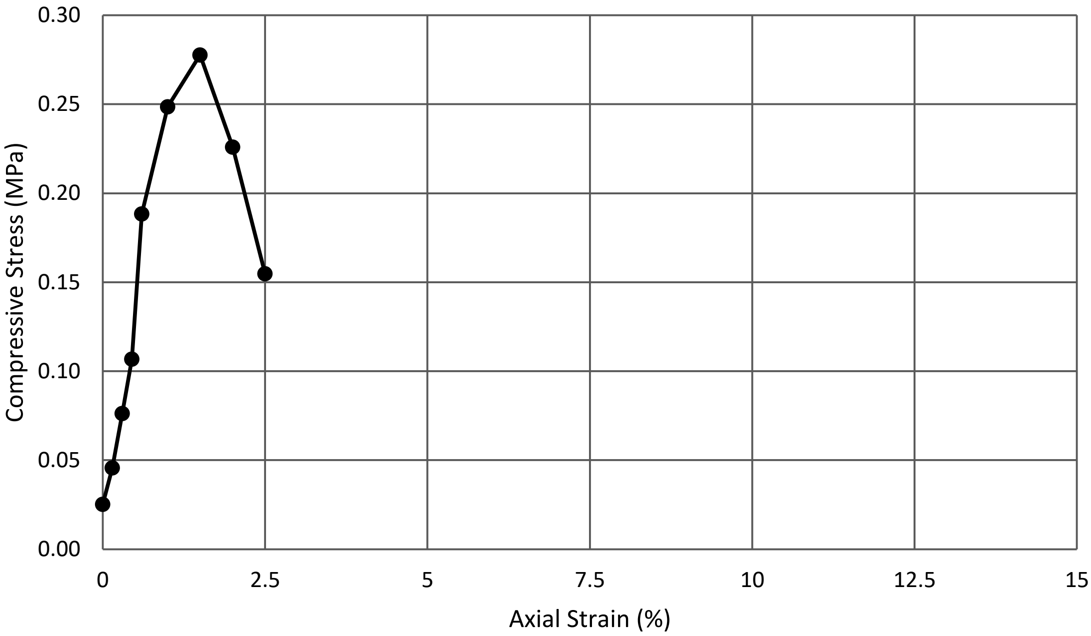

Fig. A.10: Compressive Stress vs. Axial Strain (7% cement content)

Sample designation: **M310C**

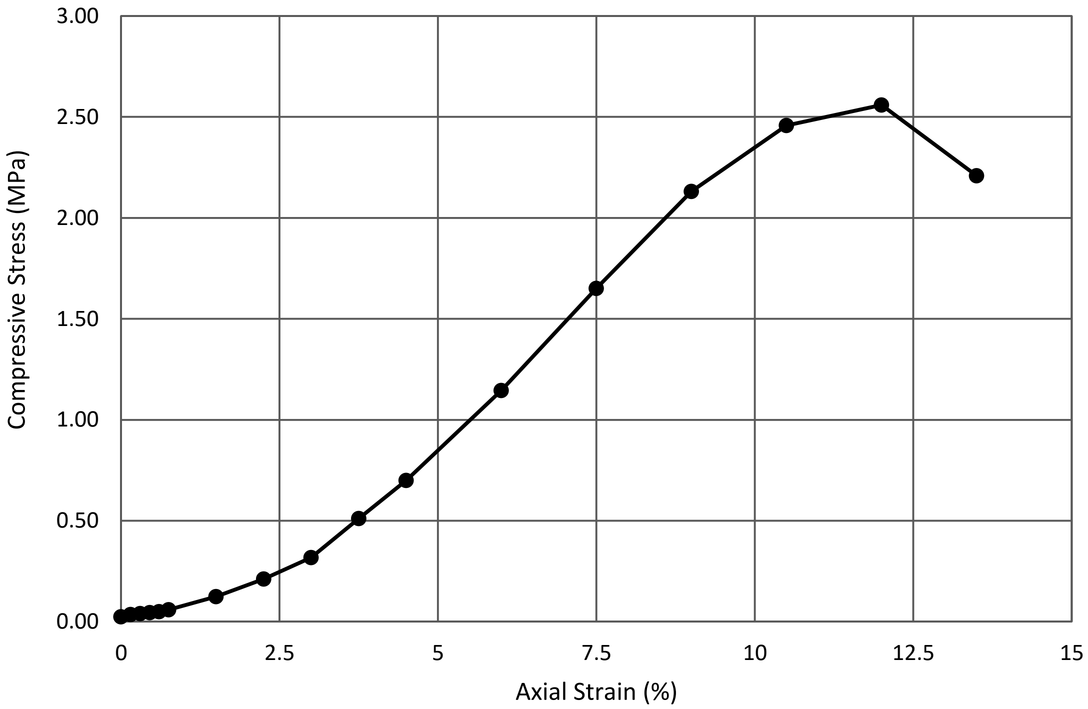

Fig. A.11: Compressive Stress vs. Axial Strain (10% cement content)

Sample designation: **M1**

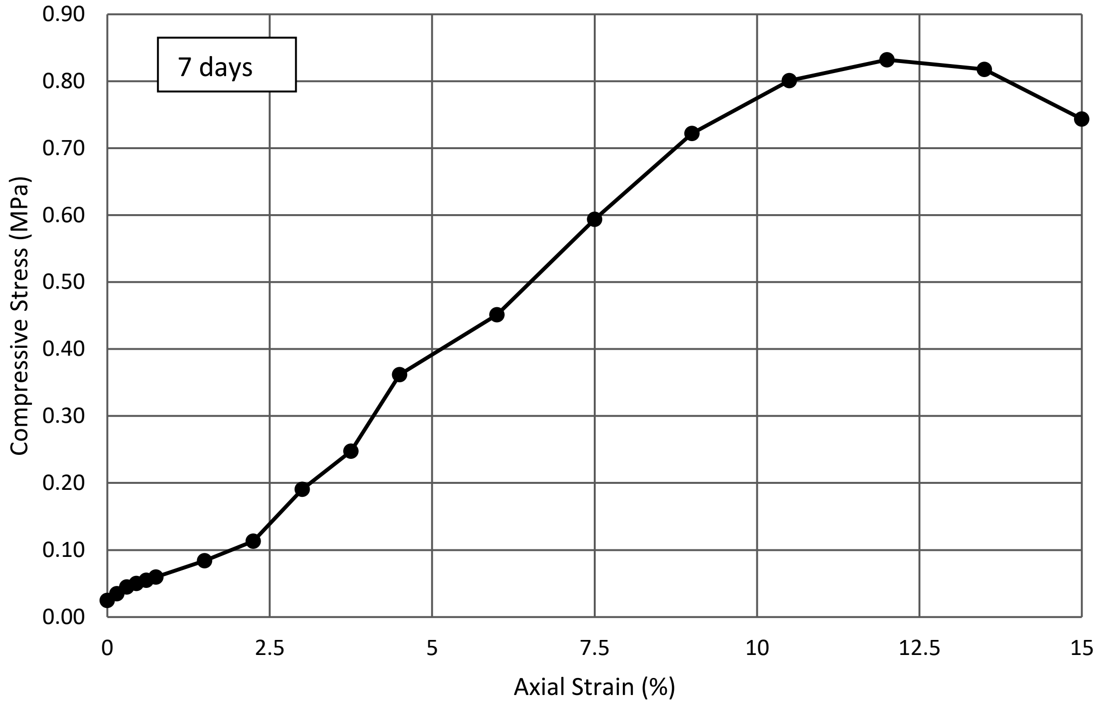

Fig. A.12: Compressive Stress vs. Axial Strain (20% fly ash, 7 days)

Sample designation: **M2**

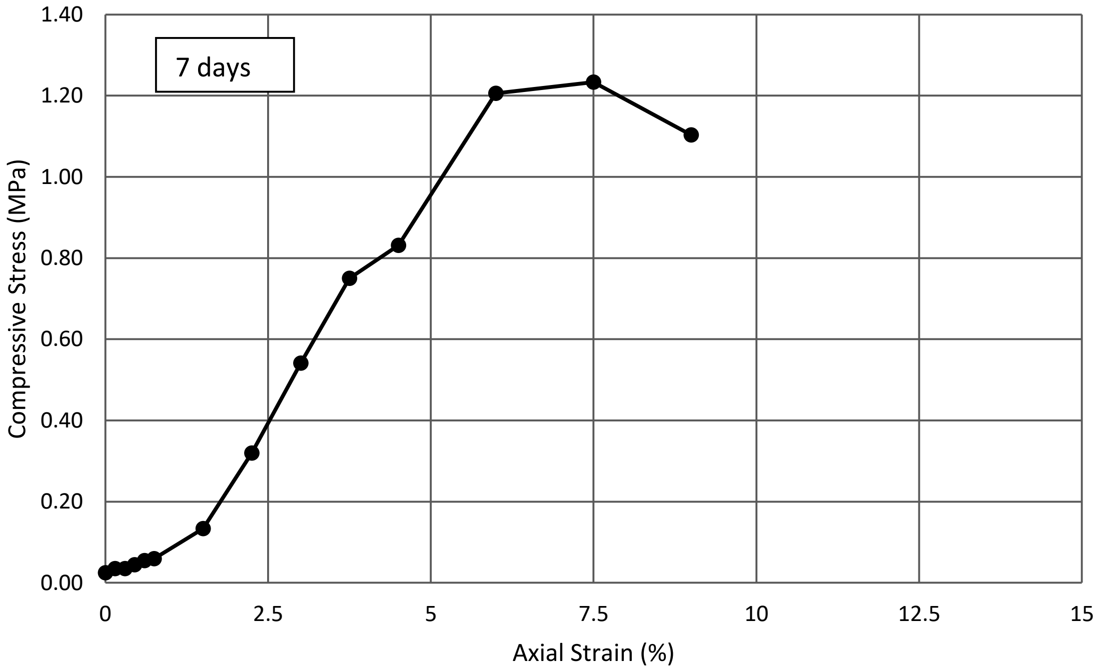

Fig. A.13: Compressive Stress vs. Axial Strain (15% fly ash, 7 days)

Sample designation: **M3**

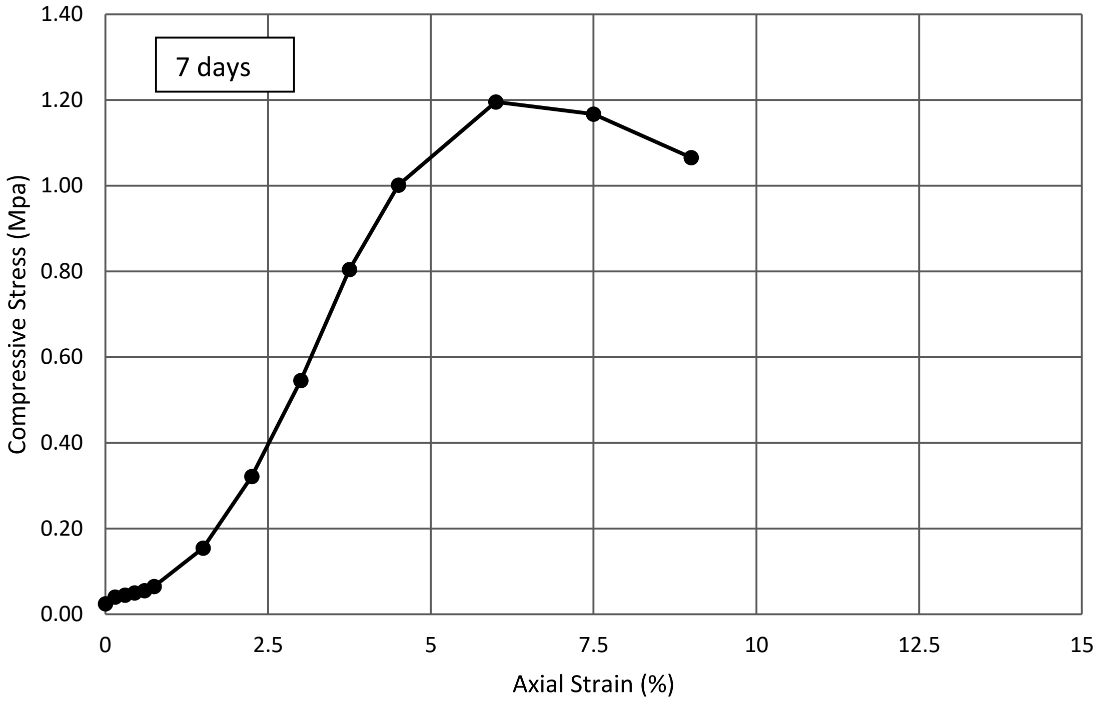

Fig. A.14: Compressive Stress vs. Axial Strain (10% fly ash, 7 days)

Sample designation: **M4**

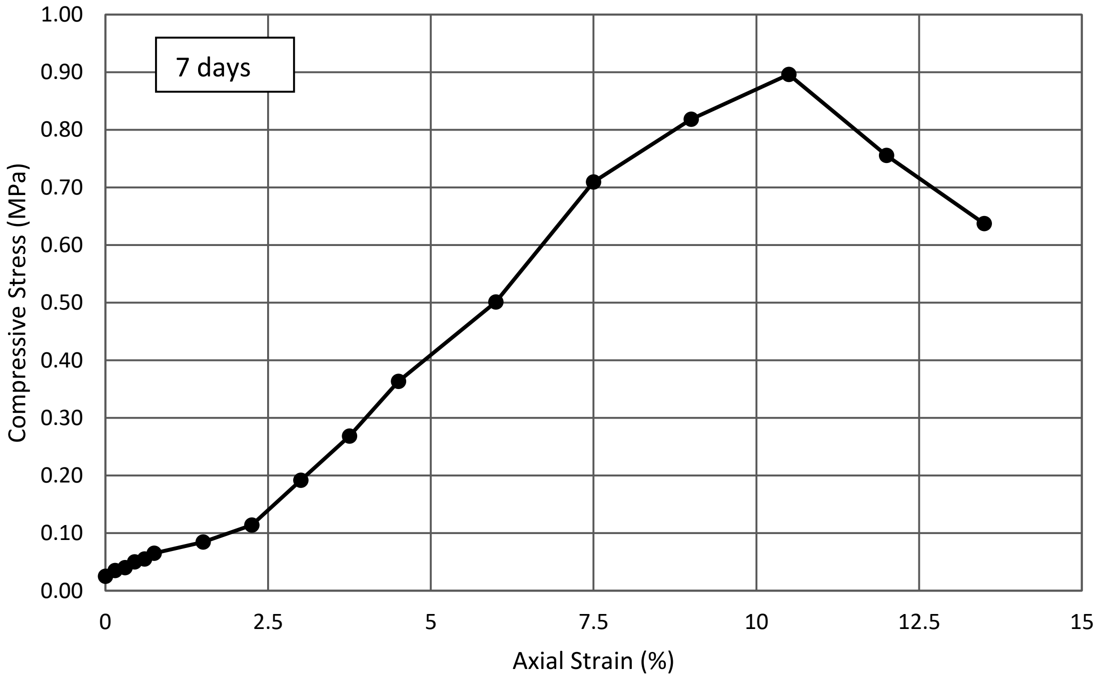

Fig. A.15: Compressive Stress vs. Axial Strain (5% fly ash, 7 days)

Sample designation: **M5**

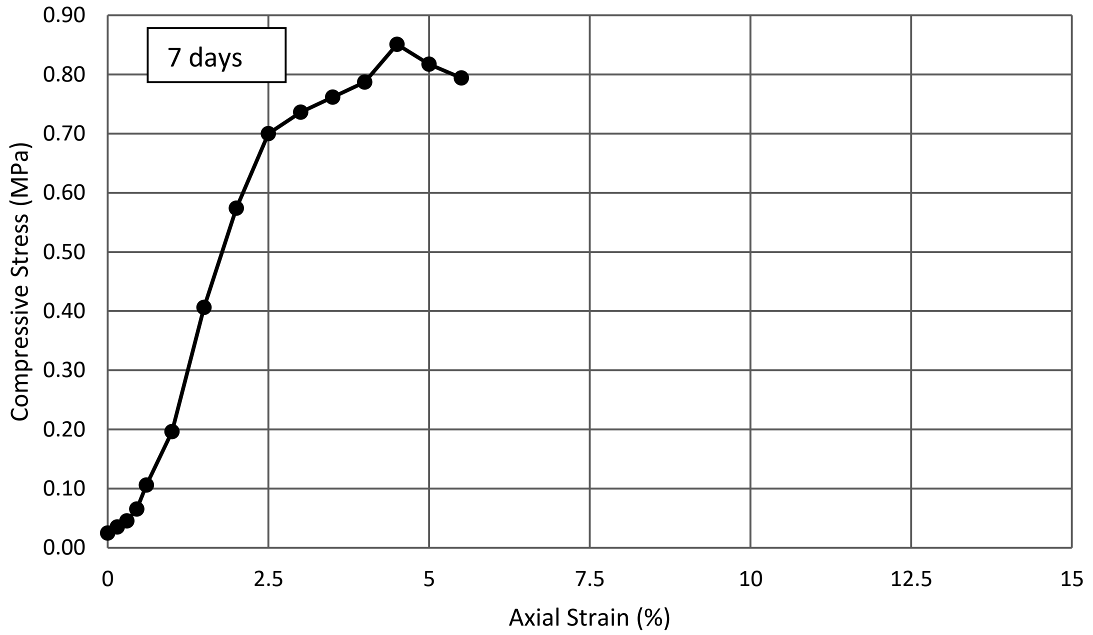

Fig. A.16: Compressive Stress vs. Axial Strain (0% fly ash, 7 days)

Sample designation: **M1**

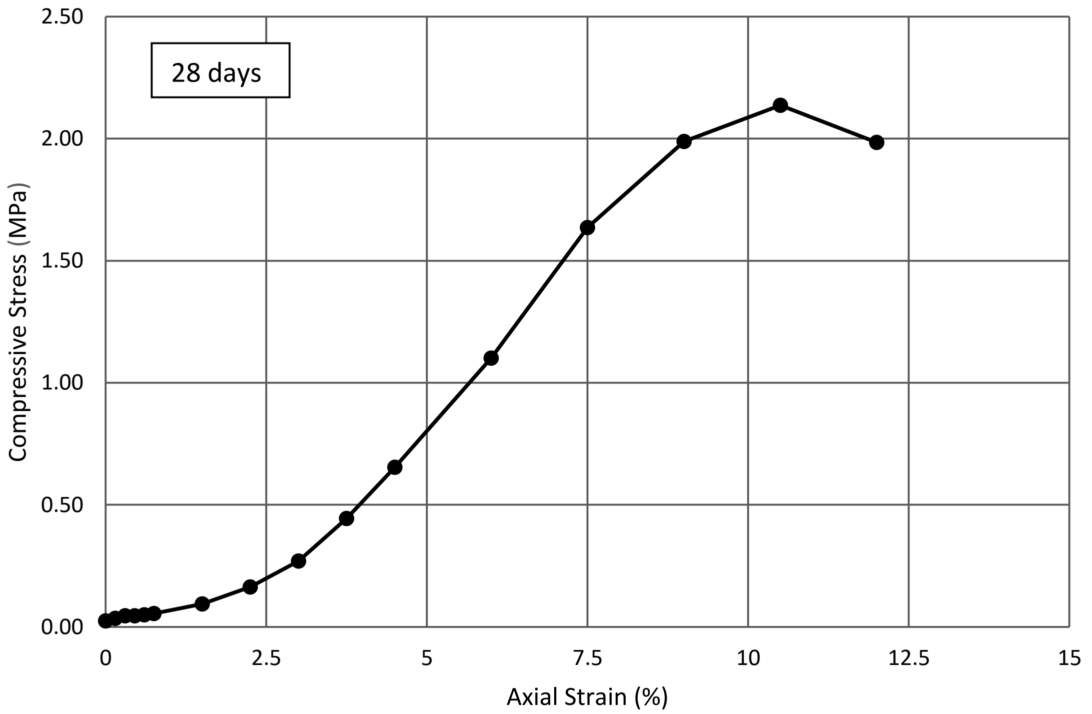

Fig. A.17: Compressive Stress vs. Axial Strain (20% fly ash, 28 days)

Sample designation: **M2**

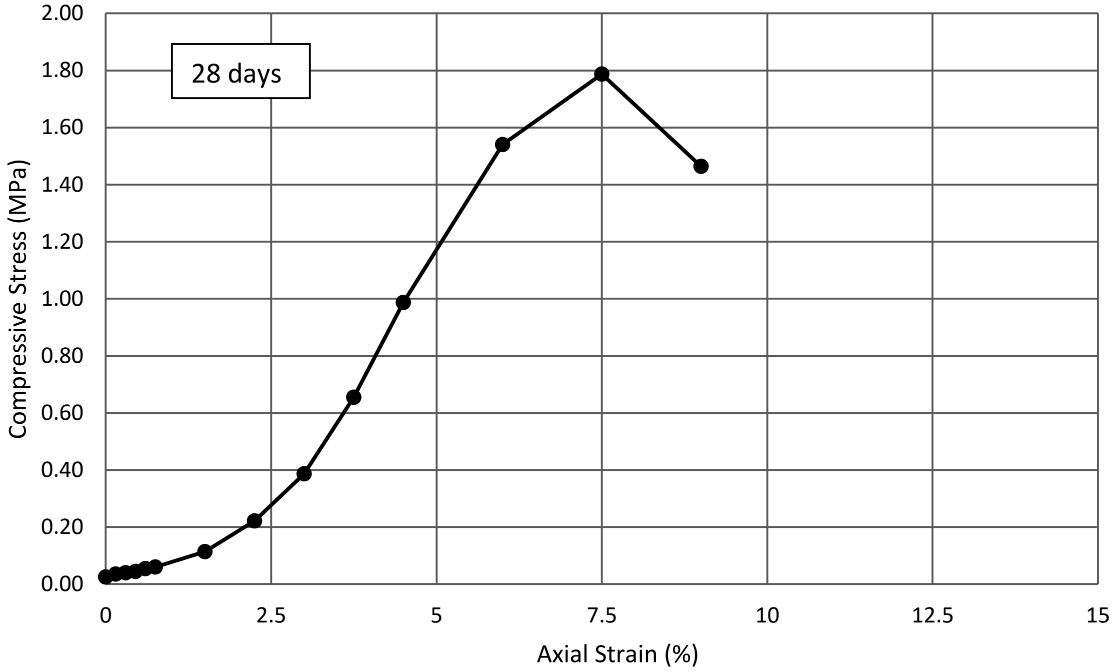

Fig. A.18: Compressive Stress vs. Axial Strain (15% fly ash, 28 days)

Sample designation: **M3**

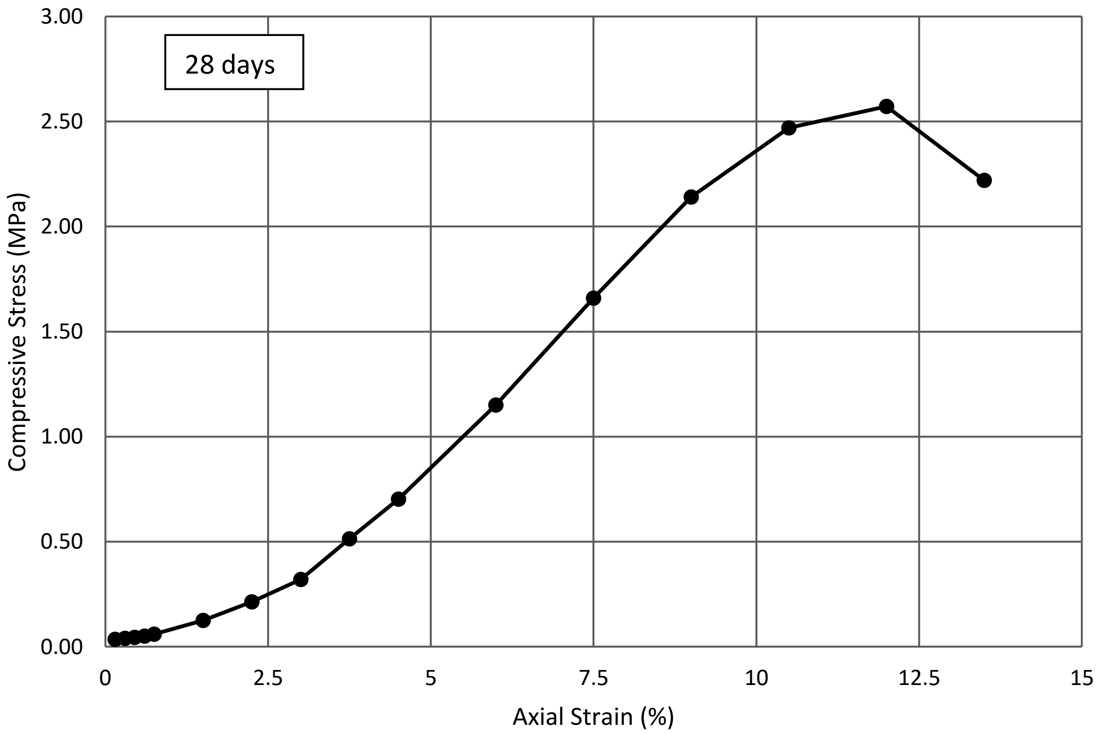

Fig. A.19: Compressive Stress vs. Axial Strain (10% fly ash, 28 days)

Sample designation: **M4**

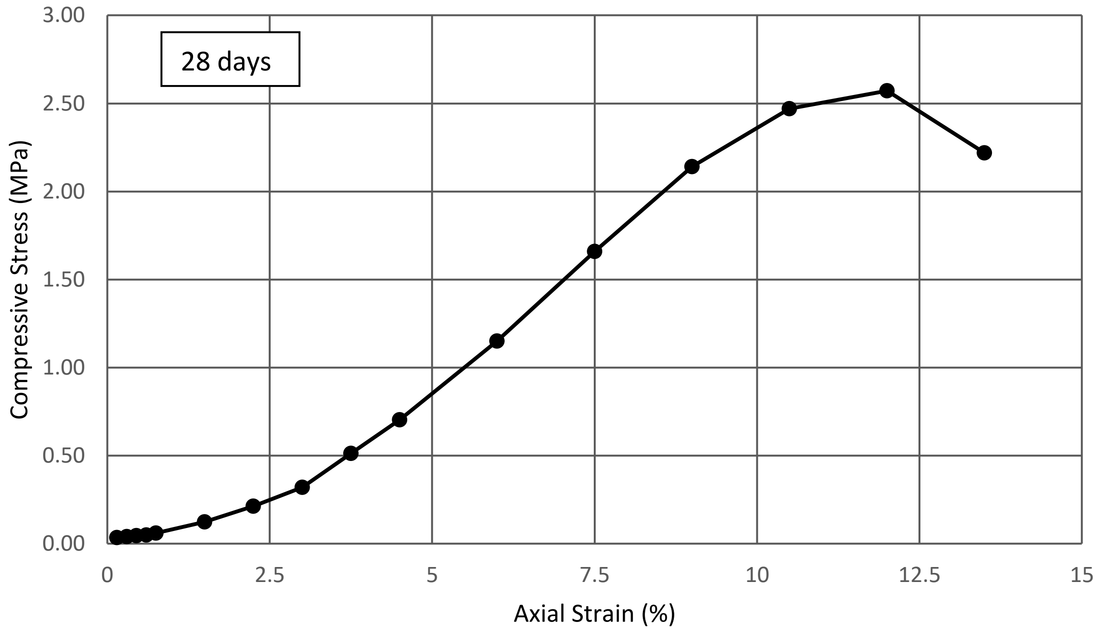

Fig. A.20: Compressive Stress vs. Axial Strain (5% fly ash, 28 days)

Sample designation: **M5**

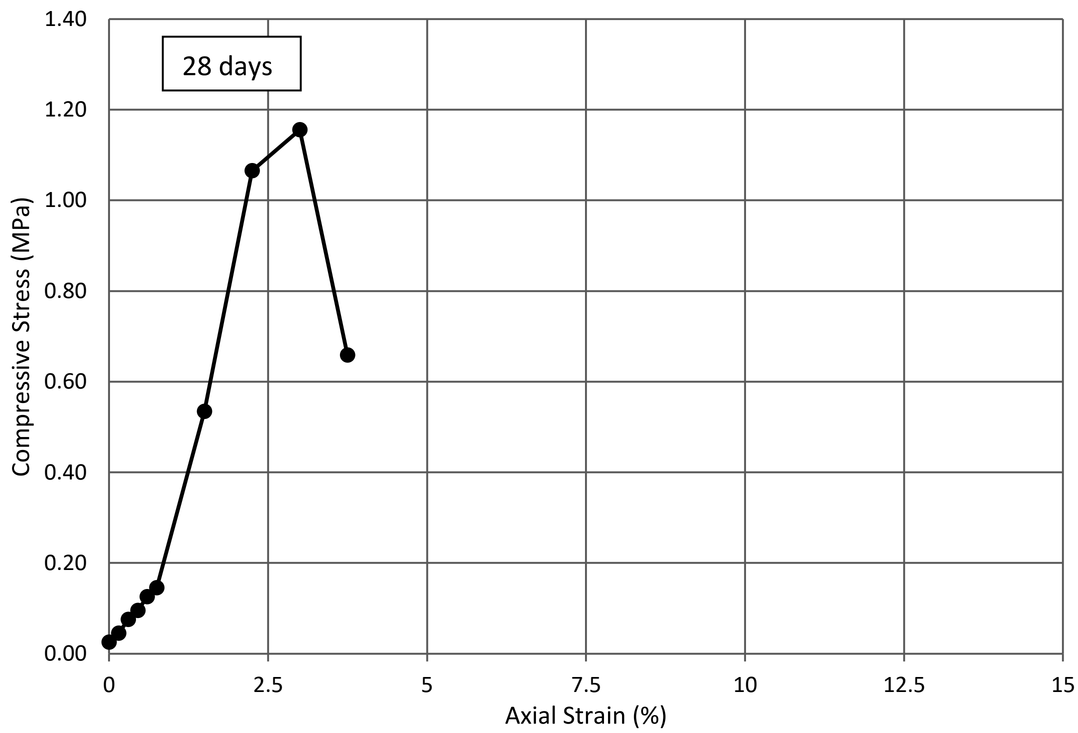

Fig. A.21: Compressive Stress vs. Axial Strain (0% fly ash, 28 days)

Sample designation: **M1**

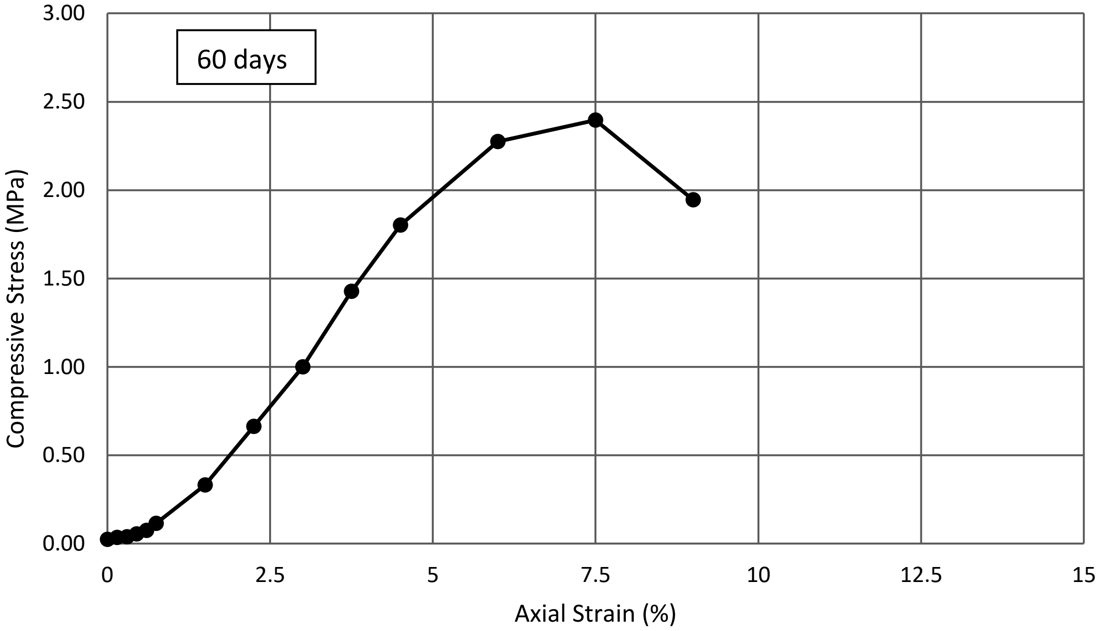

Fig. A.22: Compressive Stress vs. Axial Strain (20% fly ash, 60 days)

Sample designation: **M2**

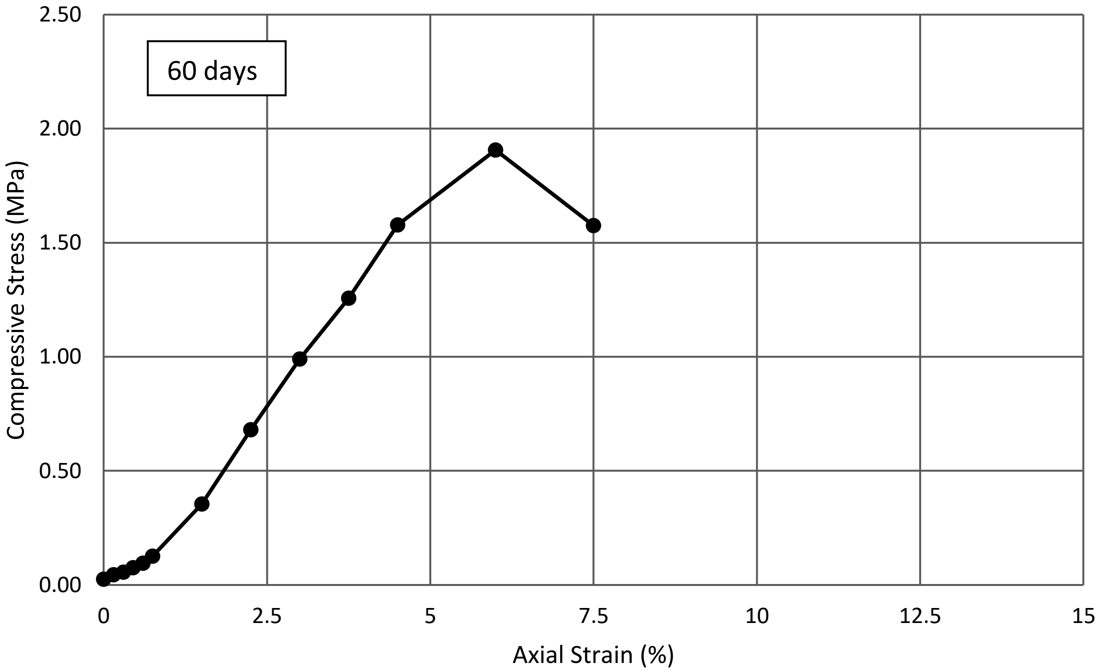

Fig. A.23: Compressive Stress vs. Axial Strain (15% fly ash, 60 days)

Sample designation: **M3**

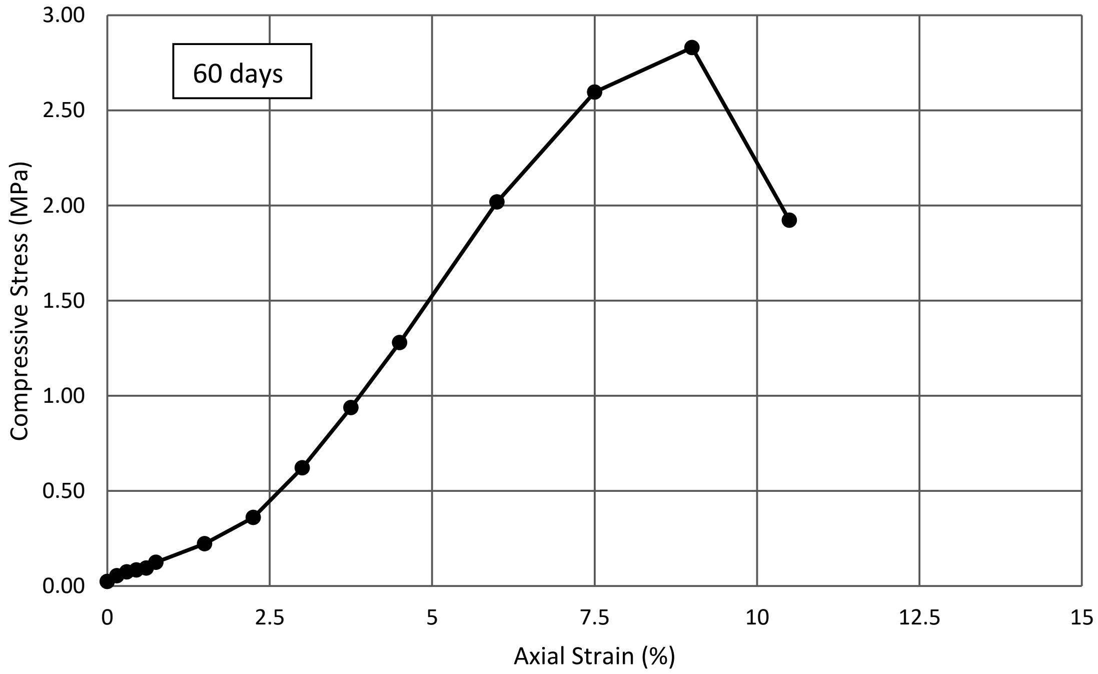

Fig. A.24: Compressive Stress vs. Axial Strain (10% fly ash, 60 days)

Sample designation: **M4**

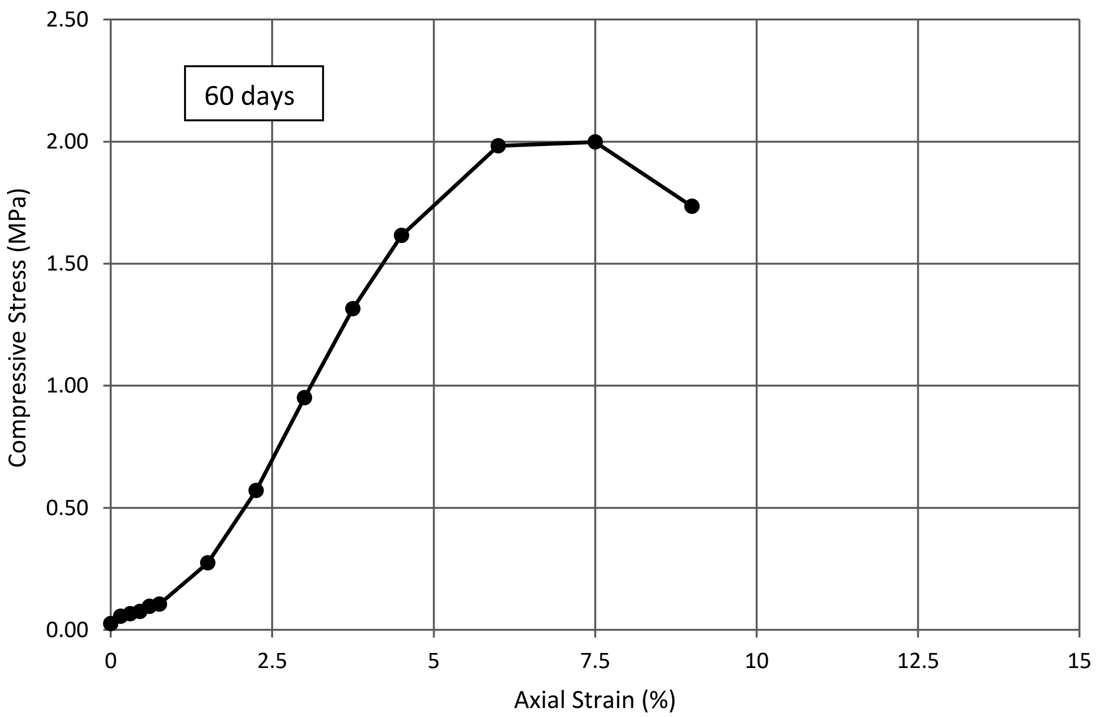

Fig. A.25: Compressive Stress vs. Axial Strain (5% fly ash, 60 days)

Sample designation: **M5**

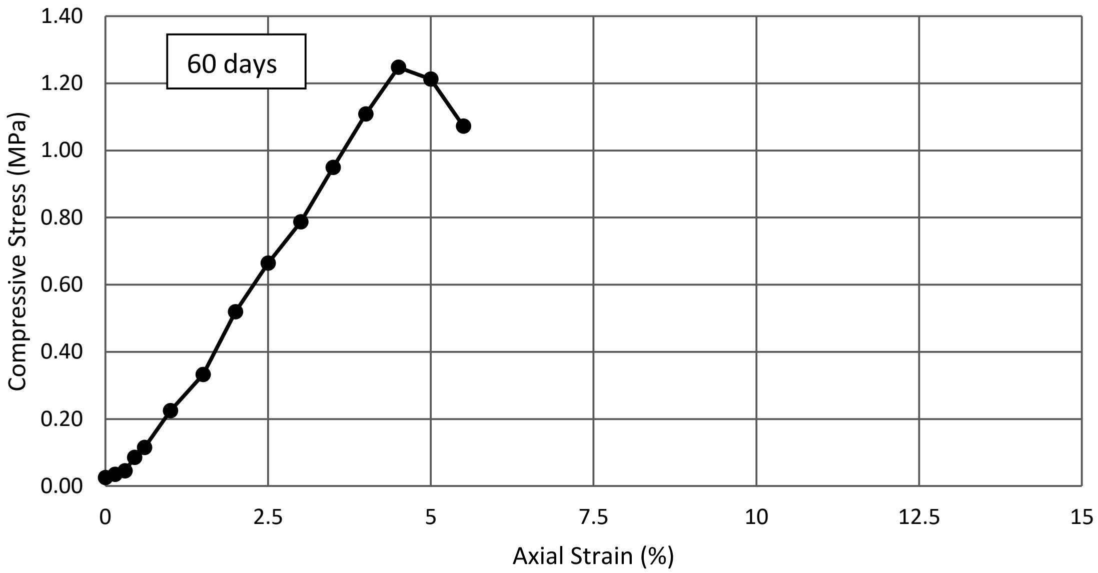

Fig. A.26: Compressive Stress vs. Axial Strain (0% fly ash, 60 days)

Absorption capacity

Table A.5: Variation of absorption capacity with mixing water content

Water Percentage	Sample Designation	Wt. of dry block (gm)	Wt. of block after soaking (gm)	Wt. of absorbed water (gm)	Absorption (%)
10%	M310	210.6	256.3	45.7	21.70
15%	M315	208.1	243.5	35.4	17.01
20%	M320	216.2	248.8	32.6	15.08
25%	M325	225.0	260.1	35.1	15.60

Table A.6: Variation of absorption capacity with pressing (no. of blows per layer)

No. of Blows per Layer	Sample Designation	Wt. of dry block (gm)	Wt. of block after soaking (gm)	Wt. of absorbed water (gm)	Absorption (%)
16	M316	209.9	240.8	30.9	14.72
32	M332	221.8	252.9	31.1	12.30
50	M350	228.4	259.7	31.3	12.05

Table A.7: Variation of absorption capacity with cement content

Cement Percentage	Sample Designation	Wt. of dry block (gm)	Wt. of block after soaking (gm)	Wt. of water absorbed (gm)	Absorption (%)
5%	M35	211	245.3	34.3	16.26
7%	M37	213.9	251.3	37.4	17.48
10%	M310	216.2	248.8	32.6	15.08

Table A.8: Variation of absorption capacity with fly ash content

Fly Ash Percentage	Sample Designation	Wt. of dry block (gm)	Wt. of block after soaking (gm)	Wt. of water absorbed (gm)	Absorption (%)
20%	M1	221.8	256.6	34.8	15.69
15%	M2	219.5	253.2	33.7	15.35
10%	M3	216.2	248.8	32.6	15.08
5%	M4	223.0	256.5	33.5	15.02
0%	M5	213.9	245.9	32	14.96