STRENGTH CHARACTERISTICS OF COMPRESSED STABILIZED EARTH BLOCK MADE WITH SELECTED REGIONAL SOIL

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ABSTRACT

Earth as a construction material has been used for thousands of years by civilizations all over the world. Due to low cost and relative abundance of materials, building with Compressed Stabilized Earth Block (CSEB) is becoming popular now-a-days mainly in less flood-prone areas. Strength-deformation characteristics of CSEB is the main focus of this research. Soil samples were collected from Savar (red clay) and 7 different places of Shariatpur (floodplain) district in Bangladesh. For making CSEB, sand, cement, jute and lime were used as stabilizer with the selected soil. This research work evaluates the effects of sand, cement, jute, and lime on the compressive strength and deformation characteristics of CSEB. In this research work, a total of 57 groups CSEB was prepared. Extensive experimental investigation has been carried out to evaluate the effects of different grain size of sand (coarse sand, fine sand and mixes of fine and coarse sand) with the addition of cement in a certain proportion on the compressive strength of Cement Sand Stabilized Block (CSSB). For making CSSB, 3-9% cement was used with 20-60% coarse sand and in some cases 30-60% mixed sand (mixes of coarse sand and fine sand) by weight. In addition to that, one group of compressed earth block was prepared without any stabilizer so that improvements due to stabilization can be studied as compared to the performance of non-stabilized blocks. A series of blocks having dimension of 240 mm × 115 mm × 90 mm were molded using "Auram Earth Block Press 3000". After manufacturing, the blocks were cured for 28 days at natural weather condition. Unit weight, moisture content, compressive strength and water absorption capacity test of the CSEBs were conducted after proper curing. The compressive strength (average strength of five blocks) 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. Moisture content and unit weight of CSEBs were varied from 0.2 to 19% and 1.2 to 2.1 gm/cm^3, respectively. However, the results obtained from this study may be useful in reducing the consumption of fired brick used as non-load bearing building block in construction sector of Bangladesh.

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ACRONYMS

FCB	Fired Clay Brick
CEB	Compressed Earth Block
CSEB	Compressed Stabilized Earth Block
USB	Unstabilized Block
CSSB	Cement Sand Stabilized Block
LSB	Lime Stabilized Block
LJSB	Lime Jute Stabilized Block
CS	Coarse Sand
FS	Fine Sand
MS	Mixed Sand (Fine Sand + Coarse Sand)
AC23	3% Cement + 20% CS
AC43	3% Cement + 40% CS
AC63	3% Cement + 60% CS
AC25	5% Cement + 20% CS
AC35	5% Cement + 30% CS
AC45	5% Cement + 40% CS
AC55	5% Cement + 50% CS
AC65	5% Cement + 60% CS
AM35	5% Cement + 15% CS +15% FS
AF55	5% Cement + 50% FS
AM45	5% Cement + 20% CS +20% FS
AM45C+	5% Cement + 26.67% CS + 13.33% FS
AM45F+	5% Cement + 13.33% CS + 26.67% FS
AM55	5% Cement + 25% CS + 25% FS
AM55C+	5% Cement + 33.33% CS + 16.67% FS
AM55F+	5% Cement + 16.67% CS + 33.33% FS
AM55F+2	5% Cement + 30% CS + 20% FS
AM65	5% Cement + 30% CS + 30% FS
AM65C+	5% Cement + 40% CS + 20% FS
AM65F+	5% Cement + 20% CS + 40% FS
AF65	5% Cement + 60% FS

AC26	6% Cement + 20% CS
AC36	6% Cement + 30% CS
AC46	6% Cement + 40% CS
AC56	6% Cement + 50% CS
AC66	6% Cement + 60% CS
AM36	6% Cement + 15% CS + 15% FS
AM36C+	6% Cement + 20% CS + 10% FS
AM36F+	6% Cement + 10% CS + 20% FS
AM46	6% Cement + 20% CS + 20% FS
AM46C+	6% Cement + 26.67% CS + 13.33% FS
AM56	6% Cement + 25% CS + 25% FS
AM56F+	6% Cement + 16.67% CS + 33.33% FS
AC47	7% Cement + 40% CS
AC57	7% Cement + 50% CS
AC67	7% Cement + 60% CS
AM37	7% Cement + 15% CS + 15% FS
AC28	8% Cement + 20% CS
AC38	8% Cement + 30% CS
AC48	8% Cement + 40% CS
AC58	8% Cement + 50% CS
AC68	8% Cement + 60% CS
AM48	8% Cement + 20% CS + 20% FS
AM68F+	8% Cement + 20% CS + 40% FS
AC29	9% Cement + 20% CS
AC49	9% Cement + 40% CS
AC69	9% Cement + 60% CS

Chapter 1
INTRODUCTION

1.1 General

Since ancient time soil is being used as a building material and one of the major reasons behind it is its availability. It was one of the oldest and most traditional building materials used by human beings dating back over at least 10, 000 years (Islam, 2010). From the civilization of Mesopotamia dated 6000 years back the use of earth as a building material is very evident (Deboucha and Hashim, 2011). Still today 50% of the population in developing countries, including the majority of the rural population and at least 20% of the urban and suburban population, live in earthen dwellings (Houben and Guillaud, 2005). The earthen house construction has drawn the attention of developed countries in the past 40 to 50 years (Islam, 2010).

In developing countries, the provision of housing is one of the most important basic needs of the low income community. It is very difficult to meet their requirements since the land and construction cost for housing is mostly beyond their ability. In order to address this problem, the governments in the developing countries take initiatives for housing scheme to facilitate some forms of housing ownership by low-income groups. These ideas afford for the self-housing scheme at low cost and easy construction. Due to limited resources within the developing countries, it is necessary to seek ways to reduce construction costs especially for a low income group as well as adopting an easy and effective solution for their repair and maintenance. Such objectives can be achieved partially through the production and use of cheap, durable and locally available building materials. Ideally, it may contribute to the improvement of development objectives of developing countries by generating local employment and rural development.

Being a densely populated country, in Bangladesh abundant use of Fired Clay Brick (FCB) is observed both in the urban, semi-urban and rural areas also. This culture leads to deforestation and generation of a huge 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 to fired brick and can save both money and environment. That is why, consciousness is growing day by day on this indigenous earth material.

There are some drawbacks of earth construction. The earth construction suffers from shrinkage cracking, erosion due to wind or driving rain and poor dimensional stability which necessitates the need for continuous maintenance (Islam and Haque, 2009; Islam and Iwashtia, 2010; Bahar et al., 2004; Guttela et al., 2006). Another drawback using earth alone as a building material is its durability which is strongly related to its compressive strength (Venkatarama Reddy and Kumar, 2009; Morel et al., 2001; Guettala et al., 2006; Heathcote, 1995). Because most soil in their natural condition lacks structure, strength and durability required for building construction. These inherent deficiencies may be overcome through a process of stabilization by mechanical compaction with addition to the soil matrix of natural fibers (Islam et al., 2016; Gowda, 2016; Islam and Rahman, 2010; Islam and Iwashtia, 2010; Islam, 2002; Bouhicha et al., 2005) and chemical binders, such as cement or lime, or waterproofing agents, such as bitumen (Walker, 1995). So, all the aspects should be considered to produce sustainable, durable, safe and environment friendly building materials.

Considerable research has been undertaken 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 to be a reliable walling unit against the more extensive fired bricks and concrete blocks (Deboucha and Hashim, 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 wet compressive strength of masonry blocks (Nagaraj et al., 2014). The compressive strength of the blocks has become a basic and universally acceptable unit of measurement to specify the quality of the masonry units, as this is an indirect measure of the durability of the blocks (Walker, 2004; Morel et al., 2007). The compressed stabilized earth blocks are made out of the soil with extraneous binding materials such as jute fiber, rice husk, banana fiber, cement, lime, bitumen, rice husk ash etc. (Gowda, 2016; Danso, 2016; Mostafa and Uddin, 2016; Ismail and Yaacob, 2011; Chan, 2011; Islam and Rahman, 2010; Islam, 2002; Guettala et al., 2002).

In this research, attempts have been made particularly to determine the strength characteristics of earthen blocks stabilized with jute fiber, cement and lime. In some cases, deformation characteristics of the blocks were also determined. Special attempts have been made to determine the strength characteristics of Cement Sand Stabilized Earth Block (CSSB) added with different graded sand.

1.2 Background of the Research Work

The oldest structure with adobes and sun dried blocks were built in Egypt in 1300 BC, the vault of Ramasseum. Human has been building structures with earth for more than 10,000 years ago which becomes evident obtained from the building remnants of the Harappa, Mohenjo-Daro and Jericho (Jagadish, 2007). Since the early 1950's considerable attention has been focused on the importance to low cost housing for low income population by researching building materials and techniques that are locally available and abundant resources (Rigassi, 1985). In this sequence, the succession of adobe brick is Compressed Earth Block (CEB). The turning point for use of compressed earth block came after the invention of Cinva-Ram Pressing machine after 1952 in Columbia. This commenced the production and application of compressed earth block throughout the world (Rigassi, 1985) and led to initiate many research works to understand the parameters of the soil and stabilization technique. With this sequence, the Auram Earth Block Press Machine was introduced to produce better compressed earth blocks.

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 greenhouse gasses (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 building materials. Earth is perhaps the most accessible and economical natural material used for building blocks (Chan, 2011). Soil blocks are attractive materials because they are inexpensive to produce (Ismail and Yaacob, 2011). The block made out soil for building materials has existed many countries for a very long time. Earth has the advantages of being recycled and hence soil blocks can be easily turned into the earth without pollution to the environment and can be reused (Rigassi, 1985). Furthermore, the energy required for producing soil blocks 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, 2000).

Fired Clay Brick (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 the 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, 2000). Therefore, CSEB has a great potential as a building material.

In this research work, Compressed Stabilized Earth Block (CSEB) was produced with jute fiber, lime, jute-lime and cement-sand. Different percentages of cement and sand was added to reinforce Cement Sand Stabilized Block (CSSB). For making CSSB specimens, fine sand and coarse sand was added at different proportions with varied percentages of cement.

In order to accomplish the targets this research work includes following objectives:

(a) To determine the characteristics of collected regional soils.
(b) To obtain the effect of different stabilizers at varied proportions on the strength and deformation characteristics of CSEB.
(c) To compare the characteristics of different stabilized CSEB to select the suitable additive.

1.3 Methodology

The research work was conducted in the following ways:

(a) Three soil samples were used for this study. Two soil samples were collected from Shariatpur and another one from Savar. Laboratory tests such as specific gravity, grain size analysis, Atterberg limit tests were conducted to determine the characteristics of the collected soil samples. Cement, sand (coarse and fine sand), jute fiber and lime were used with the selected soil to stabilize the earthen blocks.

(b) Compressive strength test was conducted on the CSEB specimens to know the effect of jute fiber, lime and cement-sand on compressive strength and failure strain.

(c) Crushing strength test was also performed to know the compressive strength of CSSB specimens.

(d) Water absorption capacity test on some typical CSSB specimens was also conducted to know the water absorption capacity. At a time, crushing strength of these wet CSSB specimens were determined and compared with those of dry CSSB specimens.

1.4 Thesis Layout

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

Chapter One is an introduction that includes the problem statement, background and objective of this study along with the thesis organization.

Chapter Two presents the literature review which includes history, techniques of earth construction, stabilization techniques of earth blocks and performance of soil as a building material. This chapter also discusses the earthen construction scenario in the world and earthen house practice in Bangladesh. Here, the aspects of CSEB in Bangladesh considering the required energy value, pollution emission and cost for the production of CSEB are briefly discussed. The advantages and disadvantages of CSEB are also narrated in this chapter. Finally, the possible solutions against the disadvantages of CSEB are discussed.

In Chapter Three, selection of study areas for the research has been discussed. Also, the selection of stabilizing material with their mechanical properties are narrated. The total compositions of CSEB specimens at different combinations are shown here. Research methodology and experimental programs are also discussed here sequentially.

Chapter Four presents the soil index properties of the collected soil samples. The results from the compressive strength test and crushing strength test of CSEB specimens are presented in this chapter. The results of the test parameters are discussed with the help of relevant figures, graphs and charts.

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

Chapter 2
LITERATURE REVIEW

2.1 General

Earth construction practice is widespread in different cultures and in different country, both in industrialized and developing countries (Achenza and Fenu, 2006). Based on the environmental conditions and traditions people used different materials for habitats but the most prominently used building material is soil (Sharma et al., 2015). It is evident that the start of civilization and the soil masonry is on the same page in the history (Deboucha and Hashim, 2010).

This chapter presents a summary of research relevant to Compressed Stabilized Earth Block (CSEB) to provide a satisfactory background of subsequent discussions. As the research work aims to focus on the strength characteristics of CSEB, a brief summary of existing research on relevant topic herein has been presented. In this chapter, an attempt has been taken to present a selective overall summary of research into the characteristics of CSEB and potential of CSEB as a building material.

Burroughs (2008) stated that although earth has been used in many developing and developed countries, the modern construction technology and material science has declined its popularity to a great extent. Indeed, the introduction of building materials such as cement, lime, steel and others have caused the low interest in the soil as building materials. This has led to not only the increased cost of housing but also the environmental impact due to its manufacturing process and high energy consumption worldwide. Considering the above facts, in this chapter of the factors affecting the improvement and performance of CSEB and the probable solutions to reduce the problems of CSEB are discussed.

2.2 Techniques for Earth Construction

Earth-based construction and building have existed for thousands of years and are still practiced today. The 12 main construction technique using soil as a building material has been shown in Fig. 2.1. Among the most extensively and popularly used techniques are cob, adobe, wattle and daube method, rammed earth and compressed earth. The above mentioned techniques are described here in a nutshell.

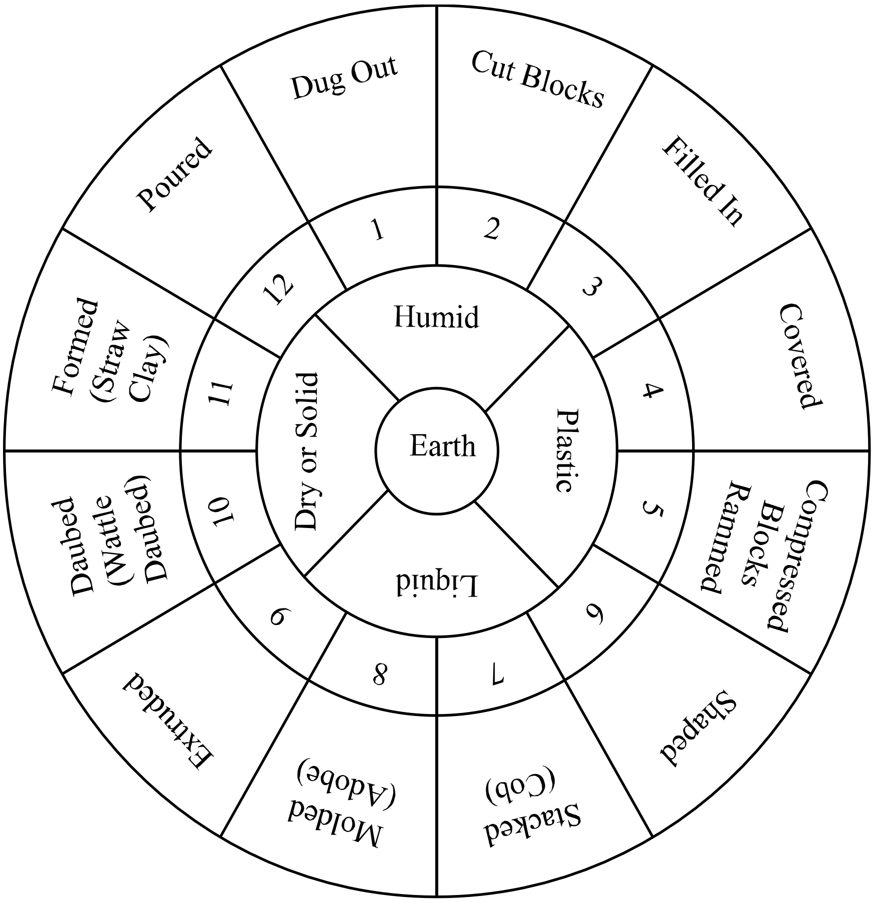


Figure 2.1: The 12 principal earth construction technique (Auroville Earth Institute, 2018)

2.2.1 Cob

Cob is one of the ancient earth construction techniques. The oldest cob house still standing is 10,000 years old. Cob is a mixture of sandy-sub soil, clay and fibrous organic material (typically straw). It is mixed by crushing the particles together by either dancing 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 might have been mixed by farm animals who would 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.

Figure 2.2: Photograph of cob structure (Kim-Carberry, 2011)

2.2.2 Adobe

Adobe is the mixture of soil and natural fibers to which water is added to until it attains plastic condition. Then it is molded into bricks and allowed to dry in climatic weather condition (Illampas et al., 2014).

Figure 2.3: Typical adobe blocks (Varga, 2009)

2.2.3 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 clayey earth is used which is mixed with a straw or other vegetable fibers to prevent shrinkage cracks upon drying (Houben and Guillaud, 1994).

Figure 2.4: Photograph of wattle and daub (Dreamstime.com, 2010)

2.2.4 Rammed earth

For rammed earth wall, the humid soil is poured into the formwork in layers and rammed manually or by pneumatic rammers to increase soil density. In modern times, rebars are also used in the techniques. The thickness of the wall is usually between 300 and 600 mm. It is one of the earth construction techniques that creates dynamically compacting soil between temporary forms to make a monolithic wall (Hall and Djerbib, 2004).

Figure 2.5: Photograph of rammed earth wall (Gowda, 2016)

2.2.5 Compressed earth block

Compressed Earth Block (CEB) is a construction technique in which earth block is made by mechanically pressing soil particles into a mold. The CEBs are made in small sizes (blocks) and installed onto the wall by hand with mortar, which is spread very thinly between the blocks for bonding. The reason for compacting soil in a mold is to improve the engineering properties of the material (Rigassi, 1985).

Figure 2.6: Typical compressed earth blocks (Tadege, 2007)

2.3 Stabilization of Soil

Stabilization of soil is the method of adding some materials to the natural soil in order to increase its strength and other properties for the purpose of constructing houses. It is done to improve the properties of a soil in the face of many constraints (Rigassi, 1985). The objectives of stabilization according to Rigassi (1985) are:

(a) To acquire an improved mechanical capability, thus increase the compressive and tensile strength of the soil

(b) To reduce the volume of voids created in the soil, thus reduce the shrinkage cracks that would develop when the soil is mixed with water

(c) To improve the durability properties of the soil, thus increase the performance of the soil against rain and any wearing condition

2.3.1 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:

(a) Stabilization by reinforcement
(b) Stabilization by water-proofing
(c) Stabilization by cementing and
(d) Stabilization by treatment with chemicals

Again, according to Rigassi (1985), there are six categories of stabilizing soil for construction purposes as described in Table 2.1.

Table 2.1: Soil stabilization techniques (after Rigassi, 1985)

Technique	Explanation of technique
Increasing density	This is done by creating a dense environment reducing blocks pores and capillary channels under application of force (compression).
Cementation	In this technique, 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 origin (agricultural waste), animal origin (wool or hair) and synthetic origin (polythene) are used with a view to increasing the properties of soil.
Bonding	It involves the use of chemicals such as acids, flocculants, lime, polymers, etc. to stabilize the soil.
Water-proofing	This technique adds materials that expand and seal off access to pores such as bitumen and bentonite to 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.

Not every soil is suitable for earth construction. So some stabilizers must be used to making earth block. Then the stabilized earth blocks may be used for building a sustainable house. According to the original soil quality, adding materials like gravel or sand can do some easy improvement. Mixing soil can also be a way for better improvement. According to the technique, the improvement of soils will vary. Often sand has to be added to the soil if CSEB's have to be stabilized with cement. Auroville Earth Institute has recommended some general guidelines and not as rules for soil stabilization to make CSEB as shown in Table 2.2 to 2.5. The selection of a stabilizer will depend upon the soil quality and the project requirements. Cement will be preferable for sandy soils and to achieve quickly a higher strength. Lime will be rather used for very clayey soil but will take a longer time to harden and to give strong blocks (Auroville Earth Institute, 2018).

Table 2.2: Suitability of soils for making earthen block houses (after Corps, 1981)

Names of soil	Suitability for earth homes	Stabilizers	Comments
Very fine sands, silty fine sands, clayey fine sands, clayey silts	Usually suitable for all types, particularly adobe if stabilized	Portland cement most suitable. Asphalt emulsions also work as do most water proofers	May be affected by frost
Gravelly clay, sandy clay, silty clay	---	Lime, sand and gravel	Can be very good if the amount of sand or gravel is high
Clays, fat clays	Should never be used for earth houses	---	---
Organic silt, organic silty clay, organic clay	Should never be used for earth houses	---	---

Table 2.3: The 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 claye
Lime stabilized block	15	30	20	35	When the soil is more claye than sandy

Table 2.4: The average stabilizer proportion for CSEB according to Aurovile Earth Institute

<table>
<tr><th>Stabilizer</th><th>Minimum</th><th>Average</th><th>Maximum</th><th>Comments</th></tr>
<tr><td>Cement stabilization</td><td>3 %</td><td>5 %</td><td>No technical maximum</td><td rowspan="2">Low percentages of the stabilizers are considered to the view point of cost effectiveness</td></tr>
<tr><td>Lime stabilization</td><td>2 %</td><td>6 %</td><td>10%</td></tr>
</table>

Table 2.5: Suitable ranges of soil compositions for making CSEB (after Ahmed, 2010)

Compositions of soil	Range of compositions
Clay	15-40%
Silts	25-40%
Sands	40-70%
Gravel	0-40%

2.4 Compaction of Soil as a Building Material

One of the factors that affect the strength of earth blocks is the compaction. Compaction is the process of mechanically densifying a soil by pressing the soil particles together to come to a close state of contact so that the occupied air can be expelled out from the soil mass. Compaction is usually referred to as tamping. Traditional tamping used the wooden tamper to manually press the earth in a wooden mold to form the blocks. Currently, earth blocks are compacted with compressed earth block machines such as advance earth construction technologies (AECT) compressed earth block machines (AECT, 2009), CINVA-RAM press (Taylor, 2011). These presses are not expensive as they do not require high energy to operate and their maintenance is not complex (Al-Sakkaf, 2009). CINVA RAM press was the first machine developed to compact soil into a high density block in Colombia during 1952 (Venkatarama Reddy and Gupta, 2005). The Auroville Earth Institute, a leading player in earth architecture and earth construction developed the only Indian-made Earth Block Press (also known as "Mud Brick Press") and it’s widely acclaimed Auram 3000. The Auroville Earth Institute developed the original Auram 3000 Earth Block Press in 1990. It has proved ideal for builders utilizing earth architecture, earth construction and appropriate building technologies without compromising the highest standards of quality, strength and durability. Today, it ranks as one of the best earth block presses for CSEB manufacture in the world.

The concept of compacting earth is to improve the quality and performance of molded earth blocks (Houben and Guillaud, 1994). According to Venkatarama Reddy and Jagadish (1989), soils blocks are often compacted to improve their engineering characteristics, and this can be done in three following ways:

(a) Dynamic compaction
(b) Static compaction
(c) Vibratory compaction for soil blocks improvement

Compressed soil blocks are generally produced by compaction of soil in a hydraulic or electrical block making machine, in which static and control pressure is applied. Houben and Guillaud (1994) have made a characterization of molding pressure for earth blocks as shown in Table 2.6.

Table 2.6: Characterization of molding pressure for earth blocks (after Houben and Guillaud, 1994)

Characterization	Range of pressure (MPa)
Very Low	1-2
Low	2-4
Average	4-6
High	6-10
Hyper	10-20
Mega	20-40 +

2.5 Performance of Soil as a Building Material

The performance of earth as a building material can be determined by three main properties. These are:

(a) Physical properties
(b) Mechanical properties and
(c) Durability properties

The physical properties deal with the physics of the soil and hence undergo non-destructive testing. It is concerned with the determination of shrinkage, apparent bulk density, size or texture, moisture content, porosity, permeability, adhesion and linear contraction.

The mechanical properties of soil involve the mechanics of the soil under applied pressure that causes deformation to the soil. The tests applied are destructive to the soil. Bouhicha et al. (2005) expressed mechanical performance of soil blocks with compressive strength, flexural strength and shear strength.

The durability properties of soil are concerned with the long-term effect of the environment on the soil as a building material. The tests applied are aggressive in nature to predict the future weathering effect on the soil. Bui et al. (2009) characterized the durability with long-term erosion of earthen walls by exposing them in the weather for 20 years. Atzeni et al. (2008) investigated durability by using wear resistance of chemically or thermally stabilized earth based materials.

2.6 Earthen Construction Scenario in the World

The practice of using the 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. 2.7). From the roof of the world in Tibet, or the Andes Mountains in Peru, to the Niles shore in Egypt or the fertile valleys of China, many are the examples of the earth as a building material.

Figure 2.7: Earth construction areas of the world (Auroville Earth Institute, 2018)

The world's oldest earthen building still standing is about 3,300 years old. The Ramasseum, made of adobes, was built around 1,300 BC in the old city of Thebes. It can still be visited on the left shore of the Nile, opposite Luxor. In India, 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 earth builders have been progressively lost. Till the half of the latter 20th century, building with earth became marginal. We owe 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).

New development of earth construction really started in the nineteen fifties (1950's) with the technology of the Compressed Stabilized Earth Blocks (CSEBs). A research program done in Colombia in the 1950's for affordable houses proposed the first manual press: Cinvaram. Since then, there have been conducted many scientific researches by laboratories. Since 1960-1970, Africa has seen the widest world developments for CSEB. Today, Africa knows a further development step with semi industrialization and standards.

Stabilized rammed earth wall has been developed a lot in the USA. Developments happen especially a lot in the south-west (California, Colorado, New Mexico and Texas).

Today benefits can be got from a vast scientific and practical knowledge from the group CRATerre (ENSAG), the International Centre for Earth Construction, which is based in France and is the leading agency for the development of earthen architecture. It is a research laboratory on earthen architecture. Since 1979, CRAterre has worked towards the recognition of earth materials as a valid response to the challenges linked to the protection of the environment, the preservation of cultural diversity and the fight against poverty. In this perspective, CRAterre's three main objectives are centered on:

(a) Optimizing the use of local resources, human and natural
(b) Improving housing and living conditions
(c) Valorising and promoting cultural diversity

India experimented with CSEB technology only in the nineteen-eighties. In a decade, India sees some wider dissemination and development of CSEB. Auroville Earth Institute (AVEI), was founded by Government of India, in 1989. It has become one of the world's top centers for excellence in earthen architecture, working in 36 countries to promote and transfer knowledge in earth architecture. The work of the institute has attempted to revive link of raw earth construction with the modern technology of stabilized earth. A lot of developments are happening in Bangalore under the impulse of the Indian Institute of Science and Architects like Chitra Vishwanath. The achievements built at Auroville show how earthen buildings can create a light and progressive architecture.

(a)

(b)

(c)

Figure 2.8: Photographs of earthen structures around the world: (a) Vaults of the Ramasseum, built in 1300 BC in Egypt, (b) Visitors center, finished on 1992 in Auroville and (c) 10.35 m span segmental vault at Deepanam school, Auroville

2.7 Earthen House Practice in Bangladesh

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. Building materials irrespective of location, housing, in general, is classified by type of materials used for construction. In this way, houses are classified into four categories as described in Table 2.7.

Table 2.7: Dwellings by structural types in Bangladesh, 2001 (Source: Population census 2001, Volume 3, Urban Area Report (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	100.0	100.0	100.0

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 the 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 (Fig. 2.9) 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. The 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.

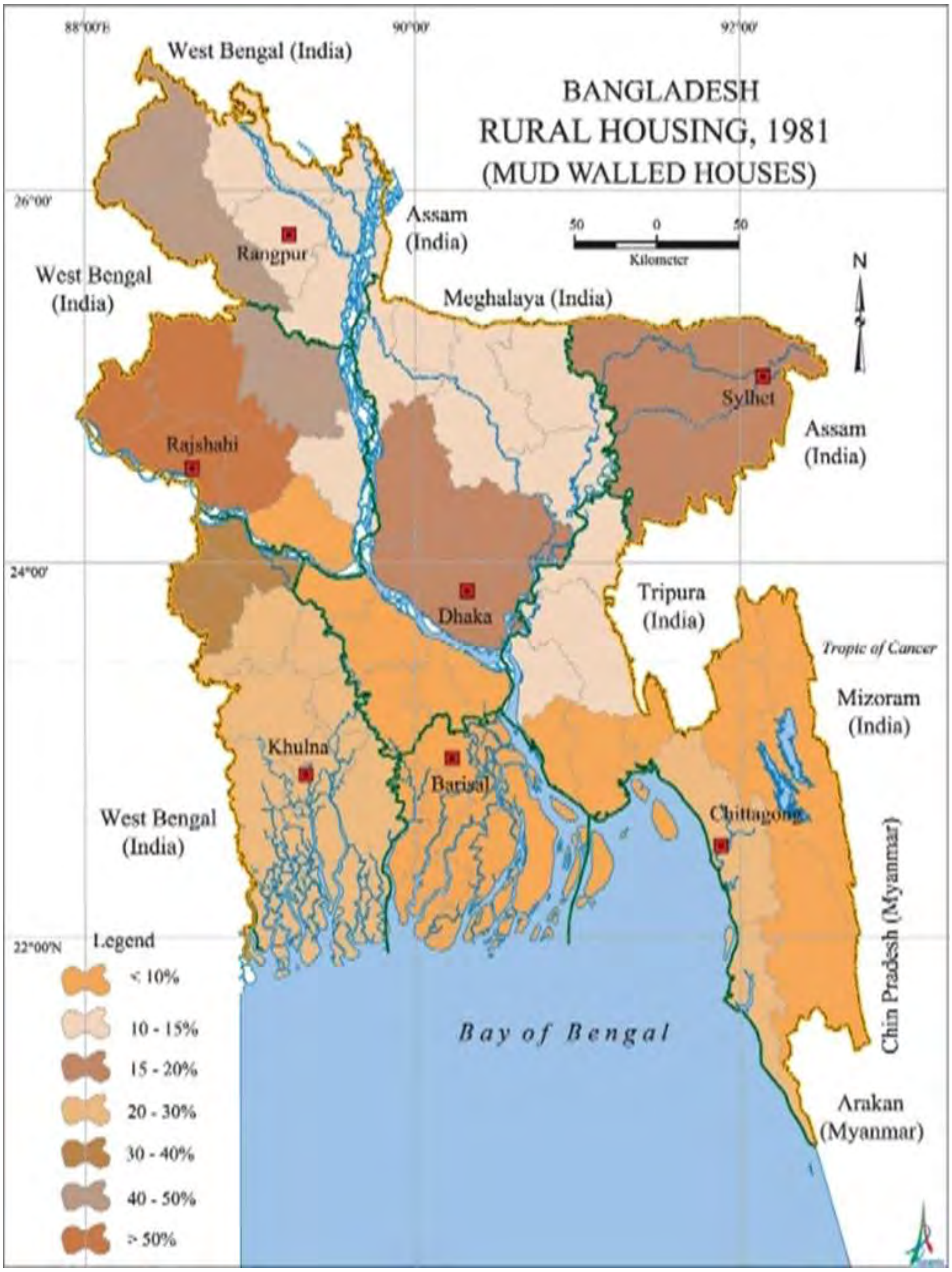


Figure 2.9: Map showing earthen house distribution of Bangladesh (Rural house, Banglapedia)

In Bangladesh, various building materials are used for construction. Mud, bamboo and CGI sheets are widely used in rural areas. But these houses are not disaster proof, and also the material are not environment friendly. In Fig. 2.10, a typical mud wall house, CI sheets house (CGI sheet) and bamboo thatch houses have been shown.

(a)

(b)

(c)

Figure 2.10: Photographs of typical earthen houses: (a) Mud house, (b) CI Sheet as a building material and (c) Bamboo thatch material

Architect Anna Heringer has recently completed the project “Hand-made school” with the help of Bangladeshi NGO “Dipshikha Society for Village Development”. It is situated in a remote rural village in the north of Bangladesh, Rudrapur under Netrokona district. To continue what has started with the Handmade METI (Modern Education and Training Institute) School: to work together with the local people on a model for a sustainable, modern architecture in a dynamic process. This is accomplished by using modern mud and bamboo building techniques.

Earth Blocks techniques are used in constructing house recently in Bangladesh. Habitat for Humanity in Bangladesh completes first house built with compressed earth blocks in Durgapur, Netrokona on 12^{th} November, 2010. Christian Commission for development in Bangladesh Human and Organizational Potential Enhancement Centre (CCDB HOPE CENTRE) (non-government organization) a newly built training complex at Baroipara, Savar, about 40 km away from Dhaka has been built in a semi-rural setting retaining the natural beauty and characteristics of the landscape dotted with mounds and depressions. The institute covering an area of 7.5 acres has been constructed using a cost-effective environment-friendly technology that avoids burnt bricks (compressed earth block). Compressed Stabilized Earth Blocks were used to build structures here.

(a) (b)

Figure 2.11: Photographs of earthen structures: (a) METI (Modern Education and Training Institute) and (b) CSEB house in Rudrapur, Netrokona, Bangladesh

Figure 2.12: Photograph of CSEB building in CCDB HOPE CENTRE premises, Savar, Bangladesh

2.8 Aspects of CSEB in Bangladesh

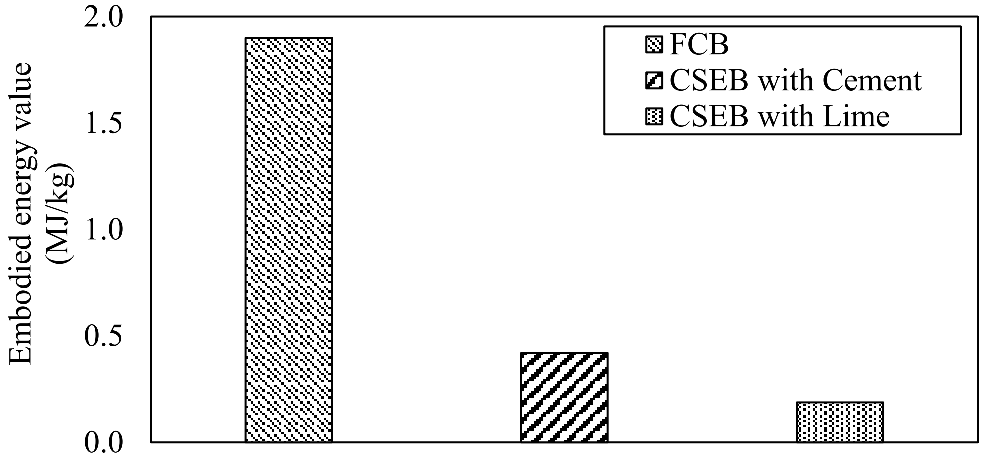
From the perspective of Bangladesh, the concept of the low cost sustainable building is a very important issue under the global climate change. In Bangladesh, around 70% of people are living in rural area. Masonry is one of the most common housing construction systems for them. Also, Bangladesh is situated in a disaster prone zone. Natural disasters like cyclone, flood, tidal surge, heavy rainfall visits almost every year in the country. These disasters cause a great damage to rural non-engineered houses. Lack of proper technological knowledge in housing pattern increase the vulnerability of natural disaster.

The major problems with the fired bricks are firstly the emission of Green House Gases (GHG) results to the air pollution caused by the kilns; and secondly, the use of topsoil from agricultural lands as the main ingredient. For the country like Bangladesh whose economy depends heavily on agriculture, this impact will be very negative. Every time the topsoil is extracted from a certain piece of land, it goes barren for at least three years which means nothing can be grown there over that duration. According to the news report of Dhaka Tribune published on 9th November 2017, the country produces 25 billion bricks every year. To meet this demand it requires excavating 60 million tons of topsoil, causing dust pollution and degrading the ground. Brick kilns also consume 5 million tons of coal and 3 million tons of wood annually, in the process emitting 15 million tons of carbon into the air.

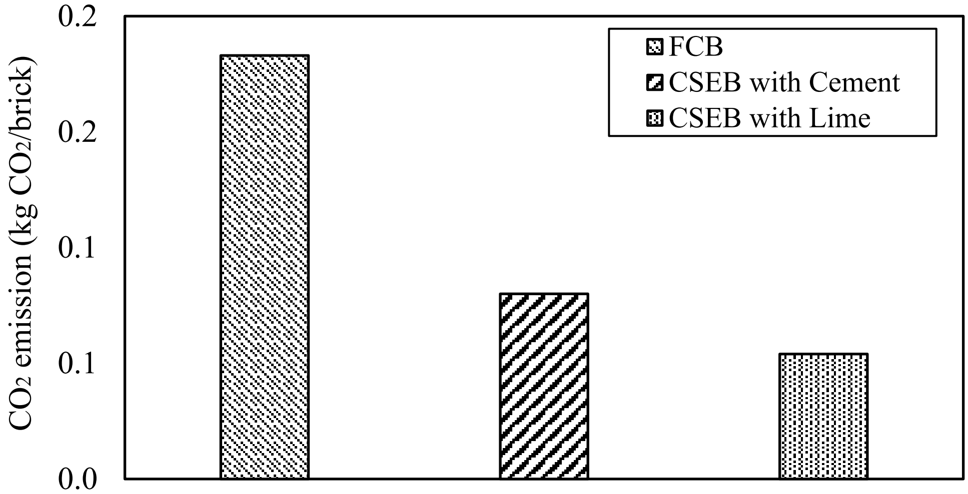
Figure 2.13: Photograph of pollution by brick kilns in Bangladesh (Published in Dhaka Tribune on 9th November, 2017)

Rising housing needs are an obvious consequence of rapid development. So, the demand for bricks cannot be reduced. Then again, agricultural Bangladesh must have exclusive rights on the topsoil. Compressed Stabilized Earth Blocks (CSEBs), Interlocking CSEB are some of the techniques for making such kinds of bricks. Technically, they might be different but there is one thing common about all of them - none of these require the clay-rich topsoil for making bricks. Now a days, Compressed Stabilized Earth Blocks (CSEBs) are being produced considering its strength and durability. They are highly cost-effective, environmentally-friendly; and can be safely used for the construction of multi-story buildings with a variety of creative and aesthetically pleasing effects.

Making CSEB is more convenient than conventional FCB with respective to pollution emission, energy consumption and production cost. In Fig. 2.14, the comparison between CSEB and FCB is shown with respect to cost, energy and pollution emission for CSEB with 5% lime, modified CSEB with 6% cement and 3% lime (Rahman et al., 2016).



(a)



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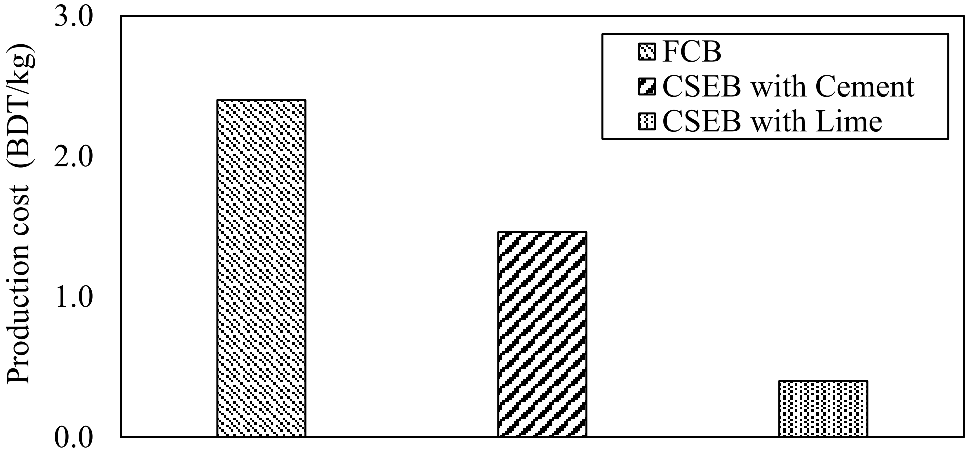


(c)

Figure 2.14: Comparison between FCB and CSEB with respect to: (a) Embodied energy value, (b) Pollution emission and (c) Production cost

2.9 Benefits of Construction Houses with Soil

Constructing houses with soil has many benefits to users of the houses. Previous studies (Rahman et al., 2016; Riza et al., 2011; Morel et al., 2007; Minke, 2009; Lal, 1995; Kateregga, 1983; Easton, 1998; Adam and Agib, 2001; Venkatarama Reddy, 2007; Morton, 2007; Walker and Stace, 1995) have expressed some of the advantages of constructing houses with soil or earth as follows:

(a) Readily and locally available materials
(b) Environmentally sustainable as sundry and no firing or burning is required
(c) Valorize cultural heritage and values
(d) Saves energy
(e) Reduces construction cost
(f) Simplicity in manufacture as it requires simple equipment and less skilled labour
(g) Good fire resistance
(h) Provides indoor thermal comfort
(i) Promotes self-help construction practices
(j) Noise control
(k) Preserves timber and other organic materials
(l) Brick can be made at the site with no transportation

2.10 Disadvantages of Compressed Earth Block Technology

Traditional wall construction using soil as a 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:

(a) Proper soil identification is required or unavailability of soil
(b) Wide spans, high and long building are difficult to do
(c) Low technical performances compared to concrete
(d) Under-stabilization resulting in low quality products
(e) Low social acceptance due to counter examples by unskilled people, or bad soil and equipment

The shrinkage or cracking is another disadvantage of CSEB technology. Understanding this behavior is crucially important and may indicate the need for soil amendments. 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 conditions.

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

2.11 Solutions to the Problems of CSEB

The disadvantages of CSEB technology can be corrected by combined chemical and mechanical action, technically known as soil stabilization. An additional binder, such as cement, lime or fiber may be included to stabilize the mix. Additionally, local fiber reinforcement may be added.

The material used for wall construction should possess adequate wet compressive strength and erosion resistance. The technique to enhance natural durability and strength of soil defined as soil stabilization. For stabilizing, cementitious admixtures such as cement and lime and bitumen are added. Cement is the most widely used stabilizing agent (Walker, 1995).

Compacted soil blocks, naturally dried are ecological and economical materials with no air pollution arising from their fabrication process. However uses of these additives also significantly increase both material cost and their environmental impact (Morel et al., 2001 and Mesbah et al., 2004). The properties of stabilized soil can be further improved by the process of compaction. The process of compaction leads to higher densities, thereby higher compressive strength and better erosion resistance can be achieved. Exploring the stabilization and compaction techniques, a cheap, yet strong and durable material for wall construction is the stabilized pressed block. The proposed solutions to the problems with CSEB are given in Table 2.8.

Table 2.8: Problems of CSEB with a possible solution

Problems of CSEB	Possible solutions
(a) Durability (b) Low compressive strength (c) Shrinkage problem	(a) Selection of soil (b) Addition of fiber (c) Addition of stabilizer/ material (d) Compaction

2.12 Summary

Due to change in social outlook, lack of knowledge about the manifold advantages of earthen houses and unknowing of the consequences of the use of industrial building products, earth construction has lost its popularity to some extent for the time being. Another big issue is vulnerability at drought, moisture and earthquake forces. In most of the cases, stabilization technique based on properties of soil is proposed as the best solution to the problem.

It is a matter of great hope that very recently earth construction witnesses growing interest both globally and locally. Model houses are being constructed at various parts of the country and other parts of the world to motivate low income people towards the use of it.

Building with earth is definitely an appropriate as well as cost and energy efficient technology for half a century. Research and development have proved the potential of earthen techniques. One of the main key points for a general revival and dissemination of earthen techniques is respect for nature and management of resources. So, it can be said building with earth had a great past, but also a promising future everywhere in the world.

There is a little study on the effect of compressive strength with different percentages of cement in addition with different grain size sand (coarse sand, fine sand and mixture of coarse and fine sand) with soil. Thus, this study aims to determine the strength characteristics of CSEB. Therefore, this study will try to fulfill the previous knowledge gap in this field.

Chapter 3
EXPERIMENTAL PROGRAM

3.1 General

Soil samples were collected from 8 different places for this experimental program. Among these collections, three soil samples were selected for making Compressed Stabilized Earth Block (CSEB). One is from Savar, where there is an existing structure with the earth of this soil sample. Lime, jute and cement were used with this soil sample to make these CSEBs. The second and third ones are from Shariatpur. Cement and sand were used to stabilize the blocks.

CSEB specimens were prepared using the soil samples collected from Savar and Shariatpur. Compressive strength test was conducted on the blocks made with soil sample collected from Savar to know the strength and deformation properties. Four types of blocks were produced with this soil sample. They are Unstabilized Block, Cement Sand Stabilized Block, Lime Stabilized Block and Lime Jute Stabilized Block. The soil samples collected from Shariatpur were used to produce Cement Sand Stabilized Blocks. There are total 47 types of combinations used to produce Cement Sand Stabilized Blocks. Different proportions of cement, fine sand and coarse sand were used to produce these blocks. Crushing strength test was conducted on Cement Sand Stabilized Blocks. In addition to this, the water absorption capacity test was conducted on some typical Cement Sand Stabilized Blocks. Wet crushing strength test was also conducted on the same blocks selected for water absorption capacity test.

This chapter presents the collection and selection of soil as well as selection of reinforcing materials. Properties of the selected reinforcing materials are described. The earthen block specimens with their materials compositions are presented here. CSEB specimens preparation and curing process, machine used for producing CSEB, experimental set-up and the test parameters are also described here with relevant figures. The identification system of CSSB specimens is illustrated here with relevant figure and table. Finally, in this chapter the water absorption capacity test conducted on some CSSB specimens are described.

3.2 Collection of Soil Sample

Soil samples were collected from Savar and Shariatpur district in Bangladesh. The locations of soil sample collections are mentioned in Table 3.1 and shown in Fig. 3.1 and 3.2.

Table 3.1: Locations of collected soil samples

Soil sample location	Soil designation	Latitude and longitude
CCDB HOPE CENTRE, Baroipara, Savar, Dhaka	SS	24°01'49.4"N 90°14'13.4"E
Purbo Char Rusundhi, 0.61 m below ground, Shariatpur	SP1	23°09'04.6"N 90°21'30.9"E
Purbo Char Rusundhi, 1.22 m below ground, Shariatpur	SP2	23°09'02.3"N 90°21'33.2"E
Middle Char Rusundhi, 0.61 m below ground, Shariatpur	SP3	23°09'23.2"N 90°20'51.4"E
Poschim Porondi, 0.61 m below ground, Shariatpur	SP4	23°11'29.6"N 90°19'06.1"E
Dorichar, Dattpara, 0.91 m below ground, Shariatpur	SP5	23°10'54.7"N 90°19'09.8"E
Bala-Bazar, Rudrokor East, 0.61 m below ground, Shariatpur	SP6	23°10'34.5"N 90°21'02.0"E
Char Jadobpur, Tula Tola Goja, 1.22 m below ground, Shariatpur	SP7	23°09'50.8"N 90°19'02.3"E

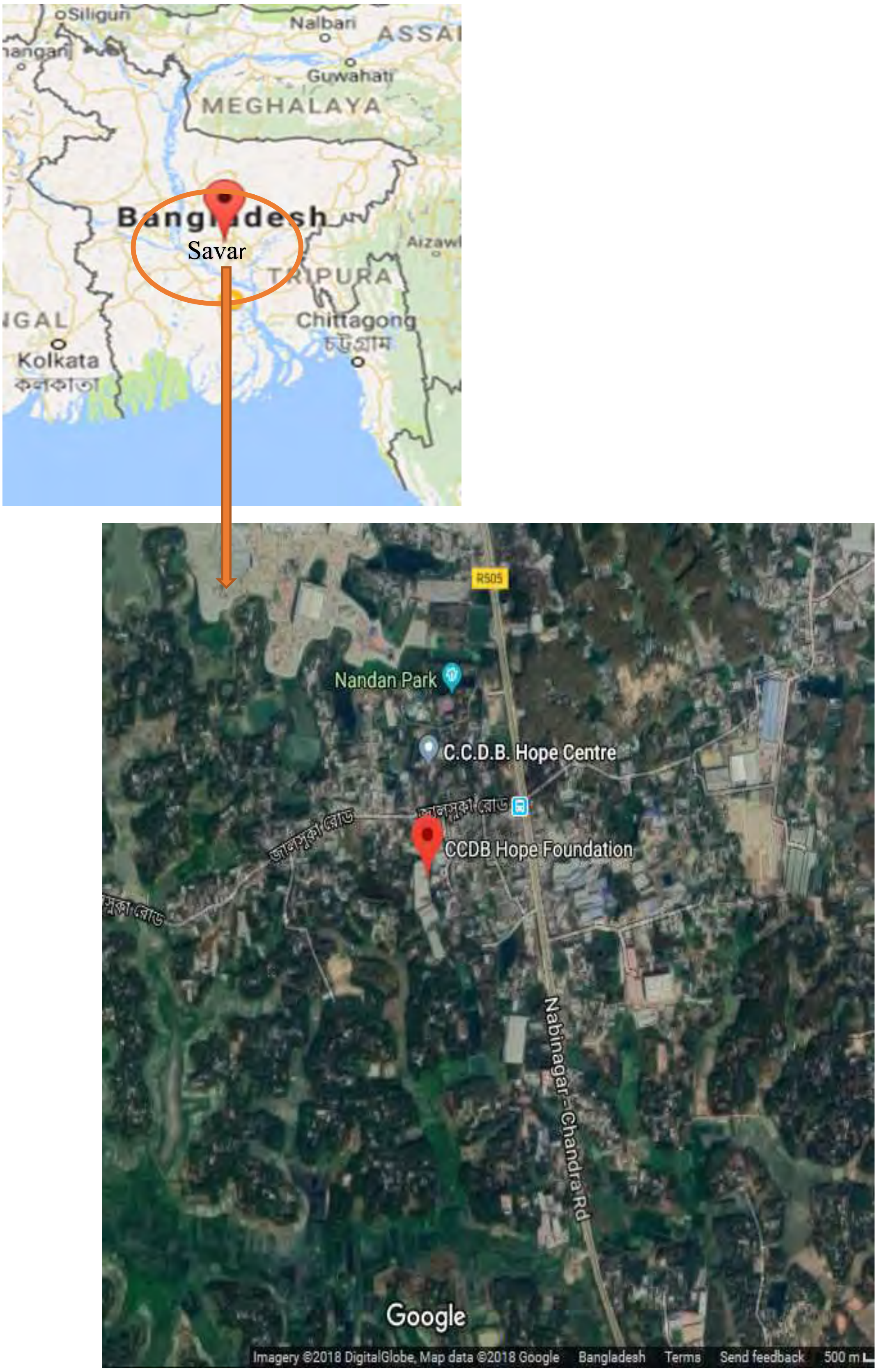


Figure 3.1: Location of soil sample collection from Savar

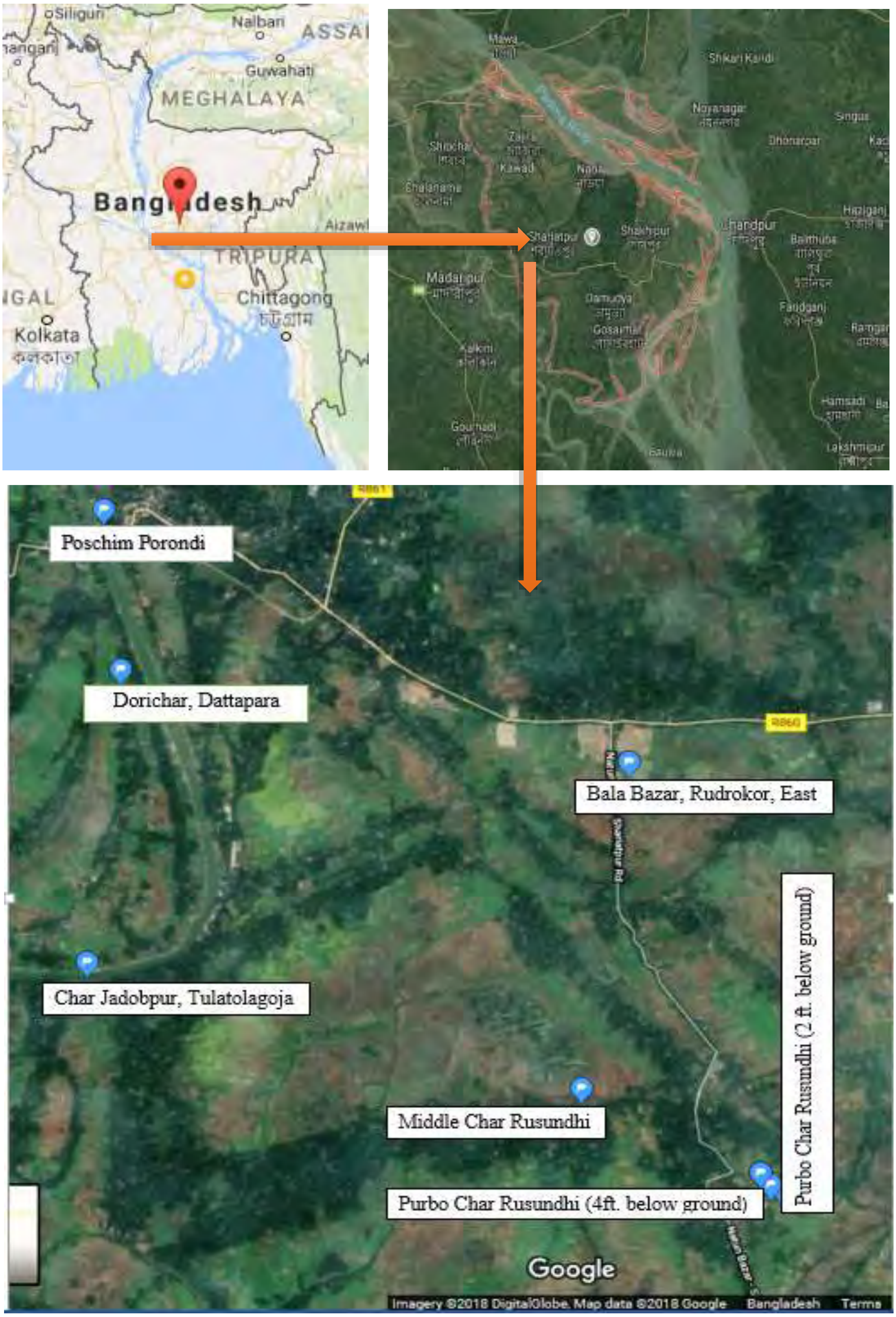


Figure 3.2: Locations of soil sample collections from Shariatpur

3.3 Selection of Soil

After the collection of eight soil samples finally, three soil samples were used for this study. One soil sample was collected from Christian Commission for Development in Bangladesh Human and Organizational Potential Enhancement Centre (CCDB HOPE CENTRE) which is located at Baroipara, Savar, under Dhaka district of Bangladesh. The soil on the premises of that institution was used for making CSEB. The second and third one is from Purbo Char Rusundhi two feet and four feet below from ground level respectively which are located at Shariatpur. The second soil sample resembles the third one.

3.4 Soil Classification

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

3.4.1 Laboratory tests on collected soil samples

The soil samples used for making CSEB were evaluated first by conducting some tests for the purpose of classifying and identifying the type of soil sample. The tests were conducted as per described in ASTM. The list of experiments and name of tests for soil identification are presented in Table 3.2.

Table 3.2: Tests conducted for soil identification

Properties of soil	Name of the test	ASTM standard	Parameters to be determined from test
Index properties	Grain size distribution	ASTM C 136	Grain size distribution curve
	Natural moisture content	ASTM D 2974	Natural moisture content
	Specific gravity test	ASTM D 854	Specific gravity
	Atterberg limit test	ASTM D 4318	Liquid limit and Plastic limit

3.5 Soil Stabilization

Many kinds of soils can be used for earth walls by adding substances known as stabilizers. The technique to enhance natural durability and strength of soil is defined as soil stabilization. It is a process of mixing admixtures with soil to improve its volume stability, strength and durability (Bell, 1993). It is considered as one of the most important attempts in the production of CSEB. The aim of the stabilization is to improve the performance of soil as a construction material.

3.5.1 Stabilization of soil with lime

Soil samples were stabilized using quick lime. Lime is found in the form of quicklime (calcium oxide: CaO), hydrated lime (calcium hydroxide: $Ca[OH]_2$), or lime slurry which can be used to treat soils. Quicklime is manufactured by chemically transforming calcium carbonate (limestone: $CaCO_3$) into calcium oxide. Hydrated lime is created when quicklime chemically reacts with water. The hydrated lime reacts with clay particles and permanently transforms them into a strong cementitious matrix. Most lime used for soil treatment contains not more than 5 percent magnesium oxide or hydroxide. On some occasions, however, dolomitic lime is used. Dolomitic lime contains 35 to 46 percent magnesium oxide or hydroxide. Dolomitic lime can perform well in soil stabilization, although the magnesium fraction reacts more slowly than the calcium fraction.

By adding lime to the soil for stabilization, four basic reactions are believed to occur: cation exchange, flocculation and agglomeration, carbonation and pozzolanic reactions. The pozzolanic reaction is believed to be the most important and it occurs between lime and certain clay minerals to form a variety of cementitious compounds which bind the soil particles together. Lime can also reduce the degree to which the clay absorbs water and so can make the soil less sensitive to changes in moisture content and improve its workability. Lime is a suitable stabilizer for clay soils. The advantages that lime has over Portland cement are that it requires less fuel to manufacture and requires relatively simple equipment to make. It is, therefore, more suitable for village scale production and use.

Here soil was stabilized using 5% quick lime. Quick lime was prepared by grinding the limestone like powder using a hammer and then oven dried the powder for 24 hours. Fig. 3.3 shows the photographs of preparing quicklime.

(a)

(b)

Figure 3.3: Photographs of preparing quicklime: (a) Grinding the limestone and (b) Oven drying of lime

3.5.2 Stabilization of soil with cement and sand

Ordinary Portland cement hydrates when water is added, the reaction produces a cementitious gel that is independent of the soil. This gel is made up of calcium silicate hydrates, calcium aluminate hydrates and hydrated lime. The first two compounds form the main bulk of the cementitious gel, whereas the lime is deposited as a separate crystalline solid phase. The cementation process results in deposition between the soil particles of an insoluble binder capable of embedding soil particles in a matrix of cementitious gel. Penetration of the gel throughout the soil hydration process is dependent on time, temperature and cement type. The lime released during hydration of the cement reacts further with the clay fraction forming additional cementitious bonds. Soil-cement mixes should be compacted immediately after mixing in order not to break down the newly created gel and therefore reduce strengthening. The basic function of cementation is to make the soil water-resistant by reducing swelling and increasing its compressive strength.

Cement stabilizers improve the bonding properties and add strength to the blocks. When, the soil requires a large percentage of cement, it can be combined with an equal amount of lime, which costs less.

Silt, sand and gravel particles supply the structural strength by combining to create a compact matrix with little void space. For silty soil, a slight crushing might be required. Sieving (6 to 10 mm) is required if the lumps are too big and cohesive. Adding 10 to 20% coarse sand might be needed to give more skeletons to the soil. Adding sand depends on the silt size. If the grain size of the silt is near to very fine sand, no sand should be added. Stabilization should be 6% minimum by weight of cement. Adding 20 to 40% coarse sand is needed to reduce the plasticity and give some skeleton for soils high in clay content (Auroville Earth Institute, 2018).

3.5.3 Stabilization of soil with jute

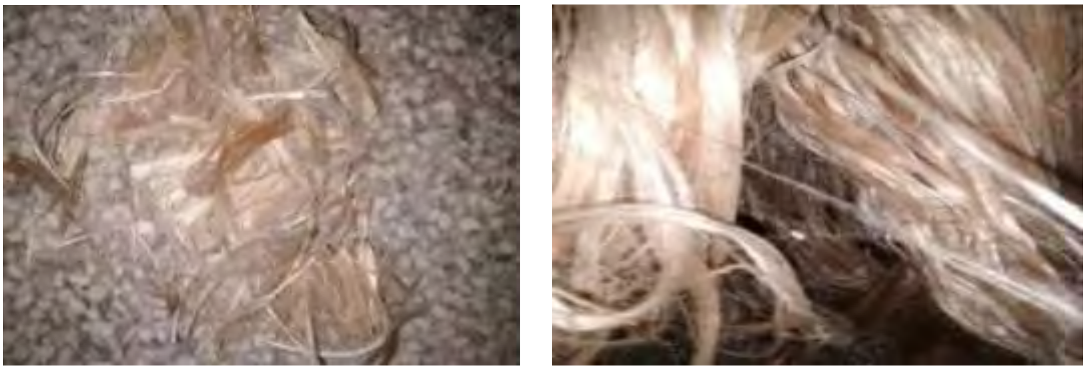
Although various natural grass or vegetables are used with soil for stabilization, a few efforts have been taken for the scientific analysis of soil fiber matrix. Fibers might be effective in the following ways:

(a) It increases the tensile strength and elasticity of the material.

(b) Fibers in the matrix will provide a way to prevent the growth of crack in the shear band when cracks will propagate due to the imposed loads and thus fiber may improve the strength, ductility and toughness of the composite (Islam et al., 2008).

Jute is used here for the reinforcement of lime stabilized earthen block. Jute is long, soft and shiny, with a length of 1 to 4 m and a diameter of from 17 to 20 microns. Though Bangladesh and India are the leading producers of jute, it is also grown in different parts of the world. Jute fibers are composed primarily of the plant materials cellulose (major component of plant fiber) and lignin (major components of wood fiber). The fibers can be extracted by either biological or chemical retting processes. Given the expense of using chemicals to strip the fiber from the stem biological processes are more widely practices. Biological retting can be done by either by stack, steep and ribbon processes which involve different techniques of bundling jute stems together and soaking in water to help separate the fibers from the stem before stripping. After the retting process, stripping begins. In the stripping process, non-fibrous matter is scraped off, leaving the fibers to be pulled out from within the stem.

Jute fiber is 100% bio-degradable, photodegradable, thermally degradable, high modulus, less extensible, hygroscopic and recyclable and thus environmentally friendly. To overcome some disadvantage of jute, several researches have been done by different researchers and organizations for the last few years. Recently, a wide range of geojute has been developed in the laboratory of Bangladesh Jute Research Institute (BJRI) by blending jute with hydrophobic fiber like coir or by modification with bitumen, latex and wax resinous materials with the collaboration of Bangladesh Jute Mills Corporation (BJMC). Fig. 3.4 shows the jute was used for stabilizing earthen block. Jute was used after cutting into pieces (average 3 inches) for better bonding with soil.



(a) (b)

Figure 3.4: Photographs of : (a) 3 cm pieces jute and (b) Jute fiber

3.6 CSEB Preparation

The CSEB production procedure with Savar and Shariatpur soil are quite different from each other. The procedures are described here in a nutshell.

3.6.1 CSEB preparation for compressive strength test

First of all, the collected soil samples were sundried for about one month. Then the soil was crushed manually by hammering. To produce the CSEB an earthen block preparation machine, “Press 3000 Multi-Mold Manual Press” also known as “Auram Earth Block Press 3000” was borrowed from CCDB HOPE CENTRE for preparing compressed earth block sized 240 mm × 115 mm × 90 mm. In summary, a block mold is loosely filled with soil particles passing a No. #8 sieve (2.36 mm). Stabilizers were mixed with the crushed soil sample. When stabilizers are used they must be thoroughly mixed with the soil or much of their benefits will be lost. The soil sample was mixed with water until it was plastic enough to mold. A hand operated hydraulic pump, connected to the mold frame through a hydraulic hose and cylinder, is used to pressurize the cylinder gradually to which in turn applies pressure to the soil in the mold. After the pressure is applied for a few seconds, it is released and the compressed earth block is extruded by exchanging the mold base for an ejection base.

During block production, a pressure of 150 kN (15 tons) was applied to the soil. This pressure is used to correspond with the applied pressure of the full-scale production machine. Manpower needed: 3 men on the machine, plus 3 more mixing and handling. Net weight of the machine was 415 kg. Immediately, after each mini-block is ejected from the small block press its dimensions (height, length and width) were measured. The blocks are carefully placed in a controlled environment and any shrinkage or cracking effects are noted before commencing tests. The entire process of preparing earthen blocks is shown in Fig. 3.5.

(a)

(b)

(c)

(d)

Figure. 3.5: Photographs for production of CSEB specimens: (a) Soil grinding for making CSEB (b) Press 3000 Multi-Mold Manual Press Machine (c) Making earthen blocks in press machine and (d) Prepared blocks

For preparing CSEB specimens for compressive strength test following combinations were followed.

Table. 3.3: Combinations used for making CSEB for compressive strength test

Blocks	Percentages of compositions (% w/w)						Block designation
	Soil	Cement	Coarse sand	Lime	Fiber	Water	
Unstabilized Block	93	-	-	-	-	7	USB
Cement Sand Stabilized Block	67	9	13	-	-	11	CSSB
Lime Stabilized Block	83	-	-	5	-	12	LSB
Lime Jute Stabilized Block	82	-	-	5	0.3	12	LJSB

The natural moisture content of the selected soil was found at 17.4%. Water used for making block was kept below natural moisture content. These blocks were cured for 28 days before commencing tests. Blocks were cured by keeping it at room temperature (around 25 ^{0}C) and spraying water in every two days interval of time. Fig. 3.6 shows the blocks after 1 day of production at the time of curing.

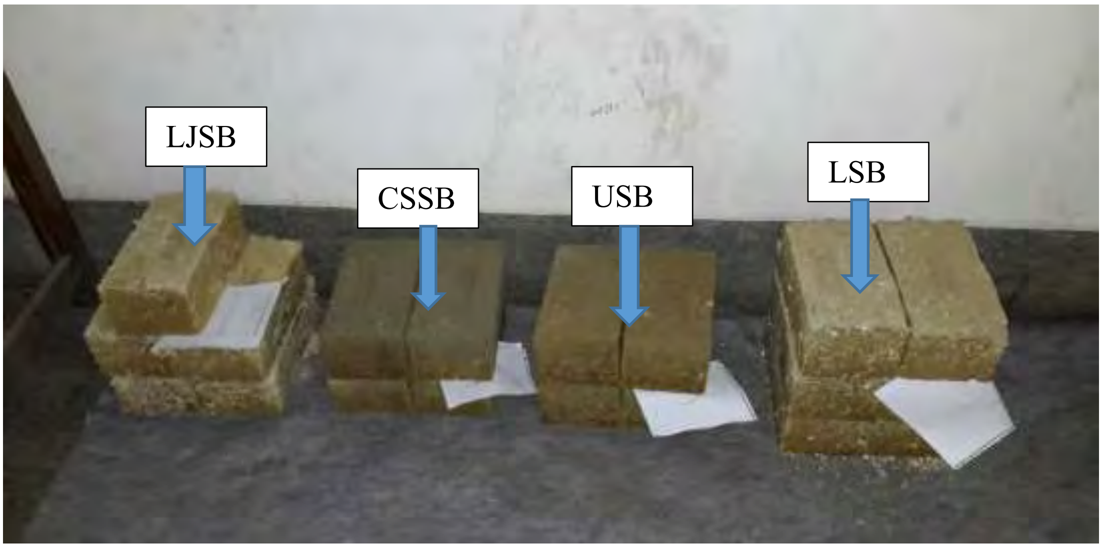


Figure 3.6: Photograph of CSEB specimens during curing period

3.6.2 CSSB preparation for crushing strength test

The basic materials required for the production of compressed stabilized earth building blocks are soil, stabilizer and water. The stabilizer, whether lime or cement or some other material, is usually available in powder or liquid form, ready for use. The soil may be in wet or dry condition, when it is first obtained and will probably not be homogeneous. In order to have uniform soil, it is often necessary to crush it so that it can pass through a 5 to 6 mm mesh sieve.

Different soil types may also be needed to be used together so as to obtain good quality products. For instance, heavy clay may be improved by the addition of a sandy soil. It is not only important to measure the optimum proportion of ingredients, but also to mix them thoroughly. Mixing brings the stabilizer and soil into direct contact, thus improving the physical interactions as well as the chemical reaction and cementing action. It also reduces the risk of uneven production of low quality blocks.

The preparation process of CSSB specimens comprised of soil preparation, measuring and mixing, pressing, curing are described here in a nutshell**.**

3.6.2.1 Soil preparation

All soil sample was sieved almost. It is necessary to remove the gravel greater than 10 mm and most of the lumps. The size of the mesh (from 5 to 10 mm) must be adapted according to soil type. It is also important to control the angle of the sieve. A very flat sieve will let coarser particle pass through. A very vertical sieve will remove more coarse particles and the soil will be thinner. Some soils, specially clayey ones were crushed. As, crushing by hand is very difficult and labor intensive, therefore, motorized crusher or pulverizer was used.

3.6.2.2 Weathering

Mostly, the dredged soil is wet and contain a high amount of moisture. Breaking into powder and pulverizing the wet soil require complex machinery. To avoid complex machinery, the collected dredged soil was kept under a shade for 15 to 25 days. In this period, the soil was weathered and dried to ease the breaking operation.

3.6.2.3 Pulverizing

The foreign objects like glass shards, grass and stone were first sorted out from the air dried soil sample. As crushing by hand is very difficult and about intensive so a motorized crusher of pulverizer was preferred for soil crushing. The machine that was used for soil pulverizing was Soeng Thai Soil Pulverizer Model SP3 as shown in Fig. 3.7. Before crushing, the soil samples were dried absolutely.

(a)

(b)

Figure 3.7: Soil pulverizing machine: (a) and (b) "Soeng Thai Soil Pulverizer Model SP3".

Main Features of the Soeng Thai Soil Pulverizer Model SP3 are:

(a) Appropriate for nodular lateritic (Stony laterite) soils or softer soils.
(b) The hopper will tilt away and screen can be removed for easy cleaning.
(c) Single-phase 3-hp electric motor or 4-hp Honda gasoline engine (CDI electronic ignition)
(d) Replaceable high quality bearings (SKF or NTN)
(e) Hardened replaceable fingers
(f) High speed rotation for a fine grind (typical particle size is less than 4 mm)
(g) Electric motor has magnetic switch for overload protection

3.6.2.4 Measuring and mixing

Measuring: The volume of every container is known as the specifications are given according to their size. All the containers used for soil and sand were filled till the top and leveled with a straight edge.

Mixing: The sand was poured on the unloaded soil. The stabilizer will be also mixed with them. This is a dry mixing. Water is mixed with dry mix uniformly. No lumps were allowed to create. The pile was moved two times to get a homogenous mixture.

3.6.2.5 Pressing

Pressing is done by Auram 3000 (Fig. 3.8) the only Indian-made Earth Block Press (also known as "Mud Brick Press").

Figure 3.8: Block producing machine: “Auram Earth Block Press 3000”

Main features of Auram Earth Block Press 3000 are:

(a) Block height is adjustable in 5 mm increments
(b) High and adjustable compression ratio
(c) Double compression (folding back lid)
(d) Easy interchangeability of molds

Table 3.4: Technical specifications of "Auram Earth Block Press 3000"

Parameters	Value
Available force	150 kN (15 tons)
Compression ratio	1.60 to 1.83
Block height (mm)	25 and 50, them up to 100 in 1 to 5 mm increments
Practical output	106 strokes per hour
Daily output	1000 plain blocks
Manpower needed	3 men on the machine, plus 4 more mixing and handling
Net weight	365 kg to 415 kg

3.6.2.6 Filling of mold

The first condition for a consistent quality is to always fill the mold with the same amount of soil. The mold was filled with a hand shovel. Soil was leveled with a ripper to ensure good compression quality.

3.6.2.7 Pressing and handling the fresh block

Compression ratio was adjusted first as per the soil so as to have the maximum compression of the soil. This was done by pocket penetrometer. The lid was not opened until the lever has been fully operated otherwise the block will not be fully compressed. Then they were pressed from sides and stacked on the initial curing and stacking area.

3.6.2.8 Initial curing and stacking

Immediately after pulled out from the mold, the stacking is started. They were stacked near the press in long piles which were covered with a plastic sheet for two days. The initial curing is necessary for the blocks to start immediately. The stacks were covered in plastic sheets which is airtight to avoid the evaporation. When there were enough chances of evaporation then a strip of humid jute cloth was used. 7 to 8 blocks are stacked upon each other immediately after production. Only 5 cm gap was kept between the blocks in the width of the row, so as to allow the hand to move out. But in the length the gap is minimal.

3.6.2.9 Final stacking and curing

Fig. 3.9 shows the block making process sequentially. At first dredged soil are broken by pulverizer machine and screened. Then raw soil is mixed with stabilizer and pressed in a press machine. Curing for 4 weeks is done on blocks.

(a) Dredged soil sample (b) Soil pulverizing (c) Screened soil sample

(d) Mixing cement with water (e) Filling in the mold (f) Freshly made block

(g) Curing by water (h) Curing in open air (i) Block after curing

Figure 3.9: Preparation of CSSB specimens in Shariatpur by Inclusive Home Solution (IHS) Ltd.

After two days the blocks were moved to their final stacking and curing areas. They were moved to flat wheel barrow so that the edge and corners are not damaged. Blocks were stacked in a compact pile with a minimum gap between them. In final curing, for cement sand stabilized blocks, as soon as the pile is completed, it was covered with jute clothes. Curing was done for 4 weeks. Jute clothes were not allowed dry during the curing time. Water is sprinkled on them daily, as many times as needed, during 28 days.

3.6.2.10 Proportions of soil-sand-cement mix

For preparing CSSB specimens having dimension 240 mm x 115 mm x 90 mm made for crushing strength test following combinations were followed as shown in Table 3.5 to 3.6. In Table 3.7 identification system for CSSB specimens has been explained. Detailed test programs for crushing strength test have been presented in Table 3.8.

Table 3.5: Different percentages of cement used to stabilize different proportions of soil-sand mixes

Cement (%)	Amount of mixes			
	Fine sand	Coarse sand	Mixed sand	Total
3	-	3	-	3
5	2	5	11	18
6	-	5	7	12
7		3	1	4
8	-	5	2	7
9	-	3	-	3
Unstabilized	-	-	-	1
Total				48

Table 3.6: Different percentages of sand used to stabilize the different proportions of soil-cement mixes

Sand (%)	Amount of mixes			
	Fine	Coarse	Mixed	Total
20%	**-**	5	**-**	**5**
30%	-	3	5	8
40%	-	6	6	12
50%	1	4	6	11
60%	1	6	4	11
Unstabilized	-	-	-	1
Total				48

3.6.2.11 Definitions of CSSB specimens prepared for crushing strength test

For easy identification of CSSB specimens presented in Table 3.8 a system was followed which has been explained in Fig 3.10 and Table 3.7. It is essential for further understanding and interpretation of this study. This system carries the percentages of cement and sand content of individual block specimens prepared for crushing strength test.

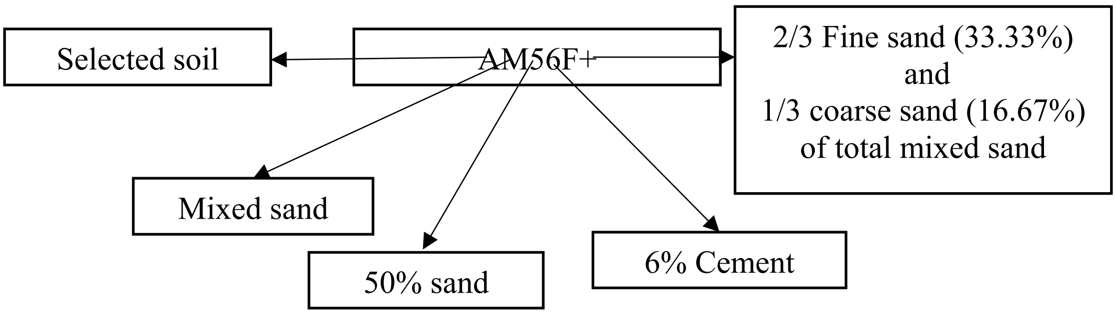


Figure 3.10: Illustration for identification system of CSSB specimens

Table 3.7: Explanation for identification system of CSSB specimens

Block designation	1^{st} alphabet (A)	2^{nd} alphabet (C-F-M) (Type of sand)	3^{rd} digit (Percentage of sand = 3^{rd} digit *10)	4^{th} digit (percentage of cement)	Special case (M, F+, C+, F+2)
AC46	Selected soil for block	Coarse	40%	6%	-
AF55		Fine	50%	5%	-
AM55		Mixed	50%	5%	Coarse sand= 1/2*50 Fine sand= 1/2*50
AM55C+		Mixed	50%	5%	Coarse sand= 2/3*50 Fine sand= 1/3*50
AM55F+		Mixed	50%	5%	Coarse sand= 1/3*50 Fine sand= 2/3*50
AM55F+2		Mixed	50%	5%	Coarse sand= 4/10*50 Fine sand= 6/10*50

Table 3.8: CSSB specimens group with material compositions

Cement (%w/w)	CSEB specimens	Sand (% w/w)		
		Fine	Coarse	Fine + Coarse
3	AC23	-	20	-
	AC43	-	40	-
	AC63	-	60	-
5	AC25	-	20	-
	AC35	-	30	-
	AC45	-	40	-
	AC55	-	50	-
	AC65	-	60	-
	AM35	15	15	30
	AF55	50	-	-
	AM45	20	20	40
	AM45C+	13.33	26.67	40
	AM45F+	26.67	13.33	40
	AM55	25	25	50
	AM55C+	16.67	33.33	50
	AM55F+	33.33	16.67	50
	AM55F+2	20	30	50
	AM65	30	30	60
	AM65C+	20	40	60
	AM65F+	40	20	60
	AF65	60	-	-
6	AC26	-	20	-
	AC36	-	30	-
	AC46	-	40	-
	AC56	-	50	-
	AC66	-	60	-
	AM36	15	15	30
	AM36C+	10	20	30

Table 3.8: CSSB specimens group with material compositions (contd.)

Cement (%w/w)	CSEB specimens	Sand (% w/w)		
		Fine	Coarse	Fine + Coarse
	AM36F+	20	10	30
	AM46	20	20	40
	AM46C+	13.33	26.67	40
	AM56	25	25	50
	AM56F+	33.33	16.67	50
7	AC47	-	40	-
	AC57	-	50	-
	AC67	-	60	-
	AM37	15	15	30
8	AC28	-	20	-
	AC38	-	30	-
	AC48	-	40	-
	AC58	-	50	-
	AC68	-	60	-
	AM48	20	20	40
	AM68F+	40	20	60
9	AC29	20	20	-
	AC49	40	40	-
	AC69	60	60	-
Unstabilized block	-	-	-	-

3.7 Experimental Setup

3.7.1 Compressive strength test

A Universal Testing Machine (Tinius Olsen Testing Machine Co. USA) capacity 60000 lb was used to measure the compressive strength of the CSEBs according to ASTM D143). The strain rate used did not allow for the stress rate to surpass the rate given by the code.

Some procedures were followed to determine the strength of CSEB using the Universal Testing Machine. These are:

(a) Bricks made by Press 3000 Multi-Mold Manual Press machine had taken to the laboratory for testing stress and strain using Universal Testing Machine.
(b) Bedding surface was cleaned to ensure even contact.
(c) The width and length of the loaded area were measured.
(d) The specimen was aligned with the testing machine.
(e) The surface of the block was filled with sand to ensure uniform loading.
(f) An extra capping of steel plate made exclusively for blocks to ensure uniform surface loading.
(g) A wooden block was placed between the plate and the machine to facilitate loading.
(h) The load was incremented 1000 lb at a constant rate.
(i) For per 1000 lb the strain was recorded form strain gauge.
(j) The maximum load was recorded at which the material failed.
(k) The strength of each specimen was calculated by dividing the maximum load by the loaded area.

To calculate compressive strength:

Compressive strength (MPa) = P/A ……………………………………………. (3.1)

Here, P = Force at failure (kN)

A = Cross-sectional area of the top face of the specimen.

Figure 3.11: Photograph of Universal Testing Machine (Tinius Olsen Testing Machine Co. USA)

(a) (b)

Figure 3.12: Photographs of compressive strength testing process: (a) and (b) Test setup of Universal Testing Machine

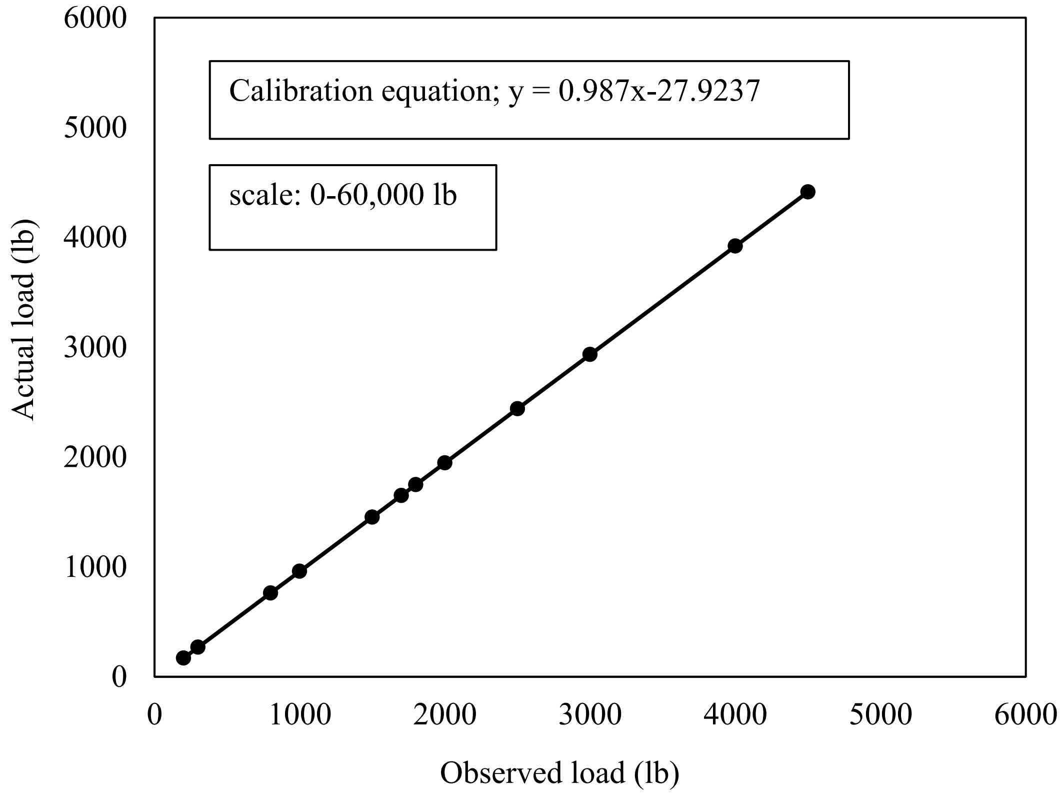


Figure 3.13: Calibration chart of Universal Testing Machine used for compressive strength test

3.7.2 Crushing strength test

The crushing strength test was done on the samples. The crushing strength test was done according to ASTM C1314. The loading rate was 500. Machine name is Tecnotest, Modena-Italy (Machine Series KD 300/R) Serial 2676. The capacity of the machine is 3000 kN. Plywood sheet of ½ inch thick was placed on either face of the half cut block as shown in Fig. 3.18 before the application of load. The calibration equation used for actual crushing strength value from observed value is shown in Fig. 3.15.

To calculate crushing strength:

Crushing strength (MPa) = P/A …………….....…….……………………………… (3.2)

Here, P= Force at failure (kN)

A= Cross-sectional area of the top face of the specimen.

Figure 3.14: Photograph of crushing strength testing machine (Technotest Modena Italy)

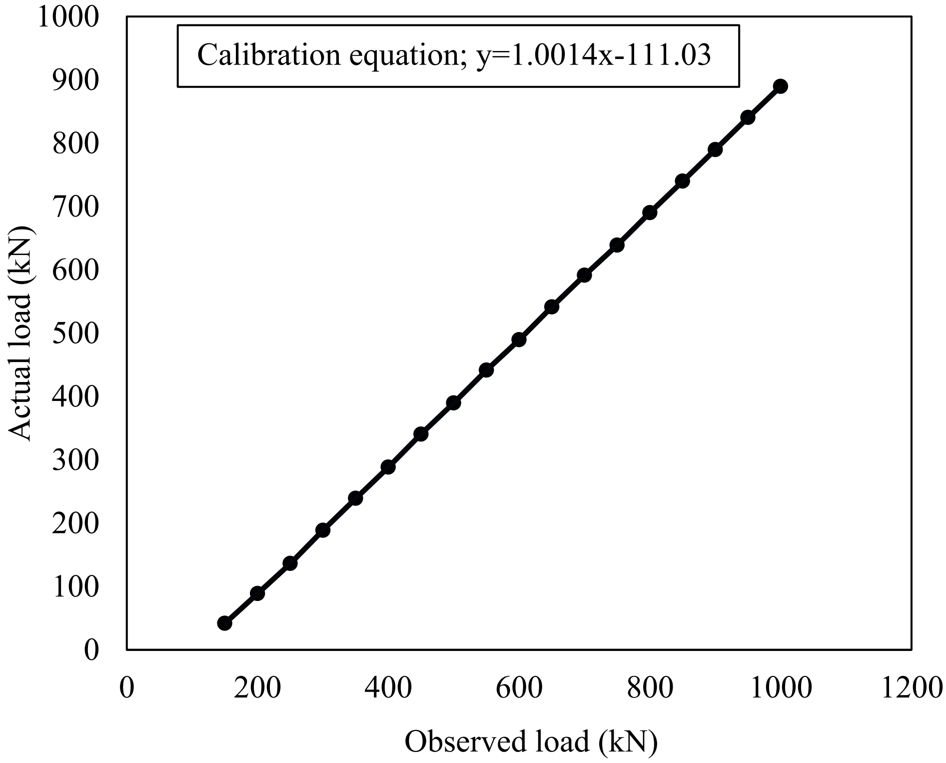


Figure 3.15: Calibration chart of crushing strength test machine

Prior to the testing, the prepared CSSB specimens were stacked in the laboratory. In Fig. 3.16 stacked CSSB specimens are shown prior to the testing. Before crushing strength test, blocks were cut into halves and then unit weight was determined. In Fig. 3.17, the machine used for cutting the blocks is shown.

Figure 3.16: Photographs of CSSB specimens before cutting

Figure 3.17: Photograph of CSSB specimens cutting prior to testing

Figure 3.18: Photograph of CSSB specimen setup for crushing strength test

3.7.3 Moisture content test

The moisture content of the crushed sample was tested from the CSSB specimens after crushing strength test. The samples were taken in the dishes. They were oven dried for 24 hours and then the moisture content was achieved by calculation.

Figure 3.19: Photograph of crushed sample preserved for moisture content test

3.7.4 Water absorption capacity test on CSSB specimens

Some CSSB specimens were selected for the water absorption capacity test according to ASTM C 830. After complete curing, the specimens were cut into halves. Then the mass of CSSB specimens were taken. After that, they were kept under water at the fully submerged condition in a basin for 24 hours. After 24 hours immersion under water, the mass of block specimens are again taken. The water absorption capacity of the blocks are then calculated by the following formula.

To calculate water absorption:

Water absorption (%) = [(W-D)/D] *100% …………………………………….. (3.3)

Here, W= Mass of the wet block after 24 hours immersion under water

D= Mass of the block after oven dry at 105^{0}C -110^{0}C

Table 3.9: CSSB combinations used for water absorption test

Cement %	CSSB specimens	Sand %		
		Fine	Coarse	Fine + Coarse
5	AF45	40	-	-
	AM45F+	26.67	13.33	40
6	AM46	20	20	40
	AM46C+	13.33	26.67	40
	AM56	25	25	50
	AM56F+	33.33	16.67	50
8	AC38	-	30	-
	AM48	20	20	40

Figure 3.20: Photograph of CSSB specimens kept under submerged condition for 24 hours

Figure 3.21: Photograph of wet CSSB specimens after 24 hours immersion under water

3.7.5 Crushing strength test on wet CSSB specimens

Crushing strength test was done on same wet CSSB specimens which were selected for the water absorption capacity test. After immersion for 24 hours under the submerged condition, they were kept in natural air condition for half an hour. Then they were taken for crushing strength test. The testing method is the same as that of crushing strength test for the specimens dried at natural weather condition.

3.8 Test Plan

First soil index properties were determined to classify the soil. Compressive strength test and crushing strength test, unit weight test, moisture content test and water absorption capacity test were performed on CSEB specimens prepared from selected soil after curing.

3.9 Summary

The present study area for the experimental program is selected in Savar and Shariatpur district in Bangladesh. The soil samples were collected from the selected locations of Savar and Shariatpur and tested in the laboratory to determine the index properties. The stabilizers used in preparing the specimens are also described. Finally, the details of the laboratory tests which have been conducted to determine the strength and deformation characteristics and in some cases, water absorption capacity test of some selected CSSB specimens are also discussed in this chapter.

Chapter 4
TEST RESULTS AND DISCUSSIONS

4.1 General

The main purpose of this research is to investigate the effectiveness of cement and sand with soil at different proportions to construct sustainable, environment friendly earthen block that can be used for building construction. The obtained compressive strength under different percentages of stabilizers is described here. Besides this, the deformation characteristics of different types of Compressed Stabilized Earth Block (CSEB) are evaluated here. Soil identification test was conducted to know if the soil was suitable to prepare the compressed earth block. Otherwise, the structures of the soil have to be improved. This chapter discusses the soil index properties, soil stabilization plan, compressive strength, deformation characteristics and water absorption capacity of the prepared earthen block specimens at different combinations.

Photographs of relevant test specimens have been presented here. The strength and deformation characteristics of CSEB specimens prepared for compressive strength test has been discussed with respective curves and comparison of charts. The crushing strength of CSSB specimens has been compared with respect to different proportions of sand and cement content. Effects of coarse sand, fine sand and mixed sand along with different percentages of cement content on the crushing strength of CSSB specimens have been discussed with respective graphs and charts. These graphs will clearly show the ranges of crushing strength for different percentages of cement and sand content. Percentages of water absorption of some selected CSSB specimens and their wet crushing strength have been compared with those of dry CSSB specimens.

4.2 Index Properties of Collected Soil Sample

Three soil samples were used for this study. The grain size distribution of collected soil samples and coarse sand which were used for making CSEB are presented in Fig. 4.1 and 4.2 respectively. The physical properties such as specific gravity, grain size distribution, Atterberg limits of the collected soil samples have been presented in Table 4.1.

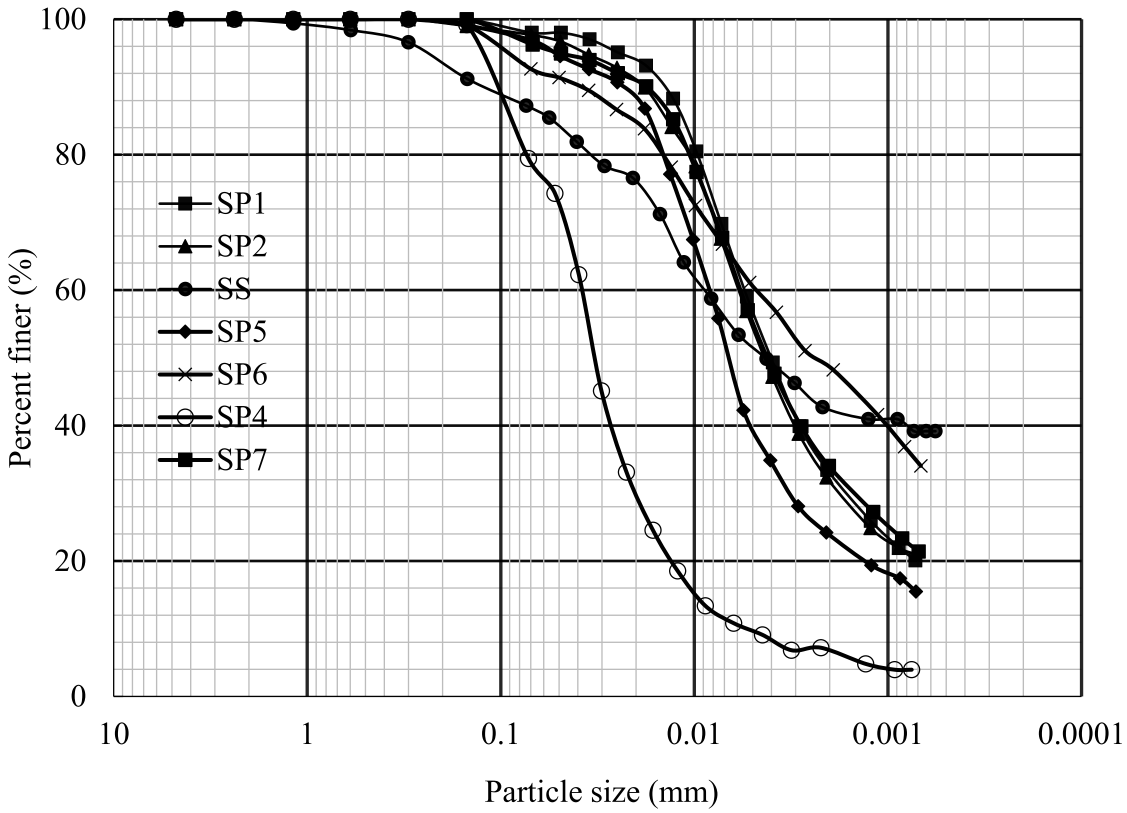


Figure 4.1: Grain size distribution curves of collected soil samples

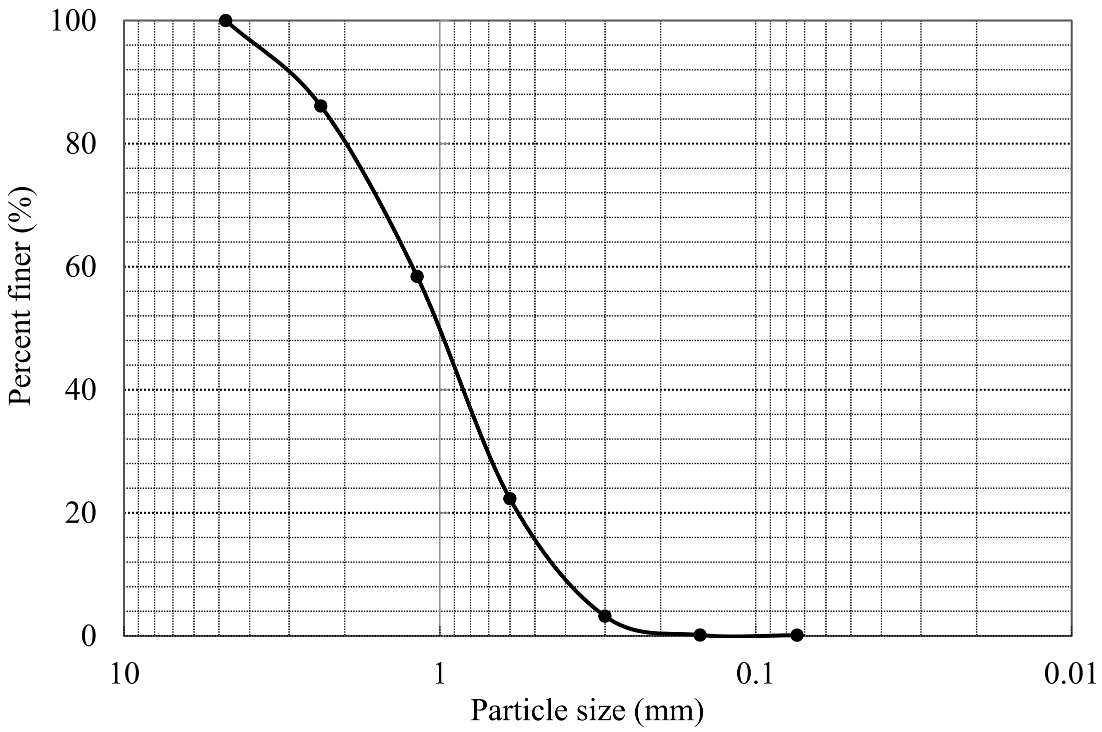


Figure 4.2: Grain size distribution curve of coarse sand used for making CSEB

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

Soil designation	Gs	PI (%)	SL (%)	Sand (%)	Silt (%)	Clay (%)
SS	2.61	32	20	12	47	41
SP1	2.71	-	-	1.2	41.5	57.3
SP2	2.68	-	-	2.1	43.2	54.7
SP3	2.69	-	-	0.50	62.60	36.90
SP4	2.70	-	-	12.9	76.6	10.5
SP5	2.73	14	19	1.40	58.30	40.30
SP6	2.70	29	11	4.30	56.40	39.03
SP7	2.76	19	25	0.50	43.60	56

Note: Gs: Specific gravity; PI: Plasticity index ; SL : Shrinkage limit

Table 4.2: Index properties and grain size distribution of sand used for making CSEB

Sand	Sand designation	F.M	Cu	Cz
Coarse sand	CS	3.29	4.06	1.18
Fine sand (River sand)	FS	0.20	-	-

Note: F.M: Fineness modulus, Cu: co-efficient of uniformity, Cz: Co-efficient of curvature

4.3 CSEB Stabilization Plan

The soil sample (SS) collected from Savar consists of 12% sand, 47% silt and 41% clay as shown in Table 4.1. Compressive strength test was conducted upon the block specimens made with SS soil to know the strength and deformation characteristics of CSEB specimens. Four groups of specimens, i.e., Unstabilized Block (USB), Cement Sand Stabilized Block (CSSB), Lime Stabilized Block (LSB) and Lime Jute Stabilized Block (LJSB) were prepared for compressive strength test.

Seven soil samples collected from Shariatpur contain very low percentages of sand as shown in Table 4.1. Finally, the soil samples (SP1 and SP2) which were selected from Shariatpur consists of 1.2-2.1 % sand, 41.5-43.2% silt and 57.3-54.7% clay. Here, the soil lacks structure and the binding capacity of silt is less than that of clay. According to Auroville guideline, when the soil is more clayey than sandy it recommends the addition of 20 to 40% coarse sand with soil to give some skeleton and reduce plasticity of the soil. According to Rigassi (1985), cement mainly reacts with sand and gravels. Hence, sufficient coarse sand, fine sand and mixed sand (coarse sand+fine sand) were added with the selected soil to improve its granular structure. In this study, the sand content for CSSB specimens was maintained in the range of 20-60% by weight of soil. Cement was added as a stabilizer in six proportions by weight such as: 3%, 5%, 6%, 7%, 8% and 9%. From the existing literature, it has been found that the economic range of cement is 7 to 8% and minimum average is 5% (Auroville Earth Institute, 2018). In this study, the level of cement was used from 3 to 9%. To demonstrate the role of sand and cement, total 47 types of different soil-sand-cement mixes blocks were produced using aforementioned cement and sand content. And finally, some blocks were made using only soil. These unstabilized blocks were prepared to compare with the stabilized blocks. Crushing strength test was conducted upon the CSSB specimens.

4.4 Properties of CSEB Specimens Made for Compressive Strength Test

Compressive strength tests were performed upon the CSEB specimens made with SS soil to compare the deformation characteristics of different types of earthen blocks. List of specimens with their material compositions is presented in Table 4.3**.** The typical stress-strain relationship for the above mentioned combinations are presented in Fig. 4.3 to 4.6. Finally, in Fig. 4.7 a combined graph was developed for the comparison of stress-strain relationship among CSSB, LJSB, LSB and USB specimens. Description of the specimens group, compressive strength and failure strain is shown in Table 4.4. Comparison of strength parameters of CSEB specimens has been shown in Table 4.5. Moreover, comparisons of ultimate compressive strength and failure strain among different types of CSEB specimens have been presented in Fig. 4.8 and Fig. 4.9. Lastly, in Fig. 4.10, the failure pattern of CSEB specimens is shown.

Table 4.3: Specimens group with material compositions prepared for compressive strength test

Specimens group	Soil type	Stabilizer content (% w/w)				
		Cement	Coarse sand	Lime	Jute fiber	Jute length (cm)
USB	SS	-	-	-	-	-
CSSB		9	13	-	-	-
LSB		-	-	5	-	3-4
LJSB		-	-	5	0.3	3-4

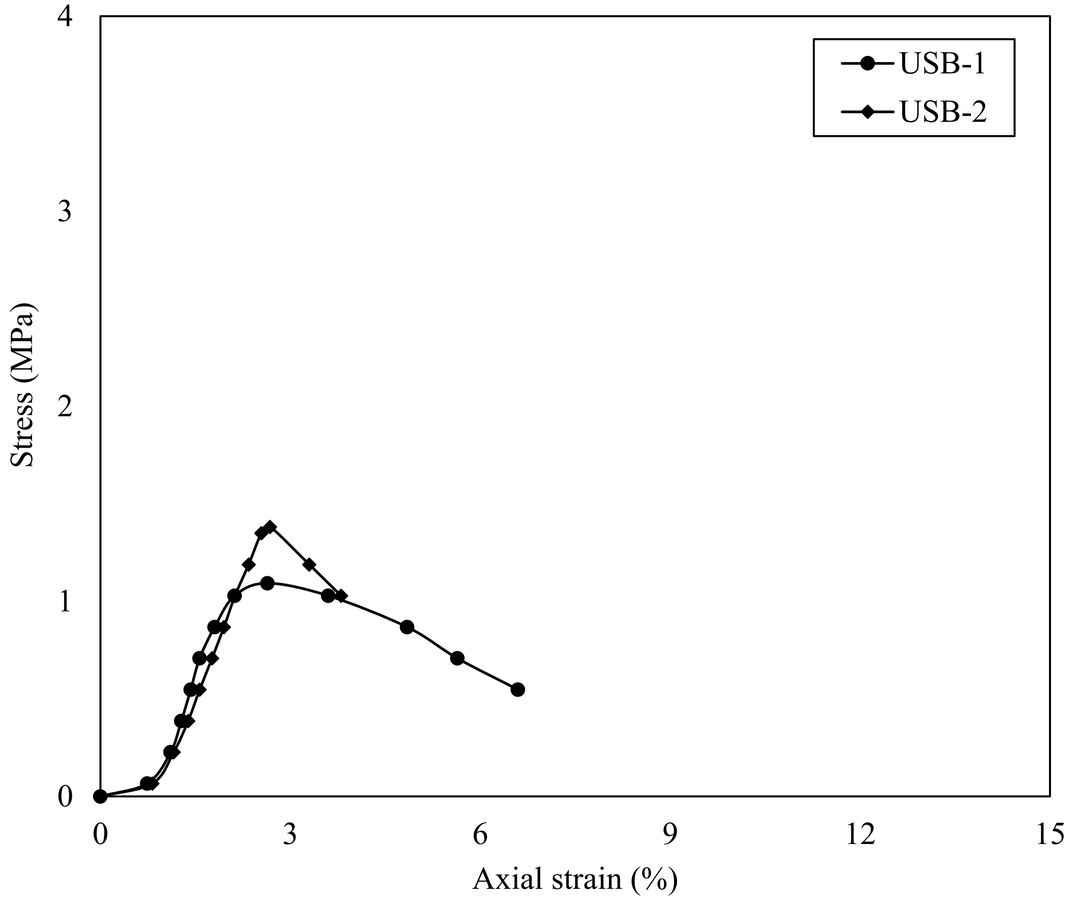


Figure 4.3: Stress-strain relationship curve of Unstabilized Block (USB)

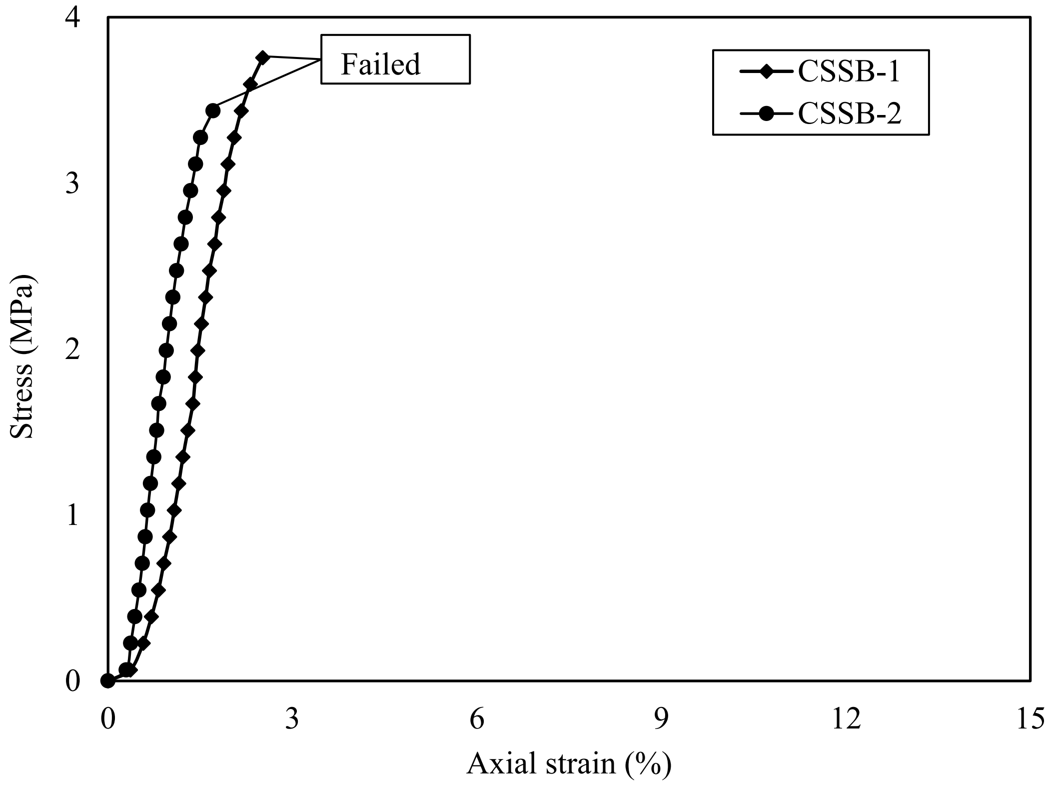


Figure 4.4: Stress-strain relationship curve of Cement Sand Stabilized Block (CSSB)

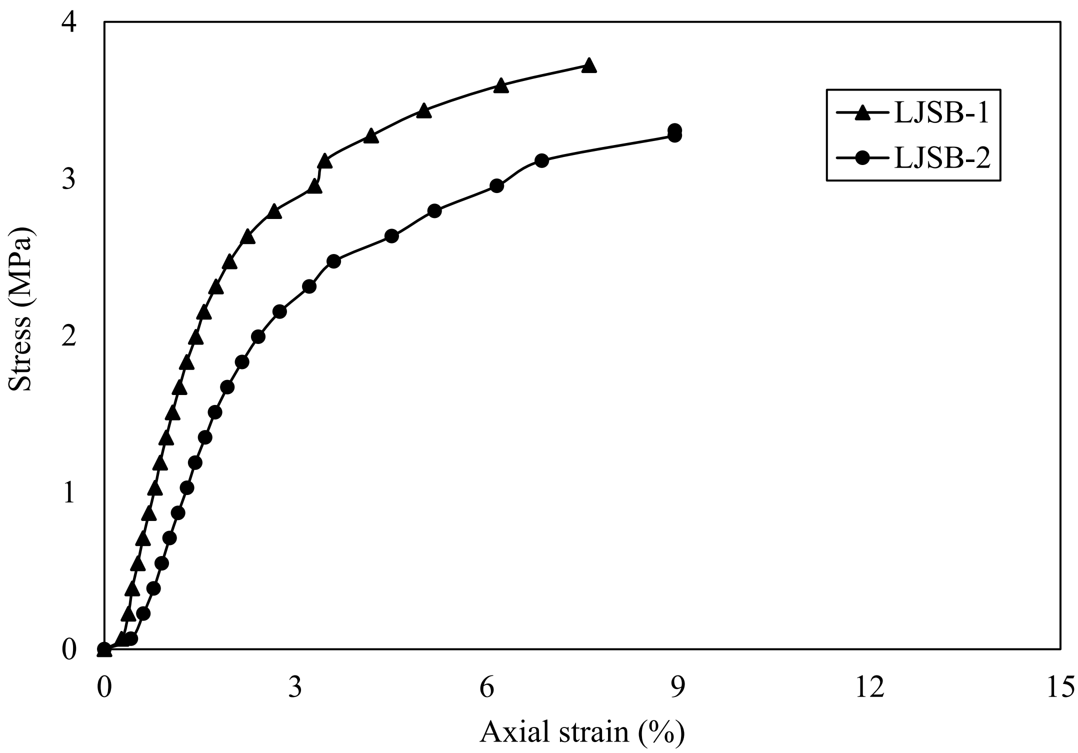


Figure 4.5: Stress-strain relationship curve of Lime Jute Stabilized Block (LJSB)

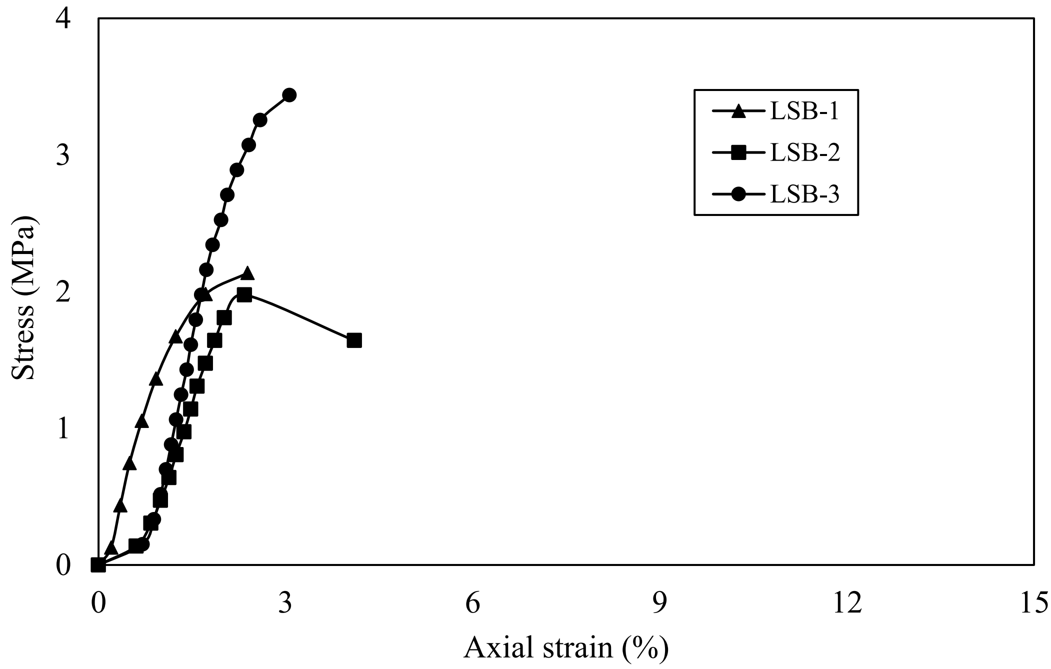


Figure 4.6: Stress-strain relationship curve of Lime Stabilized Block (LSB)

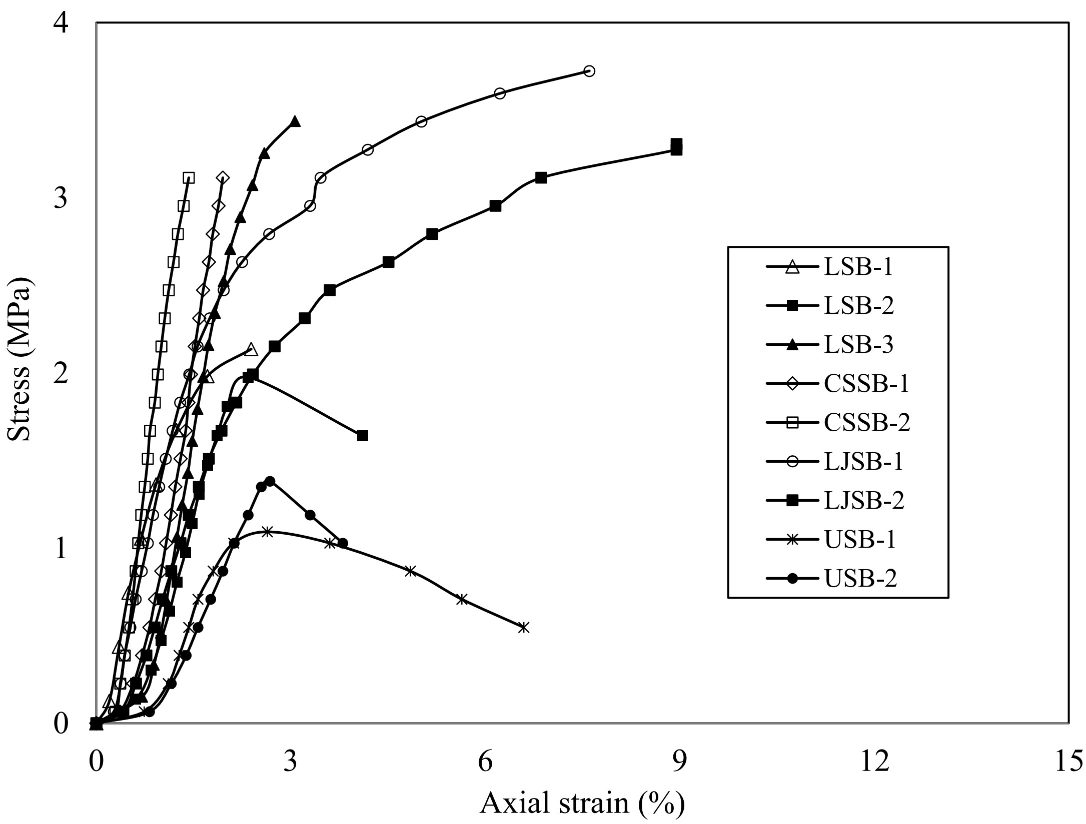


Figure: 4.7: Curve showing a comparison of stress-strain relationship of CSSB, LJSB, LSB and USB specimens

Table 4.4: Stress and strain properties of CSEB specimens

Specimens group	Specimen group ID	Ultimate compressive strength (MPa)	Failure strain (%)
LSB	LSB-1	2.1	2.4
	LSB-2	1.9	2.3
	LSB-3	3.4	3.1
CSSB	CSSB-1	4.1	3.1
	CSSB-2	3.8	2.3
LJSB	LJSB-1	3.7	7.6
	LJSB-2	3.3	8.9
USB	USB-1	1.1	3.6
	USB-2	1.4	2.6

Table 4.5: Comparison of average value of strength parameters of CSEB specimens

Specimens group	Average ultimate compressive strength (MPa)	Average failure strain (%)	Remarks
LSB	2.5	2.6	For LJSB specimen, the ultimate compressive strength has been reduced by 13.2% and failure strain has been increased by 67% compared to CSSB specimen
CSSB	3.9	2.7	
LJSB	3.5	8.2	
USB	1.2	3.1	

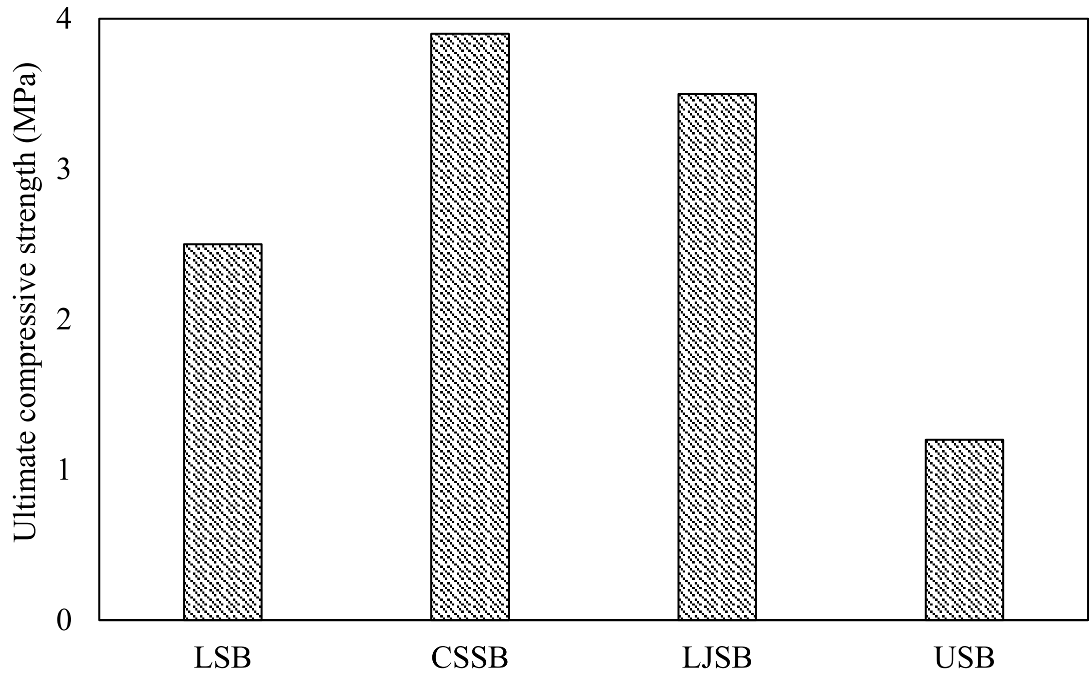


Figure 4.8: Chart showing a comparison of ultimate compressive strength among different types of CSEB specimens

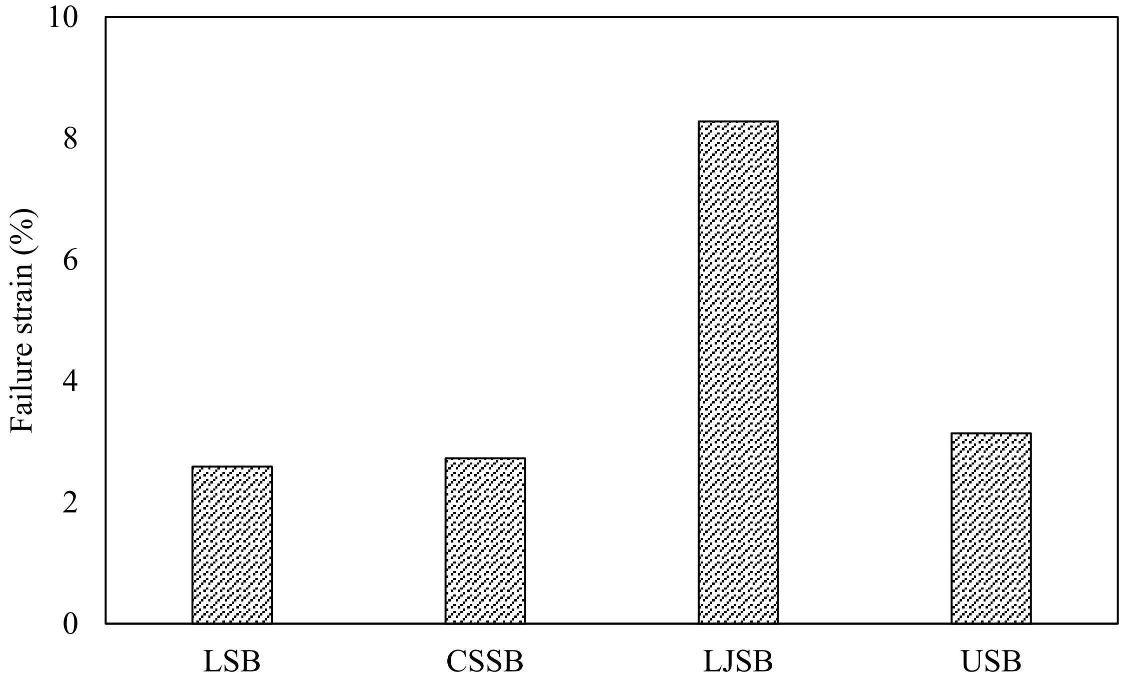
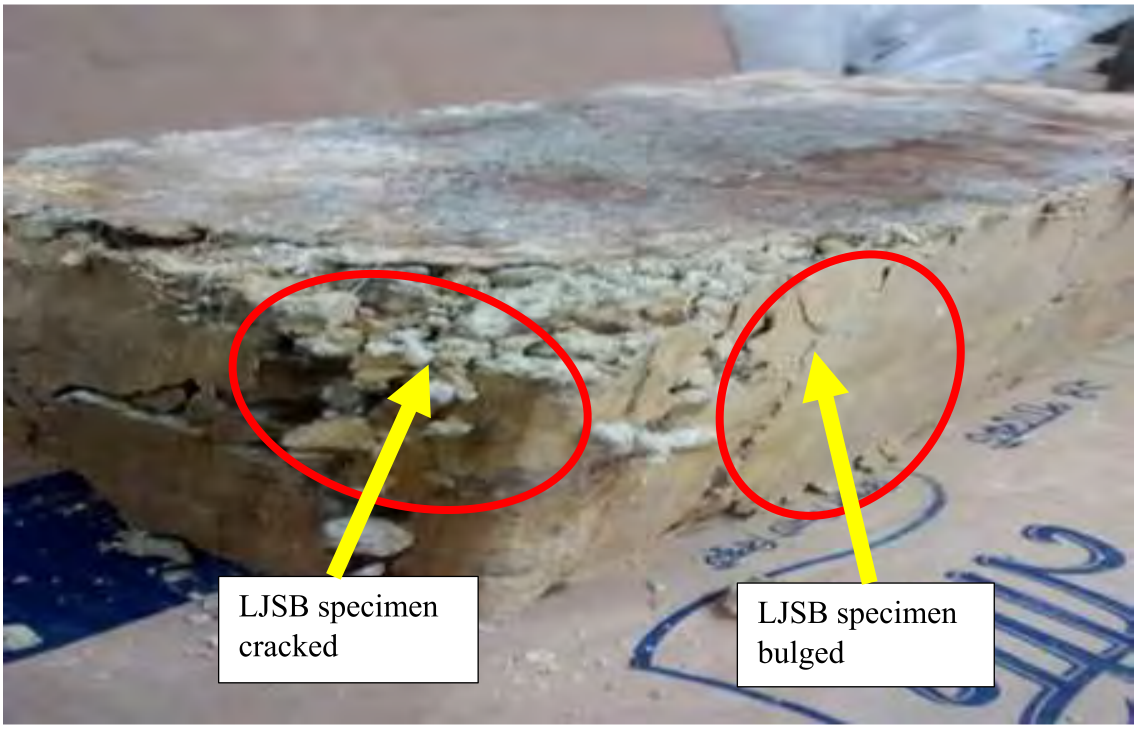
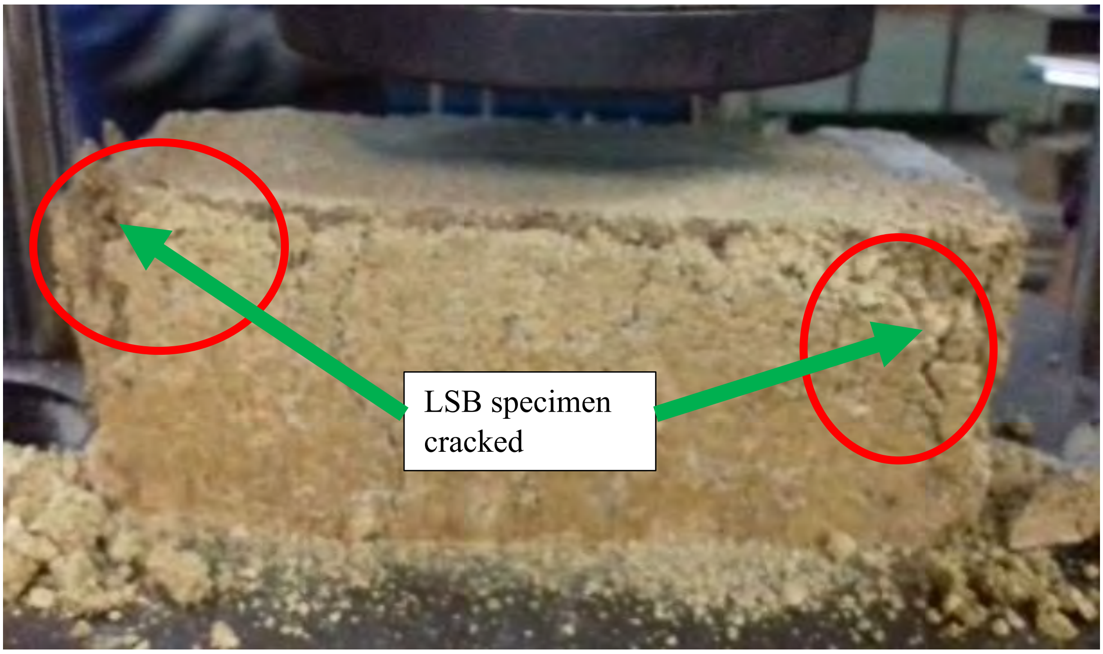


Figure 4.9: Chart showing a comparison of ultimate failure strain among different types of CSEB specimens

(a) Failure pattern of CSSB specimen



(b) Failure pattern of LJSB specimen



(c) Failure pattern of LSB specimen

(d) Failure pattern of USB specimen

Figure 4.10: Failure pattern of CSEB specimens after test: (a) Cement Sand Stabilized Block (CSSB), (b) Lime Jute Stabilized Block (LJSB), (c) Lime Stabilized Block (LSB) and (d) Unstabilized Block (USB)

4.4.1 Comparison of strength and deformation properties of CSEB specimens

CSSB specimen has improved compressive strength (3.9 MPa) than any other types of block (Fig. 4.7). LJSB specimen has improved failure strain than any other types of block (Fig. 4.7). CSSB specimens cracked but LJSB specimens bulged, continued to carry load and sometimes after carrying the load it cracked (Fig. 4.10 (a) and (b)). From Table 4.5, it is seen that the average failure strain of LJSB is 8.3%. The average failure strain of the rest other blocks have in the range of 2.6 to 3.1%. The average compressive strength of the LJSB has been found 3.5 MPa which is near to compressive strength of CSSB. The average compressive strength of LSB and USB was found 2.5 MPa and 1.2 MPa respectively.

Photographs of shear band of LJSB specimen (Fig. 4.10 (b)) indicates that after inception of failure, the randomly distributed jute fibers resist the separation of broken parts. So, the broken (but not separated) parts of the specimen continue to share in the load carrying capacity which in turn increases the failure strain with the overall increase in ductility. So, it is said that although the cement sand stabilized blocks possess high compressive strength, it has low failure strain and ductility of this block is comparatively low. Addition of small amount of lime and jute reinforcement with soil offers considerable bond strength with the development of no shrinkage crack at the time of curing. LJSB specimen stayed in one piece together for a long time at the time of loading because they have high failure strain and considerably good ultimate strength.

4.5 Properties of CSSB Specimens Made for Crushing Strength Test

Crushing strength test was performed upon the block specimens to determine the strength characteristics of Cement Sand Stabilized Block (CSSB). The blocks were prepared using SP1 and SP2 soil. Total 47 types of blocks were prepared stabilized with cement. Description of the specimens group, compressive strength, unit weight and moisture content are given in Table 4.6. Here, the results shown in Table 4.6 are for average of each five numbers blocks of the same group. The data of unit weight, moisture content and crushing strength of all the specimens are plotted in Fig. 4.11 and Fig. 4.12.

Table 4.6: Compressive strength, unit weight and moisture content of CSSB specimens in various combinations

Cement (%)	CSSB specimens	Sand (%)			Average compressive strength (MPa)	Average unit weight ($gmcm^{-3}$)	Average moisture content (%)
		Fine	Coarse	Fine + Coarse			
3	AC23	-	20	-	0.89	1.69	7.2
	AC43	-	40	-	1.13	1.77	6.0
	AC63	-	60	-	1.88	1.83	4.8
5	AC25	-	20	-	3.38	1.61	1.4
	AC35	-	30	-	3.82	1.68	1.7
	AC45	-	40	-	3.85	1.68	1.2
	AC55	-	50	-	3.49	1.77	1.8
	AC65	-	60	-	4.26	1.68	0.9
	AM35	15	15	30	3.21	1.86	0.6
	AF55	50	-	-	5.35	1.74	0.7
	AM45	20	20	40	2.98	1.69	1.9
	AM45C+	13.33	26.67	40	4.03	1.69	0.7
	AM45F+	26.67	13.33	40	5.32	1.76	0.8
	AM55	25	25	50	4.51	2.00	3.1
	AM55C+	16.67	33.33	50	4.52	1.81	1.0
	AM55F+	33.33	16.67	50	4.56	1.79	1.0
	AM55F+2	20	30	50	4.30	1.76	0.7

Table 4.6: Compressive strength, unit weight and moisture content of CSSB specimens in various combinations (contd.)

Cement (%)	CSSB specimens	Sand (%)			Average compressive strength (MPa)	Average unit weight (gmcm^{-3})	Average moisture content (%)
		Fine	Coarse	Fine + Coarse			
5	AM65	30	30	60	3.46	1.83	1.4
	AM65C+	20	40	60	4.23	1.87	1.0
	AM65F+	40	20	60	3.30	1.78	1.3
	AF65	60	-	-	3.25	1.74	1.2
6	AC26	-	20	-	3.57	1.68	5.0
	AC36	-	30	-	3.96	1.72	2.8
	AC46	-	40	-	4.25	1.73	3.6
	AC56	-	50	-	4.53	1.82	3.1
	AC66	-	60	-	4.73	1.87	2.3
	AM36	15	15	30	4.08	1.72	1.6
	AM36C+	10	20	30	4.30	1.85	2.0
	AM36F+	20	10	30	3.71	1.71	1.0
	AM46	20	20	40	5.23	1.68	0.9
	AM46C+	13.33	26.67	40	5.28	1.85	1.7
	AM56	25	25	50	5.06	1.80	2.0
	AM56F+	33.33	16.67	50	6.07	1.79	0.4
7	AC47	-	40	-	5.64	1.79	3.6
	AC57	-	50	-	5.62	1.82	3.3
	AC67	-	60	-	4.42	1.79	1.5
	AM37	15	15	30	4.66	1.74	1.6

Table 4.6: Compressive strength, unit weight and moisture content of CSSB specimens in various combinations (contd.)

Cement (%)	CSSB specimens	Sand (%)			Average compressive strength (MPa)	Average unit weight (gmcm^{-3})	Average moisture content (%)
		Fine	Coarse	Fine + Coarse			
8	AC28	-	20	-	3.54	1.68	5.6
	AC38	-	30	-	5.17	1.61	4.0
	AC48	-	40	-	5.41	1.71	2.1
	AC58	-	50	-	5.58	1.79	3.8
	AC68	-	60	-	5.62	1.82	1.1
	AM48	20	20	40	4.98	1.79	4.1
	AM68F+	40	20	60	5.24	1.93	3.7
9	AC29	20	20	-	2.75	1.75	12.5
	AC49	40	40	-	3.28	1.82	10.3
	AC69	60	60	-	5.59	1.90	5.3
Unstabilized block	-	-	-	-	1.37	1.65	4.8

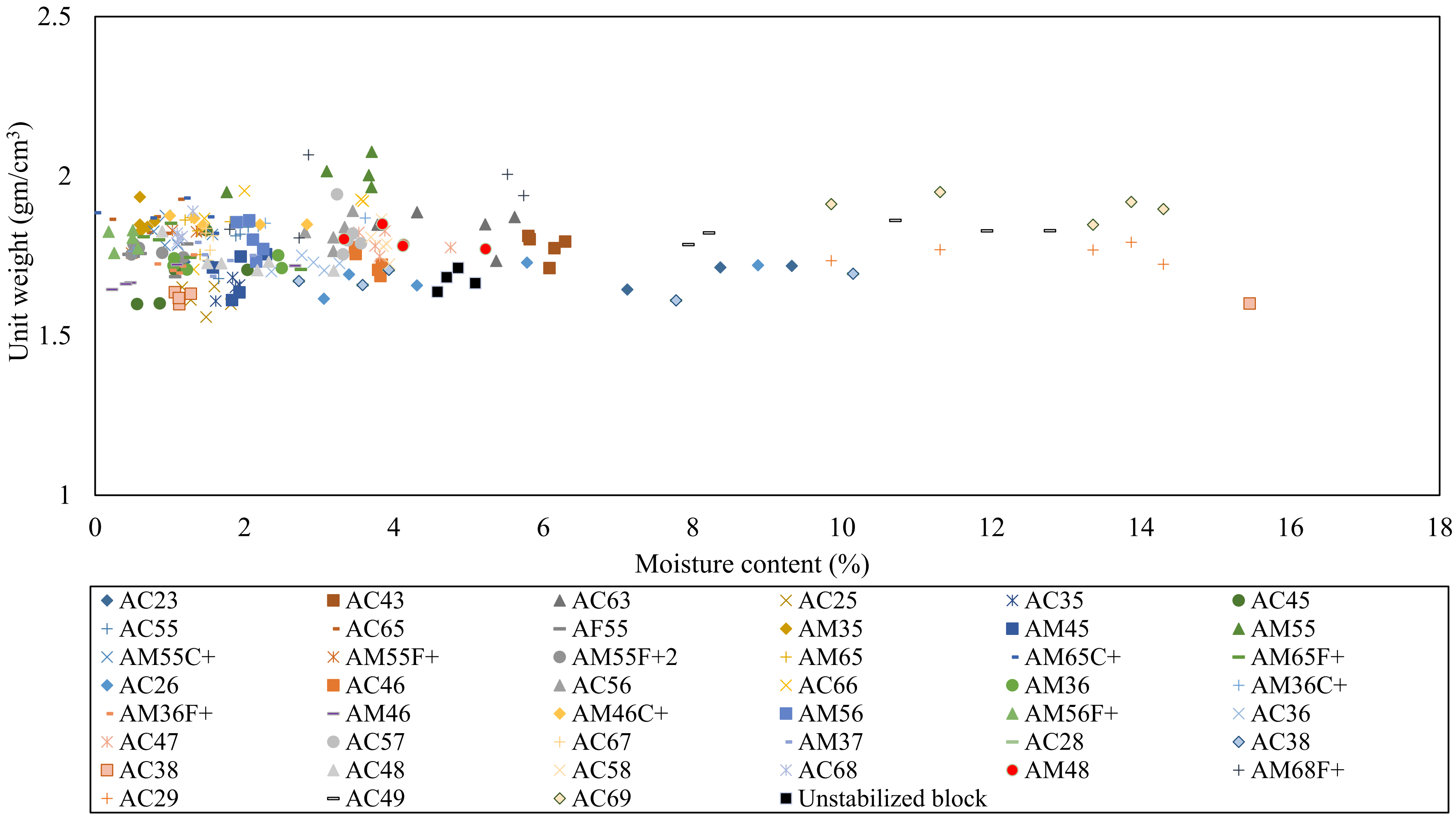


Figure 4.11: Unit weight vs moisture content of CSSB specimens

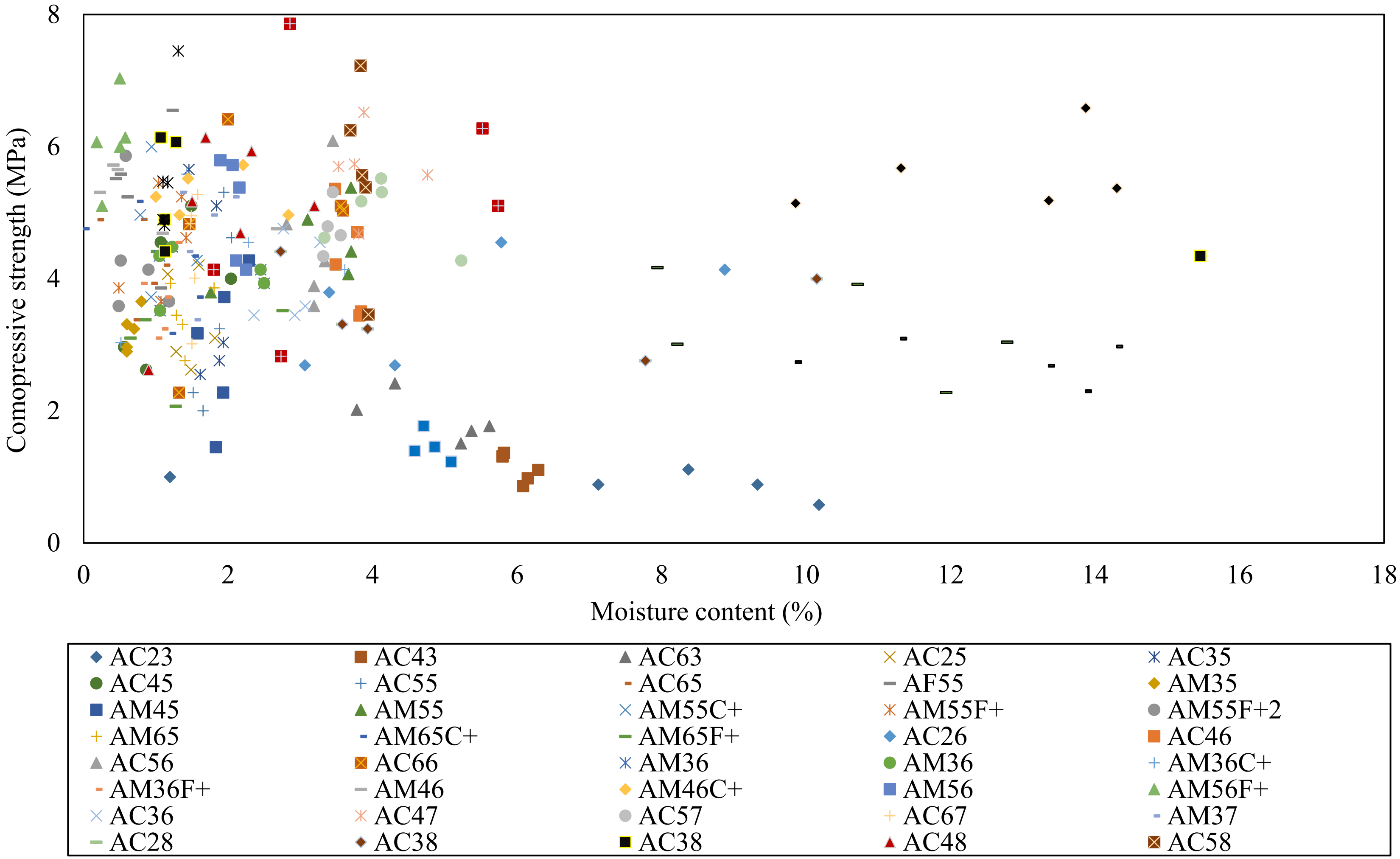


Figure 4.12: Compressive strength vs moisture content of CSSB specimens

4.6 Compressive Strength of Unstabilised Block (USB) Prepared for Crushing Strength Test

Total 5 numbers of unstabilised block have been prepared for crushing strength test. From the Fig. 4.13 compressive strength of unstabilized block (USB) has been found in the range of 1 to 2 MPa in the condition of moisture content 4.58 to 5.08 % and unit weight 1.58 to 1.82 gm/cm^3.

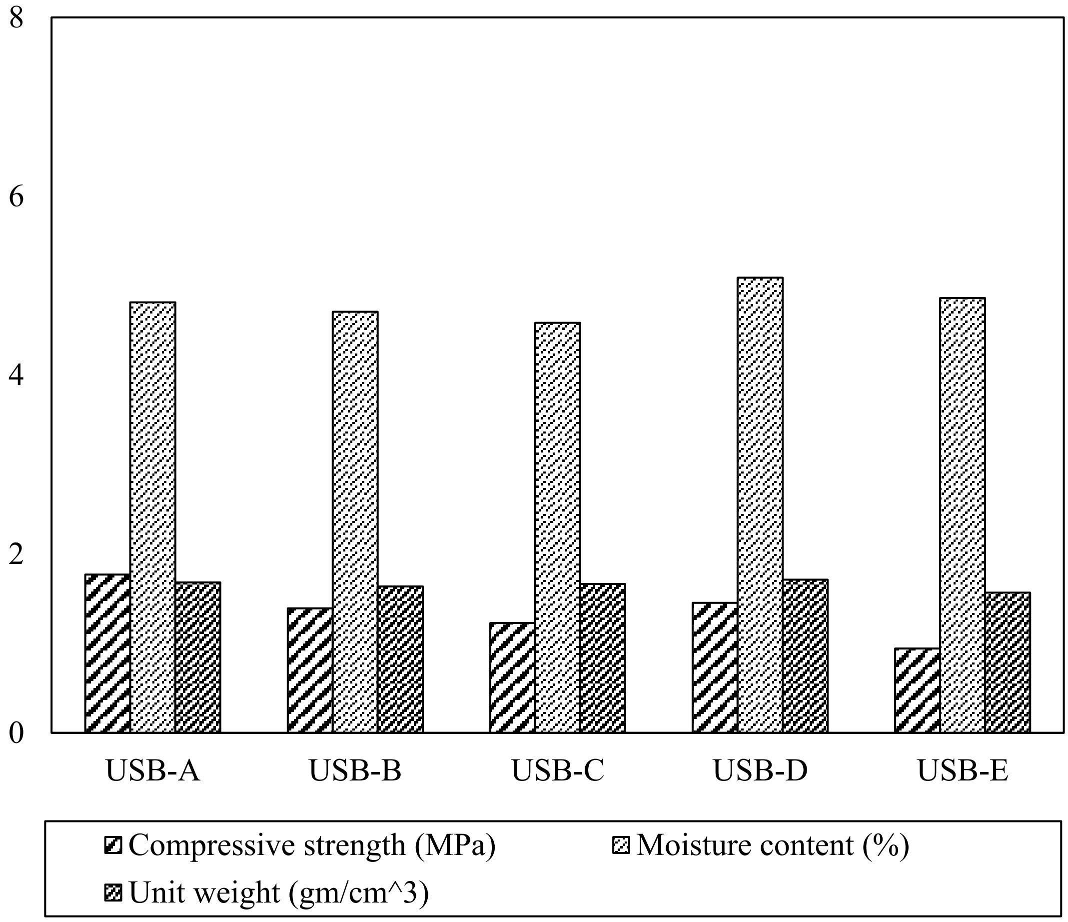


Figure 4.13: Chart showing compressive strength, moisture content and unit weight of Unstabilized Block (USB)

4.7 Variation of Compressive Strength of CSSB specimens with Cement Content

From the Fig. 4.14 to 4.23, the variation of compressive strength of CSSB specimens with cement content have been presented and lastly, a combined graph for variation of compressive strength of CSSB specimens with cement content has been presented in Fig. 4.24.

4.7.1 Variation of compressive strength of CSSB specimens with cement content for 20% coarse sand

In Fig. 4.14, the compressive strength of each five specimens prepared with 20% coarse sand has been plotted against each level of cement stabilization. In Fig. 4.15, the variation of compressive strength using an average of five specimens has been presented with cement content for the specimens prepared with 20% coarse sand.

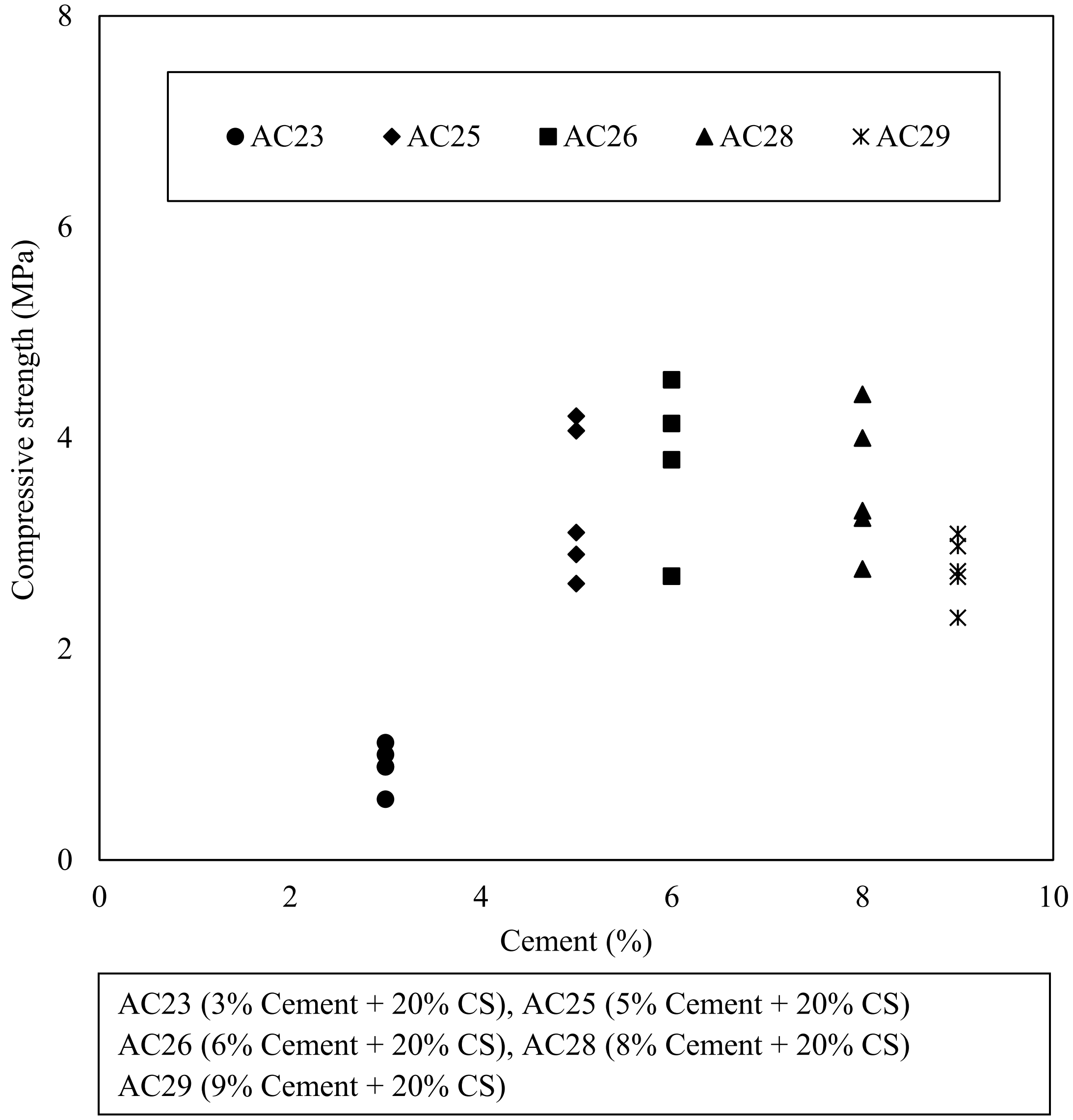
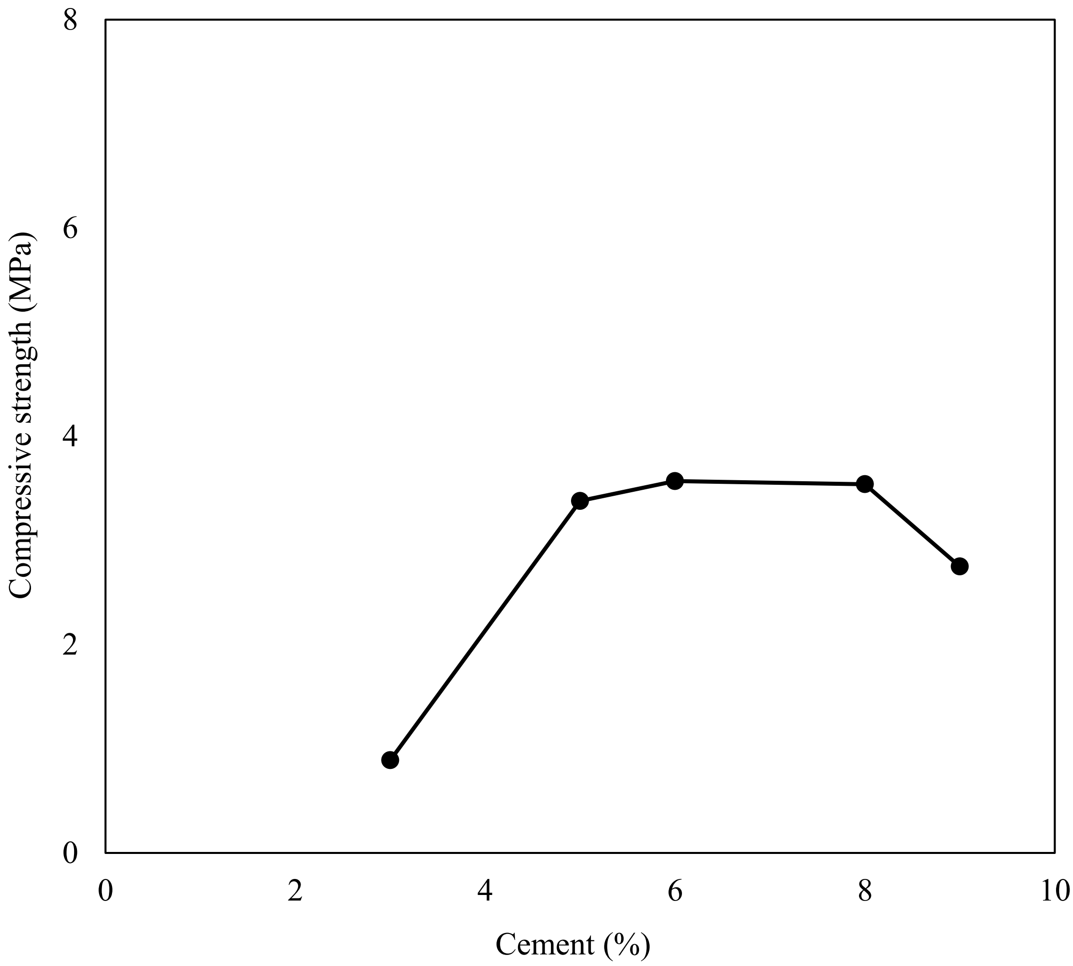


Figure 4.14: Compressive strength vs cement content (3%, 5%, 6%, 8% and 9%) for 20% coarse sand



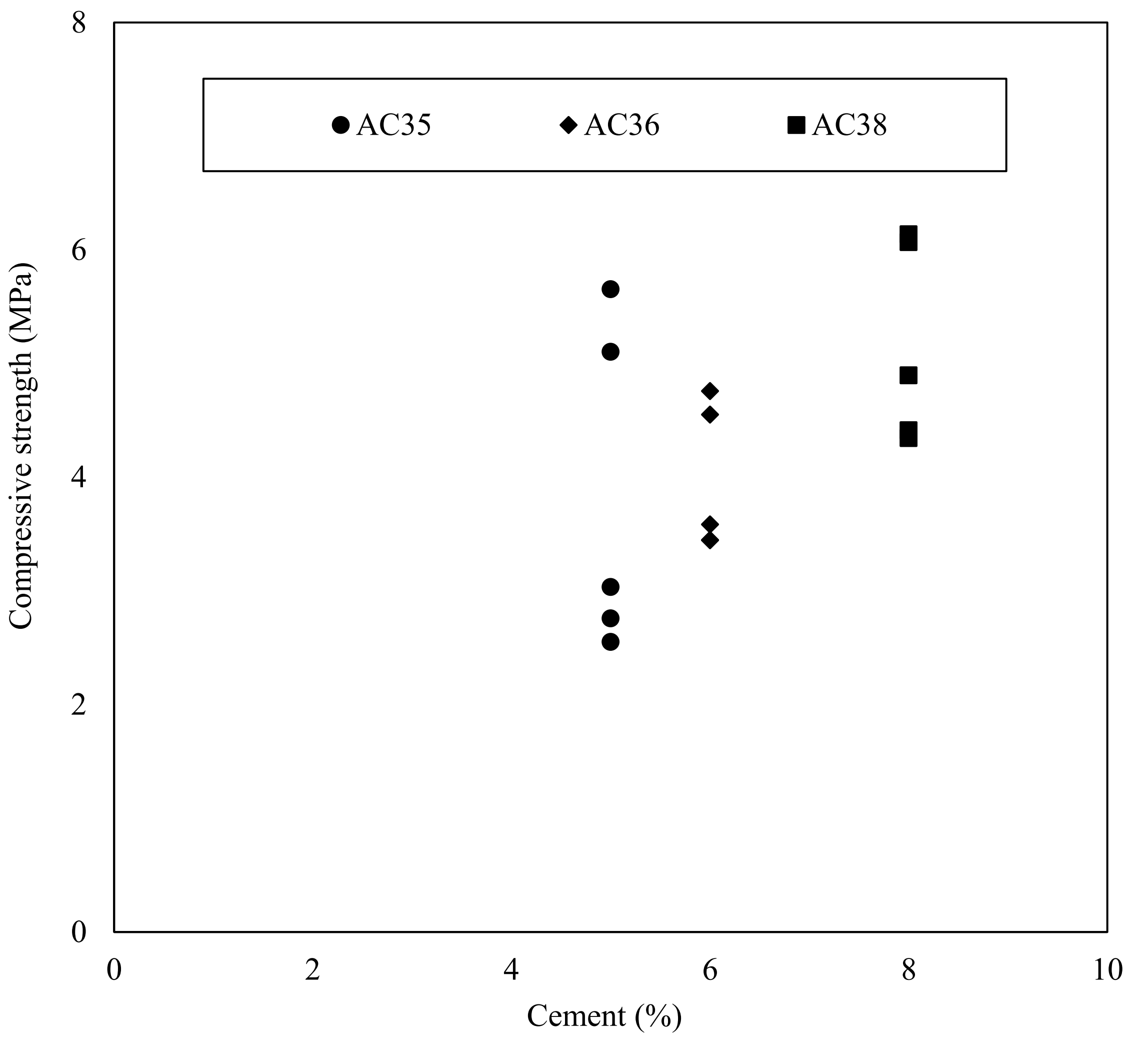
AC23 (3% Cement + 20% CS), AC25 (5% Cement + 20% CS)
AC26 (6% Cement + 20% CS), AC28 (8% Cement + 20% CS)
AC29 (9% Cement + 20% CS)

Figure 4.15: Variation of compressive strength with cement content for 20% coarse sand

From the Fig. 4.15, it is seen that the compressive strength increases from 0.89 MPa to 3.57 MPa with the increase of cement content from 3% to 6%. After this, the increment of strength becomes steady up to 8% cement. Then, the compressive strength decreases after the addition of 8% cement. From the Fig. 4.15, it can be seen that the rate of increase of compressive strength from AC25 to AC26 is 5% only. From the Fig. 4.15, it seems that 5% cement content is optimum for the CSSB specimens containing 20% coarse sand.

4.7.2 Variation of compressive strength of CSSB specimens with cement content for 30% coarse sand

In Fig. 4.16, the compressive strength of each five specimens prepared with 30% coarse sand has been plotted against each level of cement stabilization. In Fig. 4.17, the variation of compressive strength using an average of five specimens has been presented with cement content for the specimens prepared with 30% coarse sand.



AC35 (5% Cement + 30% CS), AC36 (6% Cement + 30% CS)
AC38 (8% Cement + 30% CS)

Figure 4.16: Compressive strength vs cement content (5%, 6% and 8%) for 30% coarse sand

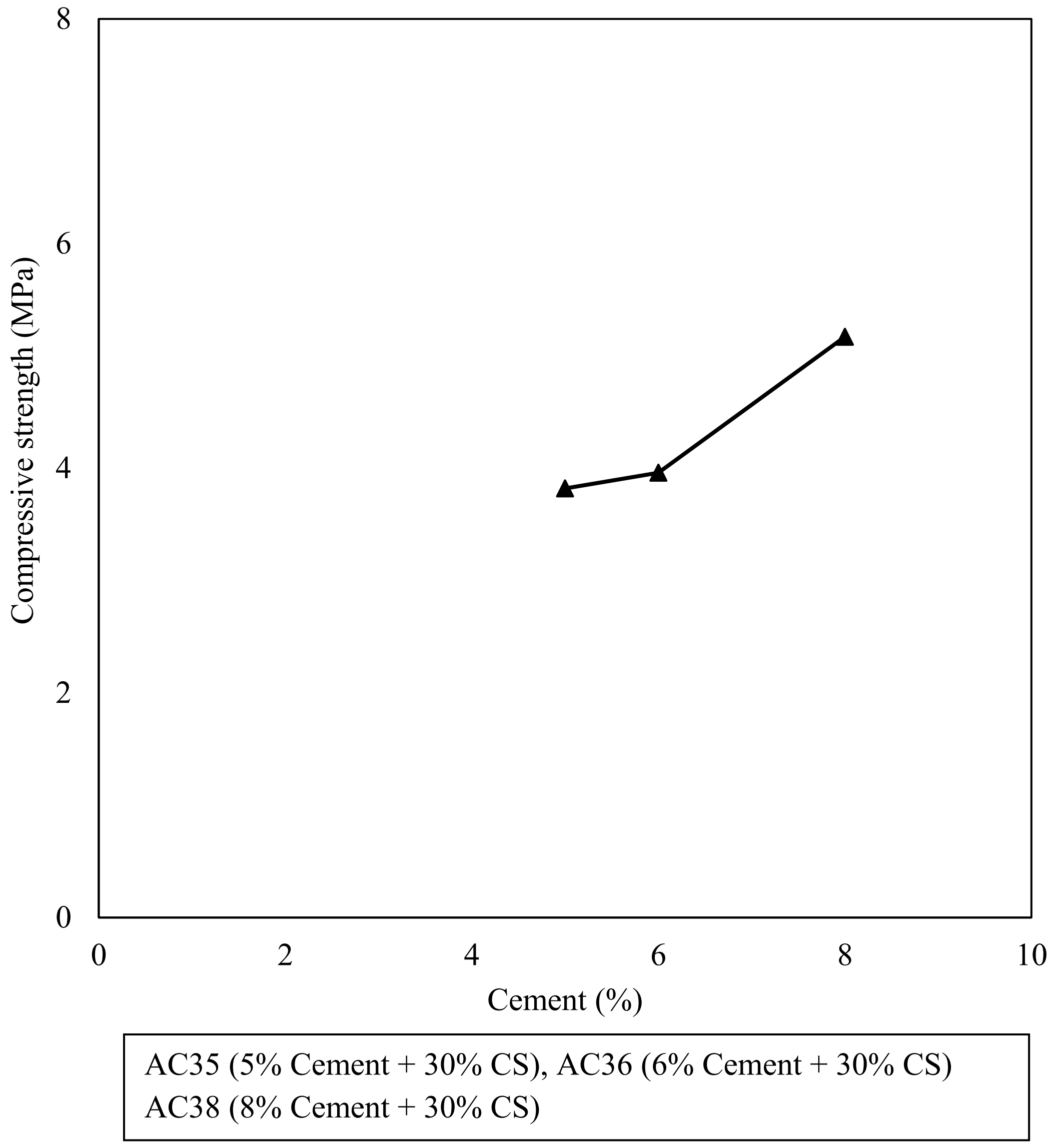
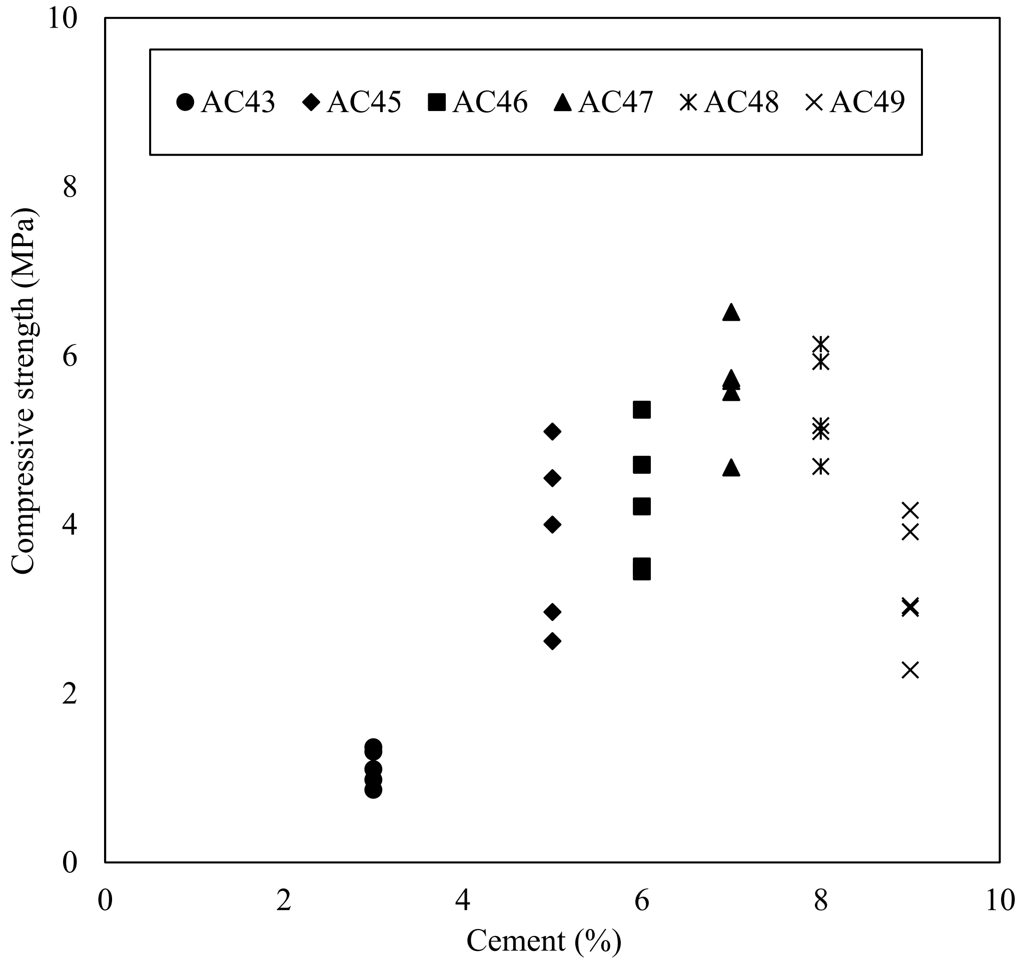


Figure 4.17: Variation of compressive strength with cement content for 30% coarse sand

From the Fig. 4.17, it is seen that the compressive strength increases with the increase of cement content. The compressive strength increases from 3.82 MPa to 5.17 MPa with the increase of cement content from 5% to 8% for the specimens prepared with 30% coarse sand. The compressive strength increases by 3.67% with the increase of cement content from 5% to 6% for the specimens (AC35 and AC36) prepared with 30% coarse sand. Again, the rate of increase of compressive strength is 30.5% for the specimens (AC36 and AC38) prepared with 30% coarse sand when cement content increases from 6% to 8%.

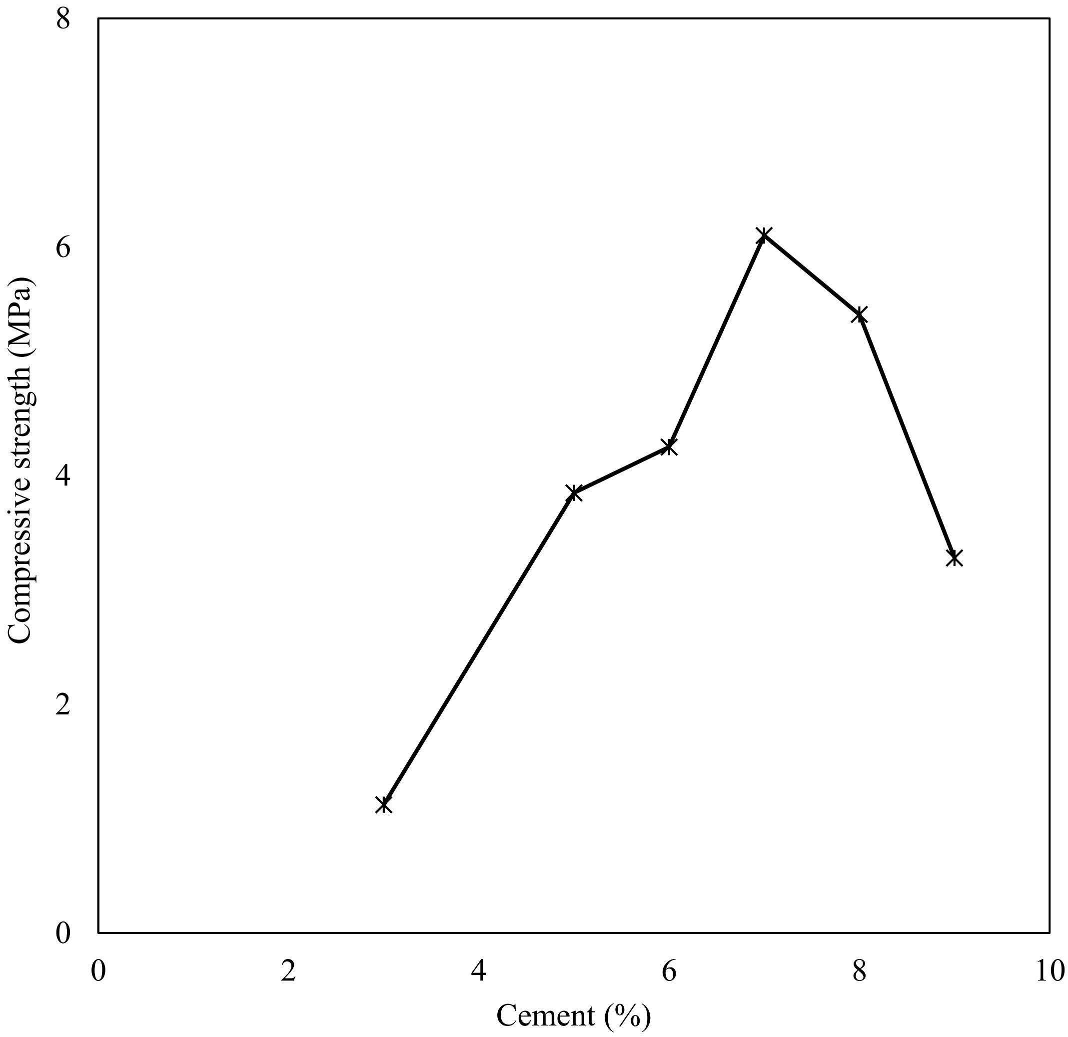
4.7.3 Variation of compressive strength of CSSB specimens with cement content for 40% coarse sand

In Fig. 4.18, the compressive strength of each five specimens prepared with 40% coarse sand has been plotted against each level of cement stabilization. In Fig. 4.19, the variation of compressive strength using an average of five specimens has been presented with cement content for the specimens prepared with 40% coarse sand.



AC43 (3% Cement + 40% CS), AC45 (5% Cement + 40% CS)
AC46 (6% Cement + 40% CS), AC47 (7% Cement + 40% CS)
AC48 (8% Cement + 40% CS), AC49 (9% Cement + 40% CS)

Figure 4.18: Compressive strength vs cement content (3%, 5%, 6%, 7%, 8% and 9%) for 40% coarse sand



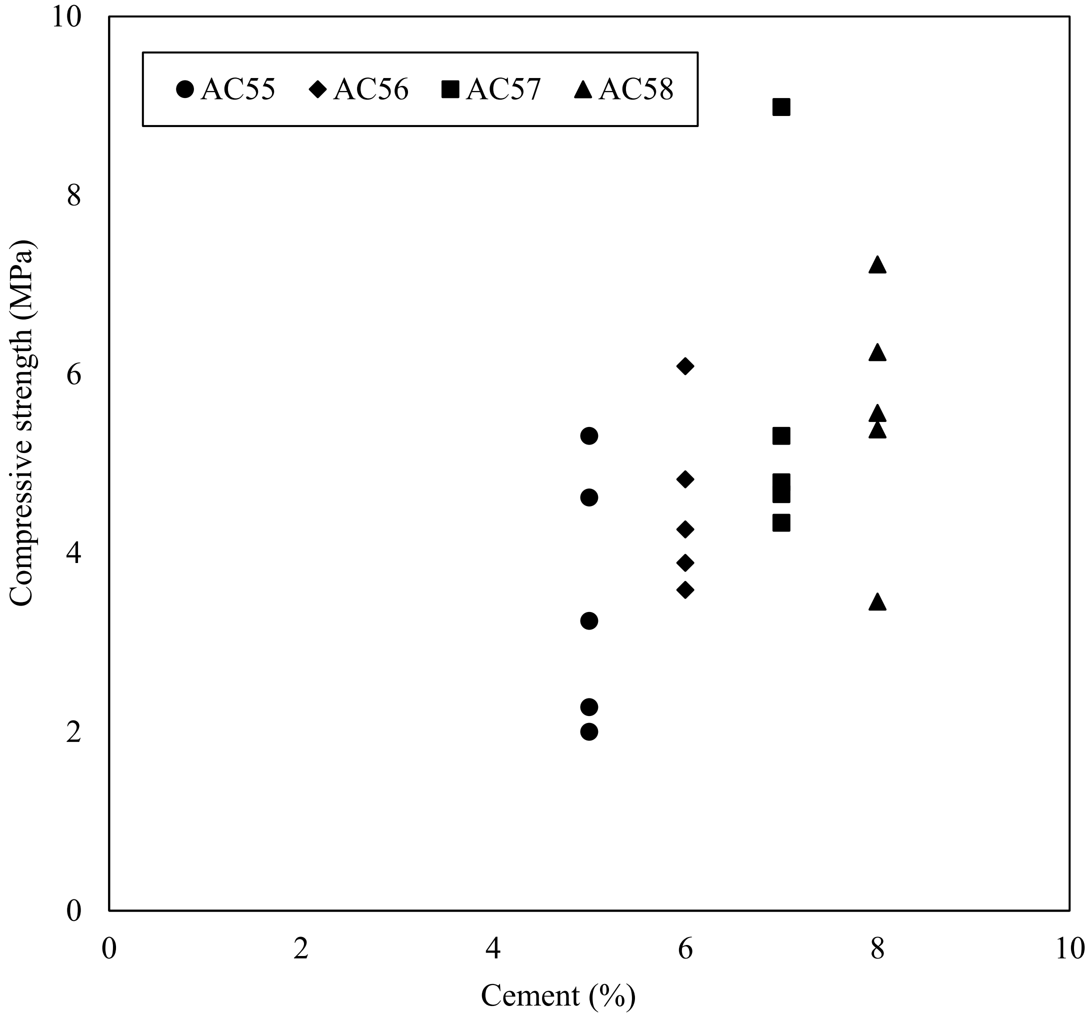
AC43 (3% Cement + 40% CS), AC45 (5% Cement + 40% CS)
AC46 (6% Cement + 40% CS), AC47 (7% Cement + 40% CS)
AC48 (8% Cement + 40% CS), AC49 (9% Cement + 40% CS)

Figure 4.19: Variation of compressive strength with cement content for 40% coarse sand

From the Fig. 4.19, it is seen that the compressive strength increases from 1.12 MPa to 6.1 MPa with the increase of cement content from 3% to 7%. After that, the compressive strength decreases. From this, it seems that 7% cement content is optimum for the CSSB specimens containing 40% coarse sand.

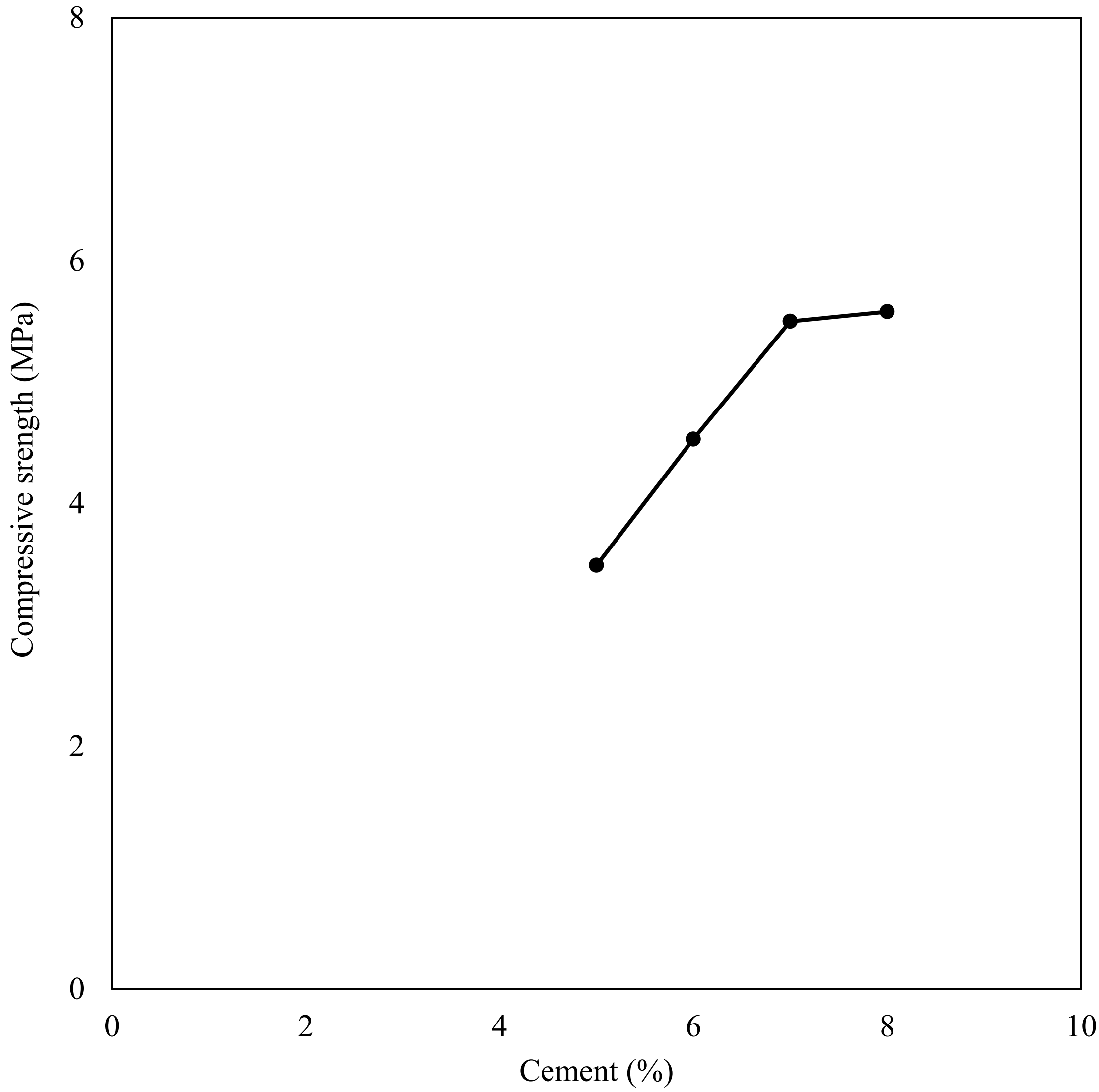
4.7.4 Variation of compressive strength of CSSB specimens with cement content for 50% coarse sand

In Fig. 4.20, the compressive strength of each five specimens prepared with 50% coarse sand has been plotted against each level of cement stabilization. In Fig. 4.21, the variation of compressive strength using an average of five specimens has been presented with cement content for the specimens prepared with 50% coarse sand.



AC55 (5% Cement + 50% CS), AC56 (6% Cement + 50% CS)
AC57 (7% Cement + 50% CS), AC58 (8% Cement + 50% CS)

Figure 4.20: Compressive strength vs cement content (5%, 6%, 7% and 8%) for 50% coarse sand



AC55 (5% Cement + 50% CS), AC56 (6% Cement + 50% CS)
AC57 (7% Cement + 50% CS), AC58 (8% Cement + 50% CS)

Figure 4.21: Variation of compressive strength with cement content for 50% coarse sand

From the Fig. 4.21, it is seen that the compressive strength increases from 3.49 MPa to 5.58 MPa with the increase of cement content from 3% to 8%. The rate of increase of compressive strength from AC57 to AC58 is 1.4% only. From this, it seems that 7% cement content is optimum for the CSSB specimens containing 50% coarse sand.

4.7.5 Variation of compressive strength of CSSB specimens with cement content for 60% coarse sand

In Fig. 4.22, the compressive strength of each five specimens prepared with 50% coarse sand has been plotted against each level of cement stabilization. In Fig. 4.23, the variation of compressive strength using an average of five specimens has been presented with cement content for the specimens prepared with 60% coarse sand.

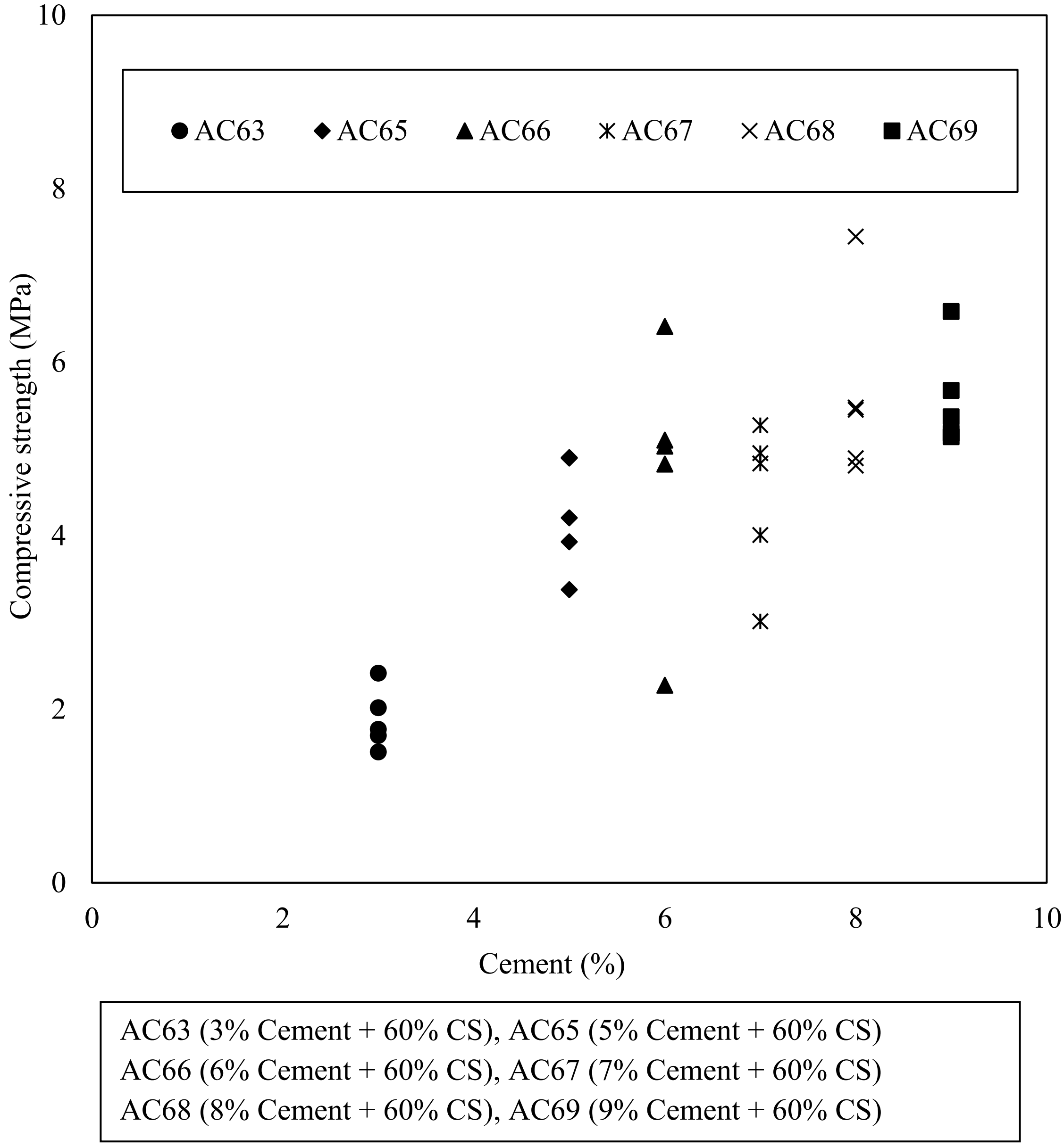
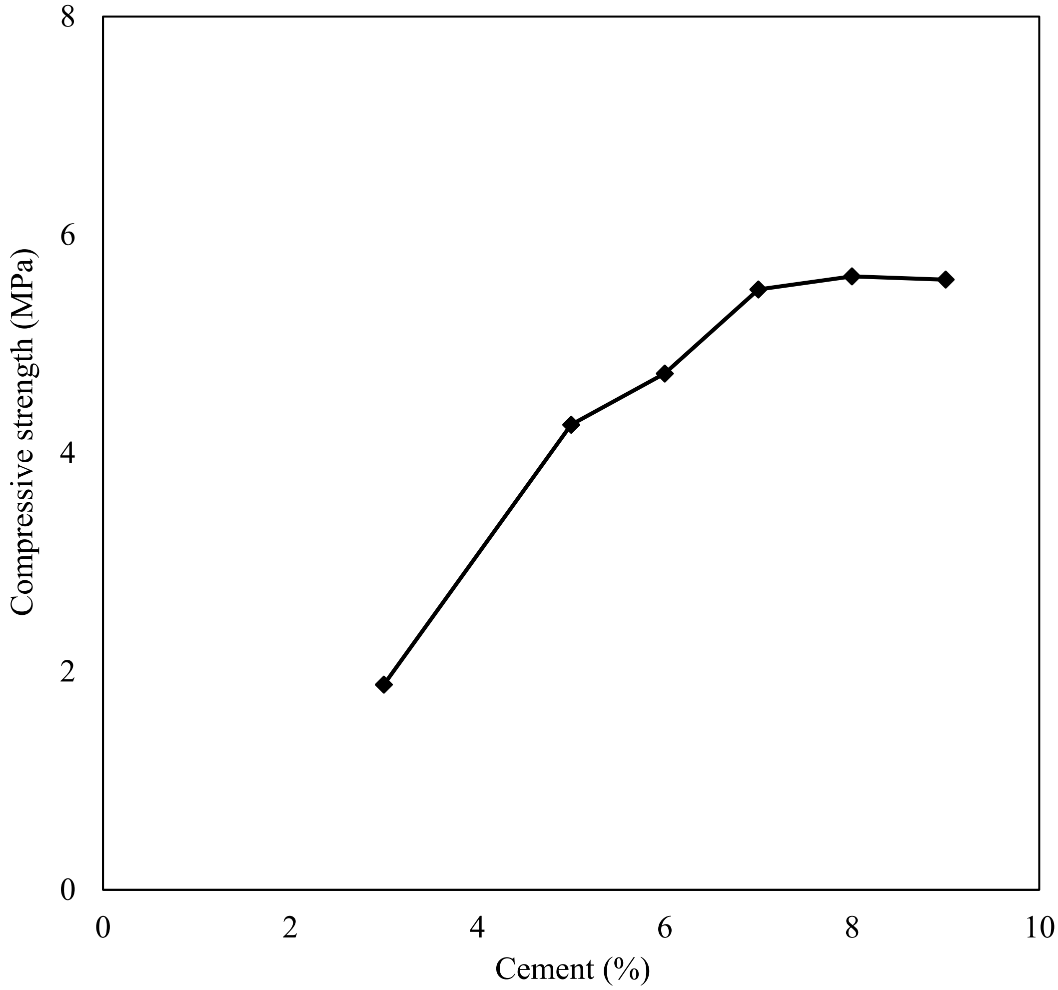


Fig. 4.22: Compressive strength vs cement content (3%, 5%, 6%, 7%, 8% and 9%) for 60% coarse sand



AC63 (3% Cement + 60% CS), AC65 (5% Cement + 60% CS)
AC66 (6% Cement + 60% CS), AC67 (7% Cement + 60% CS)
AC68 (8% Cement + 60% CS), AC69 (9% Cement + 60% CS)

Figure 4.23: Variation of compressive strength with cement content for 60% coarse sand

From the Fig. 4.23, it is seen that the compressive strength increases from 1.18 MPa to 5.62 MPa with the increase of cement content from 3% to 8%. After the addition of 9% cement the compressive strength decreases. From this figure, it can be seen that the rate of increase of compressive strength from AC67 to AC68 is 2% only. Therefore, it seems that 7% cement content is optimum for the CSSB specimens containing 60% coarse sand.

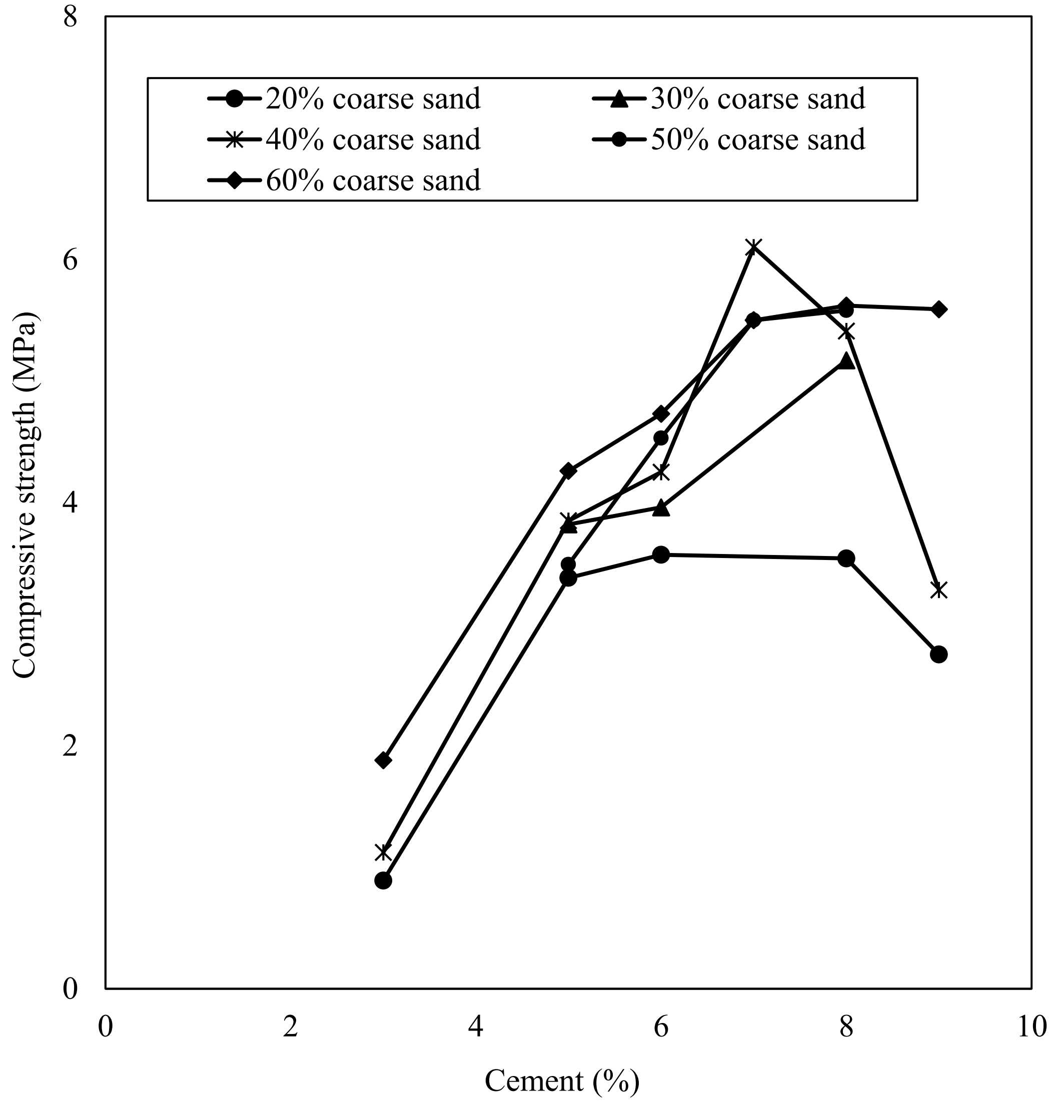


Figure 4.24: Line showing a comparison of compressive strength of CSSB specimens with cement content for different percentages of coarse sand

From the Fig. 4.15, it seems that for the CSSB specimens containing 20% coarse sand optimum cement content is 5%. From the Fig. 4.17, it can be seen that for the CSSB specimens containing 30% coarse sand, the compressive strength increases with the increase of cement content. From the Fig. 4.19, 4.21 and 4.23, it can be seen that for the CSSB specimens containing 40%, 50% and 60% coarse sand the optimum cement content is 7%. From the Fig. 4.14 to 4.23, it also seems that after addition of 40% coarse sand, compressive strength of CSSB specimens either decreases or rate of increase of compressive strength becomes low.

4.8 Variation of Compressive Strength of CSSB Specimens with Coarse Sand Content

From the Fig. 4.25 to 4.30, the variation of compressive strength of CSSB specimens using an average of five specimens with coarse sand for the specimens prepared with 3%, 5%, 6%, 7%, 8% and 9% cement content have been presented. Lastly, a combined graph has been developed in Fig. 4.31.

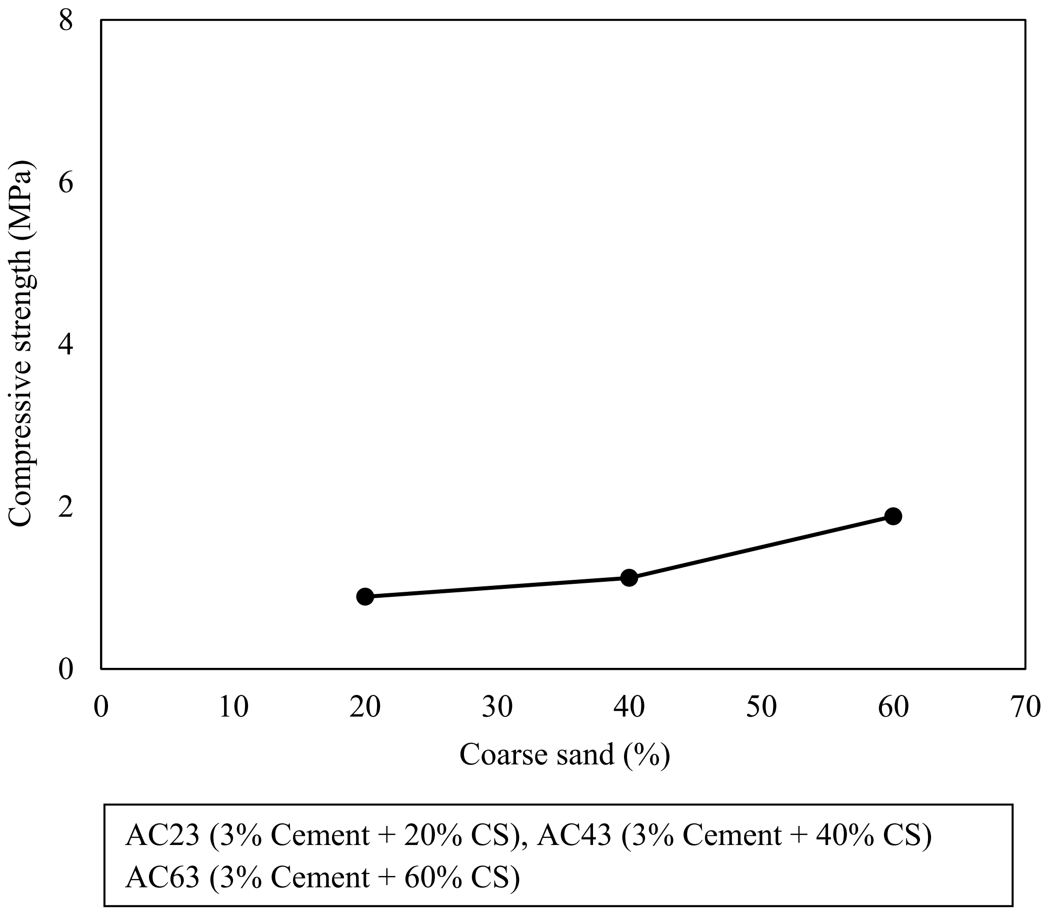


Figure 4.25: Variation of compressive strength with coarse sand for 3% cement stabilization

From the Fig. 4.25, it is seen that the compressive strength increases with the increase of coarse sand. The compressive strength increases from 0.89 MPa to 1.89 MPa with the increase of coarse sand from 20% to 60%. The rate of increase of compressive strength from AC23 to AC43 and AC43 to AC63 is 36% and 69% respectively.

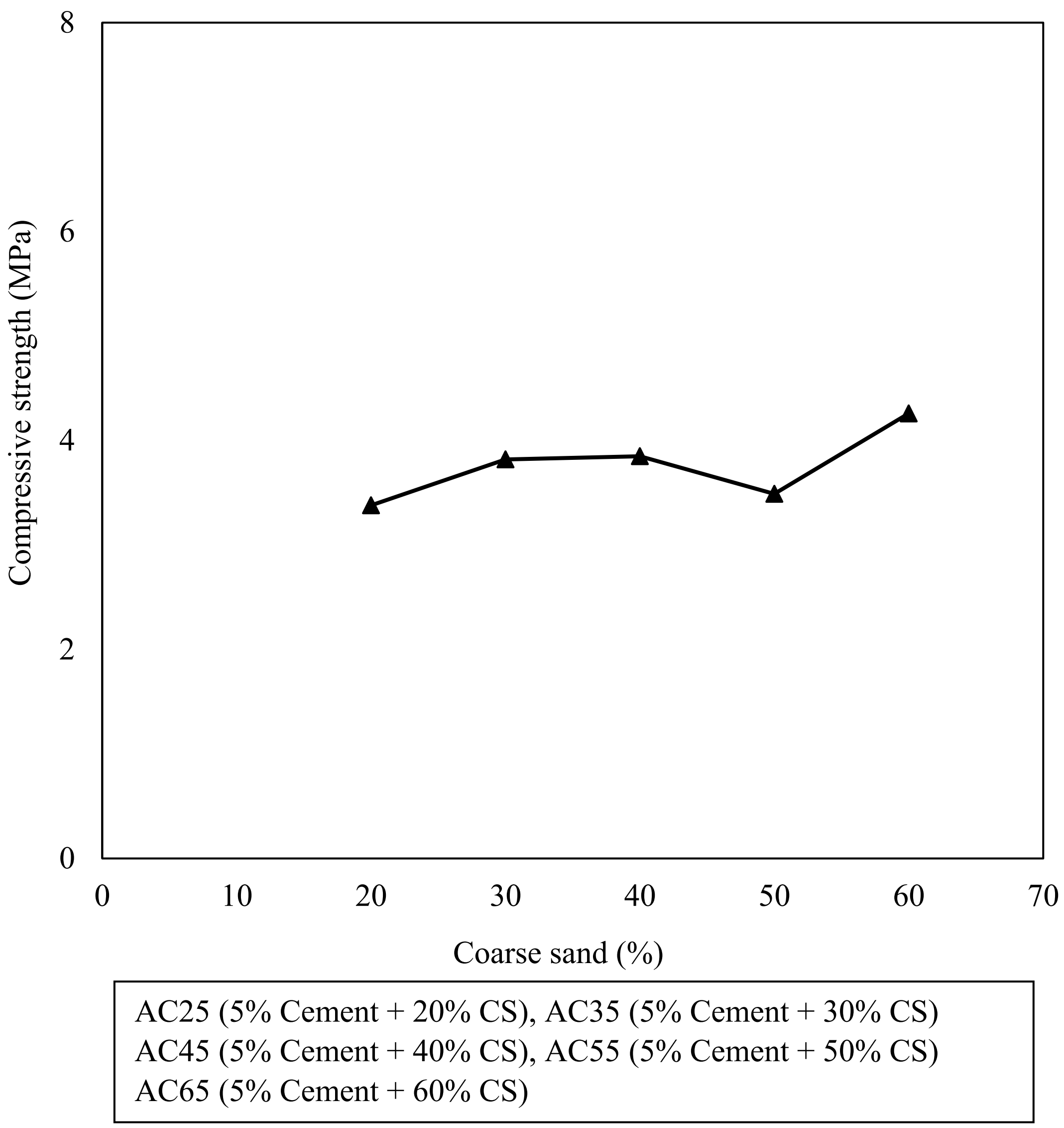


Figure 4.26: Variation of compressive strength with coarse sand for 5% cement stabilization

From the Fig. 4.26, it is seen that the compressive strength increases from 3.38 MPa to 3.85 MPa with the increase of coarse sand from 20% to 40%. After this, the compressive strength decreases after adding 50% coarse sand. Again, the compressive strength of the specimens (AC55 and AC65) prepared with 5% cement increases from 3.49 to 4.26 MPa with the increase of coarse sand from 50% to 60%. It is also observed that the rate of increase of compressive strength for the specimens (AC55 and AC65) prepared with 5% cement with the increase of coarse sand from 50% to 60% is 22%.

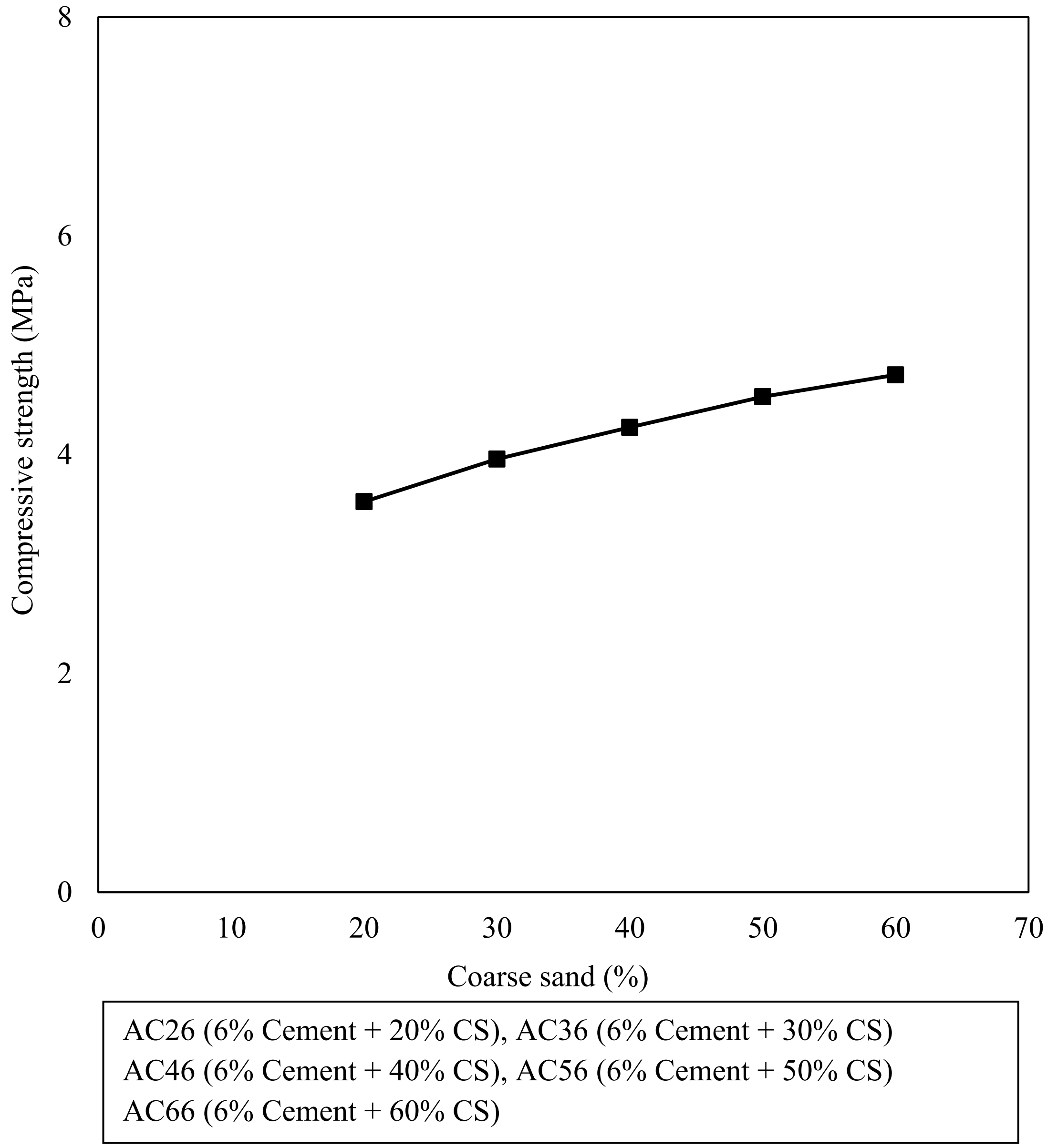


Figure 4.27: Variation of compressive strength with coarse sand for 6% cement stabilization

From the Fig. 4.27, it is seen that the compressive strength increases from 3.57 MPa to 4.73 MPa with the increase of coarse sand from 20% to 60%. The rate of increase of compressive strength from AC26 to AC36, AC36 to AC46, AC46 to AC56 and AC56 to AC66 is 11%, 7%, 7% and 4% respectively.

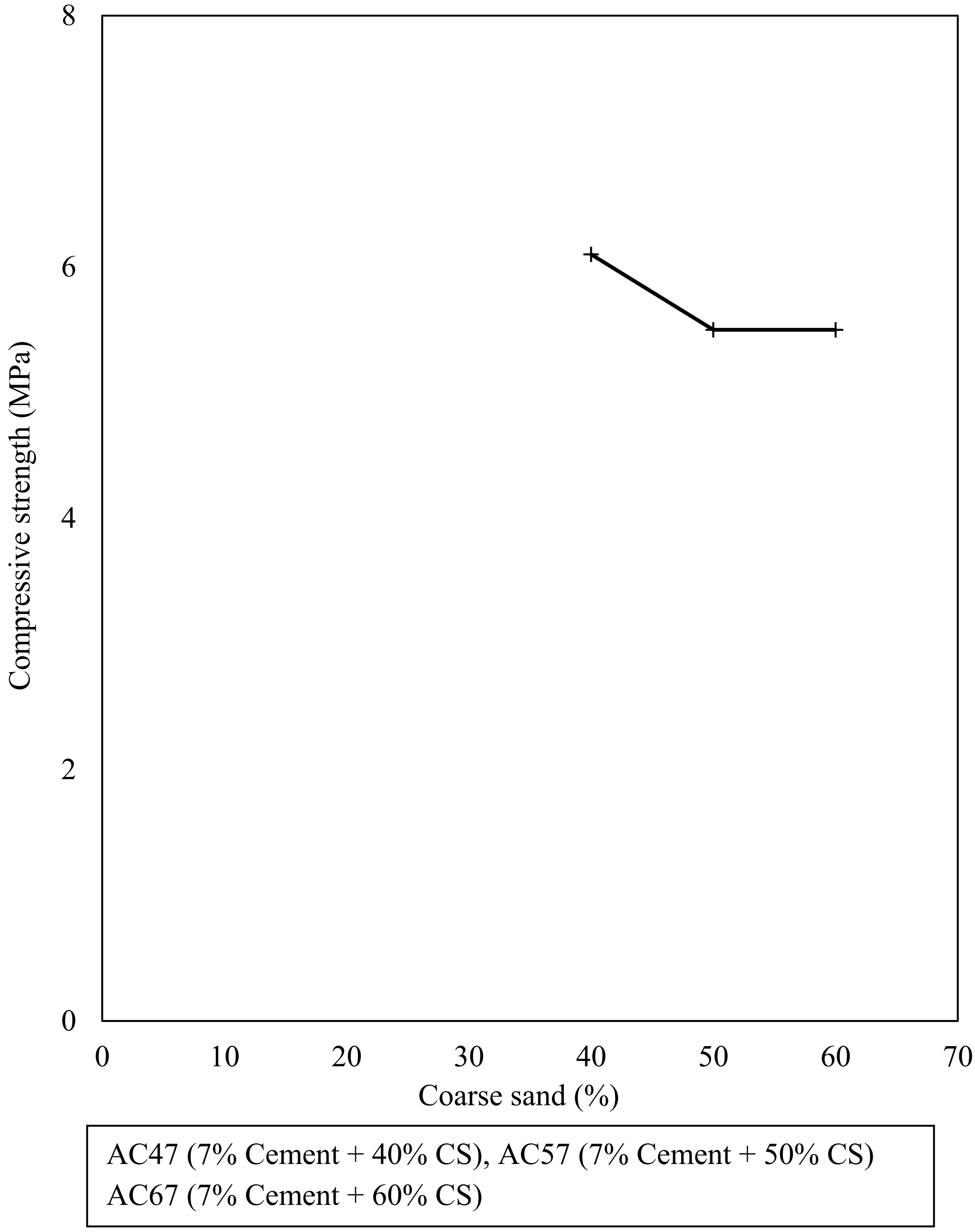
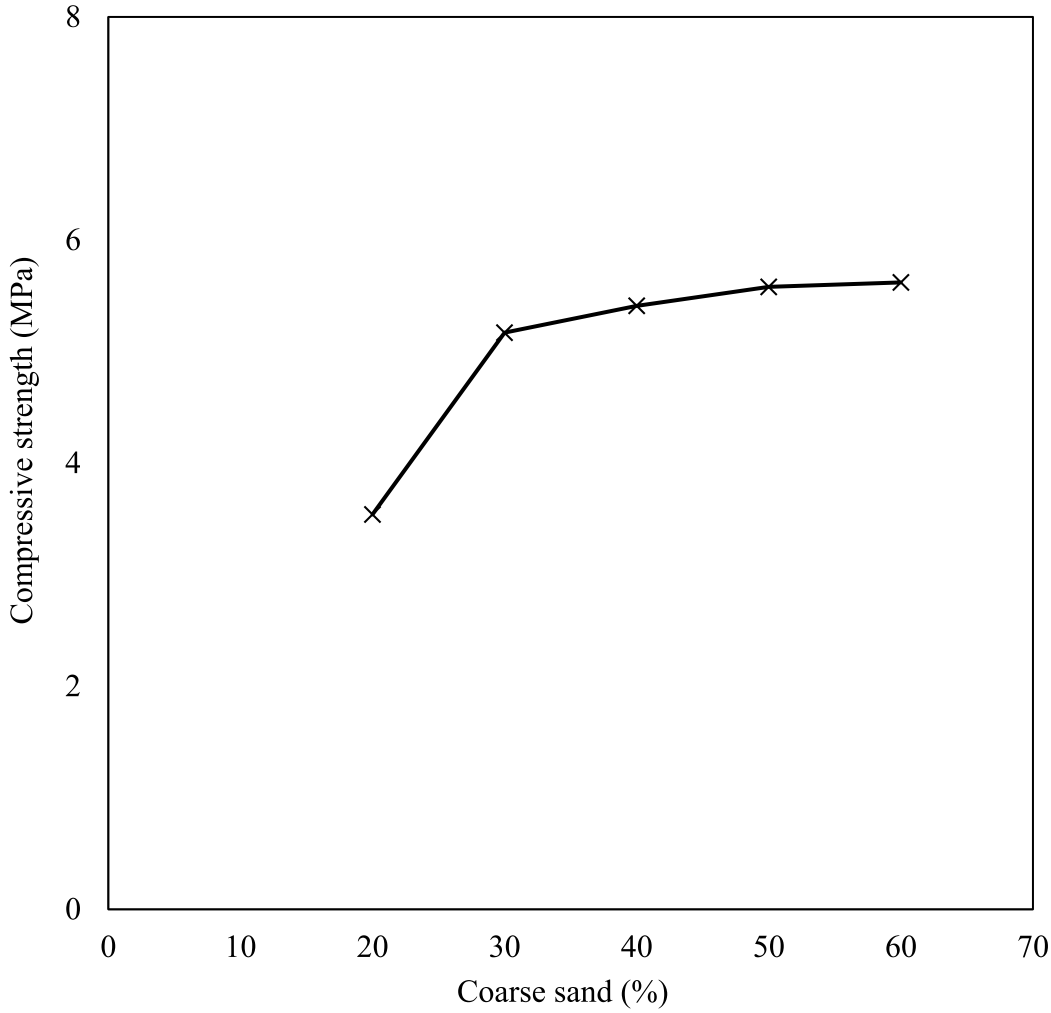


Figure 4.28: Variation of compressive strength with coarse sand for 7% cement stabilization

From the Fig. 4.28, it is seen that the compressive strength decreases from 6.51 MPa to 5.5 MPa with the increase of coarse sand from 40% to 50%. After this, the increase of compressive strength becomes steady up to 60% coarse sand.



AC28 (8% Cement + 20% CS), AC38 (8% Cement + 30% CS)
AC48 (8% Cement + 40% CS), AC58 (8% Cement + 50% CS)
AC68 (8% Cement + 60% CS)

Figure 4.29: Variation of compressive strength with coarse sand for 8% cement stabilization

From the Fig. 4.29, it is seen that the compressive strength increases from 3.54 MPa to 5.62 MPa with the increase of coarse sand from 20% to 60% for the specimens prepared with 8% cement. The rate of increase of compressive strength from AC28 to AC38, AC38 to AC48, AC48 to AC58 and AC58 to AC68 is 46%, 5%, 3% and 0.7% respectively. From the Fig. 4.29, it also seems that after adding 40% coarse sand the rate of increase of compressive strength becomes low for the CSSB specimens containing 8% cement.

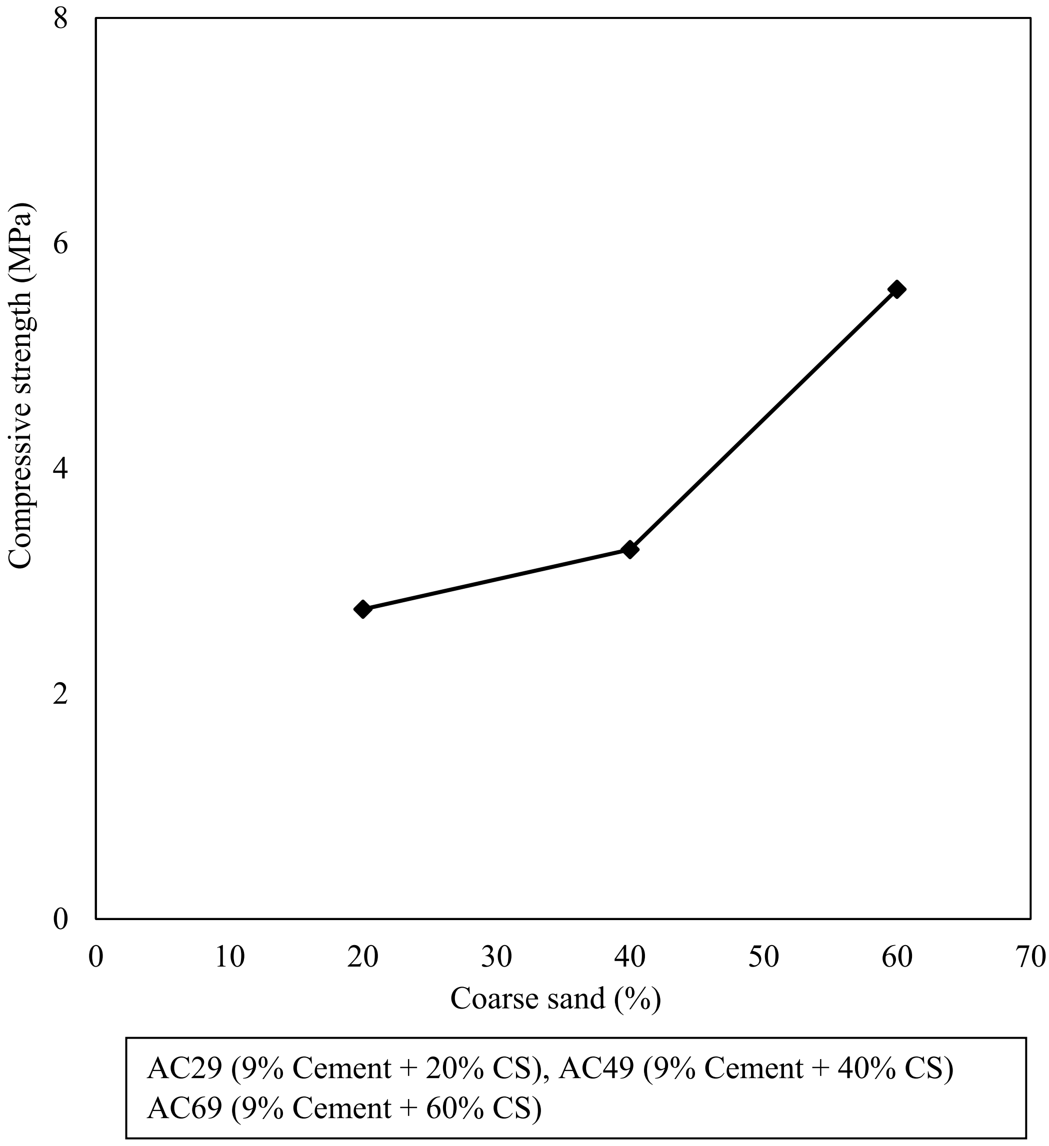


Figure 4.30: Variation of compressive strength with coarse sand for 9% cement stabilization

From the Fig. 4.30, it is seen that the compressive strength increases from 2.75 MPa to 5.59 MPa with the increase of coarse sand from 20% to 60% for the specimens prepared with 8% cement. The rate of increase of compressive strength from AC29 to AC49 and AC49 to AC69 is 19% and 70% respectively. From the Fig. 4.30, it also seems that with the increase of coarse sand the rate of increase of compressive strength becomes higher than the previous ones for the CSSB specimens containing 9% cement.

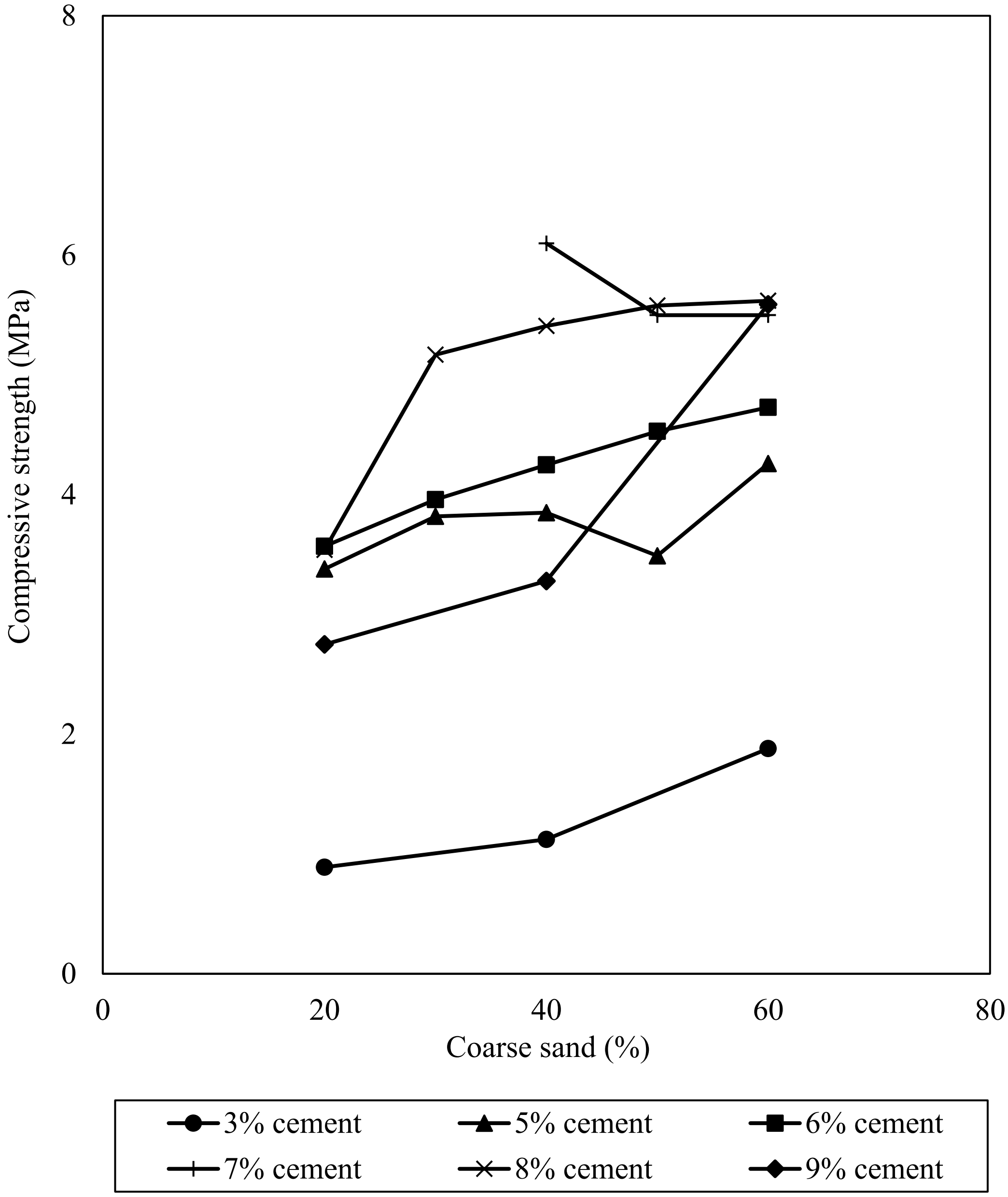


Figure 4.31: Variation of compressive strength of CSSB specimens with coarse sand for different percentages of cement content (3%, 5%, 6%, 7%, 8% and 9%)

From the Fig. 4.25 to 4.30, it seems that for 3%, 6%, 8% and 9% cement content with the increase of coarse sand the compressive strength increases. For the CSSB specimens in case of 5% cement, after addition of 50% coarse sand a tendency of increasing compressive strength is observed. For the CSSB specimens containing 7% cement with the increase of coarse sand the compressive strength decreases.

4.9 Variation of Compressive Strength of CSSB Specimens with Mixed Sand Content

From the Fig. 4.32 to 4.35, the variation of compressive strength for the specimens prepared with mixed sand has been presented.

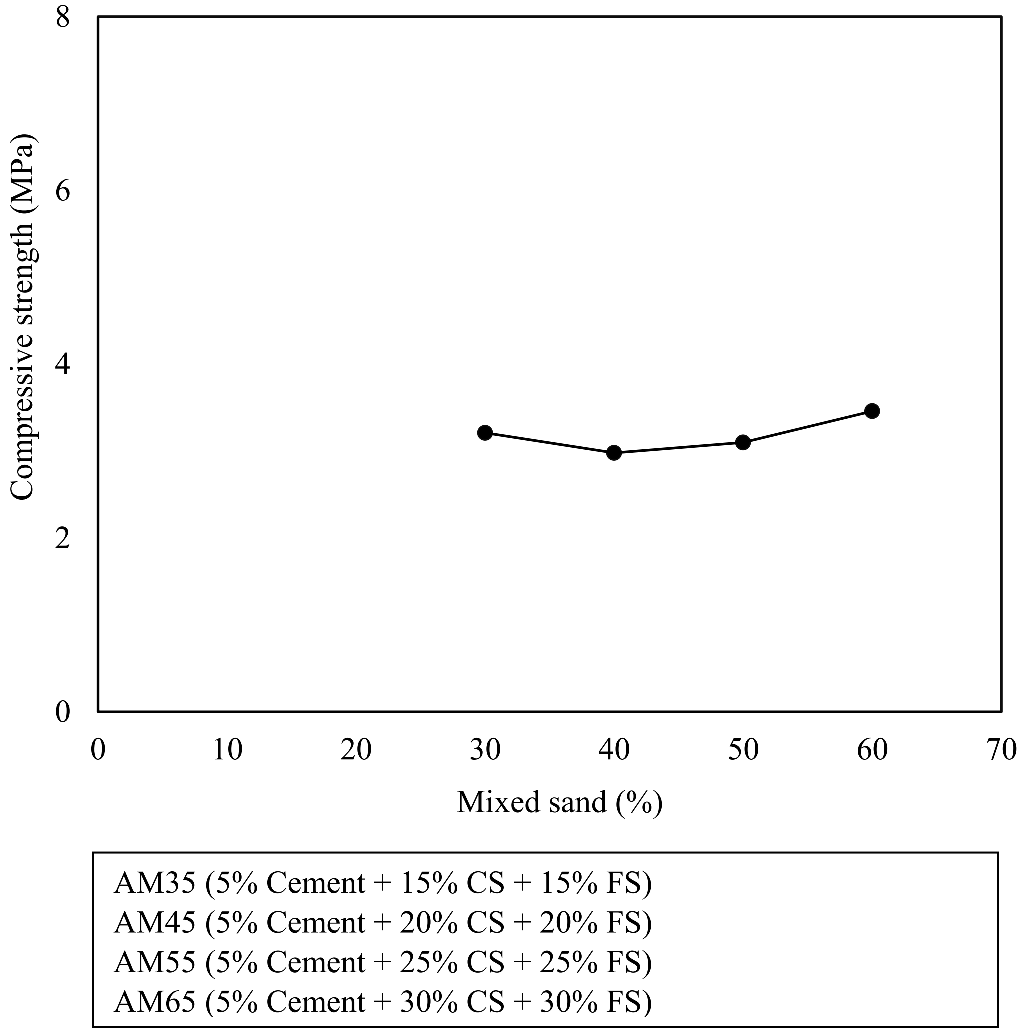
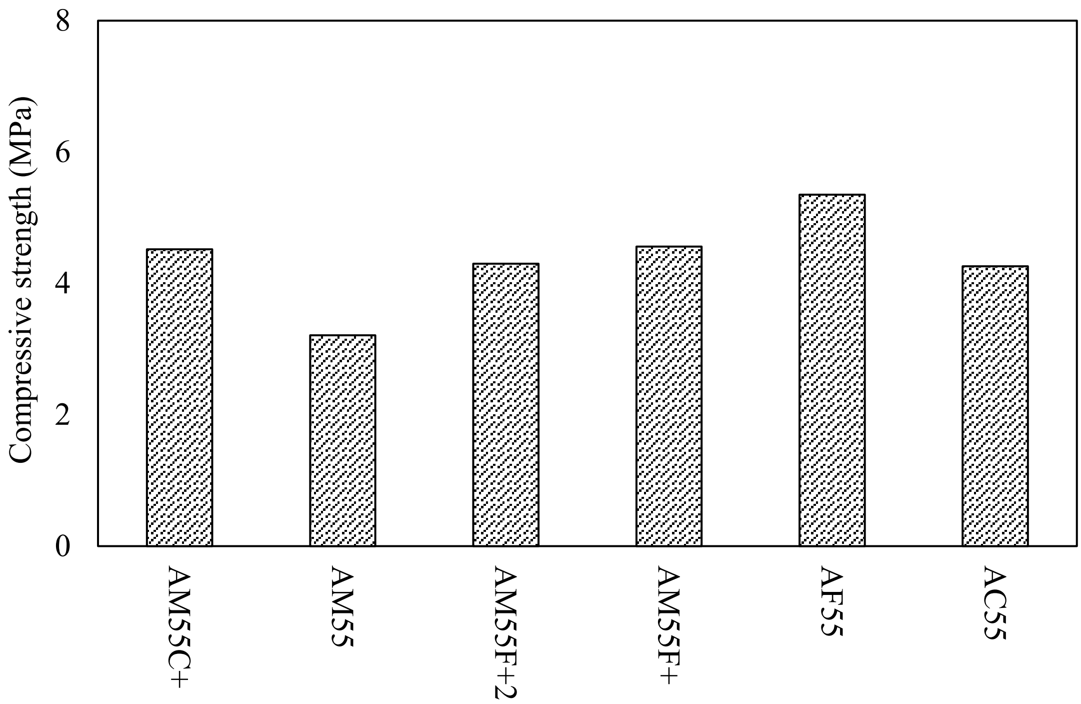


Figure 4.32: Variation of compressive strength of CSSB specimens with different percentages of mixed sand for 5% cement

In Fig. 4.32, for the specimens (AM35, AM45, AM55 and AM65) prepared for 50% mixed sand with 5% cement the compressive strength decreases from 3.21 MPa to 2.98 MPa with the increase of mixed sand content from 30% to 40%. Again, the compressive strength increases from 2.98 MPa to 3.46 MPa with the increase of mixed sand content from 40% to 60%. From the Fig. 4.32, it is also seen that after aadding 20% mixed sand to AM45 the strength of the resulting AM65 becomes 16.10% stronger (or 8.05% per 10% increase of mixed sand).



AM55C+ (5% Cement + 33.33% CS + 16.67% FS)
AM55 (5% Cement + 25% CS+ 25% FS)
AM55F+2 (5% Cement + 20% CS + 30% FS)
AM55F+ (5% Cement + 16.67% CS + 33.33% FS)
AF55 (5% Cement + 50% FS)
AC55 (5% Cement + 50% CS)

Figure 4.33: Chart showing a comparison of compressive strength of CSSB specimens for 50% sand with 5% cement

From the Fig. 4.33, it can be seen that all the specimens of 50% mixed sand with 5% cement content (AM55F+, AM55F+2, AM55 and AM55C+) have compressive strength in the range of 3.21 to 4.56 MPa. With the increase of fine sand when coarse sand decreases, with respect to AM55 the compressive strength increases by 34% , 42% and 67% for AM55F+2, AM55F+ and AF55 respectively. When AM55 (25% coarse sand + 25% fine sand) is converted into AM55C+ (33.33% coarse sand and 16.67% fine sand) the compressive strength increases by 41%. From the Fig. 4.33, it is also seen that AF55 possesses 26% higher compressive strength than AC55. From the Fig. 4.33, it also seems that for the CSSB specimens containing 5% cement with 50% mixed sand, after adding 25% fine sand compressive strength increases with the increase of fine sand.

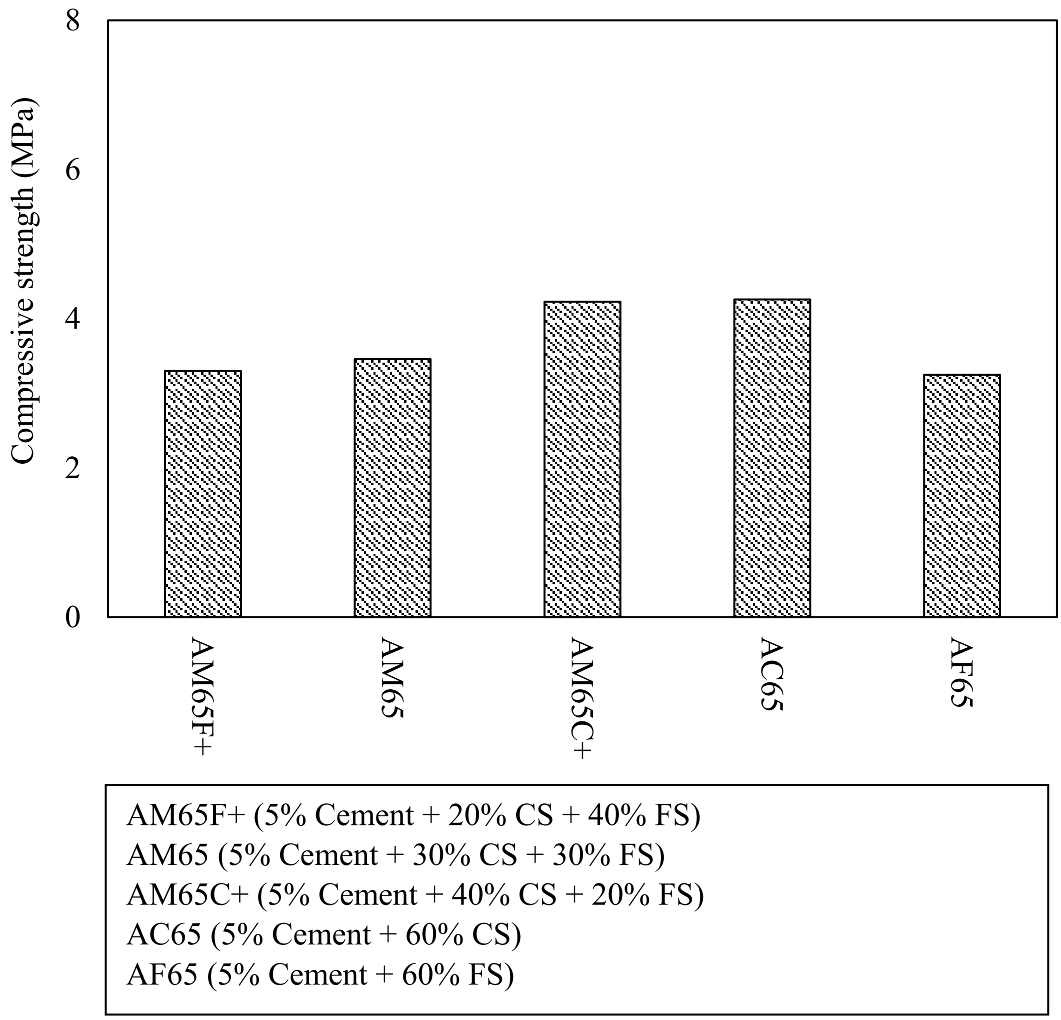


Figure 4.34: Chart showing a comparison of compressive strength of CSSB specimens for 60% sand with 5% cement

From Fig. 4.34, it is seen that all the specimens of 60% mixed sand with 5% cement content (AM65F+, AM65 and AM65C+) have compressive strength in the range of 3.3 to 4.23 MPa. With the increase of coarse sand when fine sand is decreasing, compressive strength increases with respect to AM65F+ by 5% and 29% for AM65 and AM65C+ respectively. When AC65 (60% coarse sand) is converted into AM65C+ (40% coarse sand and 20% fine sand) the compressive strength also remains almost same, which reflects the lower effect of fine sand. When AM65 (30% coarse sand and 30% fine sand) is converted into AM65C+ (40% coarse sand and 20 % fine sand), the compressive strength increases by 22.25%. From the Fig. 4.34, it is also seen that AC65 possesses 31% higher compressive strength than AF65.

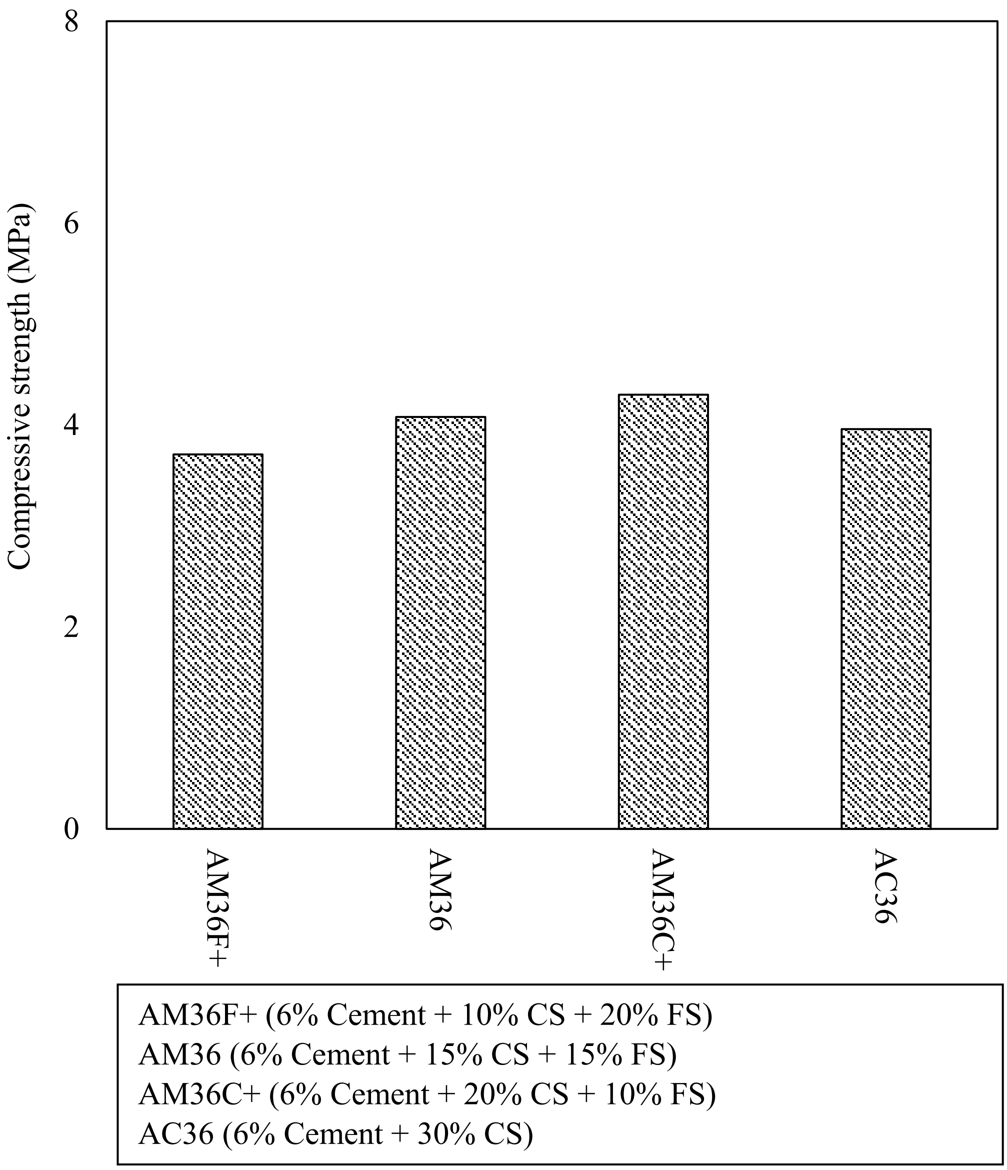


Figure 4.35: Chart showing a comparison of compressive strength of CSSB specimens for 30% sand with 6% cement

From the Fig. 4.35, it is seen that all the CSSB specimens (AM36F+, AM36, AM36C+) of 30% mixed sand with 6% cement have compressive strength in the range of 3.71 to 4.03 MPa. With the increase of coarse sand when fine sand is decreasing, with respect to AM36F+ the compressive strength increases by 10% and 16% for AM36 and AM36C+ respectively.

4.10 Compressive Strength of CSSB Specimens Greater than 5 MPa

There are total 14 numbers of CSSB specimens which have compressive strength greater than 5 MPa (Fig. 4.36). Two numbers of CSSB specimens from 5% cement, AM45F+ and AF55 have compressive strength of 5.32 and 5.35 MPa respectively. Four numbers of CSSB specimens from 6% cement AM56, AM56F+, AM46, AM46C+ have compressive strength of 5.06, 6.07, 5.23 and 5.28 MPa respectively. Again from 8% cement, the five numbers of CSSB specimens AC38, AC48, AC58, AC68 and AC68F+ have compressive strength of 5.17, 5.41, 5.58, 5.62 and 5.24 MPa respectively. The one block from 9% cement carries compressive strength 5.59 MPa.

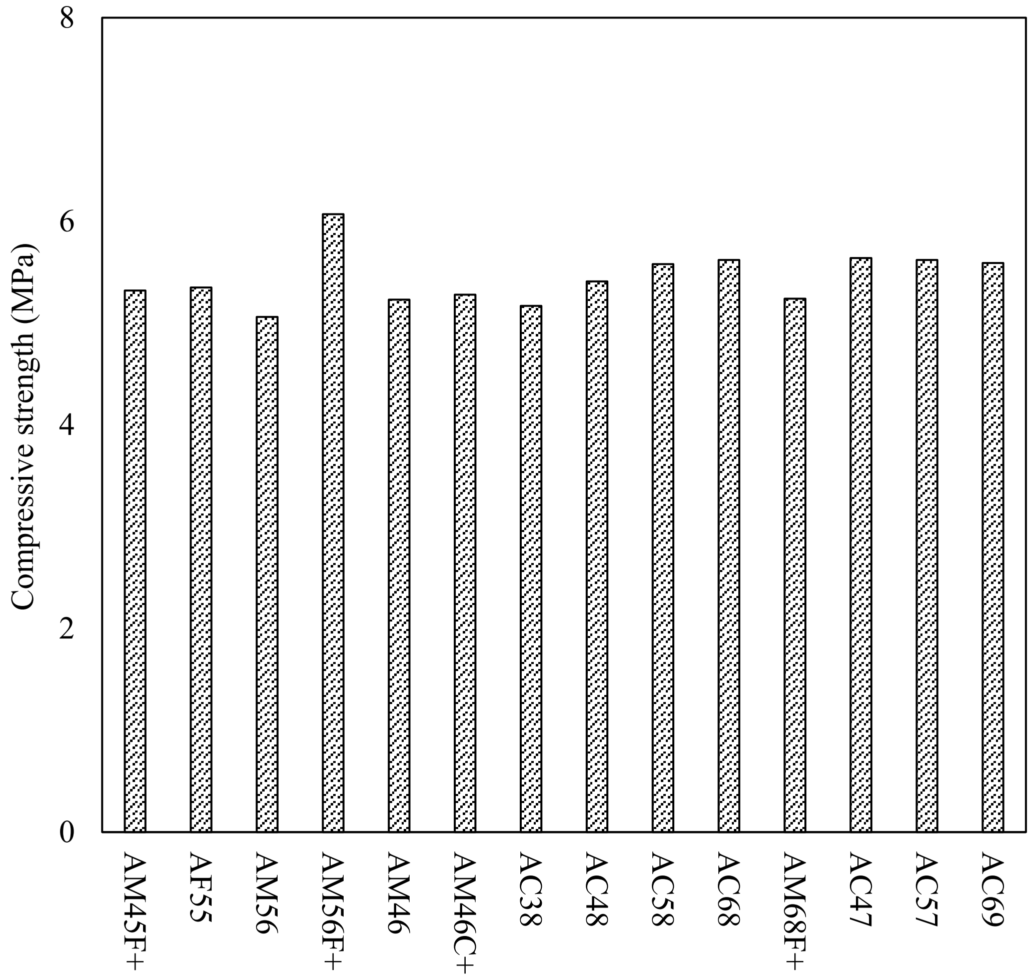


Figure 4.36: Chart showing compressive strength of CSSB specimens greater than 5 MPa

4.11 Tests on Wet CSSB Specimens

Water absorption capacity test was conducted on some typical CSSB specimens. Besides the water absorption capacity test, the crushing strength test and unit weight test of the same wet CSSB specimens were also determined after 24 hours immersion under water. Total eight numbers of CSSB specimens were selected for water absorption capacity test. Descriptions of the respective specimens group with their material compositions, compressive strength, unit weight and percentages of water absorption of these groups are presented in Table 4.7. Also, unit weight, moisture content, percentages of water absorption and crushing strength of these CSSB specimens have been shown in Fig. 4.37 to 4.39. Percentages of water absorption of the selected CSSB specimens have been presented in Fig. 4.40. Comparison of unit weight and crushing strength of dry and wet CSSB specimens have been presented in Fig. 4.41 and 4.42. Lastly, the crushing strength, water absorption, moisture content and unit weight of the wet CSSB specimens is presented in Fig. 4.43.

Table 4.7: Compressive strength, unit weight and moisture content of CSSB specimens after 24 hours immersion under water

Cement % (w/w)	CSSB specimens	Sand % (w/w)			Compressive strength (MPa)	Water absorption (%)	Moisture content (%)	Unit weight (gm/cm^3)
		Fine	Coarse	Fine + Coarse				
5	AF55	50	-	-	1.26	13.76	18.29	2.02
	AM45F+	26.67	13.33	40	0.77	16.59	17.55	2.03
6	AM46	20	20	40	0.89	12.19	19.50	1.94
	AM46C+	13.33	26.67	40	1.86	10.26	10.26	2.14
	AM56	25	25	50	1.49	9.63	9.63	2.00
	AM56F+	33.33	16.67	50	1.90	8.03	8.03	15.87
8	AC38	-	30	-	1.31	16.04	16.04	1.94
	AM48	20	20	40	1.60	10.75	19.98	1.93

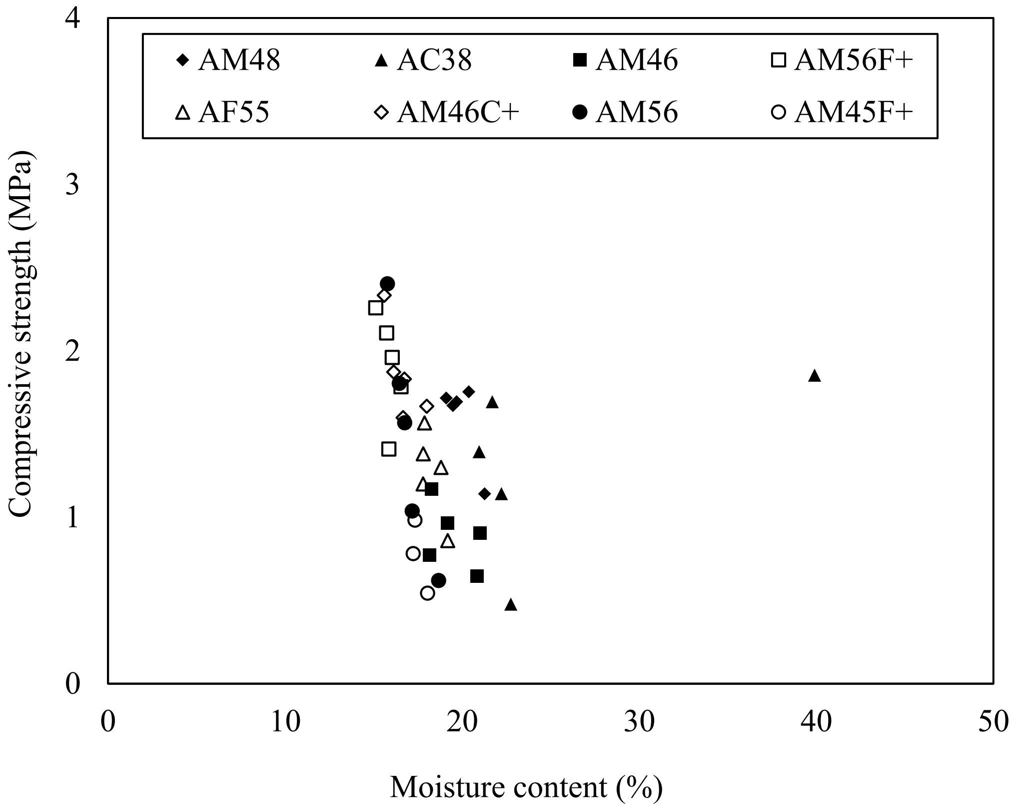


Figure 4.37: Compressive strength vs moisture content of wet CSSB specimens

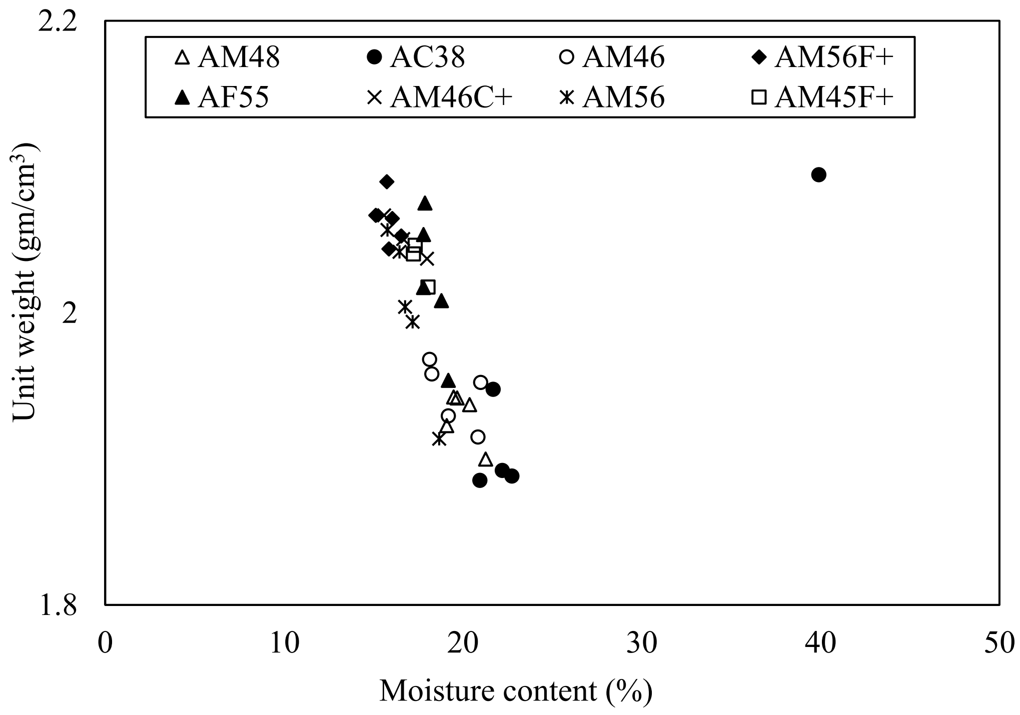
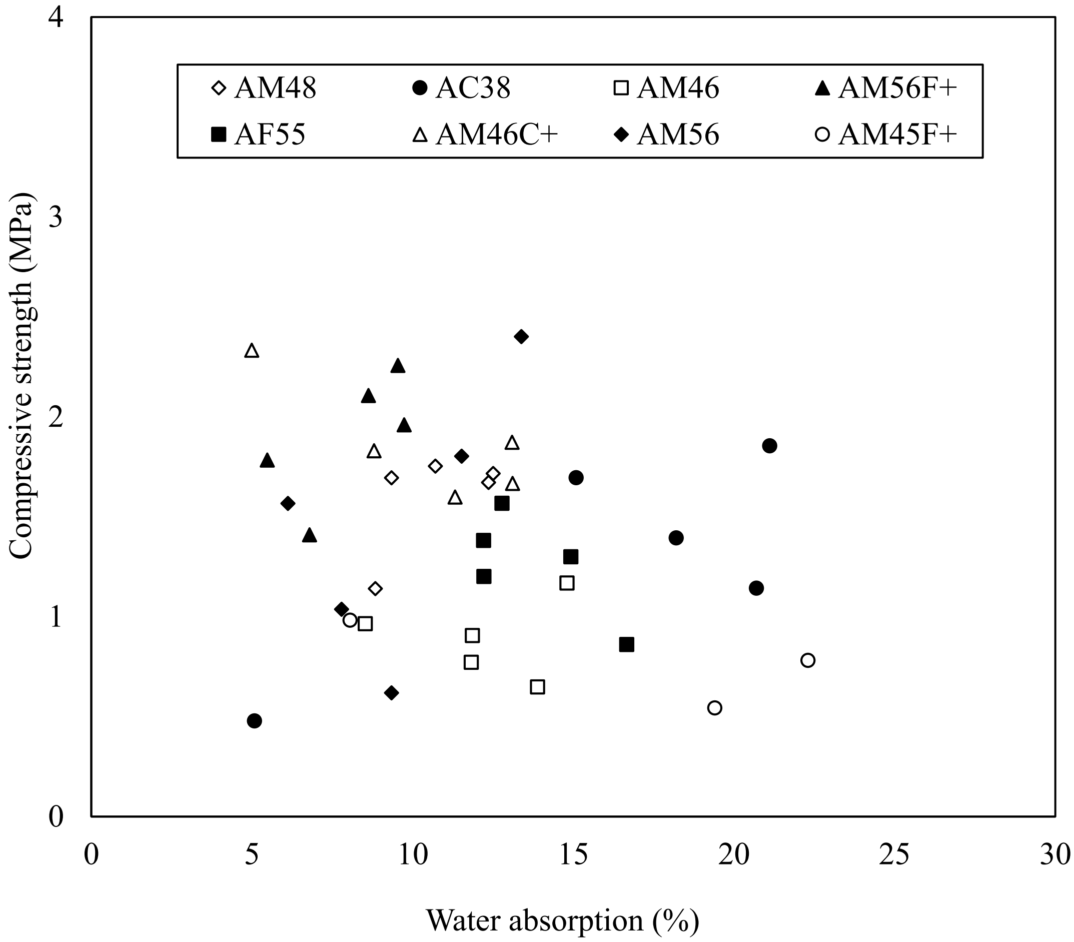
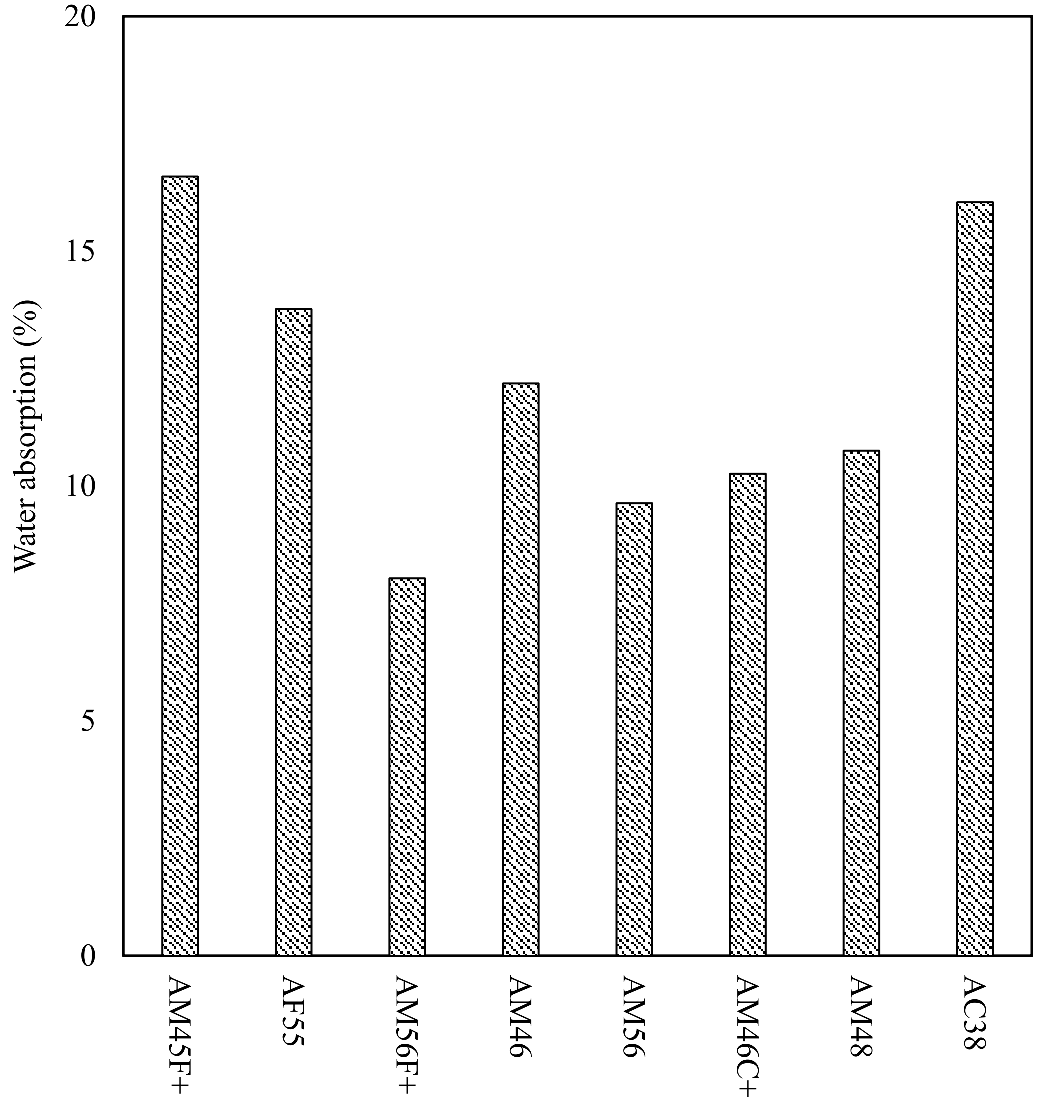


Figure 4.38: Unit weight vs moisture content of wet CSSB specimens



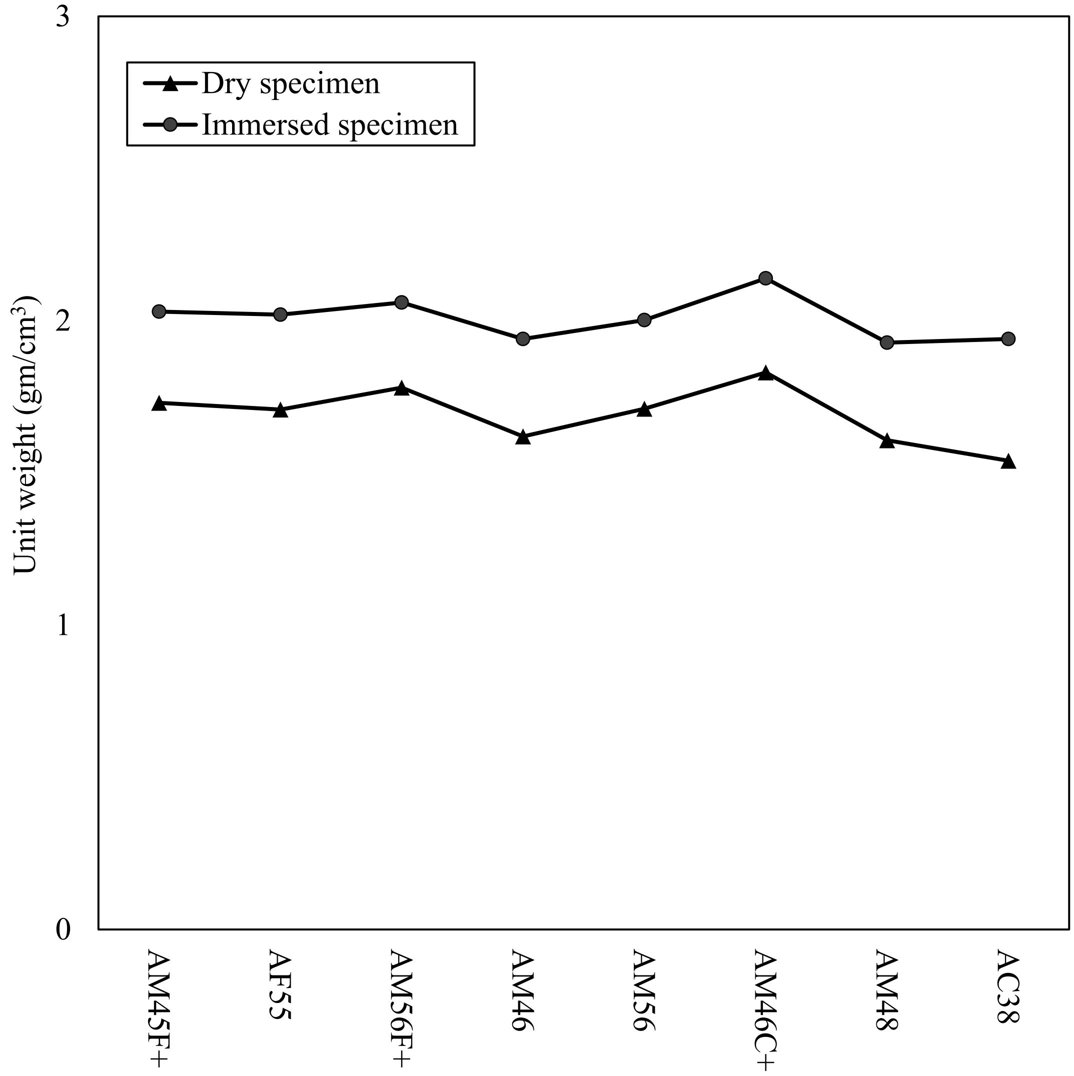
AM45F+ (5% Cement + 13.33% CS + 26.67% FS)
AF55 (5% Cement + 50% FS)
AM56F+ (6% Cement + 16.67% CS + 33.33% FS)
AM46 (6% Cement + 20% CS+ 20% FS)
AM56 (6% Cement + 25% CS + 25% FS)
AM46C+ (6% Cement + 26.67% CS + 13.33% FS)
AM48 (8% Cement + 20% CS + 20% FS)
AC38 (8% Cement + 30% CS)

Figure 4.39: Compressive strength vs water absorption after 24 hours immersion under water



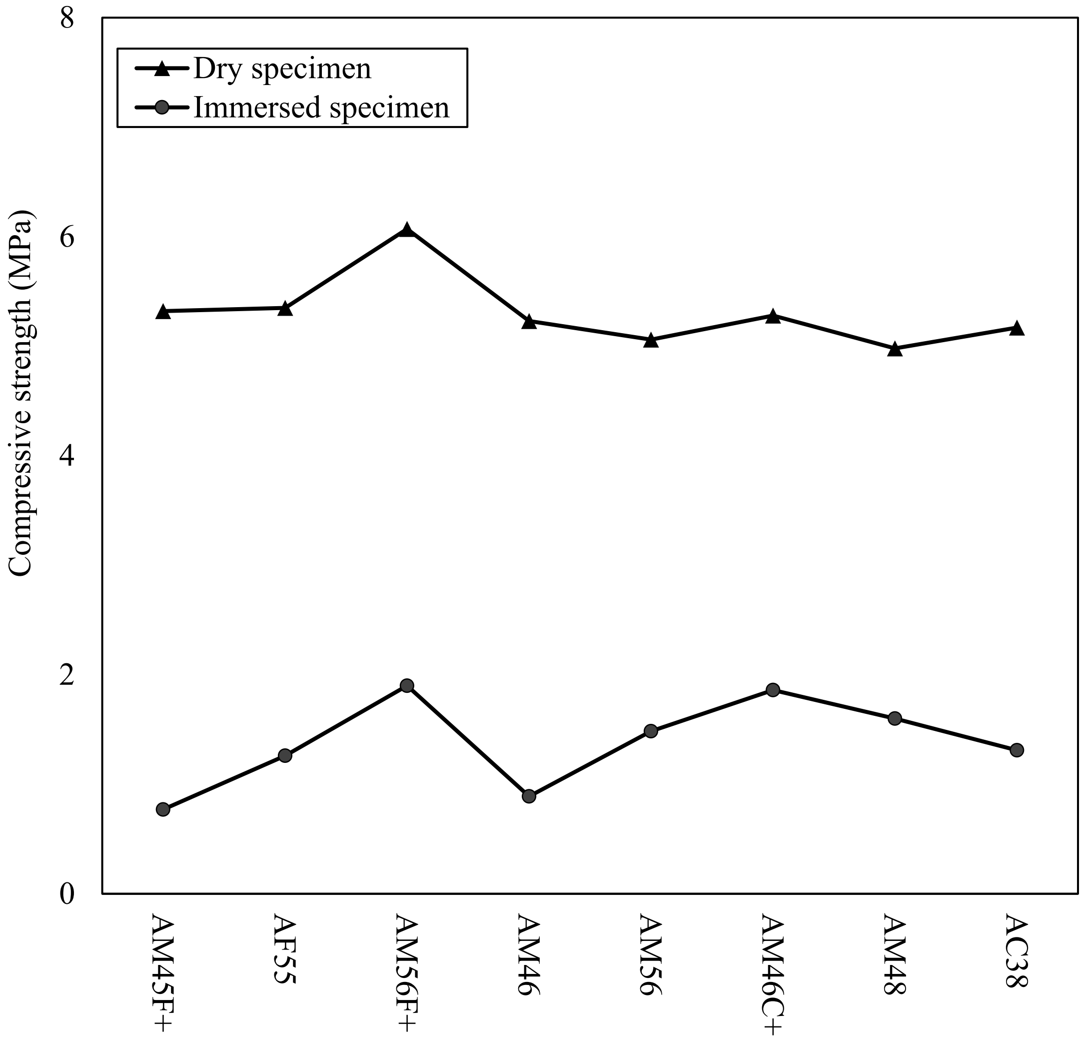
AM45F+ (5% Cement + 13.33% CS + 26.67% FS)
AF55 (5% Cement + 50% FS)
AM56F+ (6% Cement + 16.67% CS + 33.33% FS)
AM46 (6% Cement + 20% CS+ 20% FS)
AM56 (6% Cement + 25% CS + 25% FS)
AM46C+ (6% Cement + 26.67% CS + 13.33% FS)
AM48 (8% Cement + 20% CS + 20% FS)
AC38 (8% Cement + 30% CS)

Figure 4.40: Chart showing percentages of water absorption of wet CSSB specimens



AM45F+ (5% Cement + 13.33% CS + 26.67% FS)
AF55 (5% Cement + 50% FS)
AM56F+ (6% Cement + 16.67% CS + 33.33% FS)
AM46 (6% Cement + 20% CS+ 20% FS)
AM56 (6% Cement + 25% CS + 25% FS)
AM46C+ (6% Cement + 26.67% CS + 13.33% FS)
AM48 (5% Cement + 20% CS + 20% FS
AC38 (8% Cement + 30% CS)

Figure 4.41: Comparison of unit weight between dry and wet CSSB specimens



AM45F+ (5% Cement + 13.33% CS + 26.67% FS)
AF55 (5% Cement + 50% FS)
AM56F+ (6% Cement + 16.67% CS + 33.33% FS)
AM46 (6% Cement + 20% CS+ 20% FS)
AM56 (6% Cement + 25% CS + 25% FS)
AM46C+ (6% Cement + 26.67% CS + 13.33% FS)
AM48 (5% Cement + 20% CS + 20% FS
AC38 (8% Cement + 30% CS)

Figure 4.42: Comparison of crushing strength between dry and wet CSSB specimens

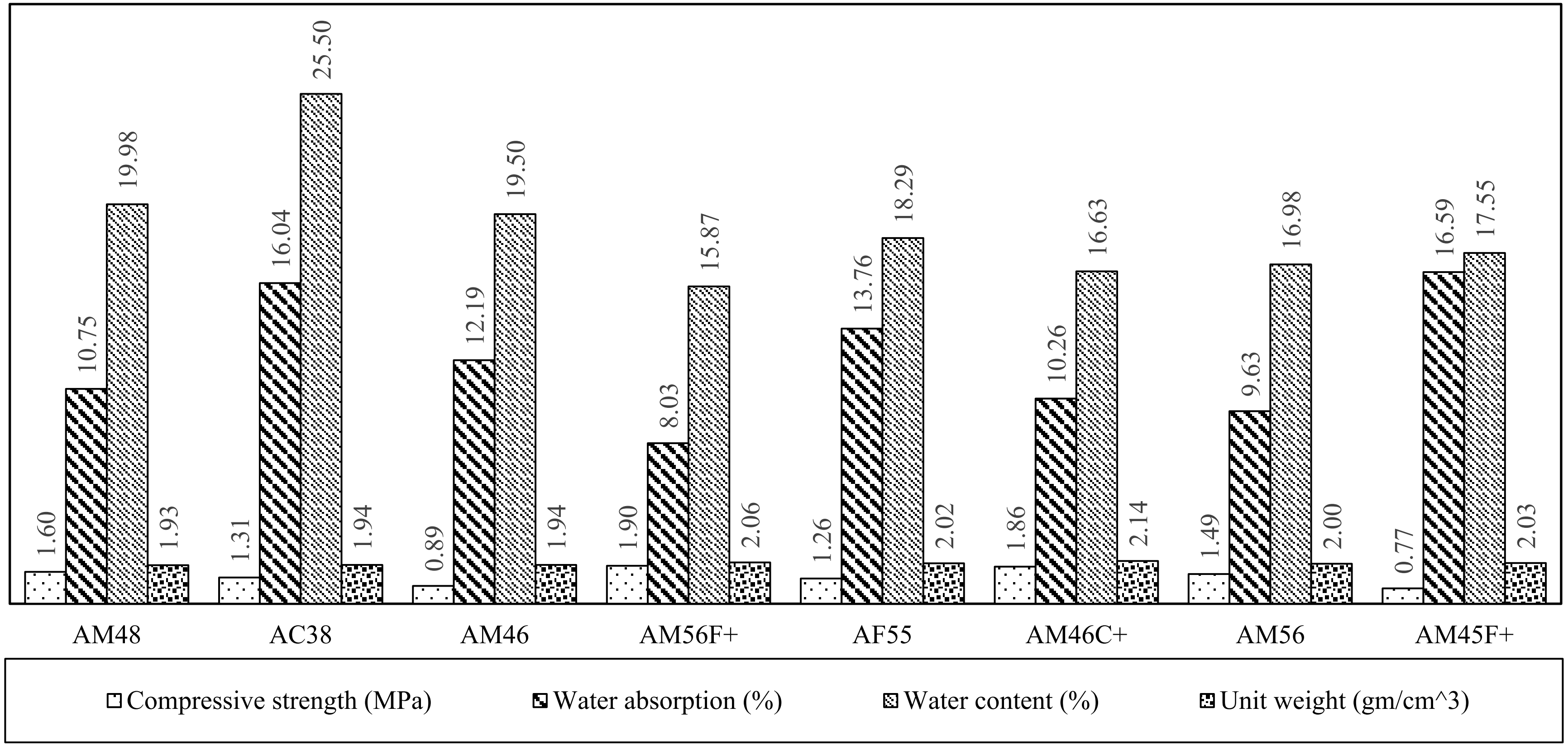


Figure 4.43: Chart showing crushing strength, water absorption, moisture content and unit weight of the wet CSSB specimens

4.12 Summary

Laboratory tests were conducted to determine the soil properties. Compressive strength test and crushing strength test were conducted to determine the strength and deformation characteristics of Compressed Stabilized Earth Block (CSEB). Crushing strength test was conducted on total 47 types of Cement Sand Stabilized Block (CSSB) specimens. The comparisons of different combinations CSSB specimens have been discussed with relevant graphs, charts and tables. Water absorption capacity of some CSSB specimens was determined after 24 hours immersion under water. Finally, the comparisons of crushing strength, unit weight and moisture content of some dry and wet CSSB specimens are presented with relevant figures.

Chapter 5
CONCLUSIONS AND SUGGESTIONS

5.1 Findings of the Study

The main findings of this study are as follows:

(a) From the grain size distribution curve of collected soil samples, it can be seen that the soil sample selected for making CSEB collected from Savar consists of 12% sand, 47% silt, 41% clay; and the soil sample collected from Shariatpur consists of 1.2-2.1% sand, 41.5-43.2% silt and 54.7-57.3% clay.

(b) From the compressive strength test results, it has been found that the average compressive strength of Lime Stabilized Block (LSB), Lime Jute Stabilized Block (LJSB), Cement Sand Stabilized Block (CSSB) and Unstabilized Block (USB) is 2.5 MPa, 3.5 MPa and 1.2 MPa respectively. The average failure strain of LSB, CSSB, LJSB and USB is 2.6%, 2.7%, 8.2% and 3.1% respectively. It is observed that Lime Jute Stabilized Block (LJSB) has higher failure strain than any other types of blocks. During the compressive strength test, the moisture content of the blocks was in the range of 7-12%. All the Cement Sand Stabilized Blocks prepared for crushing strength test contains 0.2-19% moisture content and the range of unit weight 1.5-2.1 gm/cm^3. In most of the cases, the moisture content of Cement Sand Stabilized Block remained below 5%. From crushing strength test of Cement Sand Stabilized Block (CSSB) it was found that the highest compressive strength is 6.07 MPa consisting of 6% cement, 17% coarse sand and 33% fine sand by weight in the condition of moisture content 0.2-0.5% and unit weight of 1.76-1.82 gm/cm^3.

(c) It is observed that for 20% and 40 to 60% coarse sand the optimum cement contents are 5% and 7% respectively.

5.2 Suggestions for Future Study

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

(a) In this research, the soil was collected from limited sites of Shariatpur and Savar. Soil collected from other parts of Bangladesh are not investigated for the suitable soil of CSEB.

(b) From the investigation of various soil-sand-cement mixes more satisfactory compressive strength has been found. But the ductile properties of Cement Sand Stabilized Blocks was found very poor. Therefore, a study needs to be carried out for microstructural experiment of natural fiber with cement to improve its ductile properties. A clear understanding of microstructural behavior will help in to select suitable fiber for a particular soil and construction type.

(c) From the experimental results, the same crushing strength was found from different mixes of cement-sand stabilized blocks. So, an economic analysis is needed to be done for the production of the block with sufficient strength.

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

(e) Despite the possibilities and advantages offered by stabilized earth materials, building with earth in Auroville is still not in the common practice. Either people do not want to acknowledge the advantages of this material or they do not want to get the burden to organize the block production. So, public awareness must be risen by letting them know about CSEB.

Thus, it is recommended to work on these areas in future in order to address all the problems and find out probable solutions encountered in CSEB. Finally, it is expected that the present study will be useful to all those dealing with civil engineering projects and research works on building materials. This research will also be useful to those who are involved in the development of low cost and eco-friendly house construction.

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APPENDIX-A

LABORATORY TEST RESULTS

Atterberg Limit Test Results (SS)

Sample location: Baroipara, Savar

Table A-1: Liquid limit test of the soil sample SS

No. of blows	14	20	24	28	34
Weight of container + wet soil (gm)	26.3	23.1	24.5	24.4	21.2
Weight of container + dry soil (gm)	20.8	17.6	19.9	19	16.9
Weight of water (gm)	5.5	5.5	4.6	5.4	4.3
Weight of dry soil (gm)	9.9	10.7	9.3	11.7	9.7
Water content (%)	55.5	51.4	49.4	46.1	44.3
Liquid limit	48				

Table A-2: Plastic limit test of the soil sample SS

Plastic Limit		
Container no.	191	721
Weight of container + wet soil (gm)	16.5	17.2
Weight of container + dry soil (gm)	15.2	15.7
Weight of water (gm)	1.3	1.5
Weight of dry soil (gm)	8.4	8.8
Water content (%)	15.4	17.1
Plastic limit	17	
Plasticity Index (PI)	31	

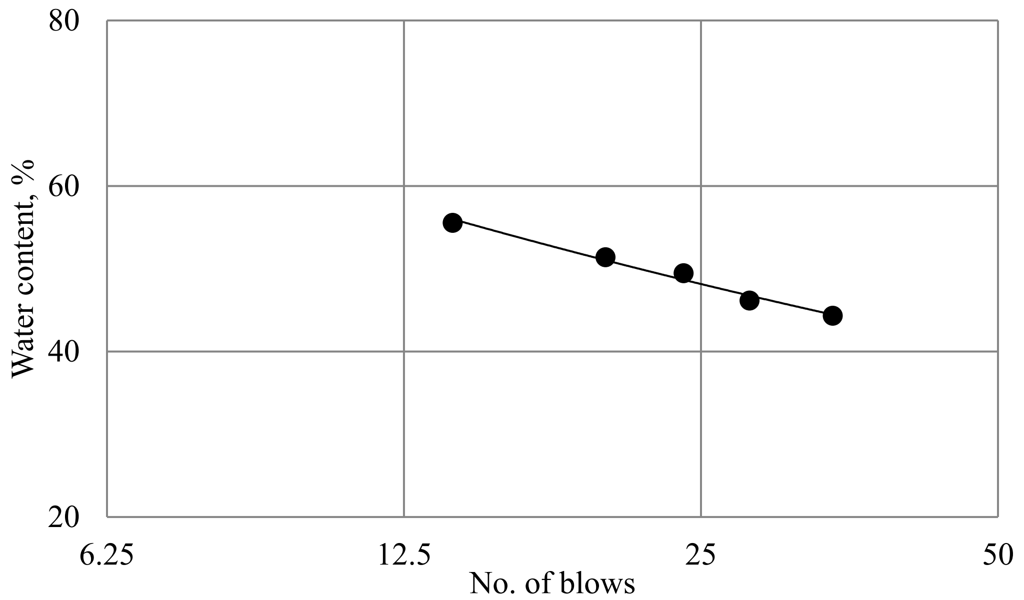

Figure A-1: Flow curve for determination of liquid limit of the soil sample SS

Atterberg Limit Test Results (SP)

Sample Location: Middle Char Rusundhi (2 ft below ground), Shariatpur

Table A-3: Liquid limit test of the soil sample SP3

No. of blows	15	18	24	29	35
Weight of container + wet soil (gm)	23.4	24.5	24.6	22.1	24.1
Weight of container + dry soil (gm)	19	19.3	20	18	19.2
Weight of water (gm)	4.4	5.2	4.6	4.1	4.9
Weight of dry soil (gm)	9.1	11.9	10.3	11.2	11.8
Water content (%)	48.3	43.6	44.6	36.6	41.5
Liquid limit	42				

Table A-4: Plastic limit test of the soil sample SP3

Container no.	2304	45
Weight of container + wet soil (gm)	19.6	17.9
Weight of container + dry soil (gm)	17.2	15.7
Weight of water (gm)	2.4	2.2
Weight of dry soil (gm)	8.4	8.5
Water content (%)	28.6	25.9
Plastic limit	28	
Plasticity Index (PI)	14	

Table A-5: Shrinkage limit test of the soil sample SP3

Dish no.	1
Weight of dish (gm)	29
Weight of dish + wet soil (gm)	57.6
Weight of dish + dry soil (gm)	49.6
Weight of dry soil pat (gm)	20.6
Weight of water (gm)	8
Weight of displaced Mercury (gm)	173.8
Volume of displaced Mercury (cc)	12.8
Volume of dish (cc)	15.1
Initial moisture content of soil pat (%)	38.8
Volume of moisture (cc)	2.2
Moisture content of dry soil pat (%)	10.7
Shrinkage limit	29

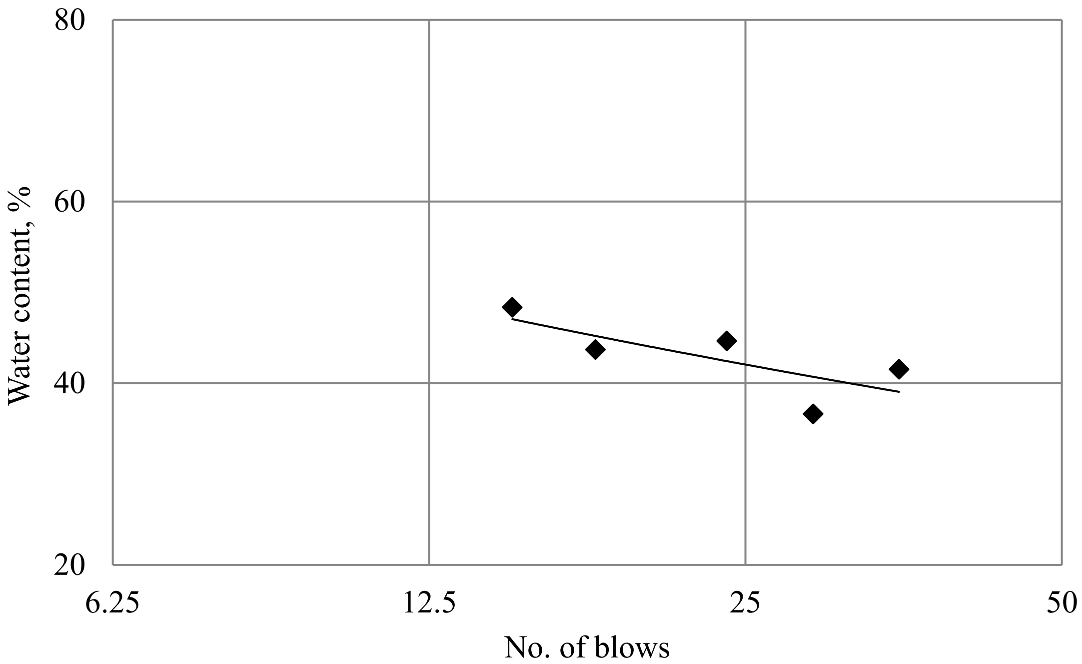

Figure A-2: Flow curve for determination of liquid limit of the soil sample SP3

Sample Location: Dorichar, Dattapara, Shariatpur

Table A-6: Liquid limit test of the soil sample SP5

No. of blows	15	20	24	29	33
Weight of container + wet soil (gm)	18.8	21.6	18.7	25.2	18.7
Weight of container + dry soil (gm)	15	16.8	15.5	21.1	15.6
Weight of water (gm)	3.8	4.8	3.2	4.1	3.1
Weight of dry soil (gm)	8.7	10.1	8	10.5	8.1
Water content (%)	43.7	47.5	40	39.0	38.2
Liquid limit	41				

Table A-7: Plastic limit test of the soil sample SP5

Container no.	137	836
Weight of container + wet soil (gm)	17.8	17
Weight of container + dry soil (gm)	15.4	14.9
Weight of water (gm)	2.4	2.1
Weight of dry soil (gm)	8.5	8
Water content (%)	28.2	26.2
Plastic limit	28	
Plasticity Index (PI)	13	

Table A-8: Shrinkage limit test of the soil sample SP5

Dish no.	7
Weight of dish (gm)	29.6
Weight of dish + wet soil (gm)	55.5
Weight of dish + dry soil (gm)	47.9
Weight of dry soil pat (gm)	18.3
Weight of water (gm)	7.6
Weight of displaced Mercury (gm)	145.1
Volume of displaced Mercury (cc)	10.7
Volume of dish (cc)	14.8
Initial moisture content of soil pat (%)	41.5
Volume of moisture (cc)	4.1
Moisture content of dry soil pat (%)	22.6
Shrinkage limit	19

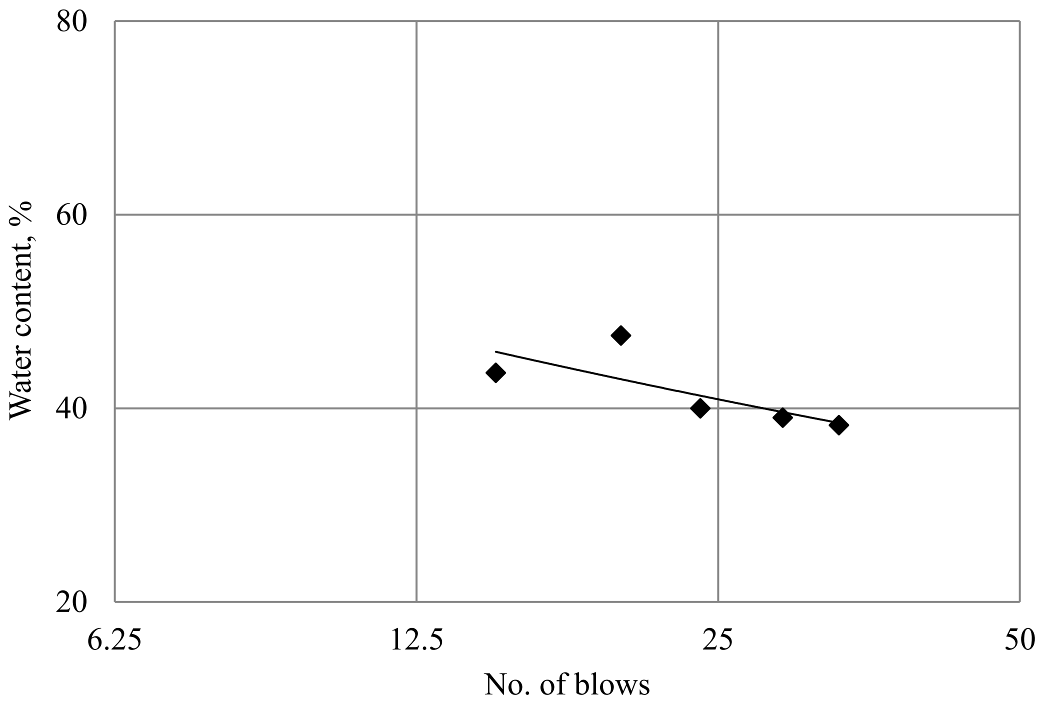

Figure A-3: Flow curve for determination of liquid limit of the soil sample SP5

Sample Location: Bala Bazar, Rudrokor East (2 ft below gorund), Shariatpur

Table A-9: Liquid limit test of the soil sample SP6

No. of blows	12	16	24	30	34
Weight of container + wet soil (gm)	19.7	20	23.4	18.4	17.8
Weight of container + dry soil (gm)	15.2	15	19.1	14.6	13.9
Weight of water (gm)	4.5	5	4.3	3.8	3.9
Weight of dry soil (gm)	7.9	8	8	7.4	6.8
Water content (%)	56.9	62.5	53.7	51.3	57.3
Liquid limit	57				

Table A-10: Plastic limit test of the soil sample SP6

Container no.	25	875
Weight of container + wet soil (gm)	17.7	20
Weight of container + dry soil (gm)	15.4	17.1
Weight of water (gm)	2.3	2.9
Weight of dry soil (gm)	8.4	9.9
Water content (%)	27.4	29.3
Plastic limit	29	
Plasticity Index (PI)	28	

Table A-11: Shrinkage limit test of the soil sample SP6

Dish no.	9
Weight of dish (gm)	28
Weight of dish + wet soil (gm)	52.8
Weight of dish + dry soil (gm)	44.2
Weight of dry soil pat (gm)	16.2
Weight of water (gm)	8.6
Weight of displaced Mercury (gm)	110.9
Volume of displaced Mercury (cc)	8.19
Volume of dish (cc)	15.1
Initial moisture content of soil pat (%)	53.0
Volume of moisture (cc)	6.9
Moisture content of dry soil pat (%)	42.6
Shrinkage limit	11

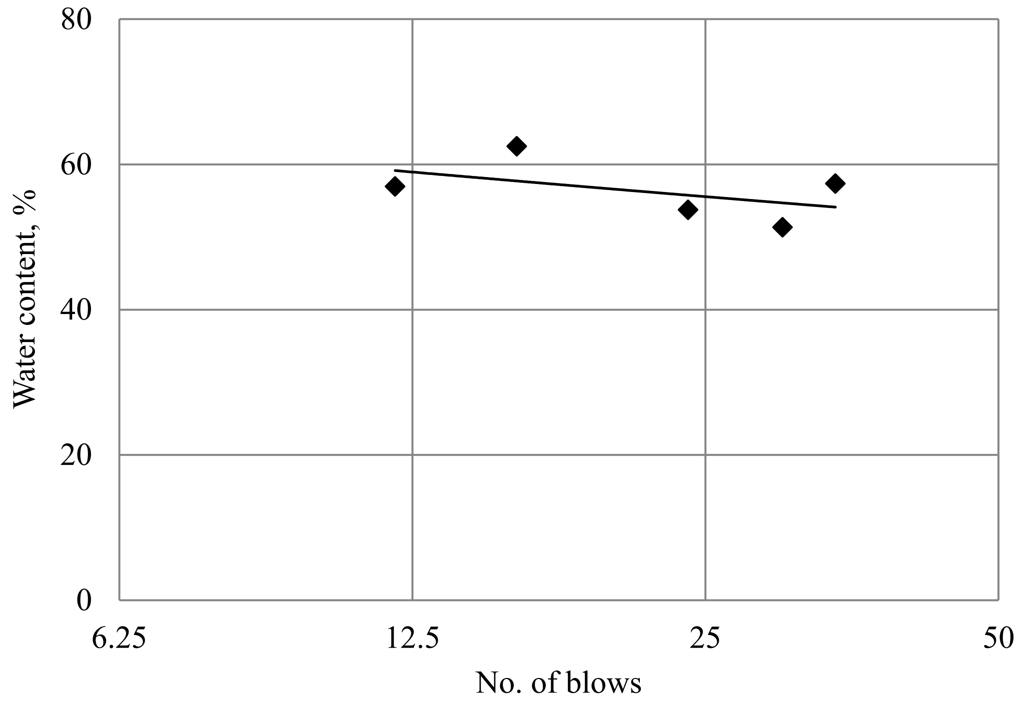

Figure A-4: Flow curve for determination of liquid limit of the soil sample SP6

Sample Location: Chor Jadobpur, Tula Tola Goja, Shariatpur

Table A-12: Liquid limit test of the soil sample SP7

No. of blows	14	20	24	28	34
Weight of container + wet soil (gm)	19.2	23.5	18.5	19.1	21.1
Weight of container + dry soil (gm)	15.5	18.6	15.1	15.6	17.2
Weight of water (gm)	3.7	4.9	3.4	3.5	3.9
Weight of dry soil (gm)	8.1	11.3	7.9	8.6	9.7
Water content (%)	45.6	43.3	43.0	40.6	40.2
Liquid limit	42				

Table A-13: Plastic limit test of the soil sample SP7

Container no.	191	721
Weight of container + wet soil (gm)	17.4	18.8
Weight of container + dry soil (gm)	15.5	16.6
Weight of water (gm)	1.9	2.2
Weight of dry soil (gm)	8.2	9.6
Water content (%)	23.1	22.9
Plastic limit	23	
Plasticity Index (PI)	19	

Table A-14: Shrinkage limit test of the soil sample SP7

Dish no.	6
Weight of dish (gm)	22.2
Weight of dish + wet soil (gm)	47.9
Weight of dish + dry soil (gm)	40.2
Weight of dry soil pat (gm)	18
Weight of water (gm)	7.7
Weight of displaced Mercury (gm)	157.1
Volume of displaced Mercury (cc)	11.6
Volume of dish (cc)	14.8
Initial moisture content of soil pat (%)	42.7
Volume of moisture (cc)	3.2
Moisture content of dry soil pat (%)	17.8
Shrinkage limit	25

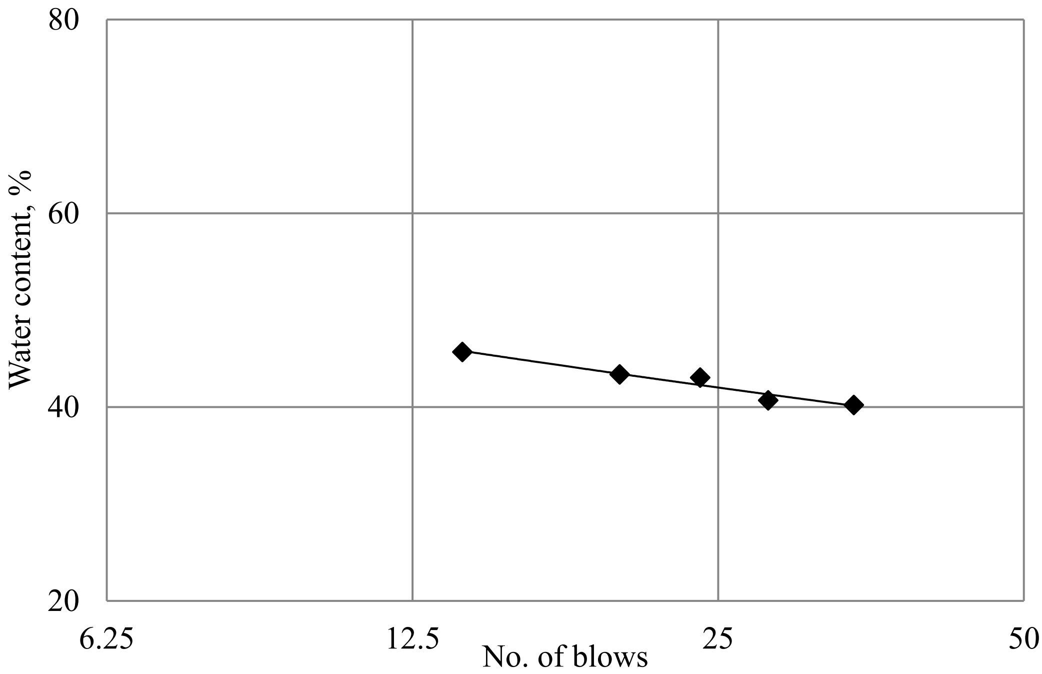

Figure A-5: Flow curve for determination of liquid limit of the soil sample SP7

Sample Location: Bala Bazar, Rudrokor (West), Shariatpur

Table A-15: Liquid limit test of the soil sample SP8

No. of blows	15	18	23	32	35
Weight of container + wet soil (gm)	23.4	24.8	24.4	24.8	26.6
Weight of container + dry soil (gm)	17.4	19.6	18.8	19.7	21.5
Weight of water (gm)	6	5.2	5.6	5.1	5.1
Weight of dry soil (gm)	10.4	10.1	11.1	10.1	10.4
Water content (%)	57.7	51.4	50.4	50.5	49.0
Liquid limit	51				

Table A-16: Plastic limit test of the soil sample SP8

Container no.	2255	2132
Weight of container + wet soil (gm)	22.9	25.1
Weight of container + dry soil (gm)	20.6	22.4
Weight of water (gm)	2.3	2.7
Weight of dry soil (gm)	9.9	12.3
Water content (%)	23.23	21.9
Plastic limit	23	
Plasticity Index (PI)	28	

Table A-17: Shrinkage limit test of the soil sample SP8

Dish no.	2
Weight of dish (gm)	28.9
Weight of dish + wet soil (gm)	53.4
Weight of dish + dry soil (gm)	44.9
Weight of dry soil pat (gm)	16
Weight of water (gm)	8.5
Weight of displaced Mercury (gm)	156.1
Volume of displaced Mercury (cc)	11.53
Volume of dish (cc)	15.03
Initial moisture content of soil pat (%)	53.12
Volume of moisture (cc)	3.5
Moisture content of dry soil pat (%)	21.87
Shrinkage limit	32

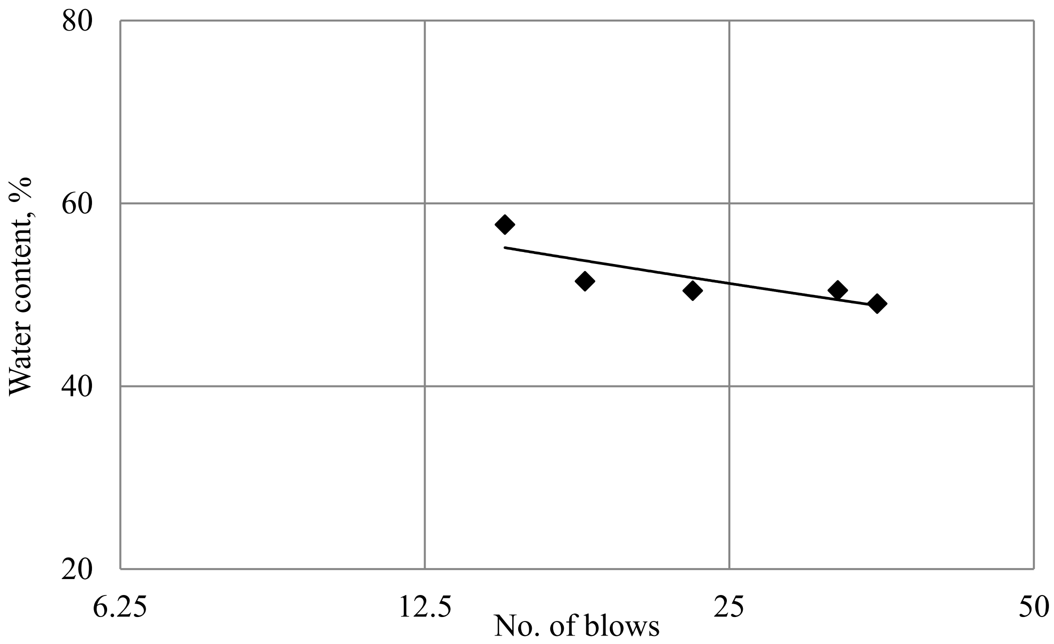

Figure A-6: Flow curve for determination of liquid limit of the soil sample SP8

Sample Location: Rudrokor, East Char Rushundi

Table A-18: Liquid limit test of the soil sample SP9

No. of blows	15	18	24	29	35
Weight of container + wet soil (gm)	21.6	20.2	27	23.2	20.2
Weight of container + dry soil (gm)	17	16.3	22.5	18.8	17.6
Weight of water (gm)	4.6	3.9	4.5	4.4	2.6
Weight of dry soil (gm)	9.6	9.4	11.8	12.3	7
Water content (%)	47.9	41.4	38.1	35.7	37.1
Liquid limit	38				

Table A-19: Plastic limit test of the soil sample SP9

Container no.	48	847
Weight of container + wet soil (gm)	16.6	22.6
Weight of container + dry soil (gm)	14.8	20.4
Weight of water (gm)	1.8	2.2
Weight of dry soil (gm)	8	9.3
Water content (%)	22.5	23.6
Plastic limit	24	
Plasticity Index (PI)	14	

Table A-20: Shrinkage limit test of the soil sample SP9

Dish no.	6
Weight of dish (gm)	22.3
Weight of dish + wet soil (gm)	48.9
Weight of dish + dry soil (gm)	41.3
Weight of dry soil pat (gm)	19
Weight of water (gm)	7.6
Weight of displaced Mercury (gm)	161.6
Volume of displaced Mercury (cc)	11.9
Volume of dish (cc)	14.8
Initial moisture content of soil pat (%)	40
Volume of moisture (cc)	2.9
Moisture content of dry soil pat (%)	15.1
Shrinkage limit	25

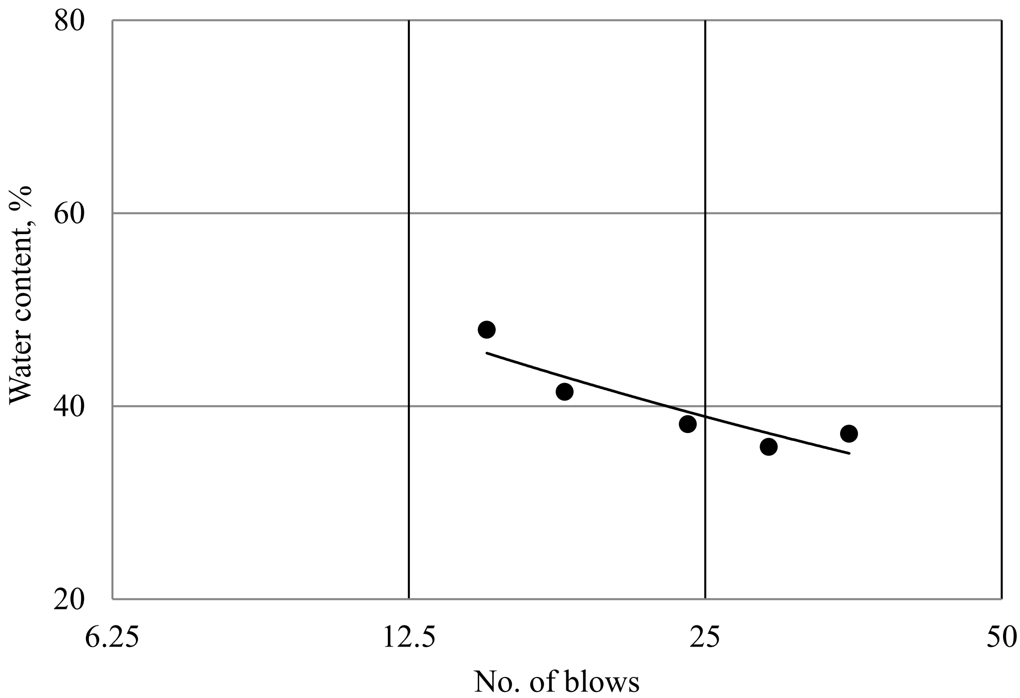

Figure A-7: Flow curve for determination of liquid limit of the soil sample SP9