Experimental Study of Cement Stabilized Fiber Reinforced Compressed Earth Blocks as an Alternative Building Material

by

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ABSTRACT

Concern and interest about the environment and ecologic systems have promoted the usage of earth as a construction material. Technology advancement has resulted in the evolution of adobe into compressed stabilized earth blocks (CSEB). CSEB's are prepared by compressing the soil-stabilizer mixture at a particular stress. In order to accomplish the required strength, cement has been used in a regular basis as stabilizing agent. It is of interest to find means to reduce the cement used in their construction without affecting its dry strength and durability. In this study, natural fibers were used along with lower proportions of cement to stabilize soil with varying fine content. Blocks were compacted at 10MPa stress and prepared by using 7%, 5% and 3% cement along with fiber content ranging from 0.25% to 2%. The effect of fine content, cement and fibers on strength and durability of the CSEB blocks were studied. Different sand/fine fractions of a native Arizona soil were used to fabricate the blocks. Results indicate that the compressive strength reaches a maximum value for blocks with 30% fine content and inclusion of fibers up to 0.5% increased the dry compressive strength. The use of 0.25% fiber by weight and 5% cement content showed comparable dry compressive strength to that of the 7% cement blocks with no fibers. The dry strength of the blocks reached an optimal condition when the combination of materials was 30% fines, 5% cement and 0.5% fibers, which satisfied the strength requirement given by the ASTM C62 and ASTM C216 standards for construction material. The CSEB's with 0.5% fiber had higher toughness. The durability was determined by subjecting the CSEBs to wetting and drying cycles. The blocks with 5% cement withstand the durability test as the dry strength was higher than that required for construction use.

The blocks were also submitted to heating and cooling cycles. After 12 cycles, the specimens showed a reduction in strength, which further increased as the number of cycles increased. Finally, the thermal resistivity of fiber reinforced CSEB was found to be higher than that for clay bricks.

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1. INTRODUCTION

1.1 General Description of the Soil Blocks

Soil is the word with which everyone is familiar with. Since ages soil is being used as a building material and one of the major advantages is its availability. Even today soil has been the primary material for construction of traditional low cost houses all over the world, however to lesser extent in extremely high rainfall areas. The 12 main construction techniques using soil as building material has been displayed in Figure 1.1. Out of these, the most extensively used techniques are cob, adobe, wattle and daub method, compressed pressed earth and rammed earth. Here is a brief description of the techniques mentioned above.

Cob: Balls of plastic soil stacked upon each other and packed using foot or hand (Tadege 2007).

Adobe: It's the mixture of the soil and natural fibers to which water is added until the soil attains the plastic state and molded in to bricks which is allowed to dry in the outside climatic condition (Illampas, et al. 2014).

Wattle and daub method: Soil plastered over the mesh of bamboo and cane frame structures.

Compressed earth: Moist soil compressed manually or by mechanized technique.

Rammed earth: Humid soil is poured into the form work in layers and rammed manually or by pneumatic rammers to increase the soil density. In recent years rebars are also used in this technique.

However, traditional earth construction techniques such as wattle and daub, cob and adobe need continuous maintenance in order to keep them in good condition. There has been considerable development in the usage of soil for building purpose. The most popular methods in recent time are rammed earth wall and compressed stabilized earth blocks (CSEB). Compressed stabilized earth blocks may be defined as compressed blocks made out of soil and an extraneous binding materials. These blocks have various advantages, such as economical, affordable, non-combustible, low thermal conductivity and low energy input. One of the attractive characteristics of CSEB is the use of innovative materials along with soil such as resins, shredded plastic and byproducts from various industries. The most common binding material used for the production of CSEB are cement, lime, bitumen, fly ash and etc.

1.2 Background

Soil blocks are long standing and less environmental impact. In most part of the world many examples of earth used as a building material can be noticed. The oldest one built with adobes and sun dried mud bricks was in 1300BC in Egypt, the vault of Ramasseum. Humans have been building structures using earth far more than 10,000 years. This has been proved based on the evidence obtained from the building remnants of the Harappa, Mohenjo-Daro and Jericho (Schroder and Ogletree 2010, Jagadish 2012). The world’s largest adobe town is located in a place known as Bam on Iranian deserts. Even today, 50% of the population reside in homes constructed out of soil material (Schroder and Ogletree 2010).

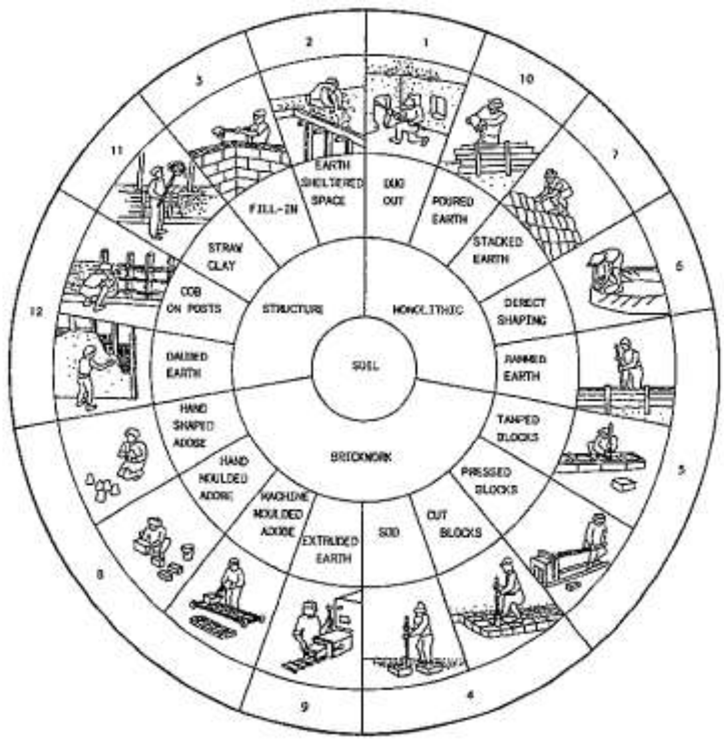


Figure 1.1. The 12 Principal Soil Construction Techniques (Stulz and Mukerji 1988)

The compressed earth blocks are the descent of the adobe block. The process of compacting the earth was carried out to obtain improved quality and performance of the earth block. The turning point in the usage of compressed stabilized earth blocks came into effect after the invention of CINVA-RAM pressing machine in 1952. This leads to the emergence of market for the production and application of the blocks throughout the world (Rigassi 1995). In 1950 the Sir Lankan government built few building using the CINVA RAM pressing machine. After that, few projects were taken up by State Engineering Corporation for constructing building using CSEB but they did not succeed as these structures failed. This initiated research work on CSEB in 1991 to understand the parameters of the soil and the stabilization technique. Then Auram Press 3000 pressing machine was introduced to produce better CSEB. In 2004 almost around 160 building were built using CSEB about all the buildings failed. This incident was considered seriously and many professional bodies including Sri Lanka Standard Institute and ICTAD (Institute for Construction Training and Development) called for standards and specification for CSEB and it was prepared and presented by Perera (2009).

In India many houses were built using earth which was stabilized with 2.5% and 5% cement during 1940's, but these houses didn't deliver the performance for longer period of time. In 1979 ASTRA (Application of science and technology to rural areas, Indian institute of science) started research on CSEB, during which almost around 500 soil samples was tested for suitability in using for CSEB and also they started training Engineers and Architects on earth block construction. This has resulted in construction of more than 200 earth buildings in Bangalore and Mysore every year. Since 1950 its practical application with technical appreciation has continued to progress.

1.3 Problem Statement

It has been mentioned that pollution emission contributed by the production of CSEB is 2.4 times less than wire cut bricks and 7.9 times less than country fired bricks (Maini 2005). Also, CO_2 emission during the production of CSEB has been reported to be 40% less compared to that of concrete blocks (Maini 2005).

Agricultural waste products like Bagasse are contributing to disposal problems (Gandhi 2012). So it is very important to study the ways by which it can be used in an effective manner so that it will be useful for the humans. As the fiber reinforced stabilized earth block usage has the above mentioned advantages it is important to extend the study of compressed stabilized earth blocks. Focus of the research is utilization of bagasse which is fiber residue from guayule plant, to evaluate the possibility of its usage in the production of suitable and sustainable CSEB.

Since 1950s CSEB is being used in construction industry, but social acceptance has been a major problem due to various failure examples. Even though many governments have promoted the usage of CSEB, it is regarded as poor building material. To facilitate acceptance, it is very important to present them with results which will make them believe that this material is durable which will provide them with a comfortable living environment if used in construction.

1.4 Significance of this Work

Due to limited means within developing countries, it is necessary to seek ways to reduce construction costs, especially for low-income housing, as well as adopting easy and effective solutions for their repair and maintenance. This can be achieved by using CSEB which can be produced with locally available materials. The application of CSEB is not popular because of many failures recorded in the past. So it is very important to study the short term and long term durability of the CSEB to build up the confidence in using this technology.

CSEB is one of the construction material which helps in bringing down the cost of construction. Even though it is in use since 1950s, customers are reluctant to use this material for construction because of the negative experiences with its use. Although failure might be attributed to a number of factors, such as unskilled labor, lack of knowledge about the type of soil to be used and bad equipment; it is important to demonstrate that these blocks are strong and durable, which can promote the usage of CSEB and will benefit many low-income groups. In addition, the usage of waste agricultural material for block production will help in solving regional waste disposal problems and hence, promote healthier environments.

This study has benefits not only in the residential construction industry, but also in pavement industry. These blocks can be used as an alternative for the pavers used in pedestrian walkways. They can also be used for residential driveways and commercial driveways that see little traffic and no heavy vehicles. The uniform, pleasing appearance of paving blocks means that they are very well-suited for use in disguising imperfections in an outdoor space and they can be used as paths, patios or mixed with other paving types to create a unique feature. They are certainly a more sustainable alternative to the traditional asphalt or macadam surfacing. CSEBs can also be used in military applications like training structures and for providing protection in combat operations. In addition, the normal brick/clay paver requires temperatures up to 2000^{o} F to reach the desired strength which contributes to carbon dioxide emissions. The production of CSEB does not require burning practices which reduces the negative impact on the environment.

1.5 Study Objective

In this research work, compressed stabilized earth blocks (CSEB) will be produced using lower proportions of cement than commonly used in practice along with natural fibers. Bagasse fibers will be used which is a grinded stem and branch left after extracting the latex for rubber production from Guayule plant. Different sand/fine fractions of a native soil from the Phoenix area will be used to fabricate the blocks. The compressive strength and durability of these blocks will be determined and compared with the specifications mentioned in the standards for its usage. The suitable mix proportion can be obtained by this comparison which can be used as an alternative building material. Along with this the thermal resistivity of the best sustainable blocks which stands out in the above mentioned checks was investigated. This result will provide necessary information to take a step for using compressed stabilized earth blocks as building material which will benefit the construction industry and people.

In order to accomplish these target, the following objectives will be completed:

1. Assessment of the dry compressive strength of the soil blocks and to determine the influence of bagasse fibers with usage of cement on its strength.
2. Examining the influence of wetting/drying and heating/cooling cycles on the dimension, mass and dry compressive strength of the soil blocks.
3. Determining the construction R value of the blocks at varying temperatures for applicability to construction industry.

1.6 Scope of Work

This research work deals with the experimental study of the fiber reinforced cement stabilized earth blocks. The experimental results are limited to a native soil from the Phoenix area and bagasse fibers from the Guayule plant. The soil was then sorted into different sizes and recombined to create three different soils with variable fine content. The three soils were prepared by thoroughly mixing the fines and sand, separated from the native soil prepared, at different proportions. Index property of the fabricated soils and the native soil was determined. The soil blocks were manufactured using the fabricated soils with addition of cement and bagasse fibers at different proportions. After the blocks were allowed to cure for 28 days, they were tested for dry compressive strength, durability and thermal resistivity.

The tests were carried out at full scale and were carried out in the Geotechnical and Structural laboratory in Inter disciplinary building 2 at Arizona State University.

The following tasks were performed:

1. Thorough literature review on the soil as a construction material, stabilized soil blocks, influence of natural fibers on the strength of the blocks and so forth was done.
2. Comprehensive laboratory test was done to determine the amount of fibers, different fine contents, different cement contents, block dimension and the process to be followed for the production of the blocks
3. The fines and sand separated from the native soil in the sieving process were dry mixed at three different proportions to get a homogeneous mixture.
4. The laboratory testing of the fabricated soils was carried out as per the ASTM standard to determine the characteristics of the soil.
5. Block pressing was then carried out using a compression machine and a mold at the predetermined compacting pressure of 10000lbs.
6. After the blocks had been cured for 28 days, strength was determined by carrying out unconfined compressive strength as per A.S.T.M D4219-08.

7. Laboratory testing of the blocks was done by exposing them to temperature variations and moisture variations which provided an idea about their durability when exposed to the environment.
8. Thermal resistivity of the best suitable blocks, decided based on the strength and durability test, were tested using the sensors at two extreme temperatures.

1.7 Organization of Thesis

The experimental findings from this research work is reported in this thesis. This thesis is written in the chronological order of the experiments performed during the research work. The thesis consists of 8 chapters and each chapter is divided into sections and subsections. The thesis is organized as follows: Chapter 1 consists of an introduction and will identify the significance of the work as well as indicate the objective and scope of the research work, Literature review will be presented in chapter 2, Chapter 3 gives information about the current recommendations for the production of compressed soil blocks. The properties of soil, cement and fiber used is reported in Chapter 4 along with mix proportion details and production process carried out. Chapter 5, 6 and 7 includes test results and discussion of dry compressive strength, durability and thermal property. Chapter 8 will sum up the conclusions made throughout the thesis and will have necessary recommendations for staging future research initiatives.

2. LITERATURE REVIEW

2.1 Introduction

Soil is the habitat for numerous living beings where they live and interact. The human beings along with their evolution figured out the use of soil in building shelters to protect themselves considering the climatic conditions (Houben and Guillaud 1994). Based on the environmental conditions and the traditions, people used different material for building habitats and one of the most prominently used construction material is soil (Sharma, et al. 2015). It is evident that the start of civilization and soil masonry are on the same page in the history (Deboucha and Hashim 2010). In the city of Shibam which is the UNESCO world heritage site in Yemen, buildings over 8 stories made out of soil blocks is still standing strong (Aubert, et al. 2013). There are so many examples of ancient structures such as the Great Wall of China and the rammed earth city wall of Tinznit in Morocco.

Soil was used in construction intensely because of the usage of local materials, simple construction techniques, thermal comfort, acoustic insulation and aesthetics. Despite having various advantages, the major drawbacks are the strength requirement for high rise buildings and the durability issues as it is sensitive to the moisture. The boom in concrete industry in the 20th century, which changed the complete view of the strength of the building materials, completely overtook the soil block concept from the people's mind. With concrete achieving up to 100MPa, strength of the blocks is now considered the parameter for durability and quality (Aubert, et al. 2013). However, in the past few years there has been a slight inclination towards the use of stabilized earth blocks, basically due to environmental concerns. According to EPA, the cement industry is the third largest source of environmental pollution, producing 500,000 tons of carbon monoxide per year, nitrogen oxide and sulfur dioxide, and 829 million tons of carbon dioxide (Hanle, et al. 2004). Brick kilns have been a serious treat for human health and environment, due to emission of carbon monoxide and sulfur oxides. These are the reasons why the researches are focusing on the stabilized earth blocks as it is a low cost sustainable material which requires less than 10% of the energy input for manufacturing compared to fired clay and concrete masonry units (Walker 1995).

2.2 Role of Stabilized Earth Blocks in the Developing Countries

Adequate housing is one of the basic need to lead a peaceful and dignified life and also represents the economic and social development of the country. However, in developing countries it is challenging to provide economical housing for working class people. The hurdle for this housing problems are high cost of land, construction materials and labor (Kabiraj and Mandal 2012). Even though governments are coming up with financial and housing schemes to help people get house ownerships, it is not helping in any ways due to the constant hike in construction cost. According to United Nations Center for Human Settlements (UNCHS) by 2030, about 40 percent of the world population will require proper housing. Unfortunately, because of limited resources in many developing countries, it is necessary to work towards finding a way to reduce the construction costs and move towards the development of low-income housing (Adam and Agib 2009). Furthermore, in response to the need for global environmental changes and the importance of ensuring environmental, social and economic sustainability, it is critical to explore a sustainable building material. This can be achieved by improving the traditional construction techniques in which locally available cheap materials is used. Moreover, the locally available material must be renewable in nature. The usage of these materials for producing construction materials will contribute towards the development of the country by generating local employment, reducing the import and improving the standards of the rural and urban people (Adam and Agib 2009).

Earthen construction is the one of the most popular construction technique used since ages. Local soil is readily available and a renewable material which suits aptly for the problems discussed above (Kabiraj and Mandal 2012). As per the statistics from UNCHS, 40% of the world population currently lives in earthen dwellings. One such technology which is a form of earthen construction is the use of compressed stabilized earth blocks (CSEB). A remarkable reduction in the building construction can be achieved by using this technique. Tadege (2007) reported that the CSEB wall construction cost is 55.2% cheaper than hollow cement bricks which proves that economical construction can be achieved by this technique.

The construction industry and building materials are important sectors which represent the socio-economic development. Development of a nation is also characterized by the ability of government and communities to keep pace with the movement of people from villages to cities and make sure the number of households living in adequate housing increases (Makay 2009). This requirement has increased the tendency of usage of CSEB for construction of low cost housing. This technique will be beneficial for the countries in developing the economy and in moving towards the sustainable future city. The carbon dioxide emissions for the experimental unfired bricks was determined to be 42.9 $kgCO_2$/ton with a total energy usage of 667.1MJ/ton. In comparison, common fired bricks has a total energy usage (input) estimated at 4186.8 MJ/t with equivalent output emissions of 202 kgCO2/ton (Oti and Kinuthia 2012). CSEB can be a source of income from carbon trading too, as there will be reduction in the carbon emission.

Setting up of CSEB production units in rural or urban areas will generate employment opportunities for local people. Economic system of the society can be improved by using the CSEB for cultural facilities, social housing, administrative buildings, and medical facilities, which also helps in improving the standard of living of the society (Tadege 2007). Mayotte, a French territory, is a development model who have been using CSEB for more than 20 years for building social housing. Since the people had no financial resources, CSEB was chosen as the building material. Until 2000, almost around 12,500 houses were built with the production of CSEB rounding up to 30,465,000. More houses are being built till today (Auroville Earth Institute). The use of CSEB helped them in setting up an industry which lead to the economy development along with the social development. Today it has become an international reference for development from CSEB production and usage strategy.

2.3 Origin of Stabilized Earth Blocks

Soil stabilization technique was started back in 1930's in the fields of highway and airfield construction (Fitzmaurice 1958). The builders were not slow in picking up this idea and soon started using this technique for building walls. The two main purpose of stabilizing the soil are to improve the strength bearing capacity and waterproofing, which is a requirement for durability (Rogers, et.al. 1996). The soil blocks used in construction are stabilized using mechanical and/or chemical methods. The soil is compacted mechanically to modify the arrangements of the soil particles; and the inclusion of other materials, which chemically react with the soil (usually pozzolanic reaction occur), to alter its properties.

Even though the compressed soil blocks were being produced using the compression technique from the 18th century, it was not too popular until Raul Ramirez invented CINVA-RAM press in 1952 (Deboucha and Hashim 2010). As a consequence, Sri Lankan, New Zealand, Australian, French, German and Indian governments promoted their usage. Several countries came up with standards and regulations for construction using compressed stabilized earth blocks. Australia was the first country to come up with regulations for earth constructions which were published in 1952 by the Commonwealth Scientific and Industrial Research Organization (CSIRO) and later replaced by the Australian Earth Building Handbook in 2002 (Pacheco-Torgal and Said Jalali 2012). The United States has no regulations for earth construction. However, New Mexico State include adobe and rammed earth construction regulations in the appendix of Housing and Construction Building Codes General in 1991, under the title New Mexico Earthen Building Materials Code, further revised in 2009. New Zealand have three standards addressing the earth construction as an integral part in the building codes. NZS 4297, N 4298 and NZS 4299, published in 1998, provide details about Engineering design of earth buildings requiring specific design and performance, materials and workmanship required in earth construction and earth buildings not requiring any specific design, respectively. Indian Standard Institution also published a standard (IS 15:1725 “Specifications for soil based blocks used in general building construction”) in 1982.

Even though these standards and handbooks do not provide complete details about the understanding of the soil and performance related to the soil type used, it has at least given a start for those people who are interested in constructing residential buildings using soil for the wellness of their family and future generations.

2.4 Cement Stabilized Earth Blocks

Cement stabilized earth blocks are the product of a combination of mechanical and chemical stabilization processes. Mechanical stabilization is done by tamping or compacting the soil at a particular energy to reduce the air void volume, thereby contributing to the increase in the density (Tadege 2007). The major contributors in the mechanical stabilization of the blocks are the reduction of permeability and increase in the strength, which are the most important parameters for the use of blocks in the construction industry. Mechanical stabilization is the most popularly ground stabilization technique which is accomplished by compacting the soil using static, dynamic and vibration means (Parsons 1992). For compressed stabilized earth block production, the soil is compacted at a steady slow rate (quasi-static) to achieve the desired compaction level or density. Improved compaction energy will have a direct influence on the strength and durability of the blocks (Montgomery 2002). The increase in the compaction energy improves the strength of the blocks, however strength reduction will be observed if the blocks are prepared using energy levels higher than the optimum compaction energy (Guettala, et al. 2002). The density achieved is significantly influenced by the gradation of the soil, so it is always recommended to use a correct proportion of sand and fines for effective results.

Mechanical stabilization increases the effectiveness of the chemical stabilizers used. For chemical stabilization, the commonly used manufactured stabilizers are lime, Portland cement, fly ash, ground granulated blast furnace slag (GGBS), bitumen, sodium silicate and gypsum.

The Portland cement is the most popular one out the list mentioned above. Soil cement stabilization technique has been in existence for a long time. A construction project near Johnsonville, South Carolina in 1935 was one of the first construction project in which cement was used as a soil stabilizer in the United States (Das 1990). The cement action is the result of a chemical reaction of the cement with silicon present in the soil during the process of hydration. There are two primary mechanisms by which cement alters the soil:

1. It increases the particle size, shear strength, reduces the plasticity index, and shrink/swell potential.
2. Brings about absorption and chemical bonding of moisture that facilitates compaction.

The properties of soil which are of main concern for block production are volume stability, strength, permeability and durability (Sherwood 1993, Euro Soil Stab 2002). Soils at different areas have different properties and requires different stabilization technique based on their properties. For a successful stabilization, laboratory tests followed by field tests are important in order to determine the engineering and environmental properties of the material. Laboratory tests may produce higher strength than the field, but it always helps to assess the effectiveness of the stabilizer in the field. Laboratory test results will enhance the knowledge on the choice of compaction energy, binders and amounts needed (Euro Soil Stab 2002).

2.5 Fiber Reinforced Stabilized Earth Blocks

Fiber reinforced CSEB is defined as a technique to improve the engineering characteristics of the soil blocks. The concept of stabilizing the soil using natural fibers was recognized 5000 years ago (Hejazi et al 2012). In earthen construction, hay and straw were used to prepare adobe blocks to provide reinforcement. The Great Wall of China was built by reinforcing the soil with branches of trees.

Vidal in 1966 demonstrated the increase in shear resistance of soil with the introduction of synthetic and plant fibers as reinforcement (Maity et al. 2012). Since then, the concept of reinforcing the soil with tensile element became famous in engineering applications. Around 4000 structures have been built so far using this technique (Hejazi et al. 2012). This concept has attracted many researchers these days and implementation in the geotechnical and construction fields has been attempted.

In recent days, synthetic fibers are gaining more popularity than natural fibers. However, due to environmental concerns, there are experimental investigations and interest on the application of natural fibers (Hejazi et al. 2012). The performance of the natural fiber used depends on several factors such as physical properties, chemical properties, fiber interaction in the composite matrix and environmental conditions (Rowell et al. 2000). It is then necessary to assess the performance of natural fibers in different applications. The coconut fibers, sisal fiber, hemp, palm, jute, flax, barely straw, bamboo and cane fibers are commonly used fibers based on availability.

Coconut are agricultural products grown extensively in tropical countries. Coir are the strands of fibers found in the husk of the coconut. Coir has high lignin content which makes it strong and durable. In 2013, Aguwa found that the increase in coir content up to 0.25% in laterite soil blocks contributed to 10% increase in compressive strength when compared to blocks without fibers. The CSEB blocks reinforced with banana fibers of 50mm in length at 0.35% by weight, lead to an increase in flexural and compressive strength of the material by 94% and 77%, respectively, in comparison to blocks which were not reinforced (Mostafa and Uddin 2015). Four percent of Sisal fiber inclusion slightly increased the compressive strength (Ghavami et al. 1999); although Prabakar and Sridhar (2002) found that with the increase in Sisal fiber content, the dry density of the soil decreased.

Taallah, et al. (2014) investigated the mechanical properties of the CSEBs filled with date palm fibers. From the results, they noticed that blocks prepared using 0.05% of fibers showed increase in strength by 6% compared to non-filled blocks. Also increase in water absorption and swelling of blocks was reported with increasing fiber content. Kabiraj and Mandal (2012) found a decrease in dry density and increase in water absorption of the CSEB with addition of 2.5cm jute fibers. However, they noticed a significant increase in compressive strength by around 110% with the addition of 1% jute fibers.

Many studies show the usage of different plant fibers affecting the physical properties, decrease in dry density, and water absorption with increase in fiber content. Nevertheless, mechanical properties such as compressive strength and ductility are improved with inclusion of fibers. Now studies have been carried out on the usage of bagasse fibers, from the guayule plant, in CSEB and the effect of fibers on the blocks when subjected to wetting/drying and heating/cooling cycles. Investigations are still needed to attain more knowledge about the influence of different natural fibers on the durability of the blocks which can contribute towards obtaining the most efficient material.

2.6 Prior Research on Stabilized Erath Blocks

A great amount of research has been carried out on compressed stabilized earth blocks. Most of the published research has focused on the effect of cement composition on the dry/wet strength and water absorption of the blocks. Findings demonstrate that the strength of the blocks increases with increase in cement content (Muntohar 2011, Tadege 2007, Pave 2007, Garg et al. 2014, Guettala et al. 2002). It has also been found that more cement is required to prepare blocks of suitable strength using soil with high clay content and that water absorption of the block increases due to the presence of clay material (Blight 1994).

Same results have been obtained by substituting cement with lime (Riza et al. 2011). The strength of CSEB increases with increase in lime content and compaction stress, while the water absorption decreases (Guettala, et al. 2002). An increase in lime addition promotes stronger cementation bonds that reduce the magnitude of axial strain and produce blocks with yield stress ranging from 3,900 to 5,200 kPa (Rao and Shivananda 2005).

Blight (1994) reported that the addition of 4% OPC15FA (85% Ordinary Portland Cement and 15% Fly Ash blend) resulted in an average block dry strength of 3MPa at 28 days of curing time. Moreover, the addition of 4% OPC15FA reduced rain induced erosion of bricks. The porosity of soil cement blocks was reduced by increasing the concentration of OPC15FA used in mix design. Blights study concluded that a 4% OPC15FA blend produced durable blocks suitable for one-story load bearing masonry construction. Therefore, the addition of fly ash to cement has shown promising results.

The cement-lime mixture used as stabilizer with soil specimens having a Plasticity index of 23 resulted in higher dry and wet compressive strengths when comparing to blocks with just cement or lime components. The coefficient of water resistance increases with the cement content. However, it remains constant for lime stabilized blocks and cement plus lime mixture blocks. The coefficient of water resistance is the ratio of dry strength to wet strength. Cement plus lime mixture blocks have shown less water absorption compared to other blocks based on which it was concluded that mixing cement and lime yielded the best resistance to wetting and had better strength than that obtained with individual components (Chaibeddra and Kharchi 2013).

Walker (1995) studied the influence of soil characteristics and cement content on the physical properties of stabilized bricks. Walker mixed two soil types, one a soil with 50% clay content and a river soil with 1% clay content to get a combination of soil properties. A manually operated machined was used to press blocks, under compaction pressures of 4MPa. Walker found some interesting results. The dry compressive strength ranged between 5.54MPa and 3MPa whilst the saturated compressive strength ranged between 0.95MPa and 3.2MPa. Compressive strengths varied largely depending on the clay content. Walker concluded that clays have a uniaxial dry compressive strength which is lost with saturation and that the drying shrinkage of the blocks is primarily governed by the plasticity index of the parent soil. Once the plasticity index exceeded 20, there was a steady increase in drying shrinkage with increasing clay content. Resistance to abrasion from the wire brush was improved with increasing cement content and reduced by clay content. Cement acts to bond soil particles together whereas clay minerals disrupt cement bonding. At 10% cement content and at maximum clay content, 11% mass was lost whilst at minimum clay content, 1% mass was lost. Water absorption increased with increasing clay content as a greater portion of water was absorbed by the clay minerals. In addition, moisture retention characteristics increased with clay content, with water absorption ranging between 13.4% at highest clay content and 8.2% at the lowest clay content (Walker 1995).

Clay content in the soil plays a major role in the property of the blocks. Walker and Stace (1996) found that the blocks strength was reduced with the increase in clay content. They concluded that blocks prepared with soil having clay content greater than 20% to 25% were unsuitable when stabilized with 5% cement. They recommended the usage of 10% cement to meet the strength requirement for the construction of low rise residential buildings. From the wetting and drying cycle test, it was found that durability increased with increase in cement usage and lower clay content. Durability deteriorated with increase in clay content above 20%. In the water absorption test greater amount of water was absorbed with increasing clay content and reducing cement content. From these test results they conclude at clay content less than 15% to 30% is more suitable for block production depending on the percentage of cement used for stabilization.

Ola and Mbata (1990), studied the effect of compaction pressure, cement content used and the stipulated rainfall on the durability of cement stabilized earth bricks. The soil material used was reddish brown clay sand having 20.3% clay and the liquid limit of the soil was 50% which is very high. The blocks were prepared by varying compaction pressure (1MN/m2, 4 MN/m2, 7 MN/m2 and 8 MN/m2) and also the cement content (0%, 2%, 5%, and 7%). Erosion resistance test was carried out using an equipment for simulating rainfall at different pressures.

From the test results they found that there was an increase in resistance to erosion with increase in compaction pressure. Higher weight loss in blocks were found with increase in terminal velocities and impact kinetic energy of rain drops. There was no much difference in erosion resistance value for the samples containing 5% and 75 cement compacted at 8 MPa. Based on this result they recommended that blocks prepared using 5% cement and 8 MPa compaction pressure is adequate for preparing specimens for erosion resistance test.

Guttala, et.al (2002) looked at the influence of different manufacturing parameters such as compacting intensity, sand content and lime content on the mechanical strength in dry and wet state, water resistance coefficient, the weight loss and the absorption. Several blends of soil-sand mix were used (0%, 10%, 20%, 30% and 40% sand) with lime content of 8% which was maintained constant and a compacting stress of 10Mpa was used for preparing blocks. Then those blocks were tested for dry and wet compressive strength and they found that the compressive strength is 30% for dry blocks and 36% for wet blocks for the 30% concentration of sand. From the water strength coefficient (determined using the compressive strength ratio for dry and wet state) they figured out that the sand content does not affect the water strength coefficient which varied from 0.51 to 0.53 when the sand content varied between 0 to 40%. The water absorption reduction by 20% was noticed when the sand content was 30%. In the Freezing and thawing test the sample containing 30% sand showed 0.45% weight loss and the sample with 40% sand had 0.35 weight loss. The dry compressive strength increased with increase in compacting stress till 17.5Mpa which was conclude to be the optimum compacting stress has the strength decreased by 7% when the compacting stress reached 20MPa for the sample with 8% lime. The water absorption reduction with increase in compacting stress and lime content was also mentioned. They concluded that, the principal effect of stabilization with lime is to prevent water attack which makes the soil blocks, prepared using soil having 30% – 40% sand, more durable.

Olaoye and Anigbogu (2000) presented the results of an empirical study carried out to examine the stabilizing properties of termite modified soil from termite mounds and evaluated its potential uses as a substitute to cement stabilized earth blocks. In this work different proportions of termite modified soil were used in the production of the earth blocks and included 5, 10, 15, 20, 30, 50, 80 and 100% replacement level by volume and no cement was used for the stabilization. Based on the results it was found that blocks with 100% termite mound material had maximum strength of 0.61 N/mm2 for 7 days cured block and 2.44 N/mm2 for 28 days cured blocks. In contrast termite mound stabilized bricks had poor resistance to water absorption.

The performance of blocks in compressive and flexural strength has been found to improve by mixing the soil with sand and adding lime and rice husk ash in the ratio 1:1 (Muntohar 2011). Curing time also has a significant effect on the strength. It was found that strength attained by blocks is higher if they are cured for longer periods of time

(Deboucha and Hashim 2010). The coefficient of water resistance increases with the cement content and it remains constant for lime stabilized blocks and cement and lime mixture blocks. In addition, cement and lime mixture blocks yields the best resistance to wetting (Chaibeddra and Kharchi 2013).

2.7 Current Recommendations for Earth Blocks as a Building Material

2.7.1 Soil properties recommended for CSEB

Soil is the material formed by the weathering process of the parent rocks. Depending on the weathering process, parent rock and the environmental conditions the characteristics of the soil varies. The soil is mainly composed of four types of particles; namely gravel, sand, silt and clay. The physical characteristics and chemical composition of the clay particles varies more from place to place relative to gravel, sand and silt. The binding property of the clay is the main reason for using the soil for building purpose. The properties of the soil are governed by the clay content and its behavior and therefore, the cohesive character of the clay contributes to the strength and durability of the soil blocks. Out of the many physical characteristics that defines the soil material, only a few characteristics such as moisture content, grains size, liquid limit, plastic limit and dry density are important in checking the suitability of the soil for preparing the compressed stabilized earth blocks. The chemical composition is not a main factor unless sulphates and organic matter are present.

Rigassi (1985), based on the previous experiences he recommended the granular composition suitable for the production of CSEB in “Compressed earth blocks: Manual of production”. The soil is considered suitable if the soil gradation falls within the shaded region represented in Figure 2.1. This is just the recommendation made but not the specifications to be compulsorily followed. Most of the soils gradation fall outside the region recommended, it can still be used by carrying out suitable testing.

Different standards and authors have different criteria for the soil gradation to be used in the production of CSEB as listed in Table 2.1. These recommendations are made based on the environmental conditions and the most prominently available soil in that particular region. The specified percentages are just the recommendations to get a good quality CSEB. Rigassi, et.al (1996) has reported that soil falling outside the recommended composition such as soil having 70% clay have given satisfactory results.

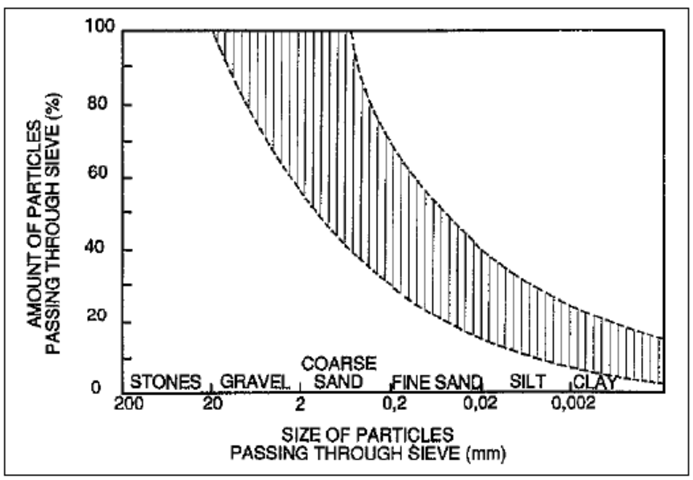


Figure 2.1. Recommended Gradation of the Soil to be used for CSEB (Rigassi, 1985)

The other geotechnical parameters which influences the suitability of the soil to be used for CSEB are liquid limit and plastic limit. These parameters provide indication about the workability of the soil. Plasticity of the soil is generally used to express the characteristics of the clay. The clay content in the soil is of major concern. Little amount of clay does not provide adhesive property and too high clay content may result in high volume change, which effects strength and durability in both the cases (Fitzmaurice 1958, Jagadish 2012).

The comparison of Liquid limit and plastic limit Plasticity index can be deduced. This numerical value is a criterion for the cohesion and plastic nature of the soil. The shaded region in the plasticity chart, as shown in Figure 2.2, is the range of plasticity of the soil recommended by Tadege (2007) for the production of CSEB. Spence and Cook (1993) have include the graphical plot on the plasticity chart, as represented in Figure 2.3, showing soils most suitable for stabilization which can further be used in block production. Few more recommended criteria based on the Atterberg limits are tabulated in Table 2.1. In order to check the importance of the clay content in the soil on the strength and durability of the compressed stabilized earth blocks fabricated soils composed of different fine content was used in this study.

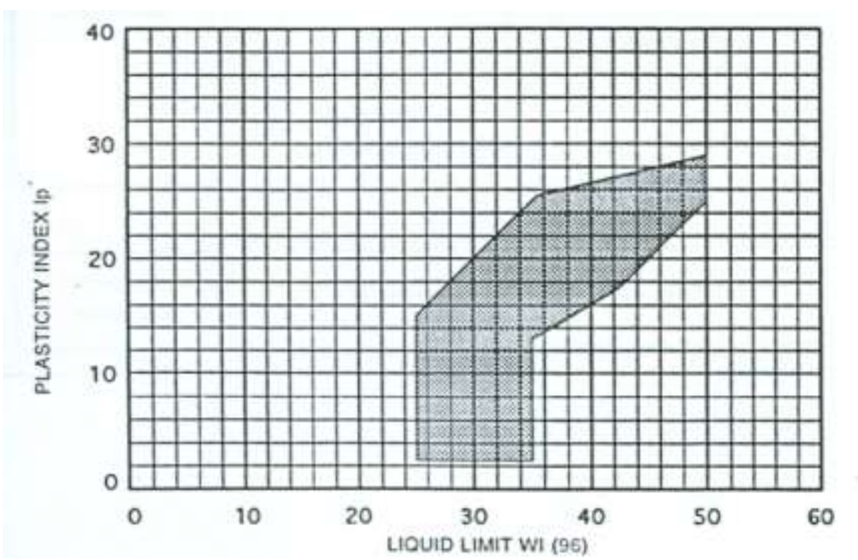


Figure 2.2. Recommended Region of Plasticity of the Soil Preferable for CSEB (Tadege 2007)

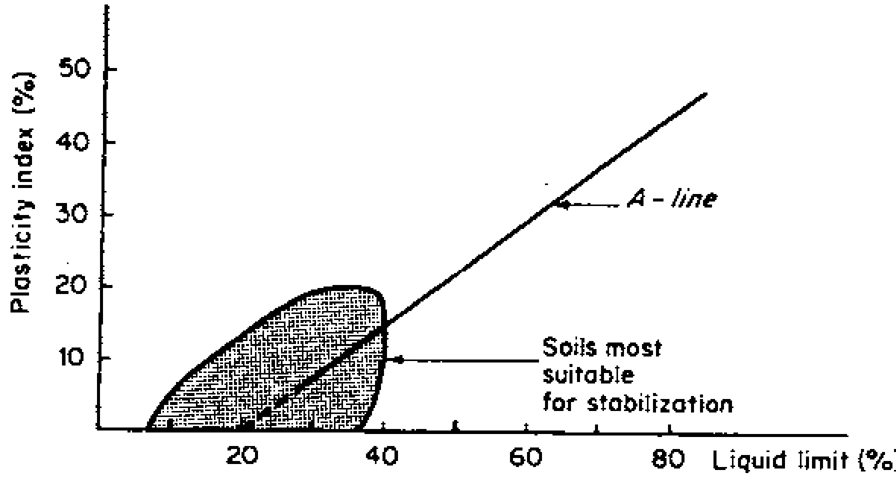


Figure 2 3. Suitable Plasticity Values for Soil Stabilization (Gooding 1993)

As listed in this section there are number of criteria put forward by various authors for the selection of suitable soil for the CSEB production. The criteria are based on the particle sizes, Atterberg limits or both. These recommendations can be used as the guide line for selecting the soil rather than as a standard rule to be followed. Variations in the recommended values can be noticed, this is due to the variability of the soil used by different authors, the method followed in the production of CSEB and the different climatic conditions. These recommendations can be used as an initial guideline for the soil selection, however, the soil suitability is not conformed until few trial blocks are prepared and tested to satisfy the required specifications.

2.7.2 Type of cement for stabilization

Soil cement stabilization technique has been in existence for a long period of time. Cement stabilization of soil is the process of transformation of soil index properties by adding cement which alters the physical and chemical properties of the soil including the cementation of the soil. The cementation of soil is due to process of hydration which is a result of chemical reaction of the cement with water. The soil is made water resistant by reducing the swelling and compressive strength is increased by the cementation process. Since the invention of the soil stabilization technique cement has been used as the major binding material. Cement is a fine powder which form an adhesive material when mixed with water. It is considered as a primary stabilizing agent as it brings about the stabilizing action required (Sherwood 1993 and Euro Soil Stab 2002). One of the major advantage of using cement as a stabilizing material is that the cement reaction is not dependent on the soil minerals (Euro Soil Stab 2002). This is the reason why cement is mostly preferred for stabilizing wide range of soils. Usually the choice of cement quantity depends on the final strength to be achieved. Different types of cement are being used for stabilizing the soil. Type I Portland cement was extensively used in the early days which has been taken over by the sulphate resistant Type II cement in the recent years.

Table 1.1.

Percentage Range of Recommended Soil Gradation and Plasticity for CSEB

Country	Document Name	Reference	Gradation				Liquid Limit	Plasticity Index
			Gravels	Sand	Clay	Silt		
	Building With Stabilized Mud	Jagdish (2012)		65-75%	20-10%	15%		
	Compressed earth blocks: Manual of production	Rigassi (1985)	0-40%	25-80%	10-25%	8-30%		
	Building materials in developing countries	Spence and Cook (1983)		60-90%	0-25%	0-25%	7-40%	0-22%
	Earth construction handbook : the building material earth in modern architecture	Minke (2000)		40-70%	30-60%			
India	Indian Standard 1725 (2010)	Matthew et.al (2012)		> 65%	10-15%			≤ 12%
Kyrgyztan	PCH-3-87 (1988)	Matthew et.al (2012)		70-90%	10-30%			2-9%
Spain	UNE 41410	Matthew et.al (2012)			≥ 10%			
Sri Lanka	SLS 1382 - 1 (2009)	Matthew et.al (2012)		55-70%	10-15%	5-20%		≤ 12%
	Building with Earth, a Handbook	Norton (1986)		45-75%	15-30%	10-25%		
United Nations	Soil-Cement, its Use in Building	Gooding (1193)		75%	25%			
	Manual on Stabilized Soil Construction for Housing	Fitzmaurice (1958)					< 40%	2.5-22%
	Appropriate Building Materials	Stulz (1983)						0 -12%

2.7.3 Standard procedure for the production of CSEB

The process of compressed stabilized earth block making involves a series of steps, which needs to be followed accurately to produce an acceptable block for the construction purpose. The process recommended by Jagdish (2007), Fitzmaurice (1958), Rigassi (1985) and Adam, et.al (2001) for the production of these blocks is summarized in this section.

Table 1.2.

Recommended Compressive Strength of Bricks as Per Various Standards and Authors

Country	Document	Reference	Classification	Minimum Compressive strength (MPa)	Test type
United States	ASTM C62		Severe weathering	17.2	Dry
United States	ASTM C62		Moderate Weathering	15.2	Dry
United States	ASTM C62		Negligeble Weathering	8.6	Dry
United States	ASTM C216		Severe weathering	17.2	Dry
United States	ASTM C216		Moderate Weathering	15.2	Dry
South Africa	SABS 227:4.4		Face bricks	1.25	Dry
South Africa	SABS 227:4.4		Non facing plastered	5.5	Dry
South Africa	SABS 227:4.4		Non facing extra	7.5	Dry
Europe	Eurocode 6		Low risk of saturation	7.3	Dry
Europe	Eurocode 6		High risk of saturation	18	Dry
Canada	CSA A82-06		Exterior grade	> 20.7	Dry
India	IS 15:1725 - 1982			1.9	Wet
	Building with stabilized mud	Jagdish 2007		3	Wet
	Compressed earth blocks production equipment	Rigassi et.al 1996		>12	Dry
	Inter-American Housing and Planning center	Jagdish 2007`		1.4	Wet
	AJK technical and general specifications		First class	13.8	Dry

The soil when extracted from the field is a blend of gravels, sand, fines, lumps of clay, roots, etc. Initially the soil has to be prepared by first pulverizing it to break down the lumps of clay. Then the soil is passed through the 4.75mm sieve to remove all the gravels so that a uniform soil mass is obtained for the block production. The soil must be air dried before being used. If required the soil gradation can be changed by adding sand to clayey soil or by adding some fines to the sandy soil which is dependent on the quality of the blocks needed, this process need to be carried out now.

The decided proportion of soil and stabilizer is weighed out for the mixing which is the next step. In order to obtain a suitable mix, the soil is first spread out, over that the stabilizer is spread evenly as a thin layer. Then the mixing should be done carefully until the mixture attains a uniform color. The mixing can be carried out manually or even mixers can be used. After the completion of the dry mixing of soil and the stabilizer 80% of the predetermined quantity of water is to be added. The amount water to be added will depend upon the density - moisture relation of the soil being used. After addition of water the mix is thoroughly mixed. Then the remaining 20% water is added and mixing process is continued until the required consistency is obtained.

The moist soil mix is ready for the block production. Block pressing can be carried out by any compression machines at the predetermined compacting pressure. The compacting pressure is dependent on the strength and the density of the blocks to be achieved. The blocks of any dimension can be prepared using the appropriate mold. Once the production is done the blocks are extruded carefully without damaging the corners of the blocks and taken for stacking.

The blocks are stacked on a flat surface and in a shaded area for the curing purpose. Direct sunlight is avoided to prevent quick loss of moisture from the blocks which affects the hydration process of the stabilizers which influence the strength of the blocks. The blocks have to be stacked close to each other to prevent air circulation and conserve moisture for curing. It is recommended to cover the blocks with a cloth or gunny bags as it will remain moist and provide moisture to blocks continuously. Spraying water at least for two times in a day will yield better curing of blocks.

2.7.4 Specifications for determining the compressive strength of building materials

Compressive strength of the blocks is determined by imposing uniaxial compression stress on the CSEB. Load is applied at a steady rate depending on the height of the specimen and the compressive strength is determined from the maximum load and the gross cross sectional area of the specimen. The compressive strength can be tested in dry or wet conditions. The moisture content in the sample during the test has a significant impact on the strength (Walker 2004).

The compressive strength of the blocks is recommended by different standards depending on the application, use and climatic conditions. These specifications include the strength, durability and aesthetic requirements. The strength requirements for the use of blocks in construction, as specified in several standards and manuals from different countries, are listed in Table 2.2. Note that these requirements are a function of the usage and type of the structure. The compressive strength is one of the suitability parameter for the usage of blocks. The variation in the strength specification is not surprising considering the variation in the climatic condition and the application.

2.8 Conclusion

From the literature review, it is clear that most of the work is been done on determining the strength and water absorption of the blocks stabilized using cement, lime, rice husk ash, fly ash, fibers or a combination of these products. Also, the effect of compression stresses, wetting /drying cycles, rainfall impact and curing time has been studied. There are also studies on use of termite mound blocks. However, studies concerning R value, environmental effects on CSEB and studying the impact of natural fibers on the durability and R value are scarce. It is important to subject these blocks to repeated cycles of wetting-drying and heating-cooling that simulate environmental conditions in order to assess their durability with the usage of fibers and the R value which gives a base line value to compare with the regularly used fired bricks and concrete blocks.

3. PROPERTIES OF MATERIALS, MIX PROPORTIONS AND BLOCK PRODUCTION

3.1 Introduction

With so many different characteristics that one could determine about a soil sample, it would be unwise to try and discover them in every situation that soil is to be used for making CSEB. In this research work only a small number of characteristics that are of real relevance to the production of CSEB is considered. The physical properties are of great interest for the production of CSEB as these will help to determine the water content to be used to achieve the decided.

The soil sample is generally characterized using two properties, by particle size distribution analysis and by plasticity index. The particle size analysis gives information on the soil ability to pack in to a dense structure and the quantity of fines present (combination of silt and fine fraction), while the plasticity index gives an idea of the cohesion of the fines.

The laboratory tests were conducted to establish numerical values for the soil sample parameters, primarily the percent distribution of the different sizes of the soil particles, plasticity index and the water-density relation. These values are subsequently used to classify the soil.

3.2 Preparation of Fabricated Soil

The soil used in this investigation is abundant in the Phoenix area. It contained soil lumps of different sizes and deleterious substances. Soil was first air dried for 2 days and then pulverized to reduce the soil grains to its natural size. In this study only fines and sand particles was used. To separate fines, sand and gravel the soil was sieved through No.4 and No.200 sieves. The soil retained on No.4 sieve is gravel, soil retained on No.200 sieve is sand and passing No.200 is fines. Only sand and fines was stored for usage in the production of the blocks and gravels were discarded. The percentage of fines in the soil is considered to be one of the parameter in studying its effect on the strength and durability of the blocks. Blocks were prepared using soil mixture prepared by mixing fines and sand at varying composition. The fines and sand extracted in the sieving process was dry mixed thoroughly on plastic sheet to get a homogeneous mixture. The compositions of fines and sand used is been tabulated in Table 3.1. Further the index properties were determined according to the ASTM standards which are reported in the following section.

Table 3.1.

Fabricated Soil Composition

Reference Name	Composition	
	Sand (%)	Fines (%)
Sand:Fines; 90:10 (F1)	90	10
Sand:Fines; 70:30 (F3)	70	30
Sand Fines; 50:50 (F5)	50	50

3.3 Index Properties of Soil

3.3.1 Particle size analysis of soil particles

The grain size distribution was performed according to the ASTM D6913 – 04 (Reapproved 2009) standard. Four soil mixes, one is the original soil from the Guadalupe area and three fabricated soils, were tested. The soil samples, split from the representative sample, were wet sieved through #200 sieve and the dry sieve was carried out on the soil sample retained on #200 sieve after drying it at 230°F for 24 hours. The mass of soil retained on each sieve was used to calculate the percentage of soil passing particular sieve size which was used to plot the grain size distribution curve.

Further the Hydrometer test was carried out to determine grain size distribution of soil particle size less than 0.075mm (#200 sieve). This was carried out as per ASTM D6913 – 04 Standard. The data obtained from the Hydrometer was also used to plot the grain size distribution curve. The particle size distribution of the original soil and the fabricated soils are illustrated in Figure 3.1. From the hydrometer analysis the clay content in the original soil and the fabricated soils was figured, are tabulated in Table 3.2.

Table 3.2.

Clay Percentage in the Soils

Soil	Clay content (%)
Original Soil	11.21
Sand:Fines;90:10 (F1)	3.21
Sand:Fine;70:30 (F3)	8.19
Sand Fines;50:50 (F5)	13.69

3.3.2 Consistency limits

The term consistency is used to denote the degree of firmness of a soil, such as soft, firm, stiff or hard. Depending upon water content four stages of consistency namely liquid, plastic semi-solid or solid state are used to described the consistency of a soil. The water contents at which the soil passes from one state to the next are known as consistency limits, also known as Atterberg limits as it was demonstrated by Atterberg, a Swedish scientist.

In a very wet condition, fine grained soil mass acts like a viscous liquid and said to be in the liquid state. With restricted reduction in water content the soil mass passes from one state to another. the limiting water contents when a soil mass passes from liquid to plastic, plastic to semi-solid and semi-solid to solid states of consistency are respectively termed as liquid limit, plastic limit and shrinkage limit.

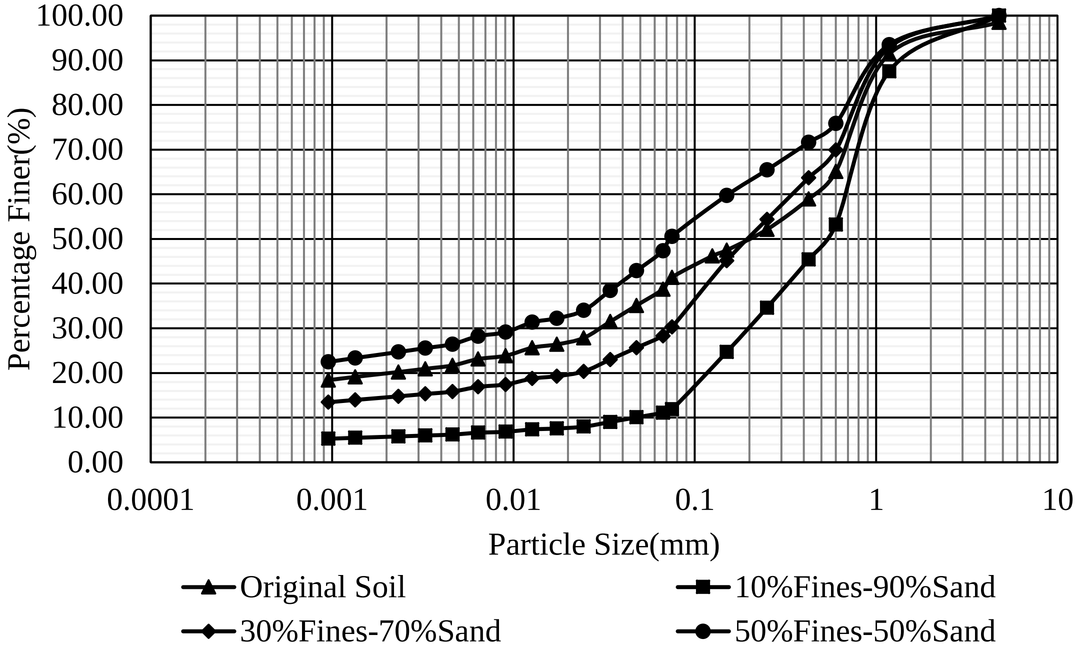


Figure 3.1. Grain size distribution curves of the fabricated soils and original soil

The numerical difference between the liquid limit and plastic limit is known as plasticity index, the plastic range of the soil. The values of liquid limit and plastic limit are used for classifying the fine grained cohesive soils. The values of these limits are also used in determining the flow index, toughness index, and plasticity index which are useful in giving an idea about the plasticity and cohesiveness of cohesive the soils.

The liquid limit and plastic limit of the soils was determined by following the procedure of ASTM D 4318-05. Dry preparation method was followed for this research work. The soils were first dried at room temperature and then pulverized in a mortar. The crushed soils were then sieved over #40 (425µm) sieve. The soil passing #40 sieve was used in this test. The liquid limit, plastic limit and the plasticity index of the original soil and three fabricated soils are reported in the table. 3.3. It can be noted that with the increase in fine content the plasticity index increased. The soil with less percent of fines, i.e. 10%, had a plasticity index of 14 and the plasticity index of 505 fine soil was 21.

Table 3.3.

Atterberg Limits Values of the Soils

Atterberg limits	Original Soil	10% Fines-90% Sand	30% Fines-70% Sand	50% Fines-50% Sand
Liquid Limit (%)	36	34	35	39
Plastic Limit (%)	20	20	19	18
Plasticity Index (%)	16	14	16	21

3.3.3 Compaction characteristics of soil

Compaction of soil is a mechanical process by which the soil particles are packed more closely together by reduction of air voids and consequently an increase in dry density. The degree of compaction is usually measured quantitatively by dry density. It is found that with increases in the moisture content, the dry density first increases and then decreases if compacted by any method. The moisture content at which the soil attains the maximum dry density is known as optimum moisture content.

Compaction of soil increases their density, shear strength capacity but reduces their voids ratio, porosity, permeability and settlement. From laboratory compaction test, the maximum dry density and optimum moisture content (OMC) of the soil was found. This test was performed to determine the moisture content to be used to attain the maximum dry density at which the blocks had to be prepared. The compaction test was executed as per ASTM D 698 – 00a. The compaction energy used for this test was 12400 ft-lbf/ft^3 (600 kN-m/m^3). On the performance of this test it was found that with increase in fine content the maximum dry density reduced and the corresponding optimum moisture content increased. Figure 3.2 illustrates the compaction curves and Table 3.4 provides details about the maximum dry density and optimum moisture content of the original soil and the other three fabricated soils.

Table 3.4.

Compaction properties of the soils

Properties	Original Soil	10% Fines-90% Sand	30% Fines-70% Sand	50% Fines-50% Sand
Maximum Dry Density (Kg/m^3) at 12,400 ft-lb/ft³ (Standart Proctor)	1825	1902	1890	1805
OMC (%)	15.3	13	13.5	16

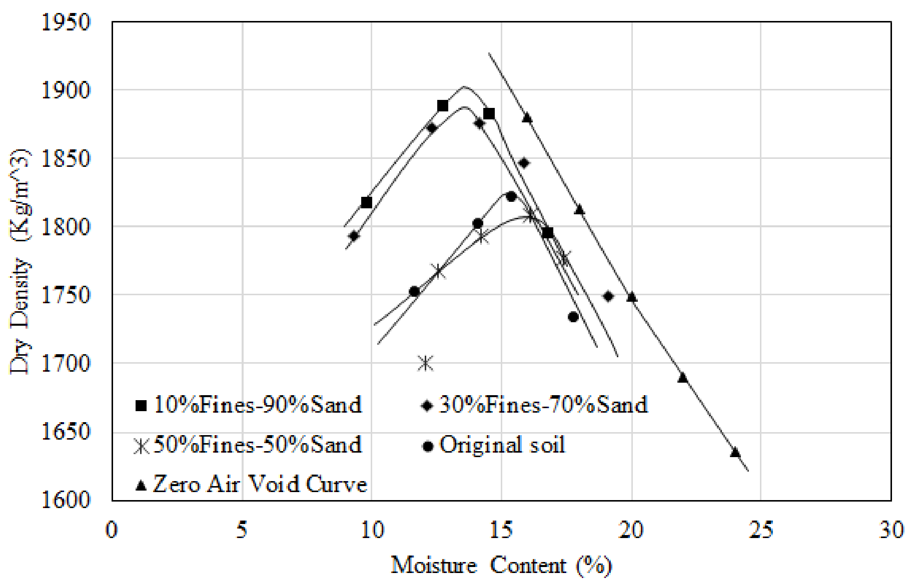


Figure 3.2. Compaction Curves of the Soils

3.3.4 Specific gravity of soil particles

The specific gravity (G_s) of a soil particle is the ratio of the mass of a unit dry soil particles to the mass density of an equal volume of distilled wafer at 20˚C. It is determined by density bottle or Pycnometer. It gives the details about how much lighter or heavier the material is than water. The test is carried out on the soil particles passing #4 (4.75mm) sieve according to ASTM specifications (ASTM D 854-92). In this research work the specific gravity value of the soils was used to determine the zero air void curve in soil compaction tests and for determining the grain size distribution curve in hydrometer analysis. The specific gravity of the soil was found to be 2.69 for all the soil used in this work.

3.3.5 Classification of soils based on unified classification system and AASHTO classification

The grain size analysis and the Atterberg limits results obtained was used to classify the soil using the procedure as per Unified Soil Classification System (ASTM D 3282 – 93) and AASHTO (Das). The original soil and fabricated soil composed of 30% fines – 70% sand was classified as Clayey sand (SC) as per USCS. According to USCS, the soil prepared using 10% fines – 90% sand was classified as Poorly grade sand with clay (SP-SC) and the 50% fines- 50% sand fabricated soil was Low plasticity clay (CL). The classification of soils as per USCS and AASTHO are tabulated in Table 3.5.

Table 3.5.

Classification of the Soils

Type of classification	Original Soil	10% Fines- 90% Sand	30% Fines- 70% Sand	50% Fines- 50% Sand
AASHTO Classification	A-6(10)	A-2-6	A-2-6(1)	A-6(55)
Unified Classification system	SC	SP-SC	SC	CL

3.4 Fibers

In the recent year's Guayule plant is being used as an alternative source of natural rubber. Guayule is a shrub which thrives in arid and semi-arid regions. Different procedures are used extracting rubber from Guayule, in the extraction process several byproducts are recovered. One of the by-products is the bagasse fiber. Bagasse is grinded stems and branches left after extracting the latex for rubber production. Bagasse is a light brown, saw dust like material having non uniform dimensions. In this study bagasse retained on No.10 sieve was used in the production of blocks (Figure 3.3a). The fiber retained on the No.10 sieve had different length ranging from 4.5 mm to 15 mm and also the diameter varied from 1.3 mm to 3.4 mm. The fibers varying in dimensions which was used in the soils blocks is shown in Figure 3.3b. The average aspect ratio of the fibers used in this research work is 0.41.

(a) (b)

Figure 3.3. Bagasse Fiber Retained on No.10 Sieve

3.5 Details about the Mix Proportions Used for Block Production

A series of mixes were prepared to compare the durability and difference in compressive strength of block samples for normal 28 days curing. The first series of mixes were prepared using the fabricated soil containing 10% fines and 90% sand; the second series was prepared using fabricated soil containing 30% fines and 70% sand; and the third series were done using soil containing 50% fines and 50% sand. In all the series of mix cement content used was 3%, 5% and 7% by weight and the percentage of fibers used were 0.25%, 0.5%, 1% and 2% by weight. Maximum dry density of the soil was considered for calculating the total dry mass of mixture. The Optimum moisture content value was used for the water content.

Since the preparation of specimens was considered to be one of the most important stages in the execution of the project, extra care had been taken with the soil, cement mix, fiber mix, moisture content, compression, curing, and sizing of the samples. The high levels of accuracy, reliability and consistency demanded by the experiments was maintained throughout the preparation of samples. The details of the mixture proportion are given in Table 3.6.

Mixture Proportions of Compressed Stabilized Earth Blocks (CSEB)

Dry density	1900			1900			1800		
Sand (%)	90			70			50		
Fines (%)	10			30			50		
Cement (%)	3	5	7	3	5	7	3	5	7
Fibers (%)	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
	1	1	1	1	1	1	1	1	1
	2	2	2	2	2	2	2	2	2
Water content (%)	13			13			16		

3.6 Preparation of Mix, Block Production and Curing

The proportions are considered as determined in the mix design. Soil, cement and fiber were weighed according to the mix proportion. Type II – V Portland cement was used considering its construction application exposed to sulfate, so that if any sulfate content in the soil used will not affect the cement hydration. Adopting dry mixing method, the weighed soil was dry mixed thoroughly with cement first till a uniform color was obtained. Then fibers were added to the soil cement dry mix and mixed thoroughly (Figure 3.4a). The predetermined quantity of water (equivalent to optimum moisture content) was added to the mix and manually mixed continuously for 5 minutes until the required consistency was obtained (Figure 3.4b).

(a) (b)

Figure 3.4. (a) Dry Mix of Soil, Cement and Fibers; (b) Thorough Mixture of Soil, Cement, Fiber and Water

Steel mold of dimensions 2in x 4in x 6in was used to produce the CSEB of dimension 2in x 4in x 2in. The wet mixture of soil, cement and fibers was added in three layers into the steel mold with a constant number of scoops for each layer, each layer of soil was gently tamped using a cylindrical rod to remove the air voids. The height was measured from the top edge of the mold to the surface of the soil mixture at all the four corners to determine by how much the soil needs to be compacted to achieve 2” height block. The mold was then placed in the chamber of SBEL compression machine and was compacted using a static load to obtain a 2” height block (Figure. 3.5a). All the mixtures were subjected to compression pressure of 10MPa.

(a) (b)

Figure 3.5. (a) CSEB Production Using SBEL Compression Machine; (b) Blocks Stacked After Extraction

The mold was dismantled immediately after compression was completed, and the blocks were removed using the extruder. The extruded samples were stacked on a plate inside the laboratory at temperature 22 ± 2° C to prevent quick loss of moisture (Figure 3.5b). They were closely stacked to prevent air circulation and conserve moisture for curing. Curing was carried out by placing wet cloth above the blocks for 28 days before carrying out the testing’s.

4. CHANGE IN COMPACTION CHARACTERISTICS AND DRY COMPRESSIVE STRENGTH OF CSEB WITH INCLUSION OF BAGASSE FIBERS

4.1 Introduction

The dry compressive strength is one of the important parameter in deciding the usage of these blocks in the construction industry. The suitability of the soil, the acceptability of the stabilization process and the usage of fiber can be ascertained by initially determining the compressive strength. The CSEB in this work is a composite material as the production was carried out using three materials having different physical properties. It is important to study the variations in the physical properties of the blocks due to the combination of different materials. In this chapter the experimental results and data of the dry density, dry compressive strength and toughness of the blocks will be presented and the effect of the manufacturing variables on these properties will be discussed. Adding on to that, the compressive strength of the CSEB in this work will be compared to the strength specifications of different standards to check its applicability in the construction of residential buildings in different countries.

4.2 Procedure Followed to Determine the Density and Dry Compressive Strength

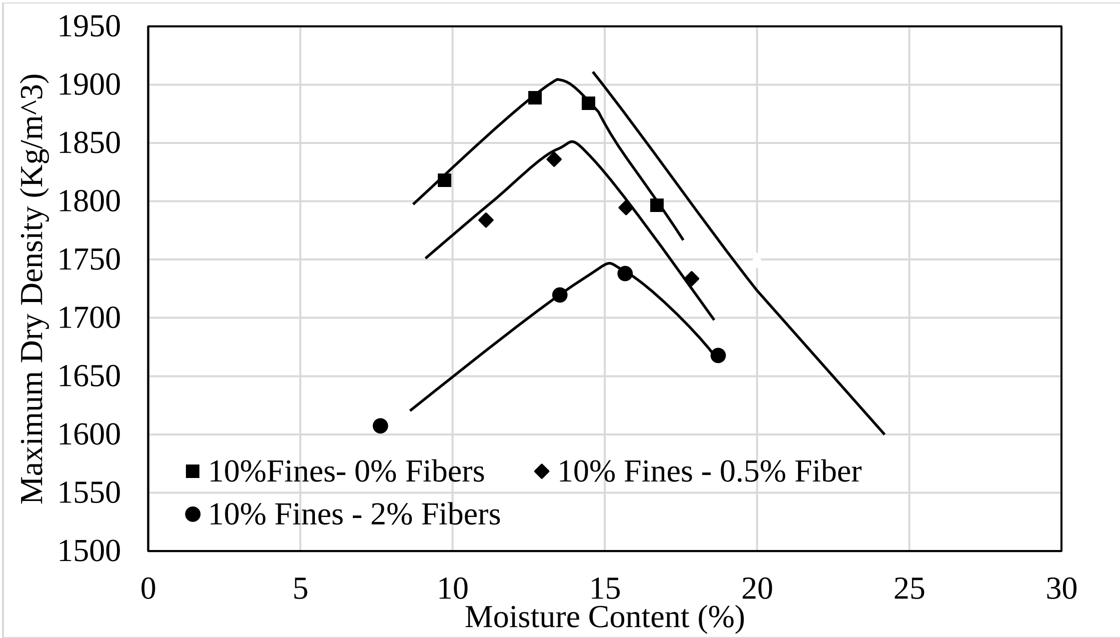
The strength of the blocks was determined by carrying out unconfined compressive strength as per ASTM D4219-08. After curing for 28 days, blocks were air dried and then placed in an oven maintained at 105^{o} C for 48 hours, after which they were air cooled to attain the room temperature. Then, 4-inch width blocks were cut at the center using a block cutting machine to get 2in x 2in x 2in blocks. Then the dimensions and the mass of the blocks were measured, which was used to calculate the dry density and stress – stain, further the unconfined compressive strength testing was carried out at a strain rate of 0.0508 cm/min.

4.3 Test Results and Discussion

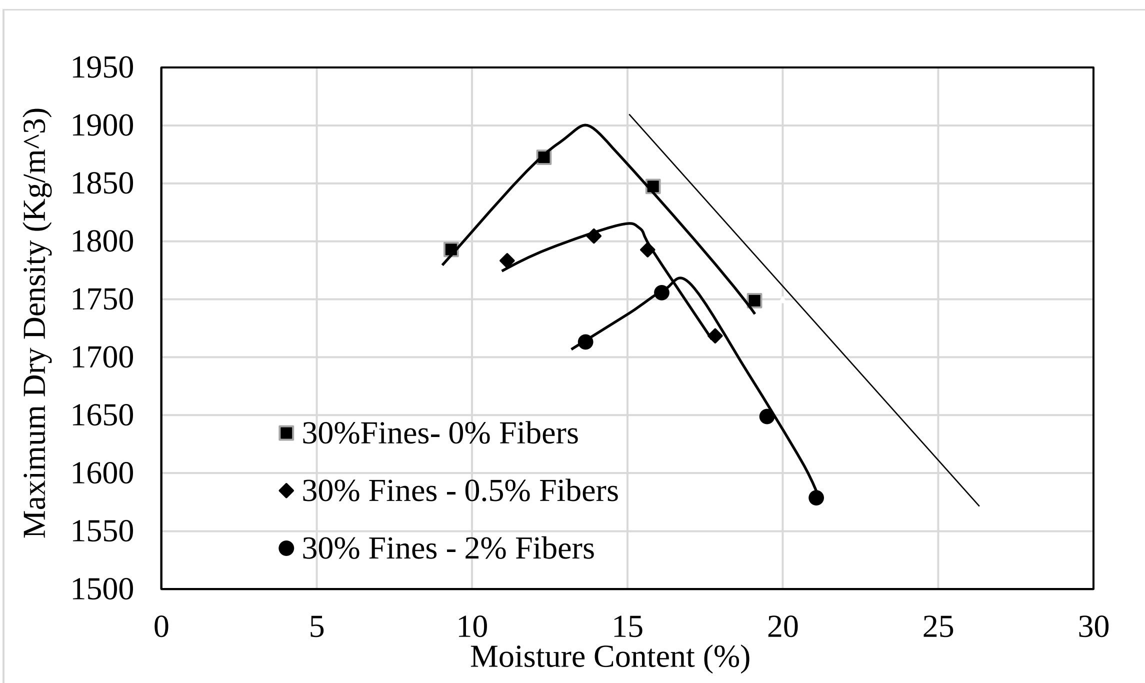
4.3.1 Dry density

The dimensions and mass of the oven dried blocks, after 28 days of curing, were recorded before subjecting the blocks for compression test and wetting-drying cycles and heating-cooling cycles. The recorded data was used to calculate the actual dry density of the blocks to verify if the blocks had the maximum dry density which was supposed to be achieved. The density data of 10% fines, 30% fines and 50% fines blocks are represented in Figure 4.2 which was compared with the maximum dry density of soil-fiber mixture plotted in Figure 4.1. It was found that there was decrease in dry density with increase in fiber content. The blocks produced using 0.25% and 0.5% fiber had the dry density equivalent to the decided dry density to be achieved.

The reduction in the density was observed due to the low density of the fibers, and with increase in the low density fiber percentage usage in the blocks contributed to the reduction in the density of these blocks. To get a clear view of the fiber impact on the density of the soil blocks, standard proctor test was carried out as per ASTM D 698 – 00a at a compaction energy of 12400 ft-lbf/ft^3 to determine the maximum density of the soil mixed with 0.5% fiber and 2% fiber.


1950
1900
1850
1800
1750
1700
1650
1600
1550
1500
Maximum Dry Density (Kg/m^3)
0
5
10
15
20
25
30
Moisture Content (%)
10%Fines- 0% Fibers
10% Fines - 0.5% Fiber
10% Fines - 2% Fibers

(a)


1950
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1800
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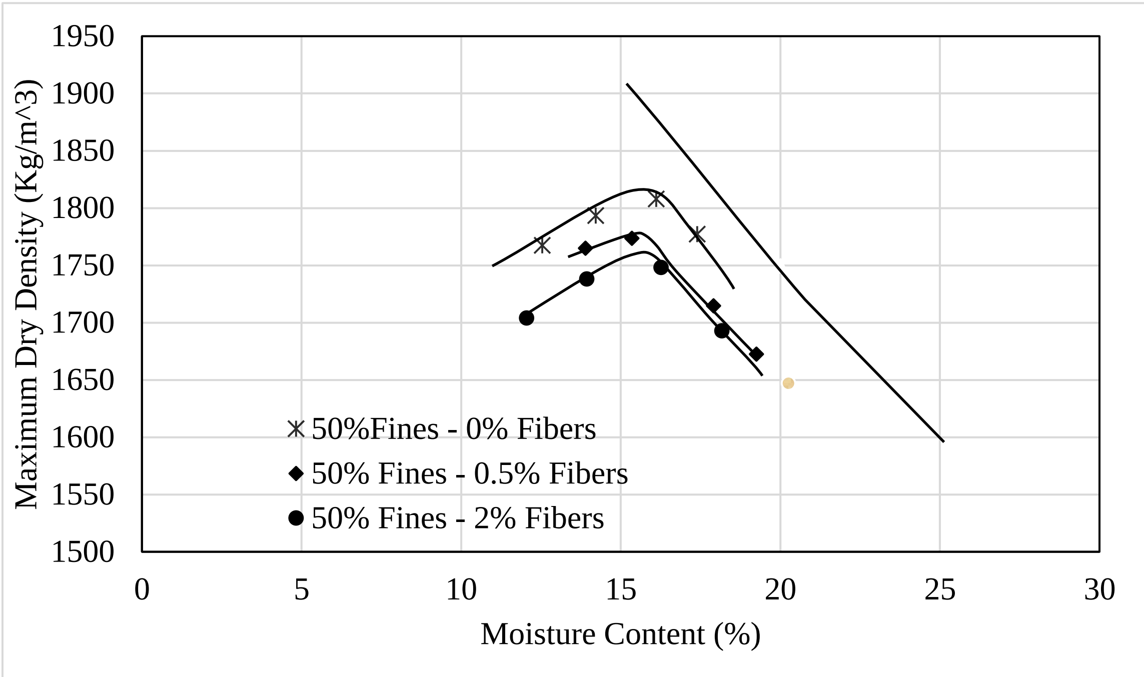
1700
1650
1600
1550
1500
Maximum Dry Density (Kg/m^3)
0
5
10
15
20
25
30
Moisture Content (%)
30%Fines- 0% Fibers
30% Fines - 0.5% Fibers
30% Fines - 2% Fibers

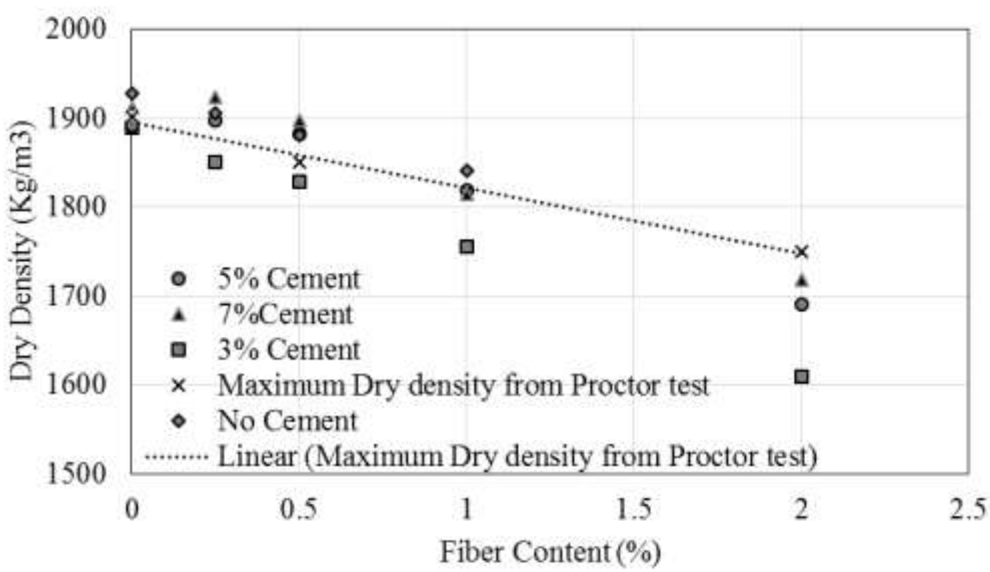
(b)



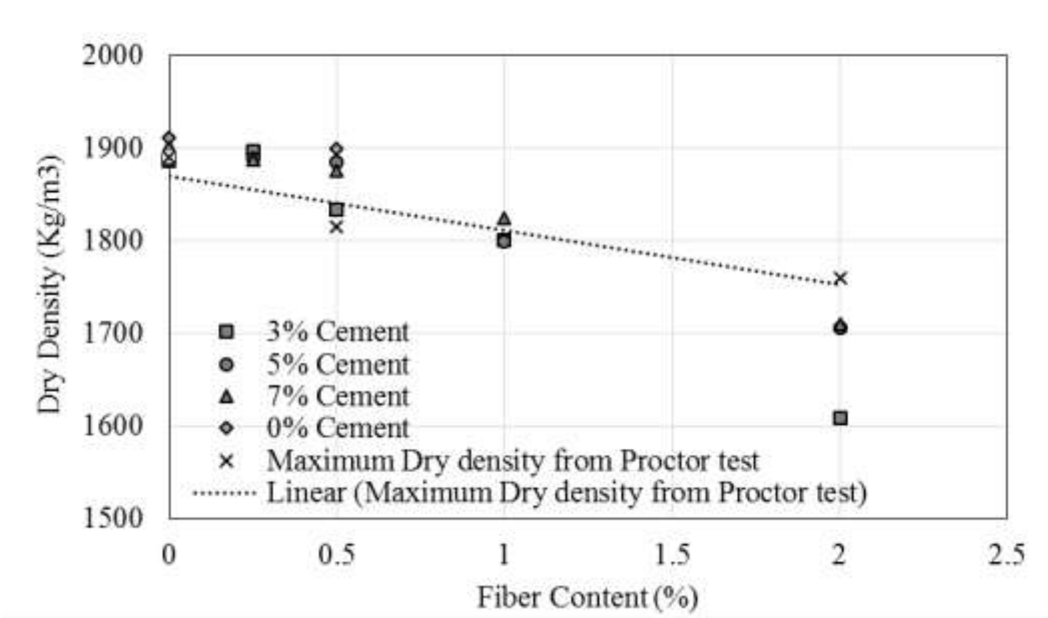
(c)

Figure 4.1. Variation of Maximum Dry Density with Fiber Addition with; (a) 10% Fines Soil, (b) 30% Fines Soil, (c) 50% Fines Soil

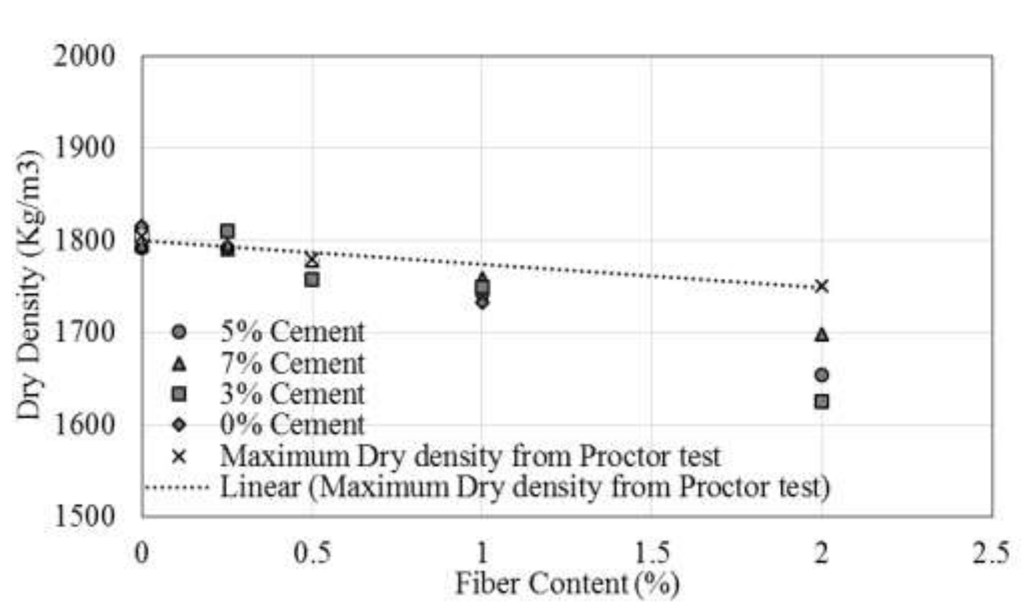
The result of the maximum dry density and the dry density of the blocks is plotted in the Figure 4.2. The plot shows a clear effect of the fibers on the maximum dry density at the same energy level. The maximum dry density reduced with the increase in fiber content. The dry density encountered by the blocks with increase in fiber content was close to the maximum dry density that the soil could achieve at that particular fiber content except for 2% fibers in the blocks which showed lower density than the maximum dry density determined from the proctor test. This was due to the relaxation of the blocks in vertical direction due to high content of the fibers which was absorbing moisture during the curing was carried out which leads to increase in swell pressure of the fiber causing the blocks to relax. The reduced mass of the blocks due to usage of 2% of fibers and increased dimension of the blocks contributed to the reduction in the density. It can also be noticed that 3% cement blocks with 2% fibers with all the three soils had lower density than the 5% and 7% cement. Low cement content was not sufficient to hold the soil against the swell character of the fiber which was resulting in expansion of the blocks. However, 5% and 7% cement contributed towards a better binding property thus reducing the impact of the fibers on the density of the blocks which helped in achieving a density closer to maximum dry density. This result explains why same dry density was not achieved for the soil blocks at all the fiber content.



(a)



(b)



(c)

Figure 4.2. Comparison of Dry Density with Fiber Content of Blocks; (a) 10% Fines Soil, (b) 30% Fines Soil, (c) 50% Fines Soil

The cement content also had effected the dry density of the blocks. From the above plots the density of the blocks with different cement was compared and was found that blocks with 3% cement had lower dry density than the once with 5% and 7% cement. Variation of 20kg/m3 in the density of the blocks was noticed between 3% and 7% cement content usage. The cement used for stabilization have proved to increase the density with increase in the usage percent in various studies carried out. The hydration process of cement, leading to formation of silicate binding gel contribute to the density of the blocks.

Fiber usage of more than 0.5% will had an impact on the density of the blocks which brings about a drastic reduction in the density. The density effects the compressive strength, water absorption and porosity of the blocks. It is important to achieve better density close to the maximum dry density of the soil being used. Based on the test results it is recommended not to use more than 0.5% bagasse fibers

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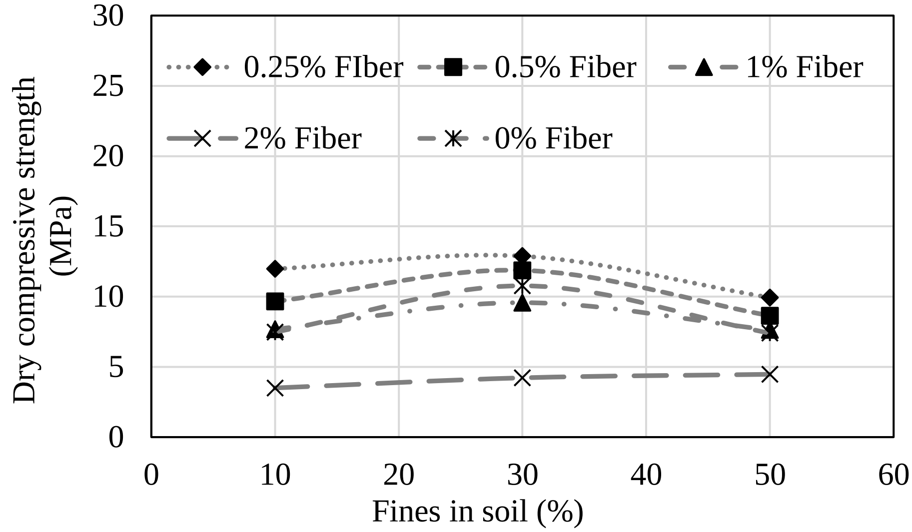
density close to the maximum dry density of the soil being used. Based on the test results it is recommended not to use more than 0.5% bagasse fibers has it will lead to the reduction in the dry density which in turn will have a major impact on the strength and long term life of the blocks.

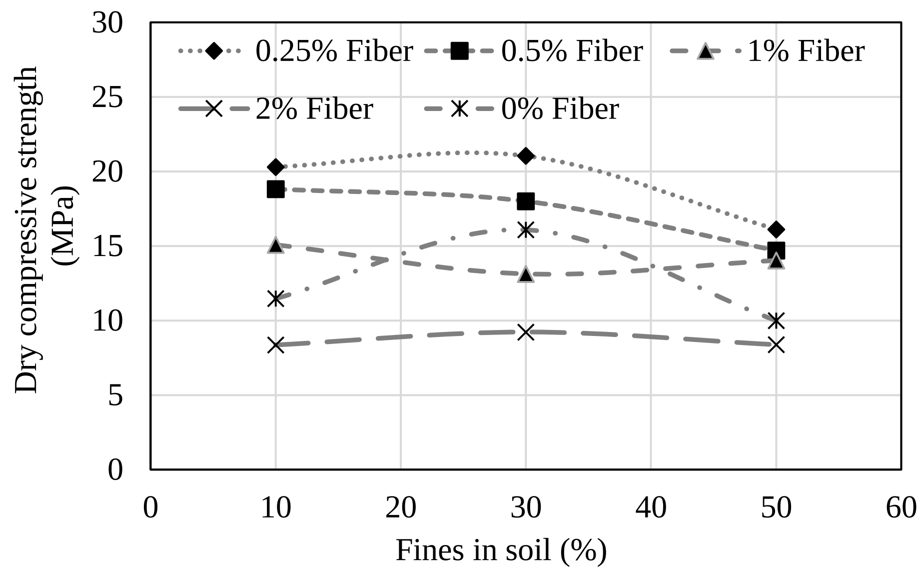
4.3.2 Dry compressive strength

The effect of fines in the soil used for the production of the CSEB is illustrated in Figure. 4.3. From the results obtained, it can be noticed that soil blocks with 3% cement produced using soil composed of 30% fines show higher dry compressive strength compared to blocks manufactured using soil with 10% fines and 50 % fines. The strength of 50% fines soil blocks is slightly more compared to blocks with 10% fines for 2% fibers, but 0.25%, 0.5% and 1% fiber block prepared using 50% fines soil has low strength in comparison with 10% fines soil.

The strength of blocks with 5% and 7% cement showed different results with variation of fines in the soil. The blocks prepared using 30% fines soil showed higher strength than the ones with 10% fines and 50% fines, except for blocks having 0.5% and 1% with 5% cement and 1% fibers and 0% fibers with 7 % cement which showed decrease in strength with increase in fines content. If only the strength of blocks with 10% fines and 50% fines are compared, 10% fines blocks showed better strength. The results clearly represent that the CSEB strength increase with increase in fines content only up to optimum value after which it starts to decrease. Better strength of the CSEB can be achieved with this soil with 30% fine content are used. It is also evident from the plots, that 0.25% fiber blocks and 0.5% fiber blocks have high dry compressive strength than the blocks without fibers, for all the three sand-fine combinations of soils.



(a)



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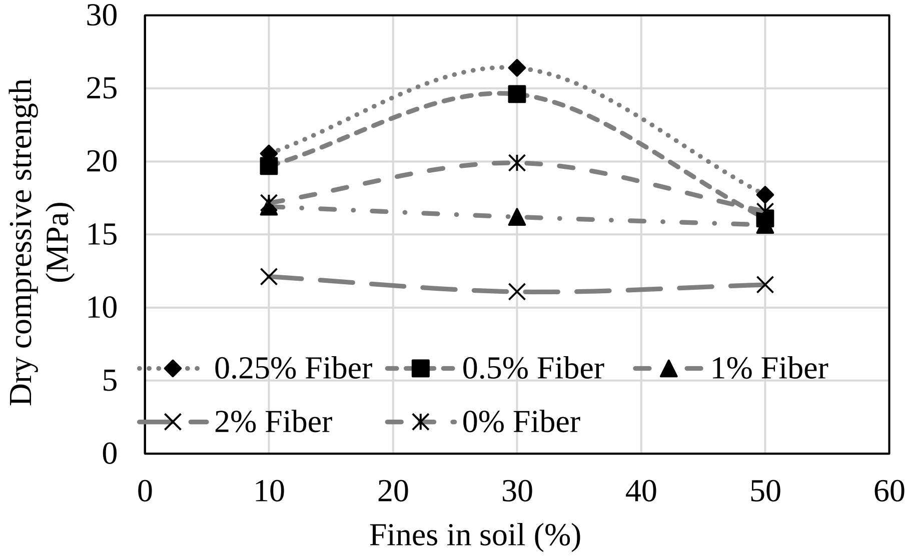


(c)

Figure 4.3. Variation of Compressive Strength of Blocks with Fine Content in Soil Used; (a) 3% Cement; (b) 5% Cement; (c) 7% Cement

The soil with 10% fines is non-plastic with less amount of fines which just helped to retain the shape of the blocks during demolding after the production, also these blocks produced using 10% fines can be considered as sand-cement blocks with large voids which is the result of low fines increasing the porosity of blocks. On the other side, blocks prepared using 50% fines had less sand content have expansive behavior and high specific surface area. Even though high clay content contribute to cohesion and easy ejection of blocks it requires large amount of cement to stabilize due to large surface area exhibited. Whereas 30% fine soil had sufficient amount of sand which exhibits low surface area and fines which provide stability during demolding. This soil composition provided densely packed arrangement due to higher contacting particles, by reducing not only the void size but number of pores. Thus, it is very essential to select a suitable soil which is well graded with sufficient amount of fines to prepare a smooth surface earth blocks with easy handle ability during production.

The same influence of the fine content in the soil was noticed (Figure 4.4) in the blocks prepared just with different fiber content without usage of cement. The plot clearly illustrates the high strength property of the blocks with 30% fines in comparison with 10% fines and 50% fines block.

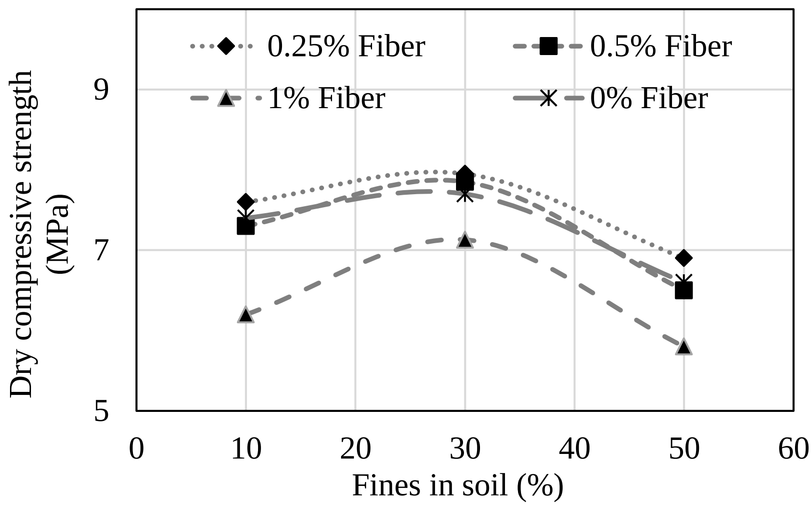


Figure 4.4. Variation of Compressive Strength Of 0% Cement Blocks With Fine Content in Soil

The comparison of dry compressive strength variation with usage of cement content is illustrated in Figure. 4.5. The plots show that with increase in the usage of cement content for stabilization increases the dry compressive strength irrespective of the soil used for the production. Increase in compressive strength is observed due to formation of cement gel between the soil particles which binds them together creating high strength. It can be noted from Figure 4.3 (a) that strength increased by almost 50% increase in strength at 0.2% fiber with the addition of 3% cement and 100% at 0.25% fibers on increasing the cement content from 3% to 5%, but there was just 2% increase in strength with 7% cement in comparison with 5% cement. The blocks with 30% fines showed a constant pattern of increase in strength with cement content. The results illustrate that with cement content increase from 3% to 5% increased the strength by 55%, but showed only around 20% increase in strength with increase in cement content from 5% to 7%. In case of 50% fines there was very minute impact on the strength with increase in cement content from 5% to 7%, however there is almost 70% increase in strength with usage of 5% cement in comparison to 3% cement used. It was also noticed that 3% cement had no effect on strength at 0% fibers in 10% fines and 50% fines blocks. However, the average increase in strength of 52% with addition of 3% cement in comparison with blocks without cement. This manifests that with increase in cement content usage for stabilization will bring about an increment in strength along with certain percentage of fiber usage.

The addition of fibers influenced the strength of the blocks. The blocks showed improvement in dry compressive strength with addition of fibers. The blocks with 0.25% fibers and 0.5% fibers showed better strength than the blocks without fibers, in all the combination of fines and cement used. It is found that blocks produced using 0.25% fiber had more strength than compared to blocks without fibers and with 0.5%, 1%, 2% fibers. In the Figure 4.5 it can be noticed that 0.25% fiber usage with 5% cement in 10% fine and 30% fine soil contributed to a higher strength in blocks than the once with 7% cement – 0% fiber. Also in 50% fine soil with 0.25% fiber – 5% cement showed almost similar strength of blocks made with 7% cement – 0% fiber. This illustrates that the usage of bagasse fibers with lower cement content will help in attaining the strength similar to CSEB produced using higher cement content. This will have an impact on the economy of the project.

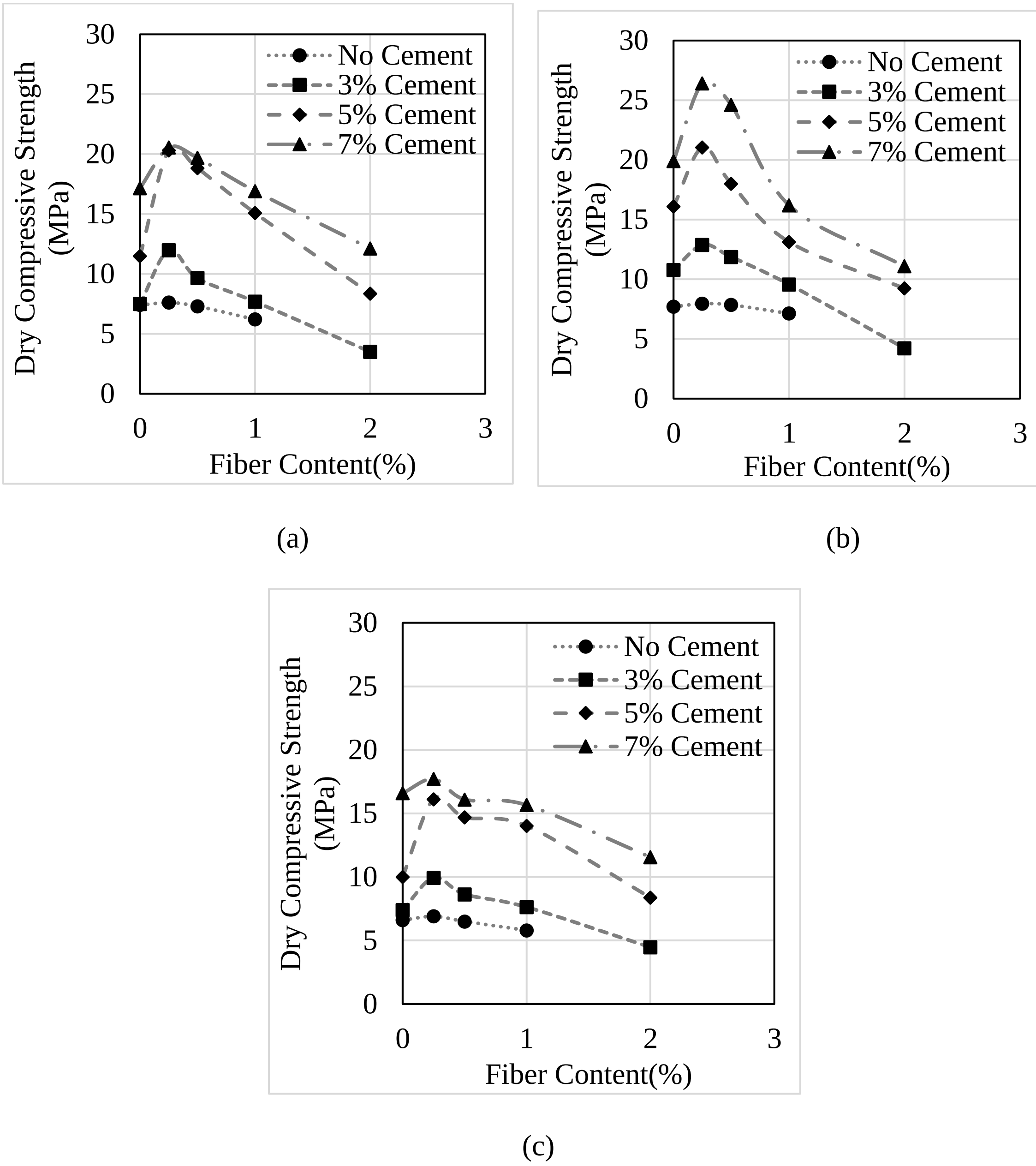
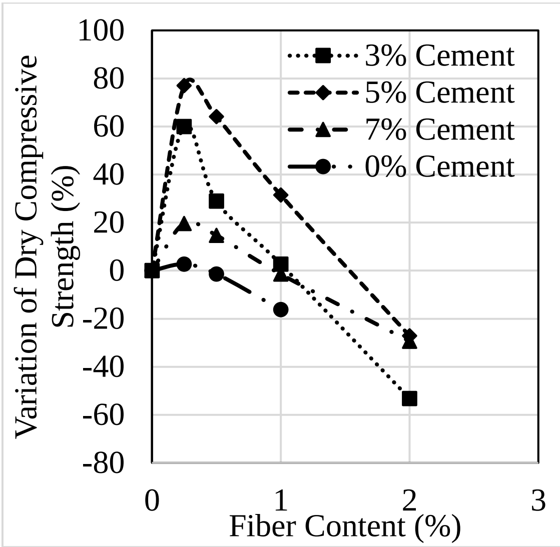


Figure 4.5. Variation of Compressive Strength of Blocks with Cement and Fiber Content; (a) 10% Fines Soil; (b) 30% Fines Soil; (c) 50% Fines Soil

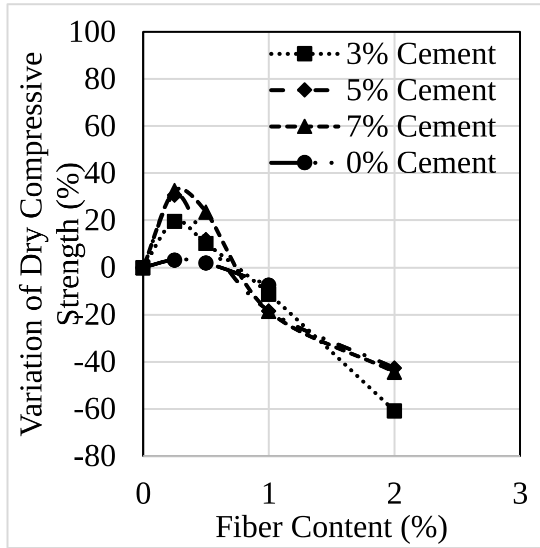
The fibers in 10% fine blocks with 5% cement had more strength increase when compared to 3% and 7% cement. Minimum contribution to strength on addition of fibers was observed in blocks with no cement. These blocks with 2% fiber had less strength than the blocks without fibers. The blocks with 30% fines soil and 5% cement composition had achieved more strength with the usage of fibers in comparison with 0%, 3% and 7% cement. Blocks with 30% fines showed reduction in strength on addition of 1% and 2% fibers when prepared using 0%, 5% and 7% cement, mean while just 2% fiber with 3% cement showed reduction in strength.

Where as in blocks with 50% fines, fibers contributed in achieving more strength gain on usage with low percent of cement i.e. in this research 3% and there was reduction in contribution percentage with increase in cement content and at 0% cement content. Only 2% fiber blocks showed lower strength with all the cement contents used adding to that even 0.5% and 1% fiber had failed in contributing to strength for blocks in which 0%, 7% cement was used.

It is clearly evident from the results that fibers had a minor impact on the strength of blocks with 7% cement showing that the influence of fibers is not evident in high cement content soil blocks. However, major contribution was observed on the strength of the blocks prepared using 3% and 5% cement. Even with increase in usage of cement content the effect of fibers on the strength is getting reduced. From the Figure. 4.6, it is clearly evident that addition of 0.25% fibers improved the strength of 3% cement blocks by at least 45% but it was just around 5% to 20% in the case of 7% cement blocks. Based on the results portrayed below it is suggested that usage of fibers up to 0.5% will have an addition impact on the strength along with any cement content with soil at all the three fine measures used.



(a)



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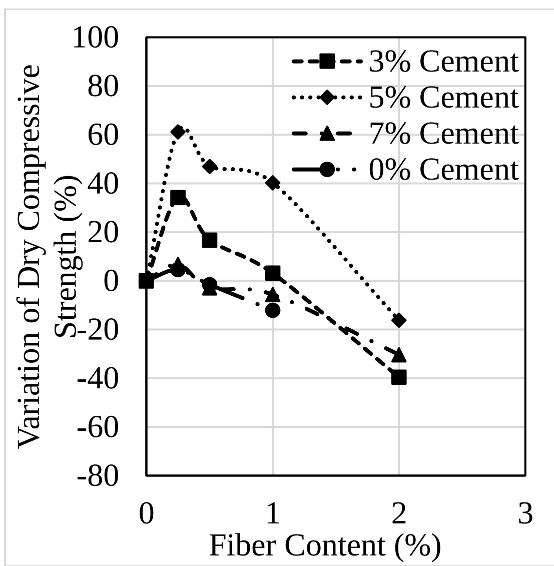


(c)

Figure 4.6. Variation of Dry Compressive Strength of Cement-Fiber Blocks with Cement Blocks; (a) 10% Fines Soil; (b) 30% Fines Soil; (c) 50% Fines Soil

It was absorbed that blocks with 2% fibers showed reduction in strength with all the combinations of cement and fines. However, 2% fiber blocks sustained more strain than any other blocks. It was observed that with increase in fiber content there was increase in the stain sustained by the blocks as per the data obtained which is been represented in Figure. 4.7. These plots were used to measure the toughness of the blocks to find how the fibers have contributed toward the toughness of the blocks.

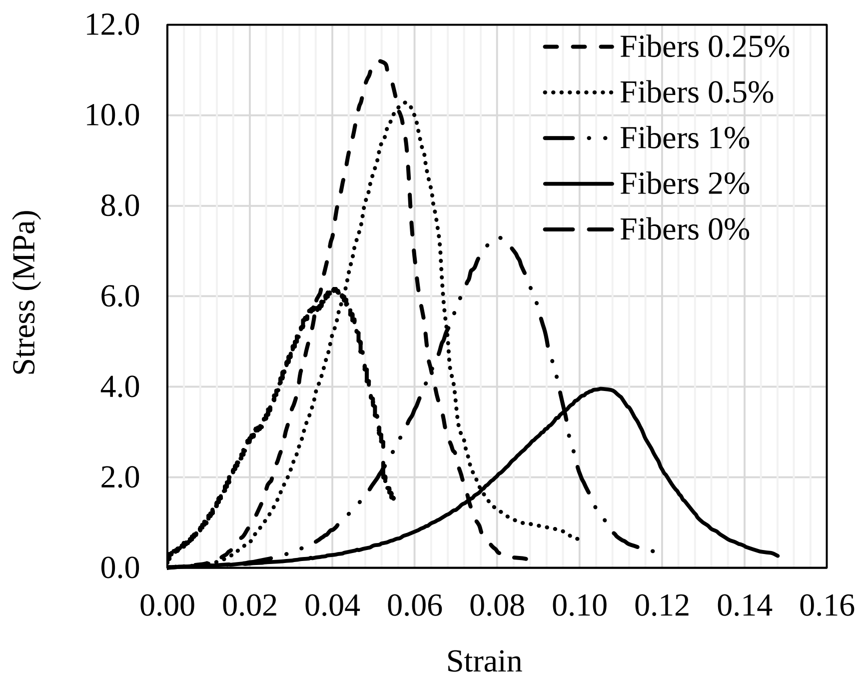


Figure 4.7. Comparison of Stress Strain Curve of Blocks with Fiber Content Used For Blocks Prepared Using 10% Fines Soil and 3% Cement

Toughness is defined as the ability of a material to deform plastically and to absorb energy in the process before failure. The toughness was calculated for all the blocks to determine which combination block as a good combination of strength and ductility. The toughness of the blocks was determined by calculating the area under the stress-strain curve up to failure strain/ maximum stress. The Figure 4.8 portrays the shaded region under the stress stain curve, of 10% fines – 3% cement – 1% fiber block, whose area was calculated to determine the toughness.

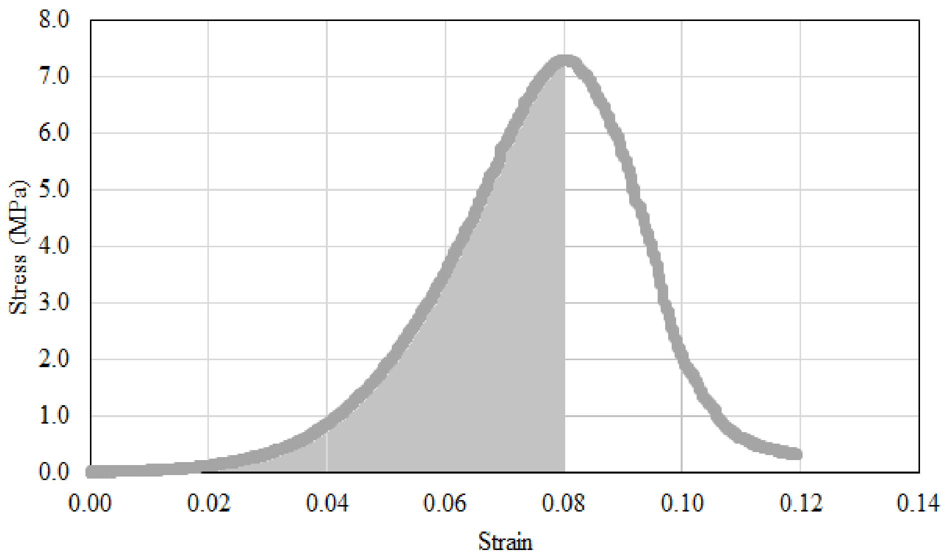
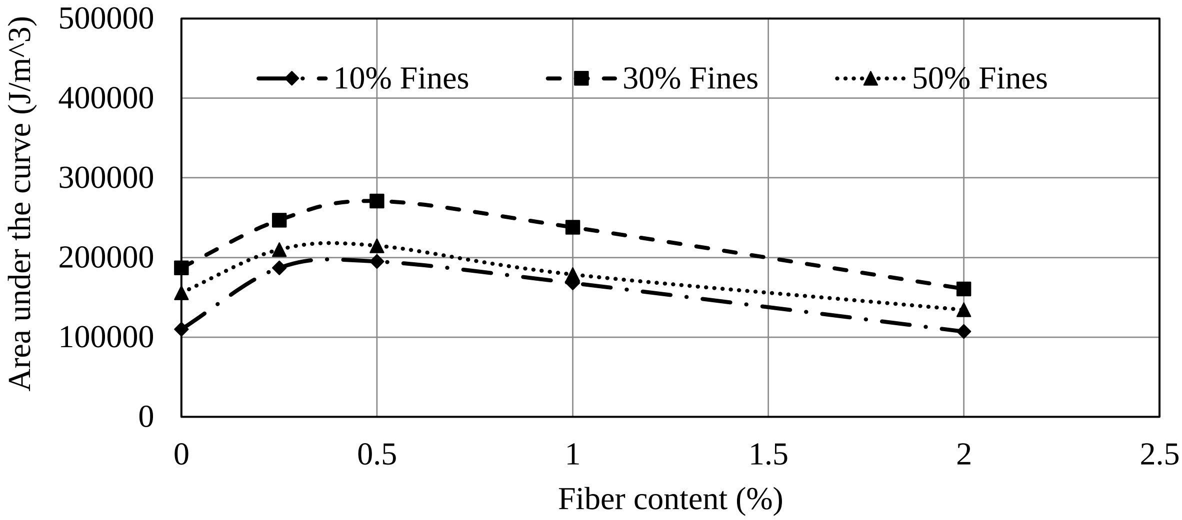


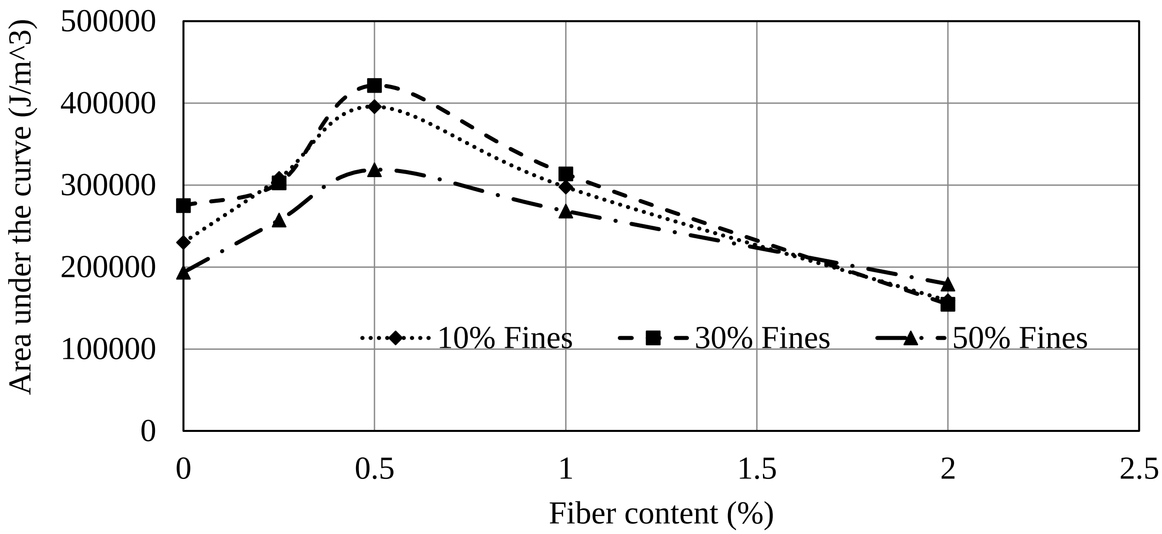
Figure 4.8. Area under the Stress Strain Curve Used To Determine the Toughness

The Figure. 4.9 exhibits the toughness of the blocks. The 0.5% fiber blocks with all the combination of cement and soil used shows to have better toughness than the once with other fiber content used and the blocks without fibers, except 10%fine-7%cement block and 50%fine-7%cement block in which 1% and 2% fiber had better toughness. Blocks with 2% fiber had lower toughness out of all the blocks with other fiber content. The usage of 0.5% fiber aided in attaining better strength and also making it ductile, thus contributing for the production of toughest blocks. If there is a need of production of blocks with high strength it is recommended to use 0.25% fiber content based on the results obtained. If ductility also becomes an important criterion along with the strength, it is better to use 0.5% fiber content.



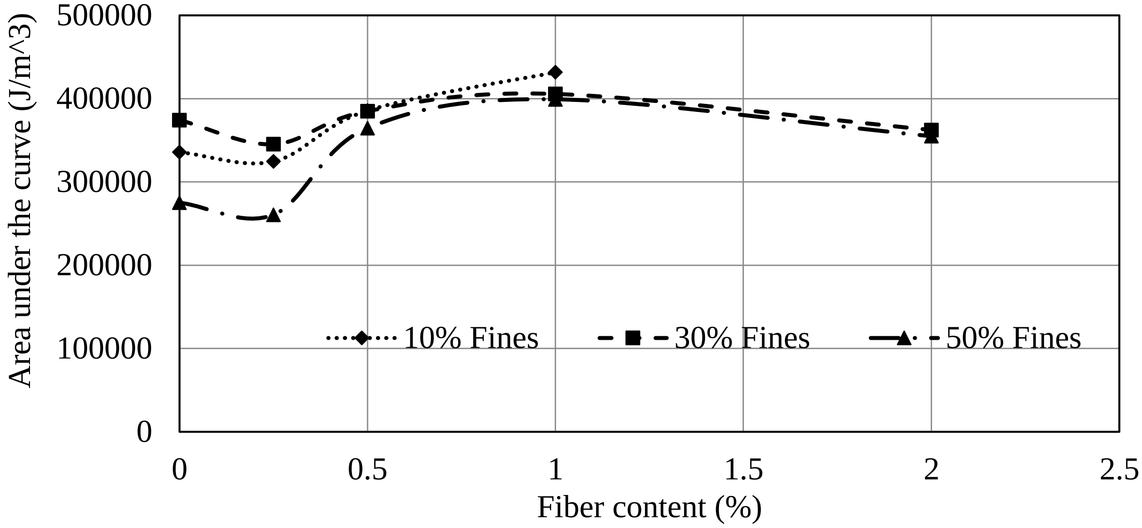
Area under the curve (J/m^3)
500000
400000
300000
200000
100000
0
10% Fines
30% Fines
50% Fines
0
0.5
1
1.5
2
2.5
Fiber content (%)

(a)



Area under the curve (J/m^3)
500000
400000
300000
200000
100000
0
10% Fines
30% Fines
50% Fines
0
0.5
1
1.5
2
2.5
Fiber content (%)

(b)



(c)

Figure 4.9. Area under the Stress Strain Curve Value of Blocks Varying With Fiber Content; (a) 3% Cement; (b) 5% Cement; (c) 7% Cement

The blocks produced using bagasse fiber of less than 0.5% with 5% and 7% cement in soil with 30% and 10% fines proves to satisfies the strength requirement of 17.2 MPa mentioned in ASTM C62 and C216 standard for severe weathering conditions. It also falls in the requirement of ASTM C62 and C216 for moderate and negligible weathering conditions. The above mentioned combination of fines, cement and fibers also fulfills the minimum compression strength recommendation made by Europe and South Africa in Eurocode6 and SABS 227:4.4 standards respectively. However, Canada demands the strength to be greater than 20.7 for exterior grade walls. This strength requirement was achieved by two combinations of materials, namely 30% fines – 0.25% fiber – 5% cement or 7% cement. It is evident from the results obtained from this work that soil block produced with usage of bagasse fibers up to 0.5% with a minimum of 5% cement can be used, based on strength requirement, in the construction leading to the reduction in the current usage of cement in this industry and making use of bagasse fibers instead of dumping into landfills.

4.3.3 Statistical sensitivity of the dry compressive strength of CSEB

The dry compressive strength of the soil blocks was influenced by three variables, those are fine content, fiber content and cement content, in this work. To generalize the influence of the above mentioned parameters on the dry strength determined statistical sensitivity was carried out in MINITAB. In this analysis mean, standard deviation and the lower – upper confidence bounds were determined. The data tabulated in Table 4.1 was used for the analysis.

The mean values of the dry compressive strength of the blocks with 10% fines, 30% fines and 50% fines were 12.06 MPa, 13.45 MPa and 10.8 MPa respectively. The standard deviation was found to be 5.45 MPa, 6.21 MPa and 4.3 MPa for 10% fine, 30% fine and 50% fine blocks. The 95% Confidence interval, the range of values that represents the reasonable estimate for the unknown parameter, for the fines with respect to dry compressive strength is plotted in Figure 4.10. It is evident from the plot that the mean value of the dry strength of the blocks with 30% fine soil is higher followed by 10% fines and then 50% fine soil blocks.

Table 4.1.

The Dry Compressive Strength Data of the Compressed Stabilized Earth Blocks

a. 10% Fine Soil

Cement	Fibers	Dry compressive Strength
%	%	Mpa
0	0	7.4
	0.25	7.6
	0.5	7.3
	1	6.2
3	0	7.48
	0.25	11.97
	0.5	9.65
	1	7.68
	2	3.5
5	0	11.47
	0.25	20.3
	0.5	18.82
	1	15.08
	2	8.36
7	0	17.16
	0.25	20.54
	0.5	19.69
	1	16.91
	2	12.12

b. 30% Fine Soil

Cement	Fibers	Dry compressive Strength
%	%	Mpa
0	0	7.7
	0.25	7.95
	0.5	7.85
	1	7.13
3	0	10.77
	0.25	12.88
	0.5	11.87
	1	9.57
	2	4.22
5	0	16.08
	0.25	21.04
	0.5	18
	1	13.13
	2	9.23
7	0	19.9
	0.25	26.4
	0.5	24.6
	1	16.2
	2	11.08

c. 50% Fine Soil

Cement	Fibers	Dry compressive Strength
%	%	Mpa
0	0	6.6
	0.25	6.9
	0.5	6.5
	1	5.8
3	0	7.4
	0.25	9.93
	0.5	8.64
	1	7.63
	2	4.47
5	0	10
	0.25	16.12
	0.5	14.7
	1	14.03
	2	8.38
7	0	16.59
	0.25	17.71
	0.5	16.1
	1	15.66
	2	11.56

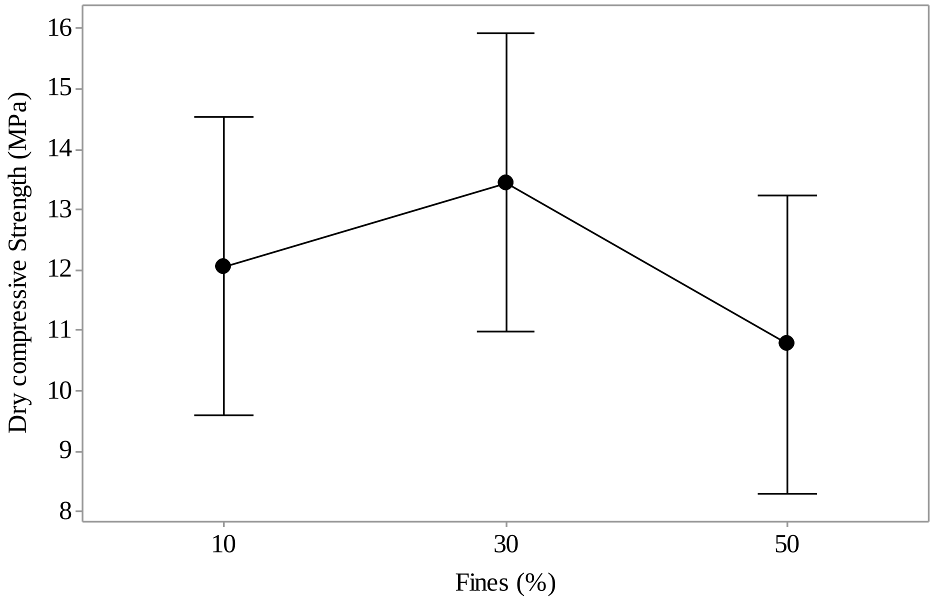


Figure 4.10. Interval Plot of Dry Compressive Strength versus Fines (With 95% CI for the Mean)

In order to compare whether the average difference between the dry strength of blocks with 10% fine, 30% fine and 50% fine is significant, which helps in discovering any difference between the population means, two sample T-test was performed in MINITAB. In order to perform this test a null and an alternative null hypothesis was determined.

The hypothesis for the test are:

H_o: The difference in mean number of strength in blocks produced using different fines content in the soil is zero

H_1: The difference in mean number of strength in blocks produced using different fines content in the soil is not zero

Then a two sample T-test for dry compressive strength was conducted between 10% - 30% fines, 30%-50% fines and 10%-50% fines. The results are tabulated in the Table 4.2.

The table gives the details about the estimate of difference between the means and the confidence intervals for the difference based on this estimate and the variability within the sample variables used. All the three p value is greater than 0.05. Thus failing to reject the null hypothesis. This means the difference is not significant and there is no relationship between the dry compressive strength of blocks with different fine contents.

Table 4.2.

Two-Sample T-Test and CI: Dry Compressive Strength, Fines: (a) T test For 10% and 30% Soil Block Strength (b) T test For 30% and 50% Soil Block Strength (c) T test For 10% And 30% Soil Block Strength

(a)

Fines	N	Mean	St Dev	SE Mean
10	19	12.06	5.45	1.2
30	19	13.45	6.21	1.4
Difference			μ(10) - μ(30)	
Estimate for difference			-1.39	
95% CI for difference			(-5.24,2.46)	
T-Test of difference			0	
T-Value			-0.73	
P value			0.469	
DF			35	

(b)

Fines	N	Mean	St Dev	SE Mean
30	19	13.45	6.21	1.4
50	19	10.77	4.33	0.99
Difference			μ(30) - μ(50)	
Estimate for difference			2.68	
95% CI for difference			(-0.86,6.22)	
T-Test of difference			0	
T-Value			1.54	
P value			0.133	
DF			32	

(c)

Fines	N	Mean	St Dev	SE Mean
10	19	12.06	5.45	1.2
50	19	10.77	4.33	0.99
Difference			μ(10) - μ(50)	
Estimate for difference			1.29	
95% CI for difference			(-1.93,4.53)	
T-Test of difference			0	
T-Value			0.81	
P value			0.425	
DF			34	

The mean and standard deviation of the dry compressive strength with the usage of the fibers and cement is tabulated in the Table 4.3. The mean value and the 95% confidence bound for the dry compressive strength versus fiber content in the blocks is plotted in Figure 4.11. This plot clearly illustrates that the inclusion of the 0.25% and 0.5% fibers in the soil blocks contribute to strength increase based on the mean value calculated. The mean value of the strength of blocks with 0.25% bagasse fiber is above the upper bound of

95% confidence interval of the 0% fiber blocks. Thus indicating the effective strength contribution by 0.25% fiber usage.

The significance level of the results of compressive strength of blocks in comparison with the different fiber content used was studied by performing the T test. The T test results are tabulated in the Table 4.4. In this test the null hypothesis was the difference in mean number of strength in blocks produced using fibers addition is zero.

Table 4.3.

Mean, Standard Deviation and Confidence Interval Values

(a) Dry Compressive Strength vs. Fibers

Fibers (%)	N	Mean	StDev	95%CI
0	12	11.55	4.68	(8.59,14.50)
0.25	12	14.95	6.35	(11.99,17.90)
0.5	12	13.64	5.87	(10.69,16.60)
1	12	11.25	4.29	(8.30,14.21)
2	9	8.1	3.31	(4.69,11.51)

(b) Dry Compressive Strength vs. Cement

Cement (%)	N	Mean	StDev	95%CI
0	12	7.078	0.686	(5.080,9075)
3	15	8.511	2.872	(6.724,10.297)
5	15	14.32	4.2	(12.53,16.10)
7	15	17.48	4.34	(15.69,19.27)

Based on the p value calculated it can be concluded that, except 0.25% - 2% fibers, 0.5% - 2% fibers and 1% - 2% fibers all the other two sample sets failed to reject null hypothesis. The above mentioned sample sets rejected the null hypothesis, as the p value was less than 0.05, thus proving that there is a statistically significant difference between the mean number of dry compressive strength in 2% fiber blocks than 0.25%, 0.5% and 1% fiber blocks. However, there is no significant difference in dry compressive strength of the blocks with other two sample sets. Thus it can be concluded that the addition of 2% fiber was leading to a drastic reduction in the dry compressive strength of the blocks leading to drop in the mean value of the strength for all the combination of the soil and cement used.

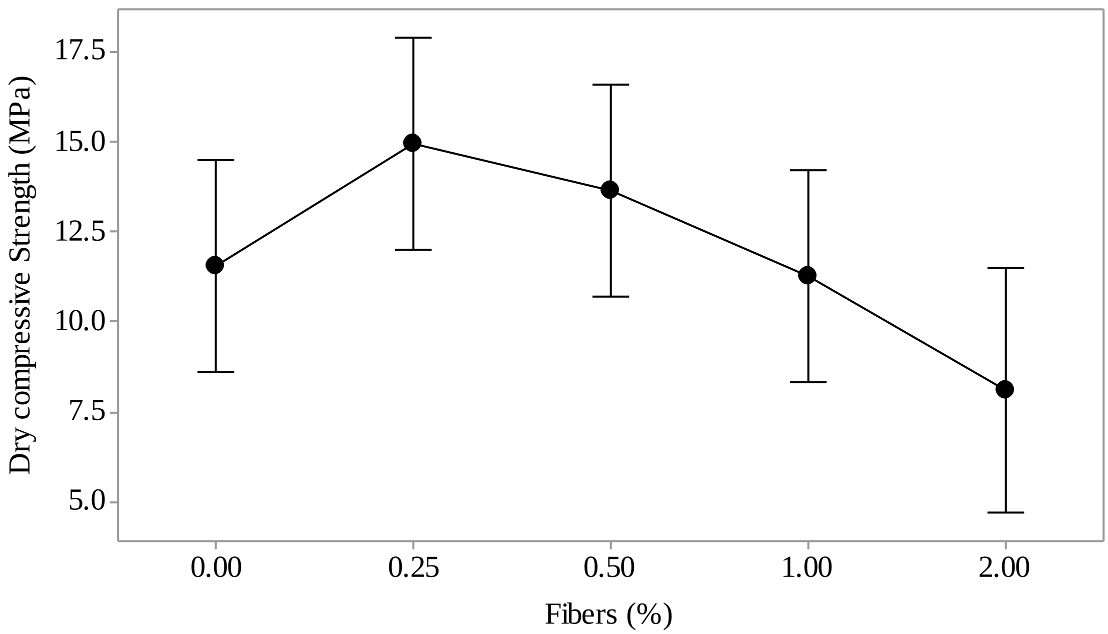


Figure 4.11. Interval Plot of Dry Compressive Strength versus Fibers (With 95% CI for the Mean)

Table 4.4.

Two-Sample T-Test and CI: Dry Compressive Strength, Fibers

Two samples (Fibers)	Estimate for difference	95% CI for difference	T-test of difference	T-value	P value	DF
0% - 0.25%	-0.34	(-8.15,1.35)	0	-1.49	0.151	20
0%-0.5%	-2.1	(-6.61,2.42)	0	-0.97	0.344	20
0%-1%	0.29	(-3.52,4.1)	0	0.16	0.874	21
0%-2%	3.44	(-0.22,7.11)	0	1.97	0.064	18
0.25%-0.5%	1.3	(-3.89,6.49)	0	0.52	0.607	21
0.25%-1%	3.69	(-0.94,8.32)	0	1.67	0.111	19
0.25%-2%	9.33	(4.86,13.80)	0	4.51	0.001	13
0.5%-1%	2.39	(-1.99,6.77)	0	1.14	0.268	20
0.5%-2%	7.68	(3.27,12.09)	0	3.76	0.002	13
1%-2%	4.77	(1.27,8.28)	0	2.9	0.011	15

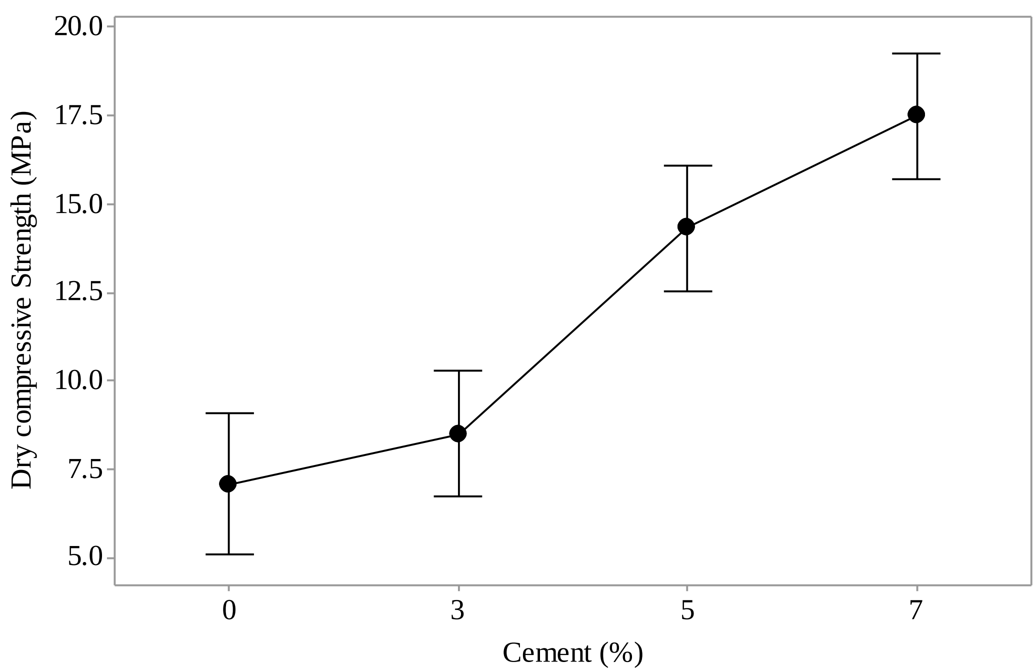


Figure 4.12. Interval Plot of Dry Compressive Strength versus Cement Content (With 95% CI for the Mean)

Studying the impact of different cement content on the soil blocks is plot representing the mean and the confidence interval of the strength values is plotted in the Figure 4.12 and the T test results is tabulated in the Table 4.5. The plot demonstrates a minute contribution to strength of the blocks with the addition of 3% cement. However, 5% cement assisted in imoproving the strength of the blocks to an effective level. The T test results in Table 4.5 i.e. the p value demonstrates that there is a significant difference in the mean of dry compressive strength between the 0% and 5% cement, 0% and 7% cement, 3% and 5% cement and 3% and 7% cement. However, there was no compelling difference between the strength of 5% and 75 cement soil blocks.

Table 4.5.

Two-sample t-test and CI: Dry compressive strength, cement

Two samples (Cement)	Estimate for difference	95% CI for difference	T-test of difference	T-value	P value	DF
0% - 3%	-1.433	(-3.069,0.203)	0	-1.87	0.082	15
0%-5%	-7.24	(-9.60,-4.88)	0	-6.52	0	14
0%-7%	-10.4	(-12.84,-7.49)	0	-9.15	0	14
3%-5%	-5.81	(-8.52,-3.09)	0	-4.42	0	24
3%-7%	-6.68	(-11.74,-6.20)	0	-6.68	0	24
5%-7%	-2.03	(-6.36,0.03)	0	-2.03	0.052	27

4.4 Multiple Regression Analysis: Dry Compressive Strength Versus Fines, Cement and Fibers

Multiple regression analysis was carried out to find an equation based on the data obtained to figure out the most influential variable out of fines, cement and fiber on the dry compressive strength of the soil blocks. MINITAB was used to do stepwise regression analysis. The equation Eq.1 represents the estimate of dry compressive strength (MPa) associated with fine content, cement and fiber content. From the equation it is evident that fibers have a significant adverse influence on the strength of the blocks. This equation represents that the usage of lower percent of fiber have less impact on the strength as the power of the percent fiber term is used. The positive cement term indicates that the cement content is directly proportional to the strength. Even though the fine content is inversely proportional its influence is infinitesimal. The Table 4.6 illustrates the p –value of each variable. p value results for each variable were less than 0.05 which indicates that the relation between all the three variable and the dry compressive strength in the model is statistically significant. The coefficients are shown in Eq.1 below:

Dry Compressive Strength (MPa) = $9.238 - 0.000015\, a^3 + 0.2392\, b - 1.760\, c^2$…… Eq.1

Where, a = percent fine, b = percent cement and c = percent fiber

Table 4.6.

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P value
Regression	3	1325.74	441.91	75.81	0
Fines	1	36.84	36.84	6.32	0.015
Cement	1	1091.58	1091.58	187.27	0
Fibers	1	334.16	334.16	57.33	0
Error	53	308.93	5.83		
Total	56	1634.67			

The blocks produced using bagasse fiber of less than 0.5% with 5% and 7% cement in soil with 30% and 10% fines proves to satisfies the strength requirement of 17.2 MPa mentioned in ASTM C62 and C216 standard for severe weathering conditions. It also falls in the requirement of ASTM C62 and C216 for moderate and negligible weathering conditions. The above mentioned combination of fines, cement and fibers also fulfills the minimum compression strength recommendation made by Europe and South Africa in Eurocode6 and SABS 227:4.4 standards respectively. However, Canada demands the strength to be greater than 20.7 for exterior grade walls. This strength requirement was achieved by two combinations of materials: 30% fines – 0.25% fiber – 5% cement or 7% cement. It is evident from the results obtained from this work that soil block produced with usage of bagasse fibers up to 0.5% with a minimum of 5% cement can be used, based on strength requirement, in the construction leading to the reduction in the current usage of cement in this industry and making use of bagasse fibers instead of dumping into landfills.

5. DURABILITY OF THE COMPRESSED STABILIZED EARTH BLOCKS

5.1 Introduction

Environment conditions affect the durability of materials. The durability of the blocks is an important framework in usage of CSEB in the construction industry. The suitability of the CSEB in a particular environment can be decided based on the performance of the blocks when subjected to the replicated extreme environmental condition in the laboratory. The blocks were subjected to wetting/drying cycles and heating/cooling cycles to figure out how it behaves against different seasonal variations. The impact of the fibers and the cement content on the durability is accomplished in this work. In this chapter the experimental results and data of the soil-cement loss, volume change and dry compressive strength of the blocks subjected to two different wetting/drying and heating/cooling cycles will be presented.

5.2 Wetting and Drying Cycles

The wetting and drying test of the blocks was carried out according to Indian Standard IS: 4332 (Part IV) – 1968 which has been reported basing the standard ASTM 559-57 (1965). According to this procedure, the blocks were dried after being moist cured for 28 days. Then, the blocks were cut to produce 2in x 2in x 2in blocks, and submerged in potable water at room temperature (Figure 5.1) for a period of 5 hours. The weight and dimensions of the block were recorded and the blocks were dried in the oven at 70^{o} C for 42 hours. The weight and dimension of the blocks were noted after taking them out of the oven. This procedure completed one cycle. One set of blocks was subjected to 12 cycles and other set was subjected to 18 cycles. Finally, after completing the wetting and drying cycle's blocks were dried to constant weight at 110^o C and then weighed after which the blocks were subjected to unconfined compressive strength. From the data collected during each cycle the average change in volume and soil-cement loss were calculated by comparing the initial mass and volume with the volume and mass of the blocks after completion of cycles. The strength was used to check the reduction in strength of blocks due to the effect of wetting and drying cycles.

Figure 5.1. Blocks Immersed In Water during Wetting Cycle

5.2.1 Soil - Cement loss in CSEB blocks subjected to wetting and drying cycles

The results of loss of soil-cement of the blocks subjected to 12 and 18 cycles of wetting and drying is been presented in this section. The blocks produced using 3% cement with all the combinations of fines and fibers used for this research, disintegrated before the12 cycles of wetting and drying was completed. Therefore, it is obvious that 3% cement and any fiber content cannot hold the soil together if it is going to be subjected to continuous cycles of extreme wetting and drying condition. The soil-cement loss for blocks with 5% and 7% cement content, after 12 cycles, is illustrated in Figure 5.2. Results show that 5% cement blocks with 30% fines lost more soil-cement and the 50% fines show less soil-cement loss with 10% fines block lying in-between. The soil-cement loss increased with increase in fiber content used, except for blocks with 0.25% fiber with 30% fine soil had lost less soil-cement compared to block without fiber and 0.5% fiber blocks with 10% and 30% fines which have more soil-cement loss than blocks with 1% fiber content. However, in 50% fines the blocks with fibers lost less soil-cement in contrast with 50% fine blocks without fibers. On comparison with fiber content effect in 50% fine blocks, 0.5% fiber portrayed less loss than 0.25% fiber blocks then the loss increase with 1% and 2% fiber content.

Blocks produced with 7% cement showed similar result as 5% cement blocks. 10% Fines and 30% fine blocks had almost similar loss of soil-cement. The loss increased with fiber content even in 7% cement blocks in combination with 10% and 30% fine soils. But fibers showed a binding impact on the 50% fine blocks has the loss decreased by 45% with addition of fiber content. It can be noticed that loss of soil-cement increased with fine content without addition of fibers. Nonetheless, on usage of fibers soil-cement loss was found to reduce in blocks with higher fine content in the soil used. Although there was no much visual damage was observed in the blocks with all the combinations of fines, cement and fibers used in this research.

The soil-cement loss after 12 and 18 cycles of blocks produced using 10%, 30% and 50% fines soils with 5% and 7% cement is shown in Figure. 5.3. The results show that with increase in cement content used for stabilization there is a decrease in soil-cement loss. The loss of soil-cement increased as the number of cycles increased. The increase in loss was found to be uniform for blocks of 7% cement and 5% cement with 10% fine soil blocks at all the fiber contents used. The 30% fine blocks showed less loss of soil-cement at higher cement content. In 50% fine soil blocks with fibers showed less loss of soil-cement in comparison with soil block without fiber.

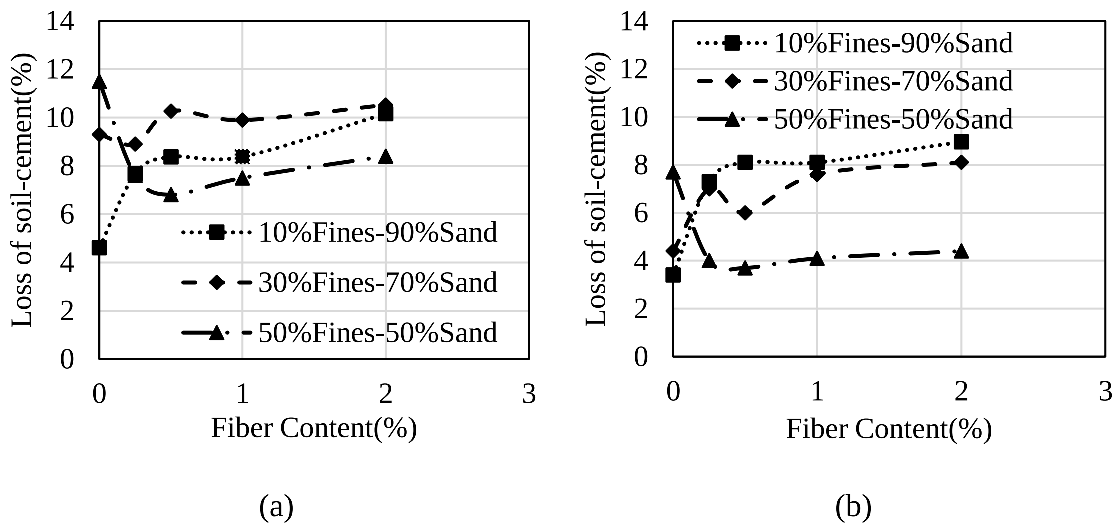
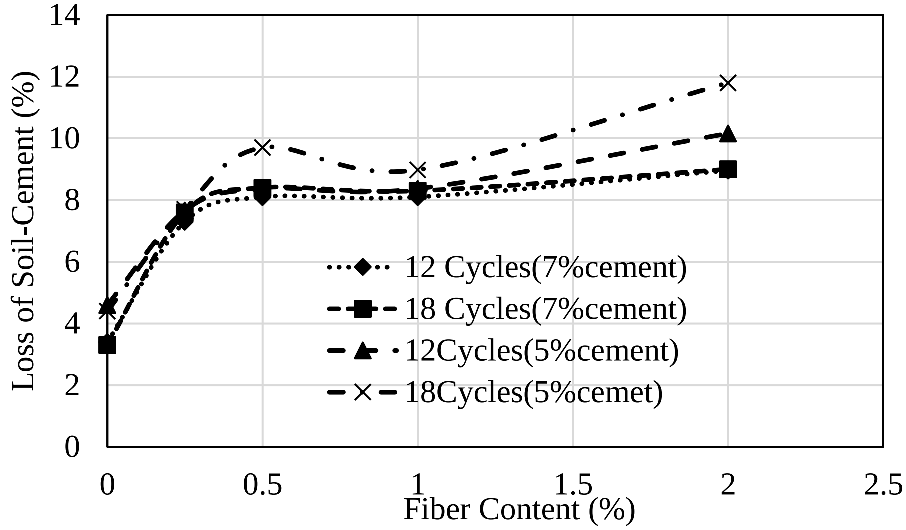
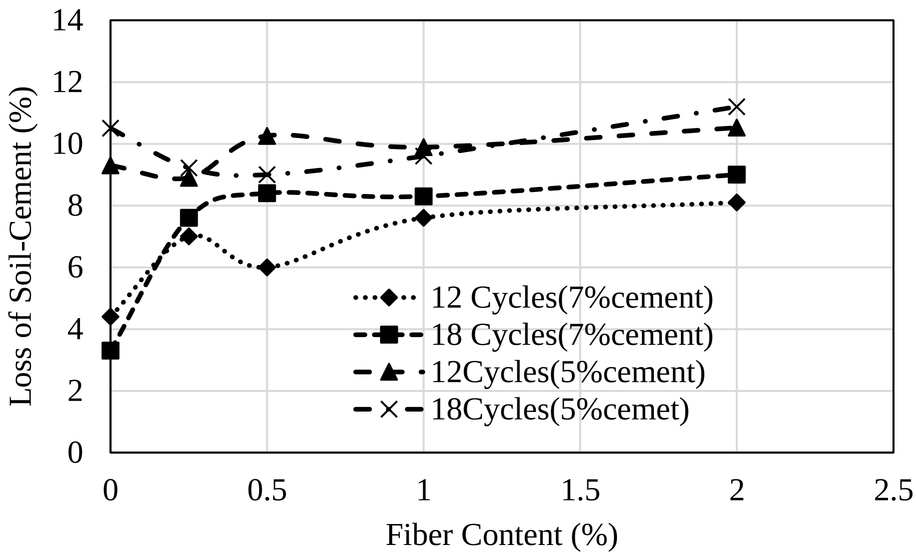


Figure 5.2. Comparison of Loss of Soil-Cement of Blocks Prepared Using Soils Having Different Fine Contents; (a) 5% Cement and (b) 7% Cement

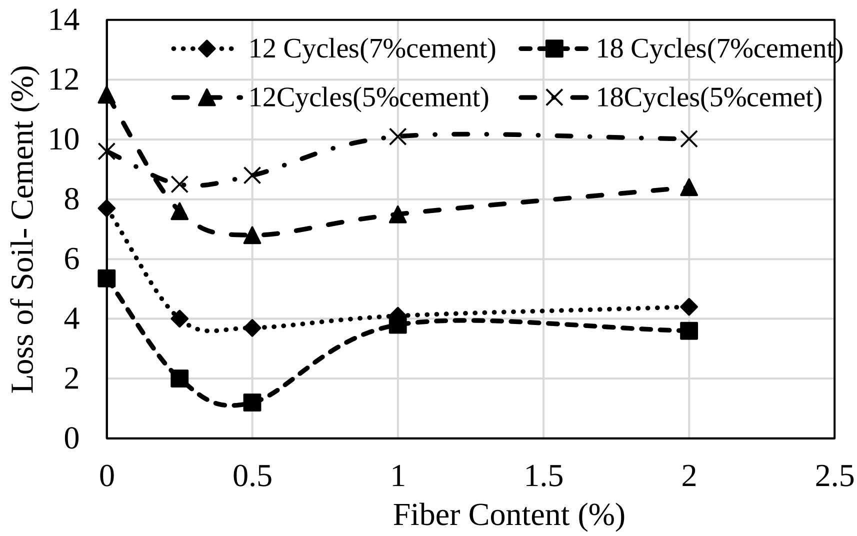
Recommendations encountered in the literature for acceptable limits of mass loss was within 10% (Spence and Cook 1983, Fitzmaurice 1958). Loss of soil-cement for 0.5% and 2% fiber blocks of 30% fines – 5% cement, and 2% fiber block of 10% fines – 5% cement was slightly over the recommended mass loss, but can be considered durable. This experimental study brought out the fact that blocks prepared using 3% cement are not durable. Therefore, 5% cement should be considered as the minimum cement content to be used to produce durable blocks.


Loss of Soil-Cement (%)
Fiber Content (%)
12 Cycles(7%cement)
18 Cycles(7%cement)
12Cycles(5%cement)
18Cycles(5%cemet)
0
2
4
6
8
10
12
14
0
0.5
1
1.5
2
2.5

(a)


Loss of Soil-Cement (%)
Fiber Content (%)
12 Cycles(7%cement)
18 Cycles(7%cement)
12Cycles(5%cement)
18Cycles(5%cemet)
0
2
4
6
8
10
12
14
0
0.5
1
1.5
2
2.5

(b)



(c)

Figure 5.3. Comparison of Loss of Soil-Cement with Cement Content Used For 12 And 18 Cycles of Wetting and Drying (a) 10% Fine Soil (b) 30% Fine Soil (c) 50% Fine Soil

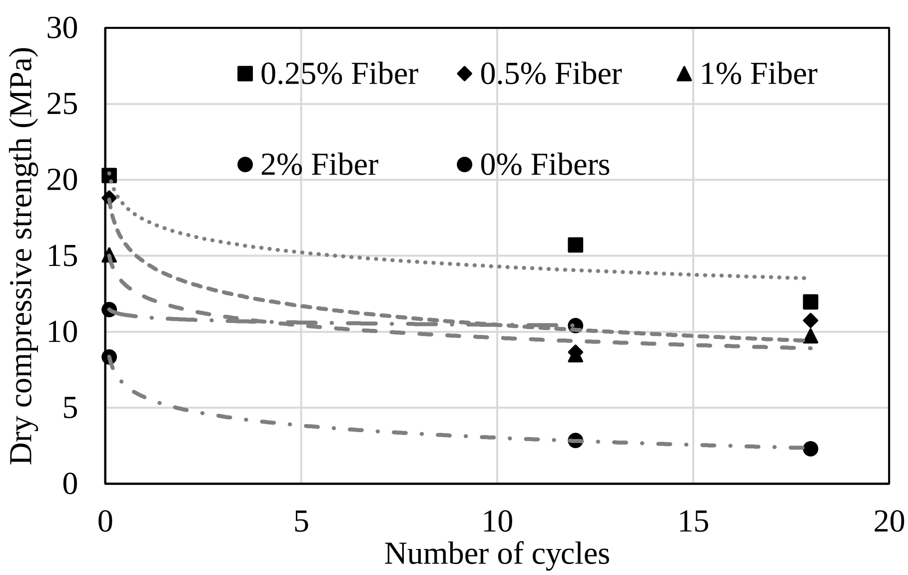
5.2.2 Dry compressive strength of CSEB blocks subjected to wetting and drying cycles

The dry compressive strength of the blocks subjected to wetting and drying cycles was compared with the strength of the original blocks to have a brief idea as to, by how much the strength would be affected by the wetting and drying cycles. The plot in Figure. 5.4 shows the effect of wetting and drying cycles on the strength of blocks with 5% cement. Reduction in strength was observed in the blocks subjected to wetting and drying cycles. It is evident from the plot that, with increase in number of cycles the strength decreased, however some combination of fine-fiber such as 10%-0.5%, 10%-1%, 30%-0.5% and 30%-1% had lower strength at 12 cycles compared to 18 cycles. The trend line was used to get a clear idea of the course followed by the dry compressive strength with increasing cycles.

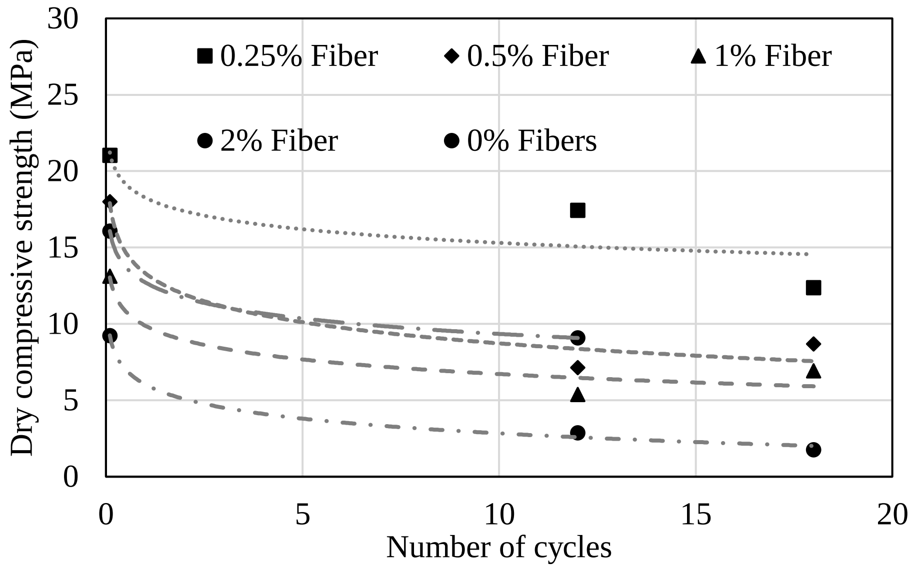
The logarithmic trend line is the best fit curved line for all the data plotted which are following similar pattern.

After 12 cycles of wetting and drying the strength reduction was found to be 19% on average of the blocks with fiber content of 0.25% at 18 cycles the reduction percent increased to 44%. The blocks with 1% and 2% fibers showed a reduction of more than 50% at 12 cycles, however it was 40% for the blocks with 0.5% fibers.

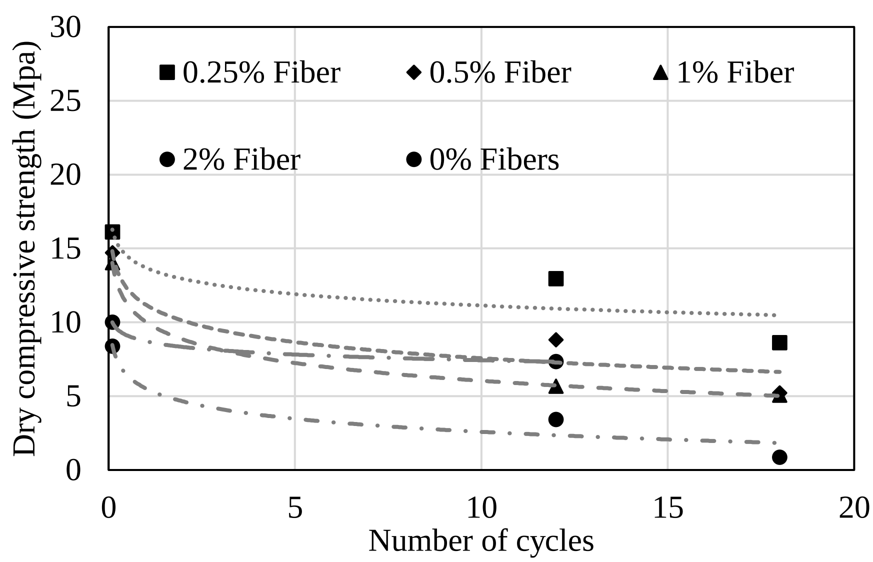
The strength reduction of 10% fine blocks with 0.25% fiber was 22.5% which was higher than blocks without fibers which showed a reduction of 9%. However, in 30% and 50% fine blocks fibers addition proved to be beneficial in dragging down the strength reduction in comparison with blocks without fibers. 30% and 50% fines with 0.25% fiber had a strength reduction of 17% and 19.6% which is lower when compared to blocks without fiber representing 43.5% and 26.7% respectively. The addition of 0.25% fiber was beneficial in holding up the soil and reduction the strength loss during the cycles.



(a)



(b)

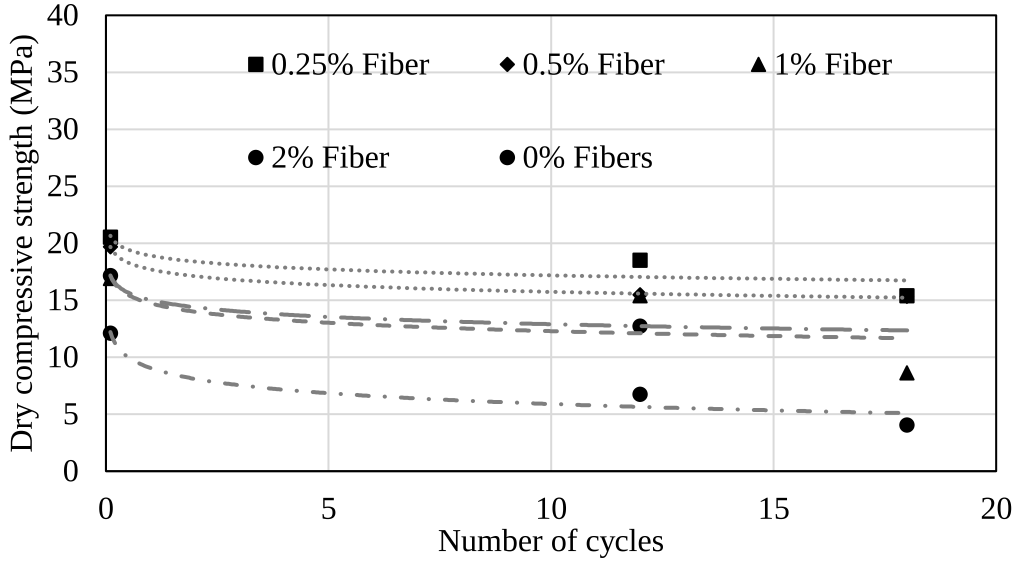


(c)

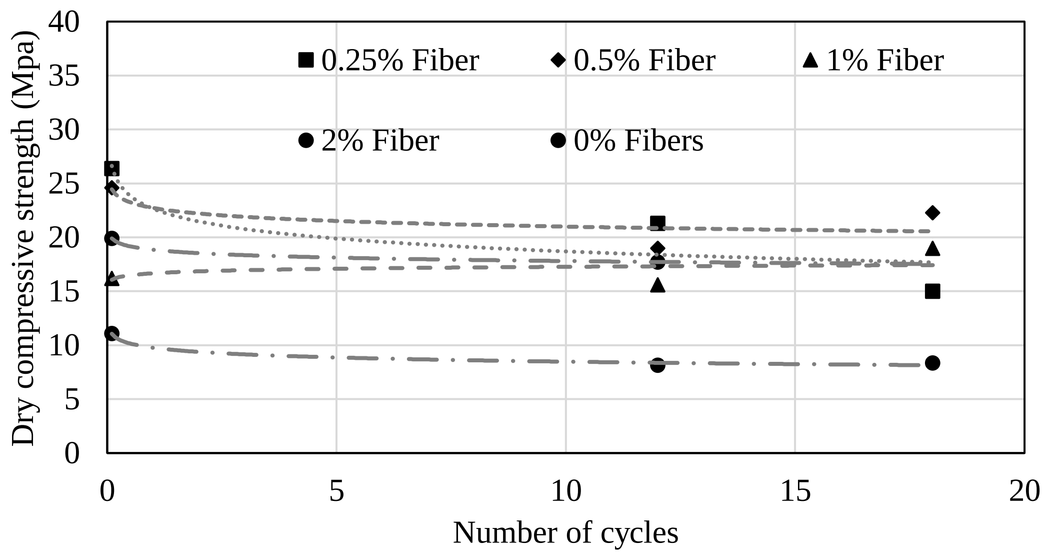
Figure 5.4. Comparison of Dry Compressive Strength of 5% Cement Blocks Subjected to Wetting and Drying Cycles; (a) 10% Fine Soil; (b) 30% Fine Soil; (c) 50% Fine Soil

The impact of wetting and drying cycles on the blocks with 7% cement is presented in the Figure 5.5 below. The 7% cement usage reduced the impact of wetting and drying cycles on the soil blocks. These blocks showed less reduction in dry compression strength than the blocks with 5% cement. Even the 0.25% fiber usage in 7% blocks showed less reduction in strength than the one's without fibers for 10% and 50% fine soils.

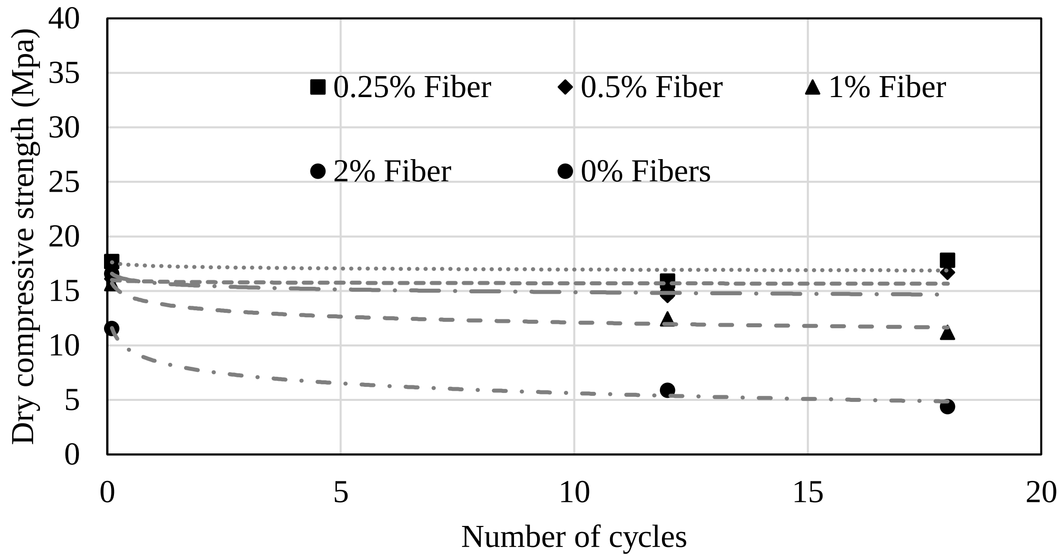
The blocks will be exposed to wetting and drying cycles due to rainfall and sunshine in the environment. It is important for the blocks to possess stability against the moisture movement, so that no cracks are developed during wetting and drying cycles in the field. During the experiment no such crack developments were observed in the blocks having 5% and 7% cement. Wetting and drying cycle experiment was designed to stimulate the long-term weather exposure effect. This was carried out for 12 and 18 cycles which are the extreme conditions of the environment not experienced in most of the places, still considering it as indicate of long-term durability test. Even after subjecting these blocks to the severe conditions blocks with 5% and 7% cement composed of fines and fiber content decide for this research showed better durability, out of which the outstanding once blocks were with the usage of 0.25% and 0.5% fiber. After 12 cycles the soil blocks of combination 30% fines-5% cement-0.25% fibers and 30% fines-7% cement-0.25% fibers still satisfied the dry strength requirement of blocks not being subjected to any durability test of 17.2 MPa as per ASTM C62 and ASTM C216 for construction in sever weathering condition, adding on, the strength requirement mentioned in SABS 227:4.4 and Eurocode 6 is also satisfied.


0.25% Fiber
0.5% Fiber
1% Fiber
2% Fiber
0% Fibers
Dry compressive strength (MPa)
Number of cycles
0
5
10
15
20
25
30
35
40
0
5
10
15
20

(a)


0.25% Fiber
0.5% Fiber
1% Fiber
2% Fiber
0% Fibers
Dry compressive strength (Mpa)
Number of cycles
0
5
10
15
20
25
30
35
40
0
5
10
15
20

(b)



(c)

Figure 5.5. Comparison of Dry Compressive Strength of 7% Cement Blocks Subjected to Wetting and Drying Cycles; (a) 10% Fine Soil; (b) 30% Fine Soil; (c) 50% Fine Soil

5.3 Sensitivity Analysis of the Loss of Soil-Cement of CSE Blocks

The CSEB in this work was a result of three ingredients making it a composite material, it was necessary to compare the mean of the loss of loss of soil-cement due to all the three materials used. To accomplish this, one-way analysis of variance was performed to compare the means of different composition of each material used in the production of CSEB. The data tabulated in the Table 5.1 was used to conduct one-way ANOVA in MATLAB program. First the means of loss soil cement was compared between fiber contents followed by fines and cement contents.

Table 5.1.

Soil – Cement Loss Data of the Compressed Stabilized Earth Blocks

(a) 10% fine

Cement	Fibers	No of cycles	Loss of soil-cement
%	%		%
3	0	4	12.6
		8	12.4
	0.25	4	9.8
		4	9.08
	0.5	8	13.3
		8	12.8
	1	7	16.5
		6	12.5
	2	3	8.45
		3	8.9
5	0	12	4.6
		18	4.4
	0.25	12	7.66
		18	7.7
	0.5	12	8.37
		18	9.7
	1	12	8.37
		18	8.98
	2	12	10.16
		18	11.8
7	0	12	3.4
		18	3.3
	0.25	12	7.3
		18	7.6
	0.5	12	8.1
		18	8.4
	1	12	8.1
		18	8.3
	2	12	8.96
		18	9

(b) 30% fine

Cement	Fibers	No of cycles	Loss of soil-cement
%	%		%
3	0	1	8.1
		1	9.7
	0.25	4	12.4
		2	8.3
	0.5	4	14.9
		4	14.8
	1	4	16.3
		4	12.7
	2	4	11.7
		4	9.5
5	0	12	9.3
		18	10.5
	0.25	12	8.9
		18	9.22
	0.5	12	10.26
		18	9
	1	12	9.89
		18	9.6
	2	12	10.52
		18	11.2
7	0	12	4.4
		18	4.2
	0.25	12	7
		18	7.6
	0.5	12	6
		18	8.2
	1	12	7.6
		18	8.6
	2	12	8.1
		18	8.9

(c) 50% fine

Cement	Fibers	No of cycles	Loss of soil-cement
%	%		%
3	0	2	10.9
		2	11.66
	0.25	7	14.2
		2	9.8
	0.5	7	14.6
		2	12
	1	7	14.1
		3	13.1
	2	2	10.3
		5	16.33
5	0	12	11.5
		18	9.6
	0.25	18	8.5
		12	7.6
	0.5	12	6.8
		18	8.8
	1	12	7.5
		18	10.1
	2	12	8.4
		18	10.02
7	0	12	5.35
		18	7.7
	0.25	12	2
		18	4
	0.5	12	1.2
		18	3.7
	1	12	3.8
		18	4.1
	2	12	3.6
		18	4.4

The Mean, standard deviation and the 95% confidence bound of soil-cement loss calculated for different fiber contents is tabulated in the Table 5.2. From the mean calculated it represents that loss of soil-cement due to 1% fiber was higher in comparison with other fiber contents used. The soil blocks without fibers had lower mean value. However, 0.25% fiber blocks had mean value closer to the blocks without fibers with a lower standard deviation value. The Mean and 95% confidence bound plot in Figure 5.6

gives a comprehensible view. The plot represents the effect of fibers on the soil-cement loss. With addition of fibers the loss increases. The significance of the loss due to different fiber was tested by carrying out the T test.

Table 5.2.

Mean, Standard Deviation and Confidence Interval Values

Fibers	N	Mean	StDev	95%CI
0	18	7.978	3.345	(6.450,9.506)
0.25	18	8.259	2.668	(6.731,9.787)
0.5	18	9.496	3.792	(7.968,11.024)
1	18	10.008	3.593	(8.480,11.536)
2	18	9.458	2.748	(7.930,10.986)

The t-test result in Table 5.3 was used to check the significance of the data obtained during the wetting and drying cycles. The null hypothesis for this test was there is no relation in soil-cement loss between the blocks at any fiber contents. Using this null hypothesis and α value of 0.05, the p value was compared with α value. It is evident that p value of all two sample fiber data sets is greater than 0.05; thus, failing to reject the null hypothesis. This proves that the data of soil-cement loss for all the fibers contents are not significantly different and there is no relation between any of them. This test aids in concluding that the addition of fibers does not have an immense impact on the loss of soil cement in the blocks due to continues wetting and drying cycles.

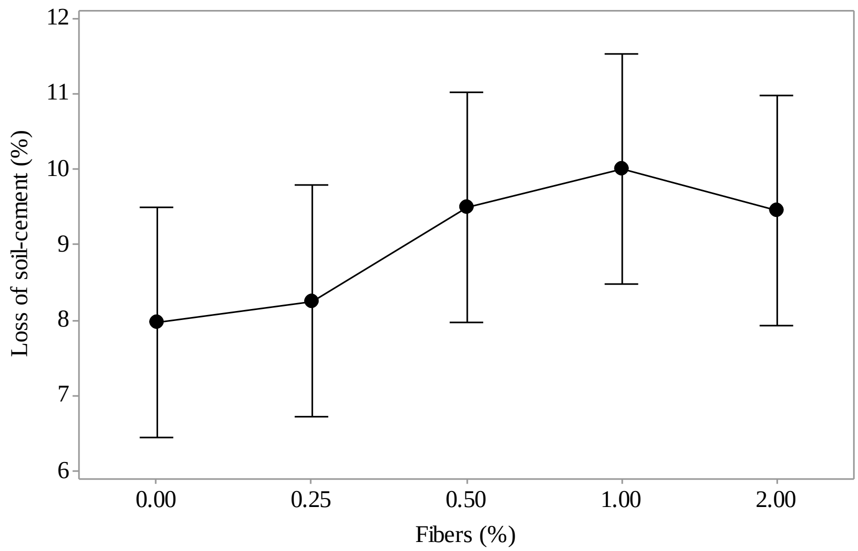


Figure 5.6. Interval Plot of Loss of Soil – Cement versus Fibers (With 95% CI for the Mean)

Table 5.3.

Two-Sample T-Test and CI: Loss of Soil-Cement, Fibers

Two samples (Fibers)	Estimate for difference	95% CI for difference	T-test of difference	T-value	P value	DF
0% - 0.25%	-0.28	(-2.34,1.77)	0	-0.28	0.783	32
0%-0.5%	-1.52	(-3.94,0.91)	0	-1.27	0.212	33
0%-1%	-2.03	(-4.38,0.32)	0	1.75	0.089	33
0%-2%	-1.48	(-3.56,0.60)	0	-1.45	0.157	32
0.25%-0.5%	-1.24	(-3.47,0.99)	0	-1.13	0.267	30
0.25%-1%	-1.75	(-3.90,0.40)	0	-1.66	0.107	31
0.25%-2%	-1.199	(-3.03,0.638)	0	-1.33	0.193	33
0.5%-1%	-0.51	(-3.02,1.99)	0	-0.42	0.68	33
0.5%-2%	0.04	(-2.22,2.29)	0	0.03	0.973	30
1%-2%	0.55	(-1.62,2.72)	0	0.52	0.61	31

The mean, standard deviation and the 95% confidence interval value of soil-cement loss of the blocks with different fine contents is presented in the Table 5.4 and the means are plotted in Figure 5.7. The mean value for the 50% fine blocks was lower than the blocks with 10% and 30% fine soil blocks. However, the standard deviation value for the 50% fine blocks was higher with 4.017% soil-cement loss. The 30% fine blocks had higher mean value but it is lower than the recommended loss of 10%.

Table 5.4.

Mean, Standard Deviation and Confidence Interval Values

Fines	N	Mean	St Dev	95%CI
10	30	9.018	2.951	(7.824,10.212)
30	30	9.58	2.762	(8.386,10.774)
50	30	8.522	4.017	(7.328,9.716)

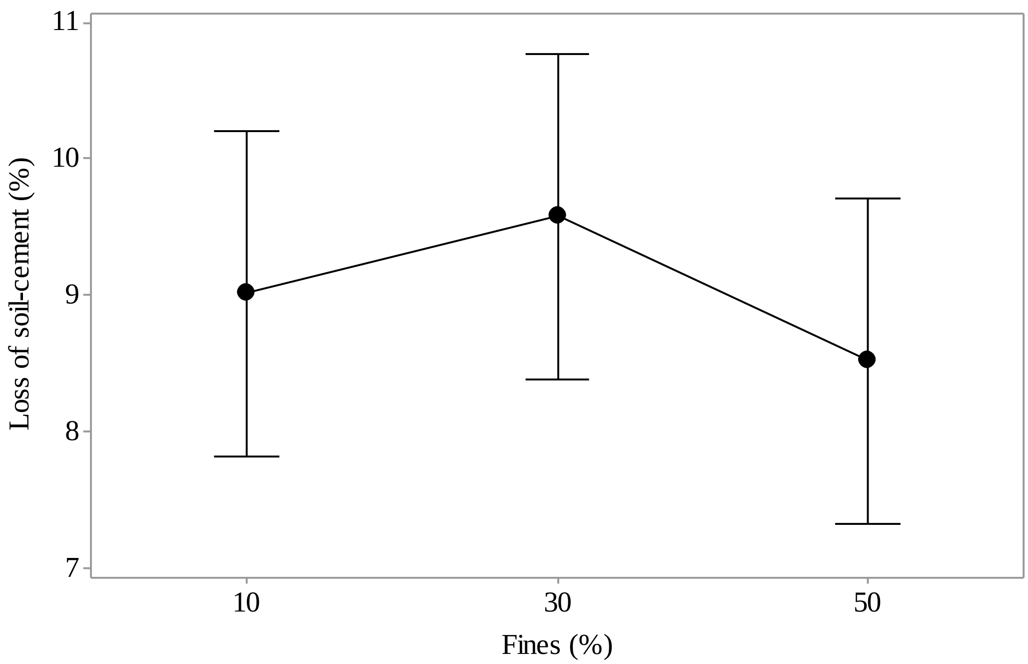


Figure 5.7. Interval Plot of Loss of Soil – Cement versus Fines (With 95% CI for the Mean)

Table 5.5.

Two-Sample T-Test and CI: Loss of Soil-Cement, Fines

Two samples (Fines)	Estimate for difference	95% CI for difference	T-test of difference	T-value	P value	DF
10% - 30%	-0.562	(-2.040,0.916)	0	-0.76	0.449	57
10%-50%	0.496	(-1.33,2.321)	0	0.54	0.588	53
30%-50%	1.058	(-0.729,2.845)	0	1.19	0.24	51

The mean values of the loss of soil cement in the blocks with 3% cement, 5% cement and 7% cement, with N value of 30, were 12.06%, 8.965% and 6.097% respectively. The standard deviation was found to be 2.49%, 1.715% and 2.352% for 3% cement, 5% cement and 7% cement blocks. The 95% Confidence interval, the range of values that represents the reasonable estimate for the unknown parameter, for the cement with respect to dry compressive strength is plotted in Figure 5.8. It is evident from the plot that the mean value of the loss of soil-cement in the blocks with 3% cement blocks is higher followed by 5% cement and then 7% cement soil blocks. This shows that with the increase in the cement content helps in holding the soil particles together even at extreme wetting and drying cycles experienced in the environment. Based on the mean value of the blocks with 3% cement, which is higher than the recommended loss of within 10%, it is not recommended to use 3% cement CSEB in humid conditions.

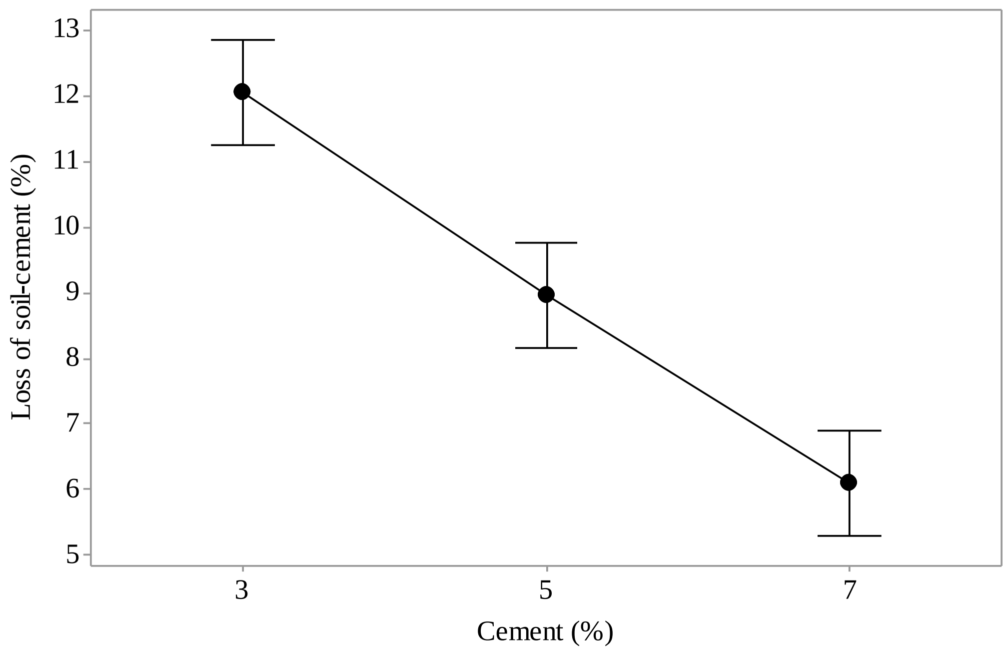


Figure 5.8. Interval Plot of Loss of Soil – Cement versus Cement (With 95% CI for the Mean)

Comparison of the significance of the loss of soil cement of blocks with 3 cement content was carried out using the two sample T test. The hypothesis for this test was "The difference in mean number of soil-cement loss in blocks produced using different cement content is zero". The results are tabulated in Table 5.6. The p value for all the three comparisons between the cement content was 0 which is less than 0.05. The null hypothesis will be rejected based on the p value. This signifies an enormous difference in the soil-cement loss data between all the three cement contents; and explains the significant of the cement content on the loss percent of soil-cement on the blocks when repeatedly exposed to wetting and drying cycles.

Table 5.6.

Two-Sample T-Test and CI: Loss of Soil-Cement, Cement

Two samples (Cement)	Estimate for difference	95% CI for difference	T-test of difference	T-value	P value	DF
3%-5%	3.092	(1.984,4.20)	0	5.6	0	51
3%-7%	5.96	(4.708,7.212)	0	9.53	0	57
5%-7%	2.868	(1.802,3.934)	0	5.4	0	53

5.4 Multiple Regression Analysis: Loss of Soil-Cement Versus Fines, Cement, Number of Cycles and Fibers

A regression was performed to learn more about the relation between the different variables, such as fine content, cement content, fiber content and number of cycles, and the loss of soil-cement. Eq.2 represents the estimate of soil-cement loss based on the four variables mentioned above. The Eq.2 represents that the cement content significantly contributes towards reduction in the loss of soil, in contrast to the other three variables (i.e. fine content, fiber content and number of cycles) direct impact in the loss of soil-cement.

The significance among parameters was studied based on the p value of each variable (Table 5.7). The fine content and the number of cycles had no significant influence on the loss of soil-cement. However, cement content and fiber content were found to be statistically significant on the loss. The coefficients are shown in Eq.2 below:

Loss of soil-cement = $15.902 - 0.000254\, a^2 - 1.776\, b + 1.417\, c^{0.075} + 0.1059\, d$ …… Eq.2

a = fine percent, b = percent cement, c = fiber percent, d = Number of cycles

Table 5.7.

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P value
Regression	4	583.564	145.891	33.07	0
Fines	1	5.746	5.746	1.3	0.257
Cement	1	315.441	315.441	71.49	0
Fibers	1	27.919	27.919	6.33	0.014
No. of Cycles	1	14.009	14.009	3.18	0.078
Error	85	375.036	4.412		
Lack-of-Fit	77	364.076	4.728	3.45	0.033
Pure Error	8	10.959	1.37		
Total	89	958.599			

5.5 Sensitivity Analysis of The Dry Compressive Strength of CSE Blocks Subjected to Wetting and Drying Cycles

The means of the dry compressive strength of the blocks subjected to 12 and 18 cycles of wetting and drying cycles are presented in the Table 5.8. The mean value of the dry strength of the blocks subjected to 18 cycles was lower than the blocks which were not subjected to wetting-drying cycles and 12 wetting-drying cycles.

Table 5.8.

Mean, Standard Deviation and Confidence Interval Values

No of cycles	N	Mean	St Dev	95%CI
0	30	15.899	4.492	(14.022,17.776)
12	30	11.353	5.264	(9.476,13.230)
18	24	10.1	5.8	8.00,12.20)

Figure 5.9 depicts the mean and the 95% confidence interval. It can be observed that the 95% confidence intervals of the 12 and 18 cycles are below the confidence interval

of the strength of the blocks not subjected to wetting and drying cycles. From the t-test results (Table 5.9), it is concluded that there is a significant difference between the results for blocks not subjected to cycles and those that were subjected. No significant difference was found in the mean strength value for blocs subjected to 12 and 18 cycles.

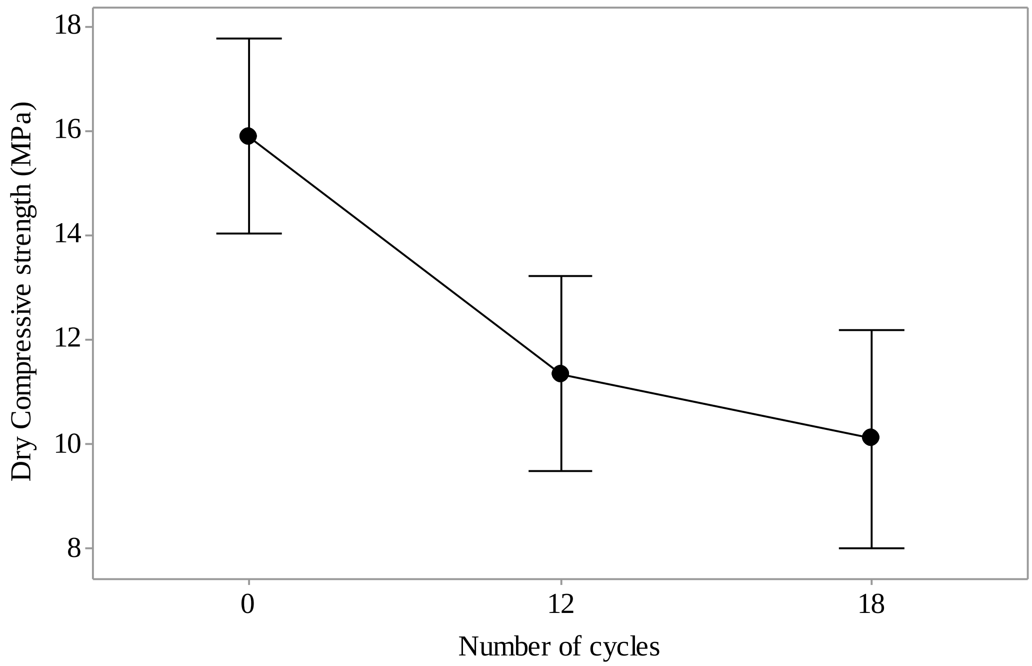


Figure 5.9. Interval Plot of Dry Compressive Strength versus Number of Wetting and Drying Cycles (With 95% CI for the Mean)

Table 5.9.

Two-Sample T-Test and CI: Dry Compressive Strength after Wetting and Drying Cycles, Number of Cycles: (a) T test for 0 and 12 Number of Cycles; (b) T test for 0 and 18 Number of Cycles (C) T test for 12 and 18 Number of Cycles

(a)

No of cycles	N	Mean	St Dev	SE Mean
0	30	15.9	4.49	0.82
12	30	11.35	5.26	0.96
Difference			μ(0) - μ(12)	
Estimate for difference			4.55	
95% CI for difference			(2.02,7.08)	
T-Test of difference			0	
T-Value			3.6	
P value			0.001	
DF			56	

(b)

No of cycles	N	Mean	St Dev	SE Mean
0	30	15.9	4.49	0.82
18	30	10.1	5.8	1.2
Difference			μ(0) - μ(18)	
Estimate for difference			5.8	
95% CI for difference			(2.89,8.71)	
T-Test of difference			0	
T-Value			4.03	
P value			0	
DF			42	

(c)

No of cycles	N	Mean	St Dev	SE Mean
12	30	11.35	5.26	0.96
18	30	10.1	5.8	1.2
Difference			μ(12) - μ(18)	
Estimate for difference			1.25	
95% CI for difference			(-1.82,4.32)	
T-Test of difference			0	
T-Value			0.82	
P value			0.416	
DF			47	

5.6 Multiple Regression Analysis: Dry Compressive Strength Versus Fines, Cement, Number of Cycles of Wetting-Drying and Fibers

The regression analysis was performed to obtain an equation for the dry strength of blocks subjected to wetting and drying cycles to figure out the relation with the variables such as fine, fibers, cement and number of wetting-drying cycles. The equation (Eq. 3) portrays that the cement content contributed to the strength of the blocks. But the fines, fibers and number of cycles had an inverse impact on the strength. However, number of cycles had a significant impact on the strength as it was in terms on natural log and even the higher fiber content impacted the strength to greater extent. Based on the p value (Table 5.10), which was less than 0.05, all the variables in this equation had an important part to play in the strength and the influence was significant.

Table 5.10.

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P value
Regression	4	2048.83	512.207	63.54	0
Fines	1	51.26	51.263	6.36	0.014
Fiber	1	955.56	955.555	118.55	0
Cement	1	521.9	521.905	64.75	0
No of cycles	1	467.77	467.769	58.03	0
Error	79	636.79	8.061		
Total	83	2685.62			

Dry compressive strength = $3.80 - 0.000783\ a^2 - 1.0623\ b^3 + 2.493\ c - 1.835 \ln(d)$…Eq.3

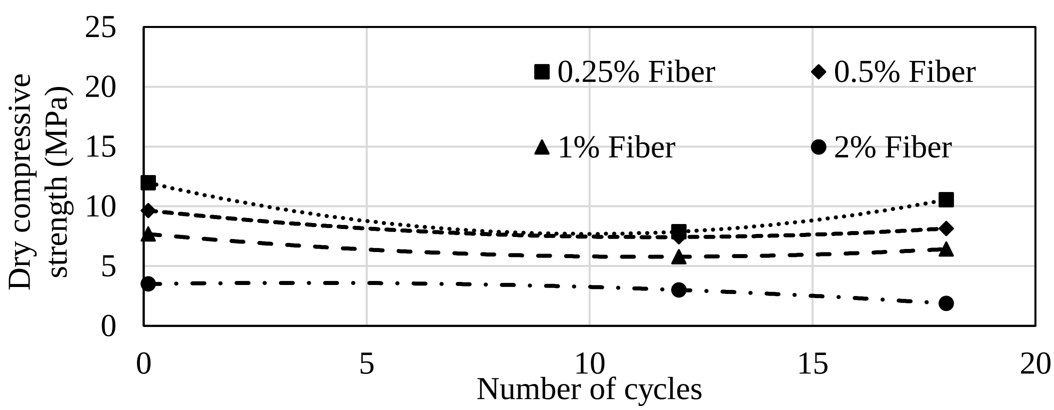
Where, a = fine percent, b = fiber percent, c = percent cement and d = No of cycles

5.7 Heating and Cooling Cycles

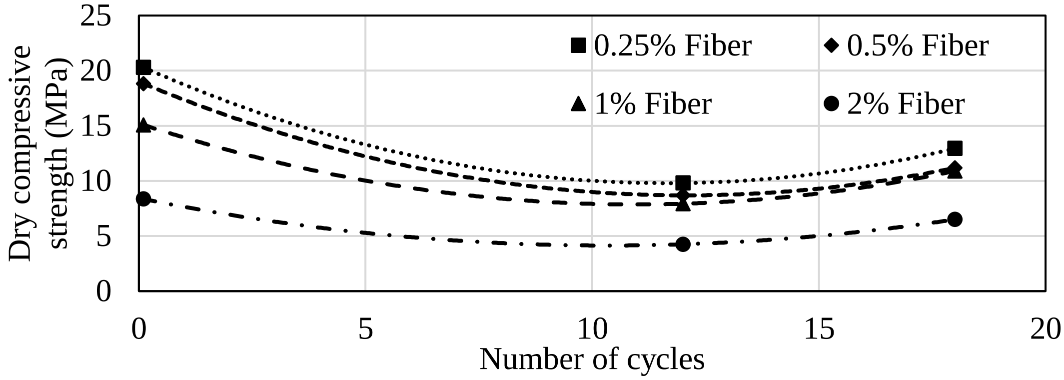
The construction materials are exposed to change in temperature in the environment. They sustain these changes without damaging the structure and make it more durable. Even the compressed stabilized earth blocks when used for construction purpose are exposed to this variation. So it’s important to study how the temperature variation affects the properties of the blocks. It will give an idea as to by how much extent the blocks will be damaged which can be linked to the durability of these blocks. Current literature, building codes and testing standards does not give guidelines for carrying out heating and cooling test. Considering the temperature variation during summer and winter in the environment it was decided to subject the blocks to two extreme temperature of 45°C and 5°C for 12hours each which will be considered as one cycle. After each cycle the dimensions and mass of the blocks was recorded. Few blocks were subjected to 12 cycles and some blocks were subjected to 18 cycles. Then the blocks were tested for strength and from the data collected the change in density was calculated. From the test results effect of heating and cooling cycles on strength and density of the blocks prepared using various compositions of fibers, cement and fines was studied.

5.7.1 Dry Compressive Strength of Blocks Subjected To Heating and Cooling Cycles

The heating and cooling cycles showed an interesting impact on the dry compressive strength. The dry compressive strength of the blocks with 10% fine soil is shown in the Figure. 5.10. The plots show initial dip in the dry compressive strength at 12 cycles then gains strength by 18th cycle. The same pattern is observed in all the blocks with 10% fine soil except for 2% fiber - 3% cement and 2% fiber - 7% cement which showed decrease in strength with increase in number of cycles from 12 to 18. Even the 30% fine and 50% fine blocks showed decrease in strength at 12 cycles then the strength increased with 18th cycles except in few combinations of cement and fibers.



(a)



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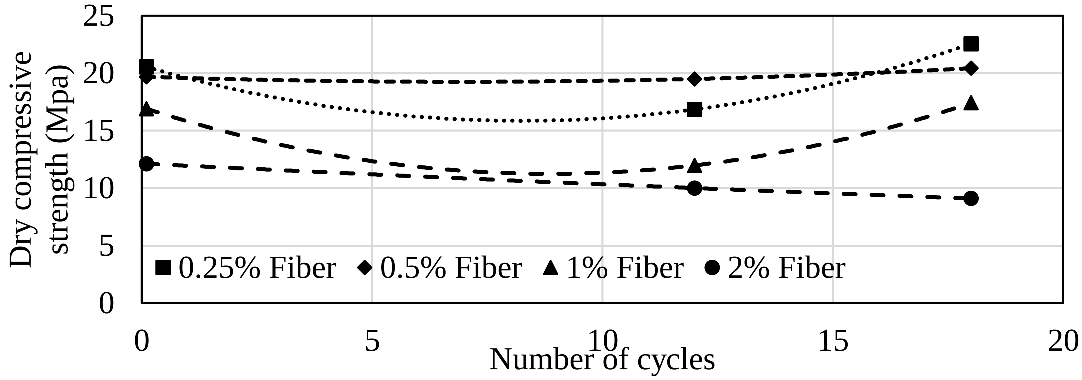
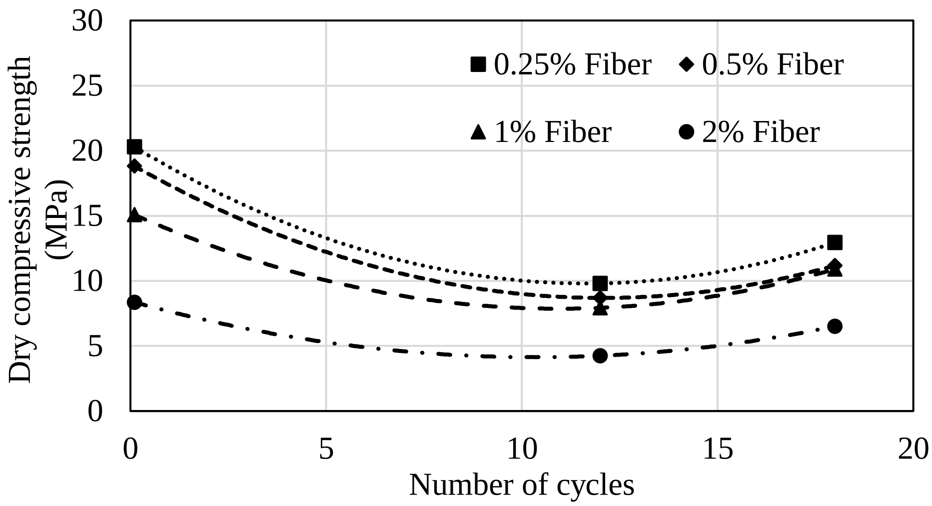


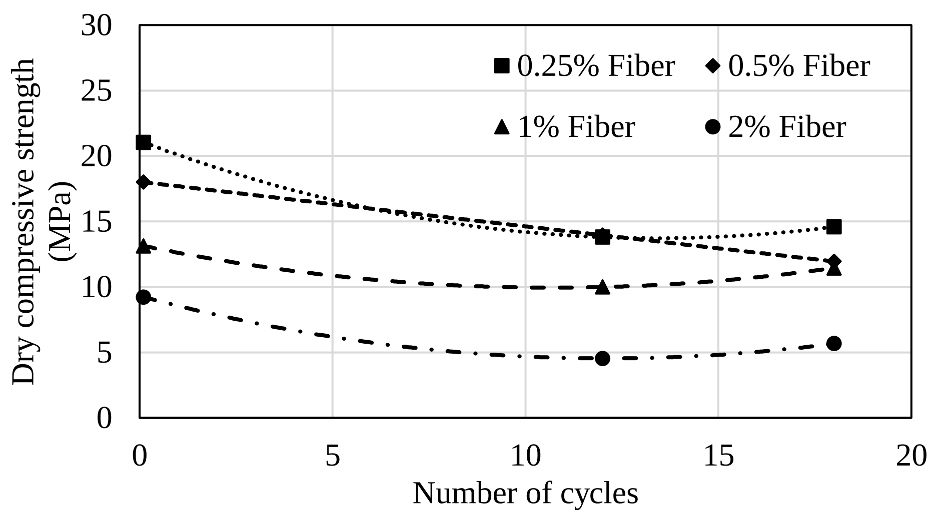
(c)

Figure 5.10. Comparison of Dry Compressive Strength Of 10% Fine Soil Blocks Subjected To Heating and Cooling Cycles; (a) 3% Cement; (b) 5% Cement; (c) 7% Cement

The variation of the dry compressive strength of the blocks produced using 5% cement and the three fabricated soils is presented below in Figure 5.11. All the fabricated soil showed increase in dry compressive strength with increase in number of heating and cooling cycles. At 18 cycles the blocks had more strength than the once subjected to 12 cycles. This trend was not observed in 30% fine soil at 0.5% fiber. The 10% fine soil at 0.25% fiber showed a reduction of 52% in strength at 12 cycles and 36.2% at 18 cycles. At 0.25% fiber usage in 50% fine soil portrayed a reduction of 37.22% and 22.5% in strength at 12 and 18 cycles respectively. In comparison with 10% and 50% fine soils 30% fine soil blocks had a lower reduction percentage of 34.4 and 30.6 after 12 and 18 cycles. The 30% fine soil revealed a lower reduction in strength in comparison with 10% and 50% fine soils at 12 and 18 cycles for all the fiber content at 5% cement content. There was no pattern was observed with the reduction at other two cement contents.



(a)



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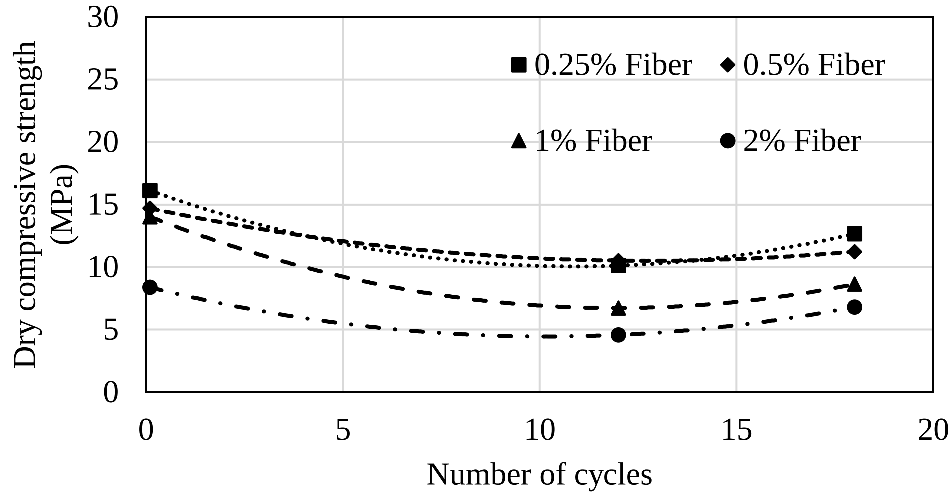


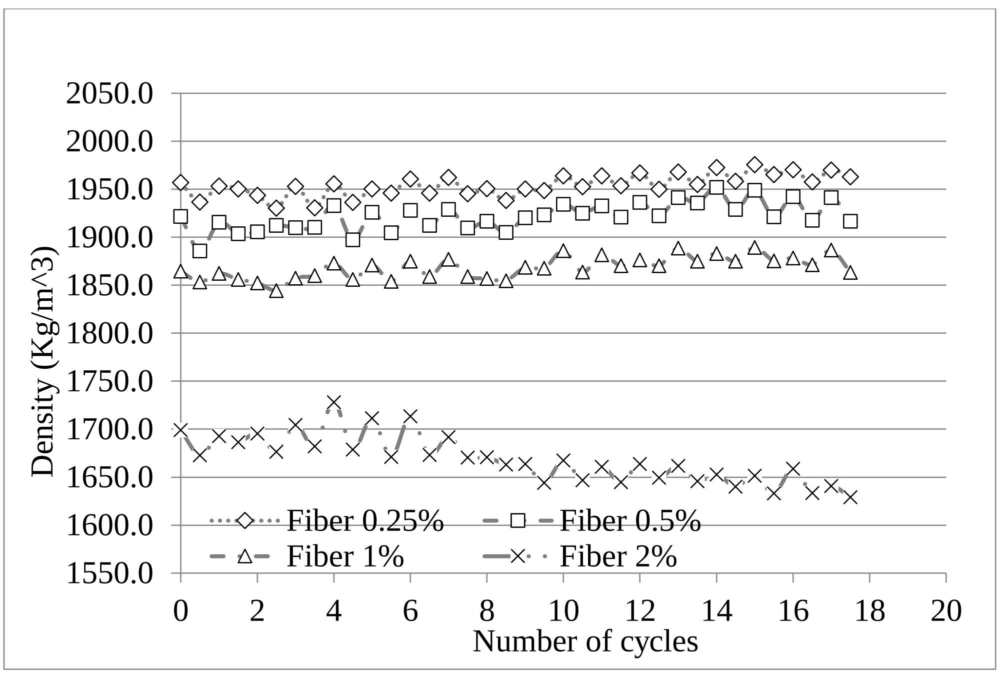
(c)

Figure 5.11. Comparison of Dry Compressive Strength Of 5% Cement Soil Blocks Subjected To Heating and Cooling Cycles; (a) 10% Fine Soil; (b) 30% Fine Soil; (c) 50% Fine Soil

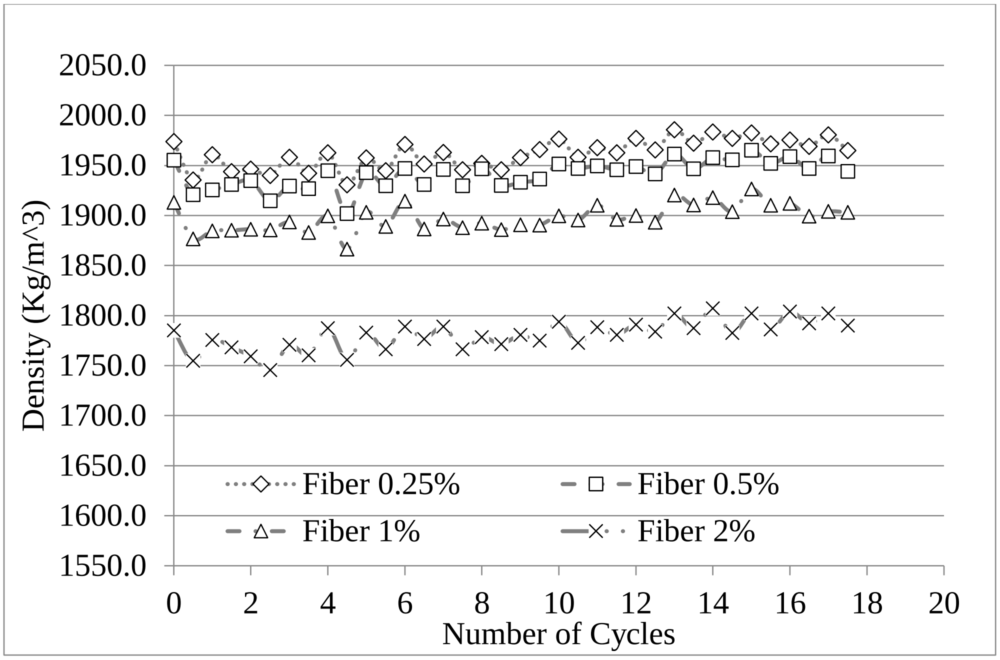
5.7.2 Density Variation of Blocks Subjected To Heating and Cooling Cycles

The blocks showed variation in the mass and very minor change in the dimensions when subjected to heating and cooling cycles which effected the density of the blocks. The blocks were gaining mass during the cooling process and then they were losing mass in the heating cycles, however it was found that there was no much effect on the volume of the blocks. The mass change had a major part in the density change that was observed during the heating and cooling cycles.

The air temperature to moisture relation plays an important role. At 45°C the air inside the chamber has a relatively low humidity thus creating a relatively dry environment. As the temperature was reduced to 5°C the humidity increases, the air becomes moist. The blocks absorb moisture at low temperature which lead to increase in the mass at 5°C and can be summarized as the movement of moisture in and out of the blocks during transition of temperatures inside the environmental chamber. The density variation of the blocks with 10% fine soil is shown in the Figure. 5.12. The density value corresponding to the decimal number points of the number of cycles axis represent the density of the blocks after experiencing cooling at 5°C and the whole number points represent density of the blocks subjected to heating at 45°C. From the plots it is clear that initially there was a decrease in the density which later on starts increasing to reach the original density of the blocks. The density variation observed during the cycles impacted the strength of the blocks. However, as the strength test was dry compressive strength the blocks were oven dried at 100^0 C until a constant mass was attained then the compression test was carried out.



(a)



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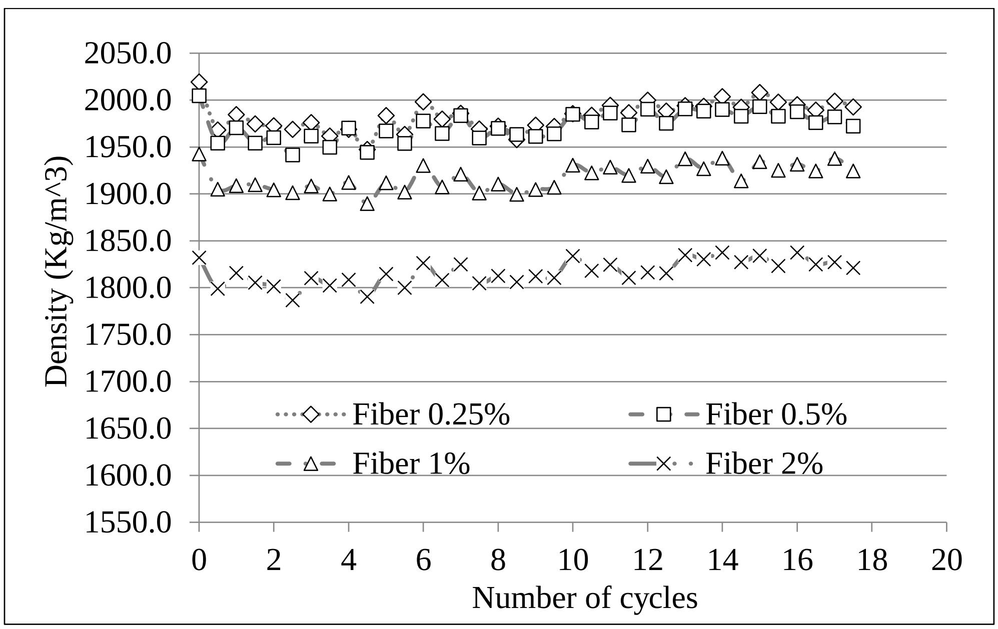

(c)

*Figure 5.12***.** Density Variation Of 10% Fine Soil Blocks Subjected To Heating and Cooling Cycles; (a) 3% Cement; (b) 5% Cement; (c) 7% Cement

5.8 Sensitivity Analysis of The Dry Compressive Strength of CSE Blocks Subjected To Heating and Cooling Cycles

The analysis of variance was performed on the strength data obtained to calculate the mean, standard deviation and the 95% confidence bound to illustrate the effect of the number of cycles of heating and cooling on the dry compressive strength of the blocks. Table 5.11 displays the calculated values and Figure 5.13 illustrates the mean and confidence interval plots at 0, 12 and 18 cycles of heating-cooling. The mean value of the strength of blocks after 12 cycles was lower than the strength of the blocks subjected to 18 cycles. There was dip in the strength of the blocks at 12 cycles compared to the original strength. It can be noticed from the plot that the confidence interval of the strength of the blocks subjected to 12 cycles barely touched the lower confidence bound of the original strength of the blocks. However, the confidence interval of the 12 cycles covered the mean strength value of the blocks subjected to 18 cycles.

Table 5.11.

Mean, Standard Deviation and Confidence Interval Values

No of Cycles	N	Mean	St Dev	95% CI
0	36	13.549	5.552	(11.795,15.303)
12	36	9.97	4.723	(8.216,11.724)
18	36	11.53	5.72	(9.38,13.67)

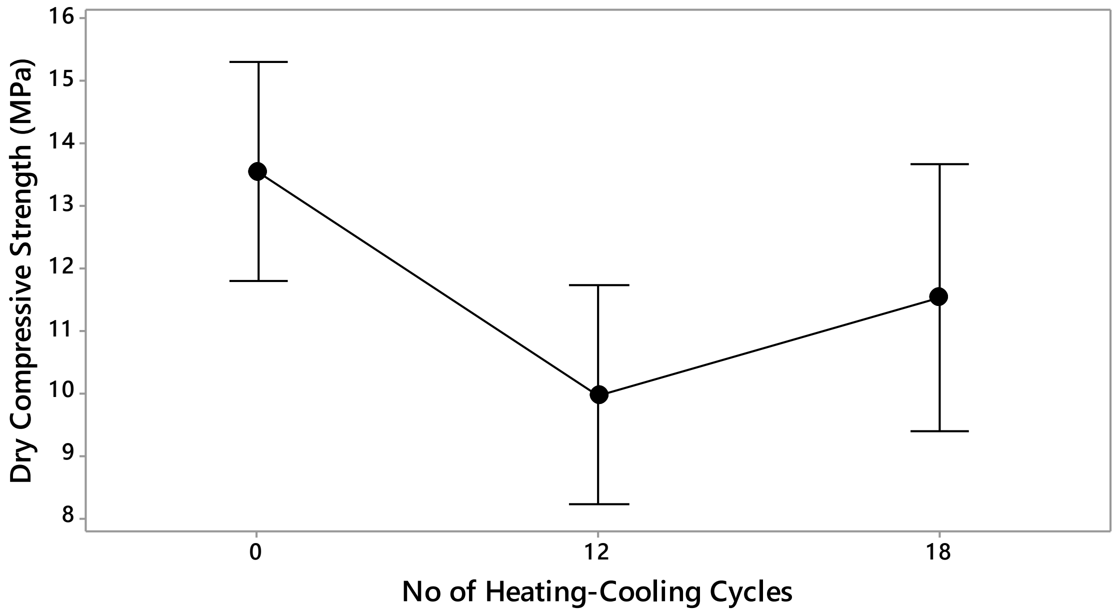

Figure 5.13. Interval Plot of Dry Compressive Strength versus Number of Heating-Cooling Cycles (With 95% CI for the Mean)

On performing the t-test with the null hypothesis of “The difference in mean of dry strength of blocks subjected to different number of heating and cooling cycles is zero” the results tabulated in the Table 5.12 was obtained.

The α value of 0.05 was used for the analysis. On comparing the p value with α value the strength of blocks at 0 and 12 cycles it was conclude that the null hypothesis was rejected thus proving that there is a significant difference in the values. However, the strength value comparison between 0 and 18 cycles did approve with the null hypothesis as the p value was greater than 0.05. This tends to state that the difference in the strength values between these two cycles is not statistically significantly different. This can also be noticed in the Figure 5.13 that the confidence bound of the 18 cycles is over the mean value of the original strength of the blocks.

Table 5.12.

Two-Sample T-Test and CI: Dry Compressive Strength, Number of Heating-Cooling Cycles

(a) T test for 12 and 18 Number of Cycles

No of cycles	N	Mean	St Dev	SE Mean
12	36	9.97	4.72	0.79
18	36	11.53	5.72	1.2
Estimate for difference			-1.56	
95% CI for difference			(-4.40,1.29)	
T-Test of difference			0	
T-Value			-1.11	
P value			0.275	
DF			42	

(b) T test for 0 and 12 Number of Cycles

No of cycles	N	Mean	St Dev	SE Mean
0	36	13.55	5.55	0.93
12	36	9.97	4.72	0.72
Estimate for difference			3.58	
95% CI for difference			(1.16,6.00)	
T-Test of difference			0	
T-Value			2.95	
P value			0.004	
DF			68	

(c) T test for 0 and 18 Number of Cycles

No of cycles	N	Mean	St Dev	SE Mean
0	36	13.55	5.55	0.93
18	36	11.53	5.72	1.2
Estimate for difference			2.02	
95% CI for difference			(-0.97,5.02)	
T-Test of difference			0	
T-Value			1.36	
P value			0.181	
DF			48	

5.9 Multiple Regression Analysis: Dry Compressive Strength Versus Fines, Cement, Number of Cycles of Heating-Cooling and Fibers

The equation Eq.4 was obtained for dry compressive strength in relation with fine content, fiber content, cement content and number of heating-cooling cycles on running a multiple regression. Along with that the p values are tabulated in the Table 5.14. The equation clearly explains that the number of heating and cooling cycles and fiber content had massive effect on the strength of the blocks. The constant value to be multiplied with fiber content is higher and the natural log term of the number of cycles was used which makes a lot difference on the strength. However, cement was directly proportional to the strength and that was the only variable which had a positive influence on the strength. The p value of all the variables was compared with 0.05 and was found that all the variables p value was less than 0.05. This proves that all the variables had influential impact on the dry strength of the blocks, as shown in Eq.4 below:

Dry Compressive Strength = $7.660 - 0.000571\ a^2 + 2.198\ b - 4.835\ c - 1.114 \ln(d)$ ….Eq.4

Where, a = fine percent, b = percent cement, c = fiber percent and d = No. of cycles

Table 5.13.

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P value
Regression	4	2445.48	611.37	139.94	0
Fine	1	26.4	26.4	6.04	0.016
Cement	1	1236.49	1236.49	283.04	0
Fiber	1	1008.22	1008.22	230.78	0
No of Cycles	1	192.91	192.91	44.16	0
Error	91	397.55	4.37		
Total	95	2843.03			

6. THERMAL PROPERTY OF THE COMPRESSED STABILIZED EARTH BLOCKS

6.1 Introduction

There is an alarming demand for the constructing energy efficiency buildings as the building sector is one of the industry contributing significantly on worlds total energy usage and greenhouse gases. The energy efficiency demand can be met by improving the thermal insulation of building. This helps in reducing the dependency on cooling and heating equipment's thus contributing towards saving of energy, irrespective off the fuel used. In US alone the residential cooling consumes 8% of the residential energy usage. This can cut down by using materials that consume less energy for the production and which has good thermal insulation properties thus helping in reducing the energy usage and emission of greenhouse gases.

Soil is being used as a construction material to build thermally comfortable structures in harsh, arid environments due to its thermal retention property. This property of the soil was learnt by people in early ages which was banked on and sought comfort living in the soil houses. Soil being one of the poor conductor of heat, i.e. less heat is conducted by the material, if used in construction provides a better comfort inside. In this chapter the thermal resistivity and R value of the CSEB will be presented and compared with the commonly used construction material, those are concrete blocks and clay bricks. In addition to that the variation in thermal resistivity of CSEB with fiber content, fine content and cement content used will be analysed.

6.2 Importance of Thermal Resistance (R Value) of Building Material

The R value is widely recognized as the measure of the insulation efficiency. Building materials are rated for the thermal performance based on the measurements of R value and U value. The insulation property of the materials used for construction tops the list of things considered to save energy costs of the building. The R-value indicates the ability of the material to insulate efficiently. Insulation is nothing more than the resistance offered by a material to the transfer of heat to a cool end from a hotter end. It makes sense that the higher the R-value, or resistance, better insulator the material is. It is a material property which depends on the density and moisture content of the sample. The R-value is calculated by dividing the thickness of the wall by the wall's thermal conductivity, a value established by the amount of heat (per sq. m. per hour) flowing from the hotter to the cooler side of the wall. The unit used for the R value is ft^2.°F.hr/Btu. It is either represented as thermal resistivity per inch or with respect to the particular thickness of the material. The R value of the material always shows linear variation with increase in the thickness. The U-value, or value of conductance, is represented by the reciprocal of the R-value and reflects the rate at which heat is conducted through material. The R value of the commonly used building materials are presented in the Table 6.1. Total R- and U- values may be calculated for a given wall by adding the sum of the values of each of the individual components of the wall structure (all insulation, interior sheathing, framing, or masonry must be taken into consideration). Both of these values reflect the rate at which heat passes through a wall only after it has achieved the steady-state condition or the state when heat energy is passing un-interrupted from one side of the wall to the other at a constant rate.

Most effective way to construct a more energy efficient building, keeping it warmer in winter and cooler in summer, is using the materials with higher R value. This can also reduce mould and damp, which is beneficial for health, by reducing the condensation within the building. Direct benefits of using higher R value material is reduction in energy usage, as it reduces the reliance on heating and cooling systems, thereby saving money and also reduction in the emission of greenhouse gases. The R value requirement of the building depends on the climatic zone in which it is located.

Table 6.1.

R Value of Common Building Materials (ASHRAE Handbook, 1999)

Masonry Material	Density Kg/m^3	Thickness inch	R value for thickness listed $ft^2.°F.hr/Btu$
Fired clay brick	1922	4	0.72 - 0.6
Concrete blocks (Normal weight aggregates)	2018 - 2178	8	1.11 - 0.97
Concrete blocks (Medium weight aggregates)	1554 - 1794	8	1.71 - 1.28
Concrete blocks (Light weight aggregates)		8	2.57 – 2.2

6.3 Thermal Resistivity Determination of CSEB

The thermal resistivity of the compressed stabilized earth blocks was determined as per the standard ASTM Test Method D5334. The blocks were not used for this test instead cylindrical sample was used as recommended by the standard. The cylindrical samples of dimension 2.8” diameter and 7” long (Figure 6.1) was prepared using the Shelby tube, of dimension 2.8” diameter and 12” long, as a mold. Thermal resistivity of few selected soil-cement-fiber combination i.e. 30%fine-0.25%fiber-5%cement and 30%fine-0.5%fiber-5%cement, based on the dry compressive strength and the durability results, was determined. In addition, to figure out the variation of thermal resistivity with fiber content, cement content and fine content this test was performed on few more combinations of fine, cement and fibers. The combinations used is tabulated in Table 6.2.

Table 6.2.

Mixture Proportions of Compressed Stabilized Earth Cylindrical Samples

<table>
<tr><th>Block ID</th><th>Sand (%)</th><th>Fine (%)</th><th>Cement (%)</th><th>Fibers (%)</th></tr>
<tr><td>F1C5F0.25</td><td>90</td><td>10</td><td>5</td><td>0.25</td></tr>
<tr><td>F3C3F0.25</td><td rowspan="6">70</td><td rowspan="6">30</td><td>3</td><td>0.25</td></tr>
<tr><td>F3C5F0</td><td rowspan="4">5</td><td>0</td></tr>
<tr><td>F3C5F0.25</td><td>0.25</td></tr>
<tr><td>F3C5F0.5</td><td>0.5</td></tr>
<tr><td>F3C5F1</td><td>1</td></tr>
<tr><td>F3C7F0.25</td><td>7</td><td>0.25</td></tr>
<tr><td>F5C5F0.25</td><td>50</td><td>50</td><td>5</td><td>0.25</td></tr>
</table>

Production of cylindrical samples was carried out similar to the blocks production process, only difference was the shape. First the wet mass of the mix needed was calculated based on the dry density and the dimension of the cylinder to be produced. Then the dry mass of soil, cement and fiber was determined based on the combination decided. The dry mass of each component was weighed out and mixed thoroughly until a uniform color was obtained. Then the water was added, equivalent to the optimum moisture content corresponding to the fabricated soil used, and mixed evenly for 5 minutes. It was made sure that the fibers were spread evenly throughout the soil.

*Figure 6.1***.** Cylindrical Sample of CSEB Used For Thermal Resistivity Test

Figure 6.2. Compacting the Soil-Cement-Fiber Wet Mix in the Shelby Tube

This wet mix was filled up in the Shelby tube in three lift and each lift was rotted using a cylindrical rod to reduce the voids. Then the soil was compacted statically using the compression machine (Figure 6.2) by placing a top plate over the soil. The compaction load used was around 10MPa. Once the required sample height was attained the compaction was stopped and then a hole was made of dimension 10 cm long, 2.4mm diameter (Figure 6.3) which is equivalent to the TR-1 sensor needle dimension, which was used to measure thermal resistivity, so that after the curing process drilling method need not be used to puncture a hole which might have caused damage to the samples. The samples were extracted using the Shelby tube extrude and once the samples were extruded they were marked with unique names. Then all the samples were wrapped with a wet cloth and were cured was 28 days at room temperature.

After 28 days of curing the samples were kept in the environmental chamber. The chamber was set to three different temperatures of 45°C, 25°C and 5°C during a course of week. At each temperature the samples allowed to equilibrate for two days before measuring the thermal resistivity using decagon KD2 Pro Thermal Properties Analyzer. The TR-1 sensor needle was inserted into the sample and allowed about 15 minutes for sample and needle to equilibrate with the temperature before taking the measurements.

Figure 6.3. Hole Being Made in the Center of the Cylindrical Sample To Insert the Sensor Needle For Measuring Thermal Resistivity

6.4 Effect of Fiber Content, Fine Content and Cement Content on The R Value of The Soil Blocks

The 30% fine soil blocks with 5% cement, based on the dry compressive strength and the durability results, was selected for studying the variation of thermal resistivity with variation in usage of fiber content. The thermal resistivity of these blocks at 45°C, 25°C and 5°C is plotted in the Figure 6.4. The plot demonstrates that the blocks with fibers have better thermal resistivity than the blocks which are not reinforced with fibers. This property is exhibited due to the resistance property of the wood shavings i.e. the bagasse fibers. However, the increase in the thermal resistivity reduced with increase in the fiber content because of the moisture retention property of the fibers which in turn tends to increase the moisture content of the composite CSEB at higher fiber content. The water content being a better heat conductor, with increase in water content the thermal conductivity of the sample increase thus reducing the thermal resistivity of the blocks. The thermal resistivity of the blocks increased by 1.6%, at 25°C, on addition of 0.25% fibers. The addition of fibers will be beneficial in reducing the usage of the insulating material required to attain the R value based on the recommendations of energy departments of that particular region.

The block used construction are exposed to the environmental temperature fluctuations. The change in temperature of the block influences the moisture movement in the blocks and thermal resistivity of the blocks. The temperature influence on the thermal resistivity of the blocks was studied. Replicating the process followed in the field, after curing the blocks for 28 days the blocks were air dried for two days before testing the thermal resistivity of the blocks. Then the thermal resistivity of these blocks were found at

5°C first then followed by 25°C and 45°C. Figure 6.4 clearly demonstrates the temperature effect on the thermal resistivity of the soil blocks. The blocks showed higher thermal resistivity at 45°C in comparison with the values at 25°C. The blocks started to dry out at 25°C which continued even at 45°C. With lowering of the water content in the soil blocks lead to increase in the thermal resistivity of the blocks at 45°C. Increase in resistivity value was just around 2.5%. However, at 5°C the thermal resistivity value of these blocks was lower than the other two temperature this is due to the increase in the moisture content of the blocks which was due to the increase in the relative humidity of the environmental chamber to bring down the temperature to 5°C.The thermal resistivity results demonstrates that with increase in temperature the thermal resistance of the blocks increases which proves to be very beneficial in resisting the heat flow from outside environment to inside environment at higher outside temperature. Thus providing a cool space to live a comfort life.

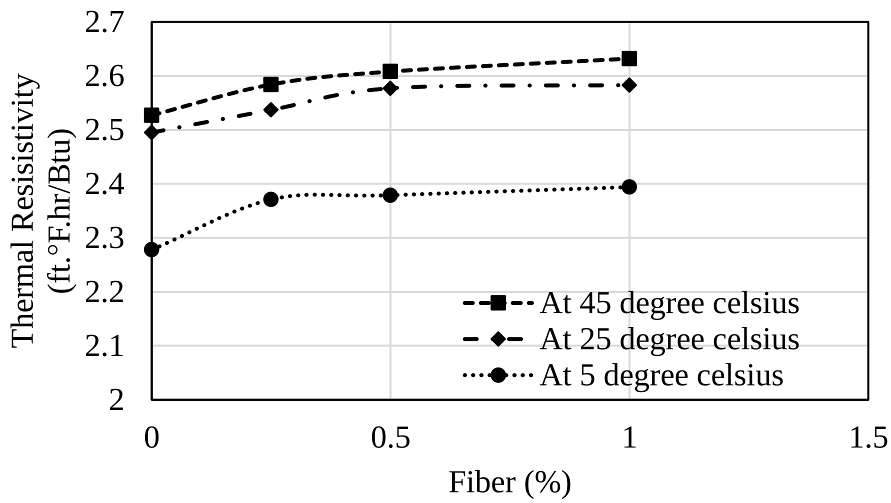

Figure 6.4. Plot Representing the Thermal Resistivity Value of 30%Fine-5%Cement Blocks at Different Fiber Contents at Different Temperatures

The influence of the fine content in the soil was also studied by finding the thermal resistivity of the soil produced using 10% fine, 30% fine and 50% fine soil blocks with 5% cement and 0.25% fiber. Figure 6.5 illustrates the variation of thermal resistivity of the blocks with three fine contents in the soil used for production. The blocks made out of soil with 10% fines had higher thermal resistivity than the blocks with other 30% and 50% fine soil blocks. The 50% fine soil blocks had lower thermal resistivity. However, the difference between the values for 10% and 30% fine blocks was just 1.8%. The heat flow in the soil occurs through the solid particles by conduction. With increase in fine content increase in conductivity is observed due to tendency of the fines to hold more moisture, because of higher capillary forces, thus leading to less contact between the soils particle than the granular soils. Thus the soil with increase in fine content in the soil thermal resistivity reduces.

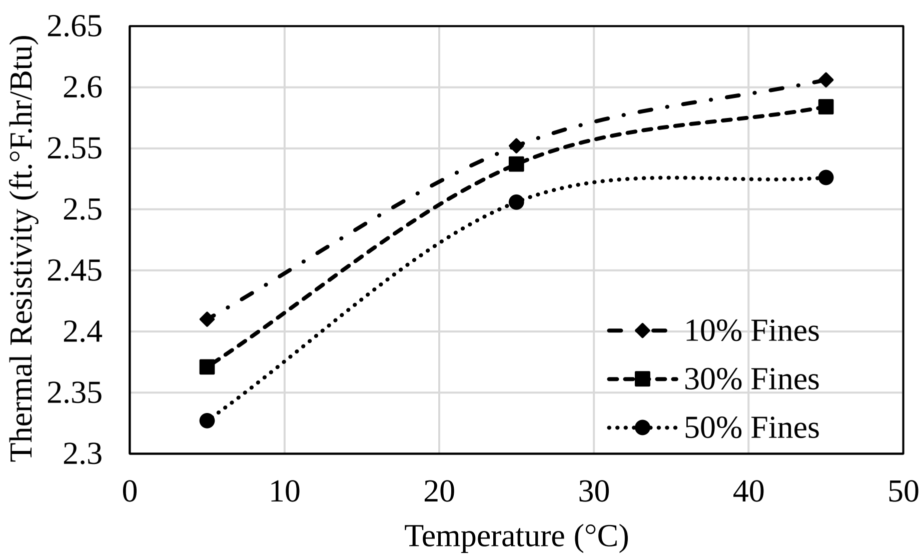

Figure 6.5. Comparison of Thermal Resistivity Values Of 5%Cement-0.25%Fiber Blocks Produced Using Soil Having Different Fine Contents

Thermal resistivity data of the 30% fine – 0.25% fiber blocks at different cement content are plotted in Figure 6.5. It is observed that with increase in the chemical additive i.e. cement tends to reduce the thermal resistivity of the blocks. The increase thermal resistivity value was significant, about 7%, with reduction in cement content from 7% to 5% cement but there was just 1.4% increase in the value of thermal resistivity with reduction in cement content from 5% to 3%. Reduction in thermal resistivity can be related to increase in thermal; conductivity. On increasing the cement content leads to reduction of pores in the soil blocks due to increase in the hydration products, thus providing a soil path way for easy conduction of heat. The advantage of reducing the cement usage and addition of fibers for the stabilization of compressed stabilized earth blocks will be improvement of thermal resistance property of the material in addition to contribution towards the strength equivalent to blocks at higher cement contents.

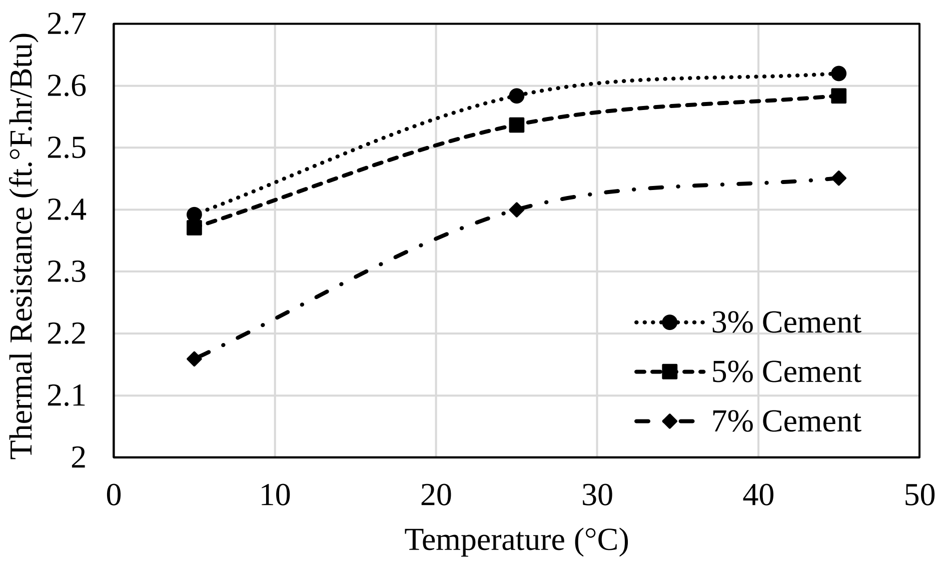

Figure 6.6. Thermal Resistivity Of 30%Fine-0.25% Blocks Produced Using Different Cement Contents

6.5 Comparison of R Value Of CSEB Produced with Concrete Blocks and Brick

The R value of the 30% fine block with 5% cement (Table 6.3) was compared with the R value of the building material tabulated in Table 6.1. The R value of 4 inch fired clay brick is 0.72 which is compared with the R value of CSEB. It is observed that R value of CSEB at all the fiber content was higher than the R value of brick. On comparing the R value with the concrete blocks it can be noted that soil blocks had higher R value than the concrete blocks with normal weight and was within the range of R values of medium weight aggregates. R value of CSEB without fiber was within the range of R value of concrete block with medium weight aggregate. The concrete block with light weight aggregate had higher R value than the CSEB produced for this testing. This is more advantageous which results in the construction of energy efficient buildings at a lower cost in comparison with clay bricks and concrete blocks. Furthermore, cost reduction can be achieved on air-conditioning and heating equipment's moving towards environmental friendly building construction. These test results demonstrate that the cement stabilized fiber reinforced earth blocks comply with the brick masonry thermal requirement.

Table 6.3.

R Value of 30% Fine-5%Cement Blocks for Two Thickness Values

Fines %	Cement %	Fiber %	R value based on thickness ft2.°F.hr/Btu	
			4 in	8 in
30	5	0	0.832	1.663
		0.25	0.846	1.691
		0.5	0.859	1.718
		1	0.861	1.722

7. CONCLUSIONS AND RECOMMENDATIONS

The conclusions and recommendations that were drawn from the experimental results of this work is are summarized in this chapter.

7.1 Conclusions

Dry density of the earth block is the main parameter in the usage of these blocks which directly effects the strength and the durability of the blocks. It was found that with increase in Guayule plant bagasse fiber reduction in the dry density was noticed. This is due to the low density of the fiber. This was confirmed when standard proctor test was carried out with the addition of fiber. The dry density of the blocks with 2% fiber was lower than the dry density determined by conducting the standard proctor test. The 2% fiber content caused the blocks to relax in the vertical direction by creating horizontal cracks due to absorption of the water by the fiber during curing of the blocks. Also the fiber mass is lower than the solids which lead to reduction in the mass of the block. The reduction in the mass and increase in the dimension of the blocks lead to reduction of the dry density. However, the blocks with 0.25% and 0.5% fiber had a dry density similar to the dry density decide to be achieved i.e. the maximum dry density of the fabricated soils. Even the dry density was affect by the cement usage. With increase in usage of cement content increase in dry density was noticed. But, it wasn’t that prominent in comparison with the fiber impact on the density.

The dry compressive strength is the initial framework on deciding the usage of these blocks in the construction industry. It was found in this research work that the fine content in the Guadalupe soil impact the strength of the blocks. The blocks produced with 30%

fines in the soil showed better strength than the soils having 10% fines and 50% fines. Blocks containing 50% fines showed lesser strength in comparison to those blocks with 10% and 30% fine content. This was due sufficient amount of sand and fine which provided densely packed arrangement because of higher contacting particles leading to reduction in the voids at the same time fines contributing towards the natural binging of the sand particles. However, the difference in the strength of the blocks with different fine content in the soil used didn't show significant difference, based on the range of dry strength data obtained with different cement and fiber content used, when Two-sample T test was performed.

It was found that bagasse fiber had a beneficial impact on the dry compressive strength of the blocks. In most cases examined, the addition of 0.25% and 0.5% fiber increased the dry compressive strength by 40% and 25% respectively, on average, when compared to that obtained on unreinforced blocks. Important point to be mentioned is with the addition of 0.25% fiber with 5% cement had higher strength than the blocks with 7% cement without fibers. It can be concluded that lower usage of lower cement content with 0.25% fibers will achieve similar strength as the blocks with higher cement content thus helping in the reduction of usage of cement. Furthermore, the addition of fiber increased the flexibility of the blocks as those with higher fiber content sustained higher strain without failing. The blocks with 0.5% fiber showed higher strength and also higher toughness, which is a property related to the energy absorbing capacity of the material.

Stabilization of soil blocks using cement fulfills a number of objectives that are necessary to achieve a lasting structure from locally available soil, including a better compressive strength (leading to better mechanical characteristics) and better cohesion between particles. Compressive strength of blocks increased with increase in cement content. By increasing the cement content from 3% to 5%, a 70% increase in compressive strength of the block was achieved; while a 35% increase was obtained by increasing the cement content from 5% to 7%.

The 3 cement blocks were unable to sustain extreme wetting and drying cycles. Soil blocks with 5% cement and 50% fines had less soil-cement loss on addition of fibers. The 50% fines blocks showed a reduction in loss of soil cement by 27% with addition of 0.25% fibers. Also with increase in number of cycles of wetting and drying the loss increased in most cases. There was no significant difference in loss of soil-cement between 30% fines blocks without fibers and 30% fines blocks with fibers. However, the loss of soil-cement was within the recommended loss of 10%. Increasing fiber content in blocks showed increase in loss of soil-cement 10% fines. Fiber use in 30% fines blocks reduced the amount of soil-cement lost by 8% with increase in number of cycles, in comparison with blocks without fibers. Increase in cement content reduced the loss of soil-cement due to the increase in binding effect.

Strength reduction was observed on subjecting the blocks to wetting and drying cycles. Subjecting the blocks to 12 cycles reduced the strength by 31% on average and after 18 cycles the strength reduced by 41%. Blocks with 7% cement showed less reduction in strength in comparison with blocks having 5% cement. The fiber content, fine content and number of cycles had a negative impact on the strength and cement content had positive impact on the strength. The strength of soil blocks of combination 30% fines-5% cement-

0.25% fibers and 30% fines-7% cement-0.25% fibers satisfied the strength requirement of ASTM C62 and ASTM C216 for construction in sever weathering condition and the strength requirement mentioned in SABS 227:4.4 and Eurocode 6 even after subjecting the blocks to 12 cycles of wetting and drying cycles.

The blocks subjected to heating and cooling cycles exhibited variation in the mass after each cycle. This resulted in variation of density, being the lowest during the initial cycles and then increasing with the number of cycles. Furthermore, a reduction in strength was observed on the blocks subjected to 12 heating and cooling cycles, but the strength increased on those blocks that sustained 18 cycles. Addition of 0.25% fibers proved beneficial for 30% and 50% fine blocks as the strength reduction reduced by 25% and 7% in comparison with the blocks without fibers.

Data from the thermal resistivity test conducted showed that the fiber inclusion in the soil blocks increases the thermal resistance of the blocks. These blocks had a better R value than the normal fired clay bricks and this value was similar to the concrete blocks. This proves to be advantageous in using these blocks contributing towards saving energy by preventing heat transfer into the building. With increase in fine content of the soil used for the blocks reduces the thermal resistivity and with increase in cement content thermal resistivity increases. The CSEB can be used for the construction of energy efficient low-cost housing helping in reducing the cost of heating and cooling.

7.2 Limitations of this Research Work

- Results and observation of this research work is only applicable to Guadalupe soil. Same conclusions and recommendations are not applicable for other soil with different characteristics. The same goes with fiber used. For different fiber the content usage differs based on its physical property.

- The dry density of the soil used was considered for the production of the blocks. However, the influence of cement and fiber needs to consider in finding the maximum dry density and that needs to be used for the production.
- In this research work more importance was given to the dry compressive strength. However, it is important to even check the wet compressive strength of the blocks which also gives a better idea on performance of the blocks in humid region.
- A new test method was performed on the blocks i.e. heating and cooling cycles. There is not standard available for this test procedure. The data obtained from this test may not be applicable for other CSEB blocks.
- Thermal resistivity value of the soil block found in this research work is not applicable for other CSEB as the thermal property of the soil depends on various factors such as mineralogy of the soil, water content, density, temperature, curing time and permeability.

7.3 Recommendations on the Production of the CSEB Using Guadalupe Soil and Guayule Plant Fibers

- Based on the fiber content impact observed on the dry density of the blocks it is recommended that bagasse fiber higher than 0.5% should not be used. Fiber usage of more than 0.5% will have a deteriorating impact on the dry density and density being an important factor in the block production it will have a negative impact on the strength and longevity of the blocks.

- Usage of 5% by weight should be the minimum cement content used for production of durable CSEB.
- 10% fine and 30% fine soil is best suitable for production of high dry compressive strength blocks.
- The strength of soil blocks of combination 30% fines-5% cement-0.25% fibers and 30% fines-7% cement-0.25% fibers satisfies the strength requirement of many standards even after subjecting them to 12 cycles of wetting and drying cycles.

7.4 Future research recommendations

- A more detailed relation between fines and cement has to be worked on to figure out the influence of higher fines content and plasticity of soil on the effectiveness of the cement content.
- Decay rate of the fibers due to influence of wetting-drying cycles and heating-cooling cycles should be worked on to figure out it association with the strength of the blocks which influences the long term usage of the soil blocks.
- Further work on the thermal resistivity of the soil blocks need to be carried out to find it relation with the relative humidity, density, different fibers, aspect ratio of the fibers used and the curing method followed.
- Usage of plant resin instead of cement as a binding agent will be a great step towards building cement free environment. The main things to be focused on are the temperature at which the resin melts, mix ability with soils, water-resin interaction and development of molds because of the resin used.

- Studies on the spreading the market for CSEB and building confidence in the construction industry will enable many manufacturers to invest in this technology. Which will further enhance the social acceptance.
- Studies on the added benefit of silica precipitation from silica-rich fibers.

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APPENDIX A

SIEVE ANALYSIS

Original Soil

Original Mass of Soil = 500.6g

Sieve Size	Opening Size (mm)	Sieve Mass (g)	Sieve w/ Soil (g)	Mass of Soil (g)	Cumulative Mass of Soil (g)	% Retained	% Passing
No. 4	4.75	518.6	526.1	7.5	7.5	1.50	98.50
No. 10	1.18	488.5	524	35.5	43	8.59	91.41
No. 30	0.6	401.6	533.4	131.8	174.8	34.92	65.08
No. 40	0.425	356.2	386.9	30.7	205.5	41.05	58.95
No. 60	0.25	324.2	358.4	34.2	239.7	47.88	52.12
No. 100	0.15	333.7	356.9	23.2	262.9	52.52	47.48
No. 120	0.125	309.3	315.8	6.5	269.4	53.82	46.18
No.200	0.075	331.1	354.9	23.8	293.2	58.57	41.43
Pan		365	380	207.4	500.6	100.00	0.00
		Sum		500.6			

Fabricated Soil with 10%Fines – 90%Sand

Original Mass of Soil = 500g

Sieve Size	Opening Size (mm)	Sieve Mass (g)	Sieve w/ Soil (g)	Mass of Soil (g)	Cumulative Mass of Soil (g)	% Retained	% Passing
No. 4	4.75	499.1	499.1	0	0	0.00	100.00
No. 10	1.18	489.1	551.4	62.3	62.3	12.47	87.53
No. 30	0.6	401.5	572.9	171.4	233.7	46.77	53.23
No. 40	0.425	378.3	417.3	39	272.7	54.57	45.43
No. 60	0.25	347.3	401.3	54	326.7	65.38	34.62
No. 100	0.15	338.2	387.8	49.6	376.3	75.31	24.69
No.200	0.075	302.3	366.4	64.1	440.4	88.13	11.87
Pan		487.5	546.8	59.3	499.7	100.00	0.00
		Sum		499.7			

Fabricated Soil with 30%Fines – 70%Sand

Original Mass of Soil = 500g

Sieve Size	Opening Size (mm)	Sieve Mass (g)	Sieve w/ Soil (g)	Mass of Soil (g)	Cumulative Mass of Soil (g)	% Retained	% Passing
No. 4	4.75	499.1	499.1	0	0	0.00	100.00
No. 10	1.18	489.2	524.8	35.6	35.6	7.12	92.88
No. 30	0.6	401.7	516.5	114.8	150.4	30.10	69.90
No. 40	0.425	378.4	409.4	31	181.4	36.30	63.70
No. 60	0.25	347.3	393.9	46.6	228	45.63	54.37
No. 100	0.15	338.3	384.5	46.2	274.2	54.87	45.13
No.200	0.075	302.2	376.5	74.3	348.5	69.74	30.26
Pan		487.5	638.7	151.2	499.7	100.00	0.00
		Sum		499.7			

Fabricated Soil with 50%Fines – 50%Sand

Original Mass of Soil = 500g

Sieve Size	Opening Size (mm)	Sieve Mass (g)	Sieve w/ Soil (g)	Mass of Soil (g)	Cumulative Mass of Soil (g)	% Retained	% Passing
No. 4	4.75	499.1	499.1	0	0	0.00	100.00
No. 10	1.18	489.2	521.7	32.5	32.5	6.50	93.50
No. 30	0.6	401.8	490	88.2	120.7	24.15	75.85
No. 40	0.425	378.6	399.7	21.1	141.8	28.38	71.62
No. 60	0.25	347.3	378.1	30.8	172.6	34.54	65.46
No. 100	0.15	338.3	366.8	28.5	201.1	40.24	59.76
No.200	0.075	302.2	348	45.8	246.9	49.41	50.59
Pan		487.5	740.3	252.8	499.7	100.00	0.00
		Sum		499.7			

APPENDIX B

LIQUID LIMIT AND PLASTIC LIMIT

Original Sample

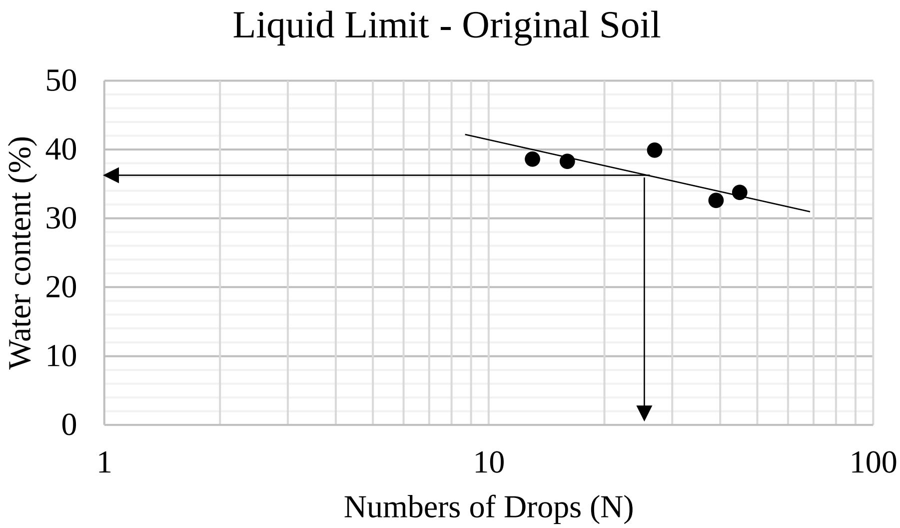
Liquid Limit

Sl Number	Container Number	Mass of container (gms)	Mass of wet soil + container (gms)	Mass of dry soil + container (gms)	Number of blow count (N)	Water content %
1	75	14.12	19.94	18.47	45	33.79
2	54	13.87	19.44	18.07	39	32.62
4	5	14.13	19.53	17.99	27	39.90
5	FA-2	14.23	24.31	21.52	16	38.27
6	13	14.03	21.46	19.39	13	38.62

Plastic Limit

Sl Number	Container Number	Mass of container (gms)	Mass of wet soil + container (gms)	Mass of dry soil + container (gms)	Water content %	Average
1	3	7.21	9.11	8.8	19.50	19.98
2	33	7.19	8.24	8.06	20.69	
3	42	7.35	9.29	8.97	19.75	

Liquid Limit = 36%
Plastic Limit = 19.97
Plasticity Index = Liquid limit - Plastic Limit = 16.03%



Fabricated soil – 10%Fines-90%Sand

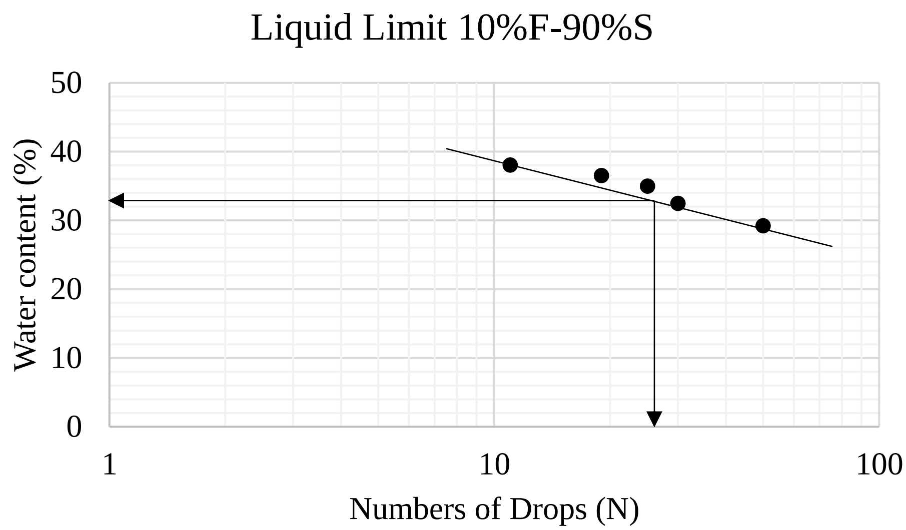
Liquid Limit

Sl Number	Container Number	Mass of container (gms)	Mass of wet soil + container (gms)	Mass of dry soil + container (gms)	Number of blow count (N)	Water content %
1	24	14.016	17.541	16.744	50	29.22
2	12	13.989	18.233	17.192	30	32.50
4	23	13.931	17.651	16.687	25	34.98
5	2	14.084	19.687	18.188	19	36.53
6	29	14.153	23.486	20.914	11	38.04

Plastic Limit

Sl Number	Container Number	Mass of container (gms)	Mass of wet soil + container (gms)	Mass of dry soil + container (gms)	Water content %	Average
1	F1	7.196	7.464	7.422	18.58	19.56
2	F3	7.384	8.203	8.066	20.09	
3	S3	7.463	8.321	8.178	20.00	

Liquid Limit = 33.5
Plastic Limit = 19.56
Plasticity Index = Liquid limit - Plastic Limit = 13.94



Fabricated soil – 30%Fines-70%Sand

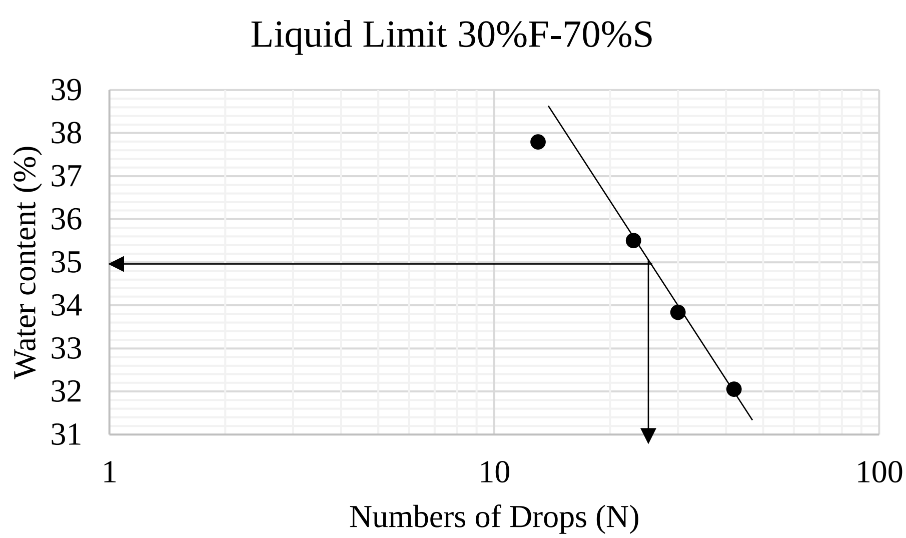
Liquid Limit

Sl Number	Container Number	Mass of container (gms)	Mass of wet soil + container (gms)	Mass of dry soil + container (gms)	Number of blow count (N)	Water content %
1	42	14.196	20.149	18.704	42	32.05
2	14	14.012	18.07	17.044	30	33.84
4	7	13.761	20.444	18.693	23	35.50
5	44	13.748	19.33	17.799	13	37.79

Plastic Limit

Sl Number	Container Number	Mass of container (gms)	Mass of wet soil + container (gms)	Mass of dry soil + container (gms)	Water content %	Average
1	1	7.13	7.8766	7.75	19.54	19.35
2	2	7.212	7.735	7.65	19.45	
3	3	7.294	7.779	7.70	19.06	

Liquid Limit = 35
Plastic Limit = 19.35
Plasticity Index = Liquid limit - Plastic Limit = 16



Fabricated soil – 50%Fines-50%Sand

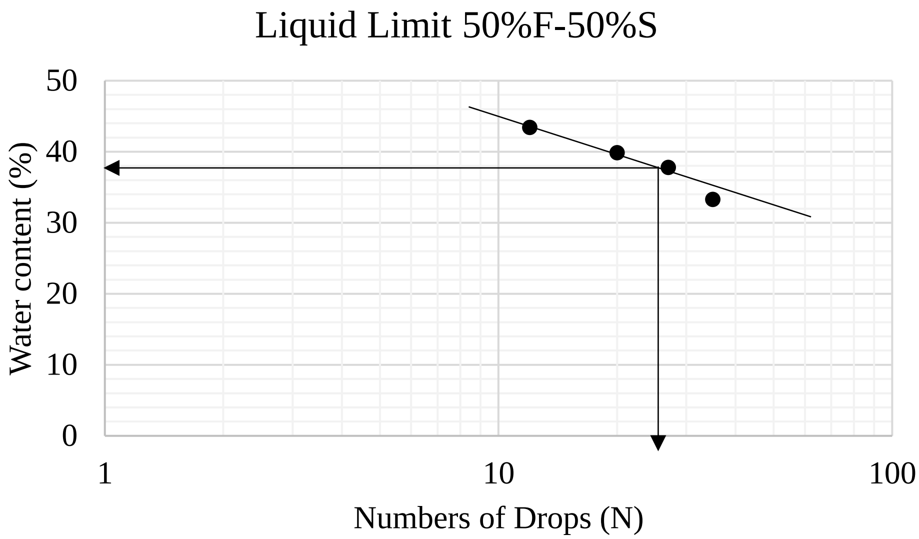
Liquid Limit

Sl Number	Container Number	Mass of container (gms)	Mass of wet soil + container (gms)	Mass of dry soil + container (gms)	Number of blow count (N)	Water content %
1	22	14.233	20.375	18.841	35	33.29
2	35	13.784	18.679	17.336	27	37.81
4	1	14.134	18.28	17.098	20	39.88
5	25	13.887	19.545	17.832	12	43.42

Plastic Limit

Sl Number	Container Number	Mass of container (gms)	Mass of wet soil + container (gms)	Mass of dry soil + container (gms)	Water content %	Average
1	_	7.317	7.662	7.61	18.12	18.13
2	41	7.307	7.7064	7.64	18.23	
3	27	7.209	8.126	7.96	18.05	

Liquid Limit = 38.8
Plastic Limit = 18.13
Plasticity Index = Liquid limit - Plastic Limit = 20.7


Liquid Limit 50%F-50%S
50
40
30
20
10
0
Water content (%)
1
10
100
Numbers of Drops (N)

APPENDIX C

MOISTURE-DENSITY RELATION

Original Soil

Target w%	Actual	M_mold+soil	M_soil (g)	M_soil (kg)	Density_wet (kg/m^3)	Density_Dry (kg/m^3)	Dry Unit Weight (kN/m^3)
10.00	11.61	6043.00	1846.60	1.85	1956.14	1752.66	17.19
12.00	14.11	6138.80	1942.40	1.94	2057.63	1803.20	17.69
14.00	15.34	6180.80	1984.40	1.98	2102.12	1822.54	17.88
16.00	17.74	6123.80	1927.40	1.93	2041.74	1734.11	17.01

Fabricated Soil with 10%Fines – 90%Sand

Target w%	Actual	M_mold+soil	M_soil (g)	M_soil (kg)	Density_wet (kg/m^3)	Density_Dry (kg/m^3)	Dry Unit Weight (kN/m^3)
8	9.74	6060	1863.5	1.8635	1995.182	1818.099	17.83555
11	12.72	6185.3	1988.8	1.9888	2129.336	1889.049	18.53157
14	14.46	6210.6	2014.1	2.0141	2156.424	1883.998	18.48202
17	16.72	6154.9	1958.4	1.9584	2096.788	1796.426	17.62294

Fabricated Soil with 30%Fines – 70%Sand

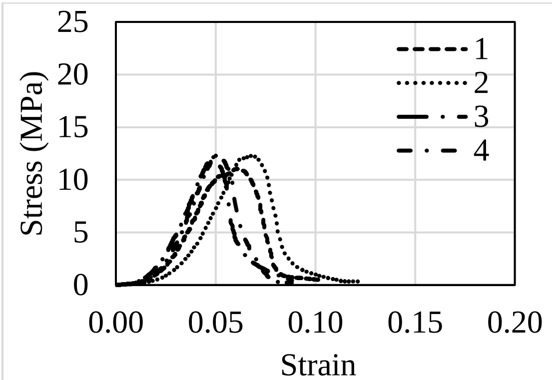
Target w%	Actual	M_mold+soil	M_soil (g)	M_soil (kg)	Density_wet (kg/m^3)	Density_Dry (kg/m^3)	Dry Unit Weight (kN/m^3)
8	9.33	6027.6	1831.1	1.8311	1960.493	1793.188	17.59117
11	12.31	6160.9	1964.4	1.9644	2103.212	1872.685	18.37104
14	14.12	6196	1999.5	1.9995	2140.792	1875.913	18.40271
17	15.83	6195.1	1998.6	1.9986	2139.829	1847.387	18.12287
20	19.09	6141.8	1945.3	1.9453	2082.762	1748.898	17.15669

Fabricated Soil with 50%Fines – 50%Sand

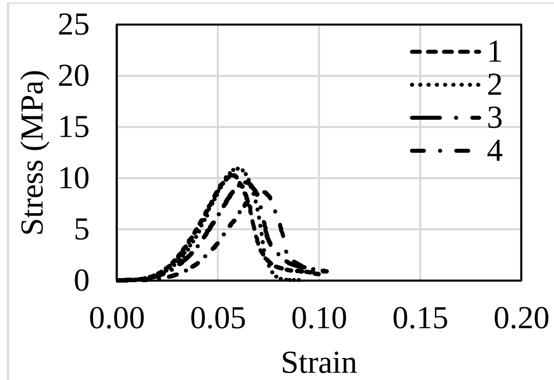
Target w%	Actual	M_mold+soil	M_soil (g)	M_soil (kg)	Density_wet (kg/m^3)	Density_Dry (kg/m^3)	Dry Unit Weight (kN/m^3)
10	12.06	5995	1798.6	1.7986	1905.297	1700.247	16.67942
12	12.54	6074.1	1877.7	1.8777	1989.089	1767.451	17.33869
14	14.22	6130.2	1933.8	1.9338	2048.517	1793.484	17.59407
16	16.11	6178.2	1981.8	1.9818	2099.364	1808.082	17.73729
18	17.4	6165.9	1969.5	1.9695	2086.335	1777.116	17.43351

APPENDIX D

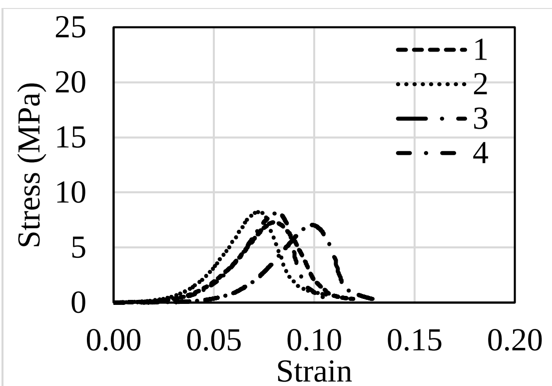
DRY COMPRESSIVE STRENGTH PLOTS



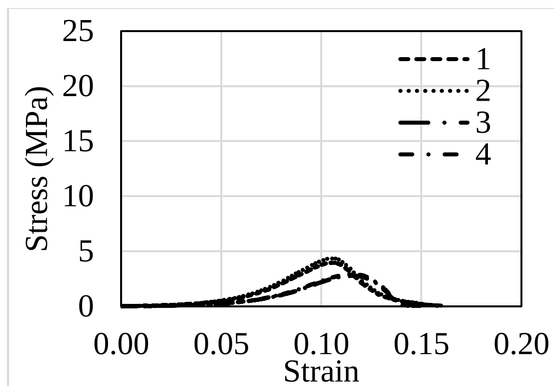
10% Fines – 3% Cement - 0.25% Fiber



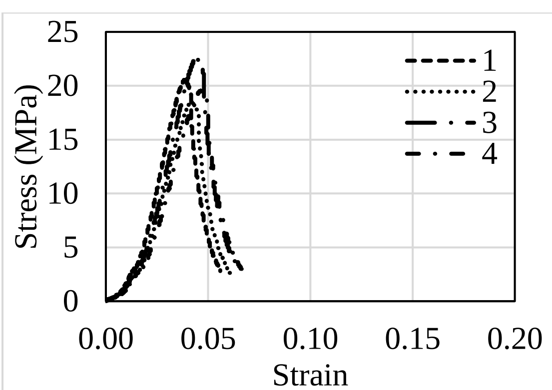
10% Fines – 3% Cement - 0.5% Fiber



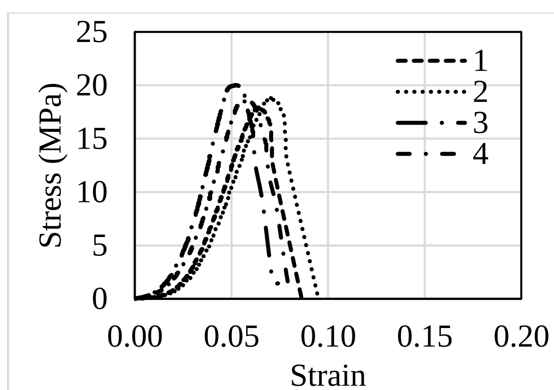
10% Fines – 3% Cement - 1% Fiber



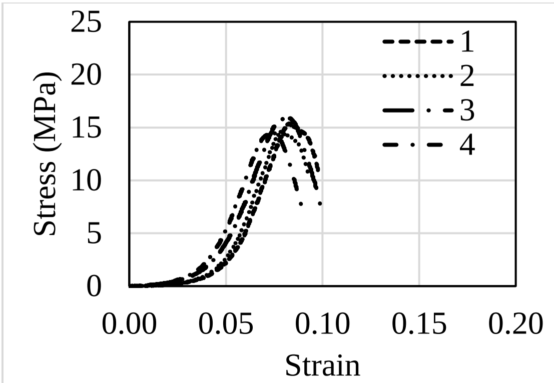
10% Fines – 3% Cement - 2% Fiber



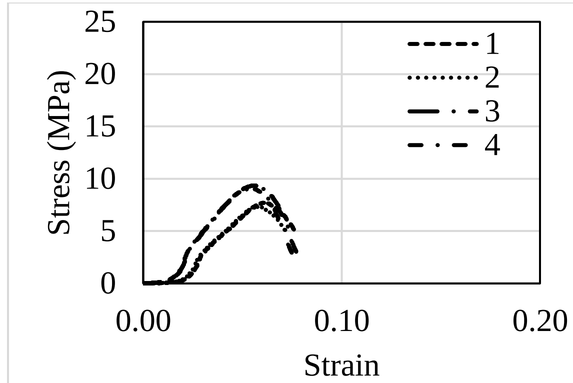
10% Fines – 5% Cement – 0.25% Fiber



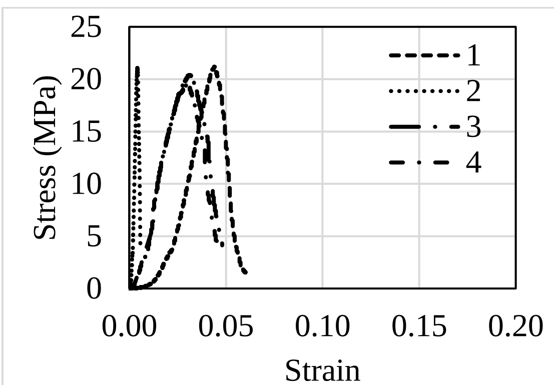
10% Fines – 5% Cement – 0.5% Fiber



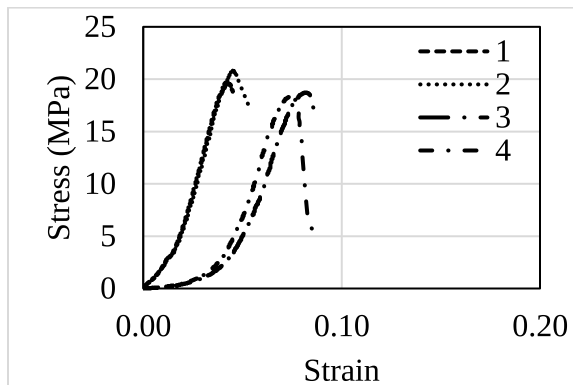
10% Fines – 5% Cement – 1% Fiber



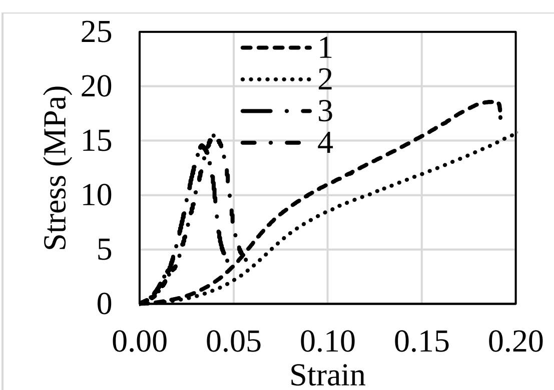
10% Fines – 5% Cement – 2% Fiber



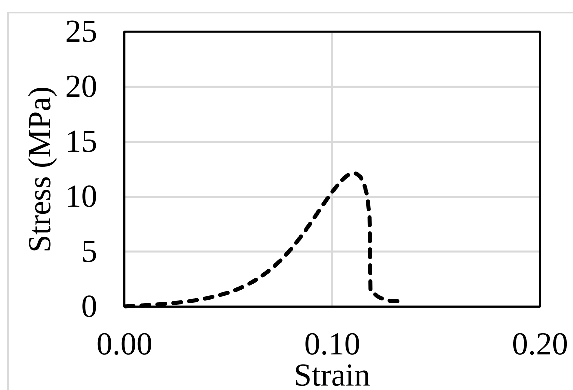
10% Fines – 7% Cement – 0.25% Fiber



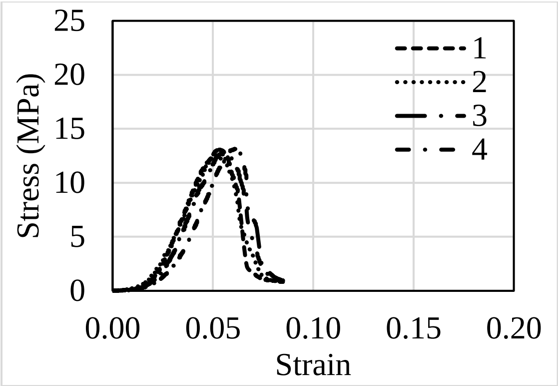
10% Fines – 7% Cement – 0.5% Fiber



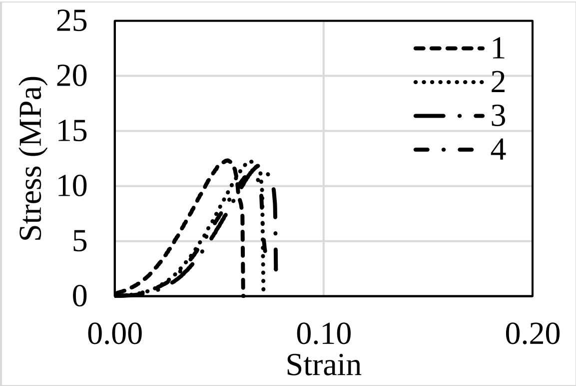
10% Fines – 7% Cement – 1% Fiber



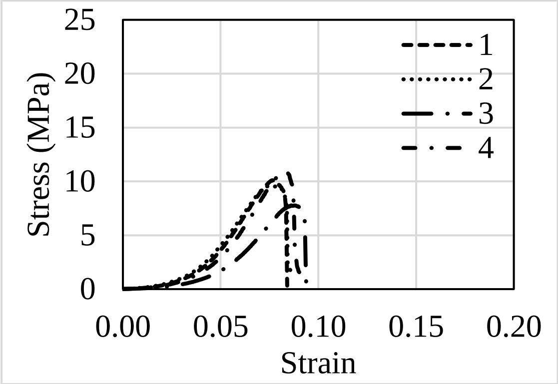
10% Fines – 7% Cement – 2% Fiber



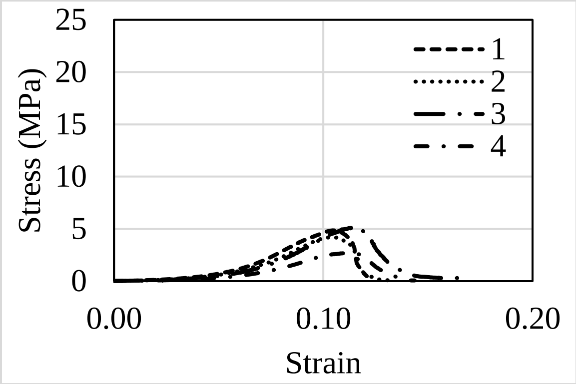
30% Fines – 3% Cement - 0.25% Fiber



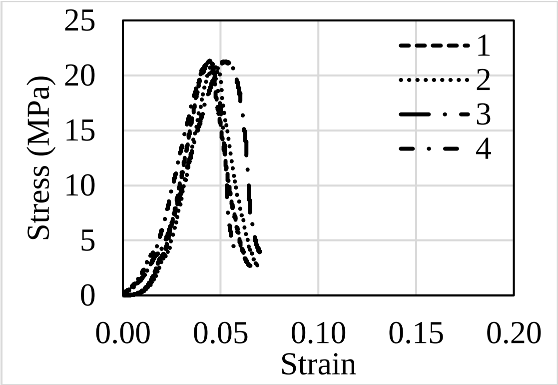
30% Fines – 3% Cement - 0.5% Fiber



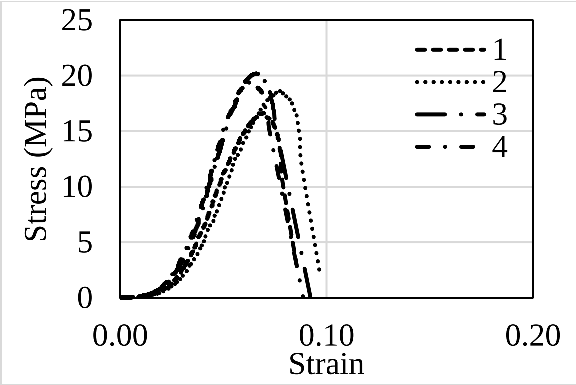
30% Fines – 3% Cement - 1% Fiber



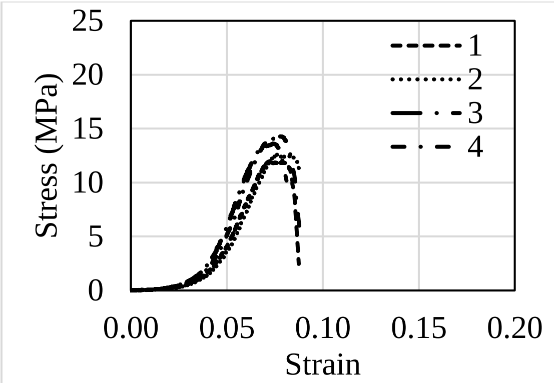
30% Fines – 3% Cement - 2% Fiber



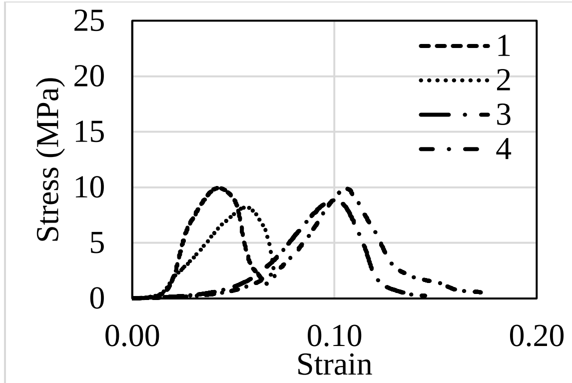
30% Fines – 5% Cement - 0.25% Fiber



30% Fines – 5% Cement - 0.5% Fiber



30% Fines – 5% Cement - 1% Fiber



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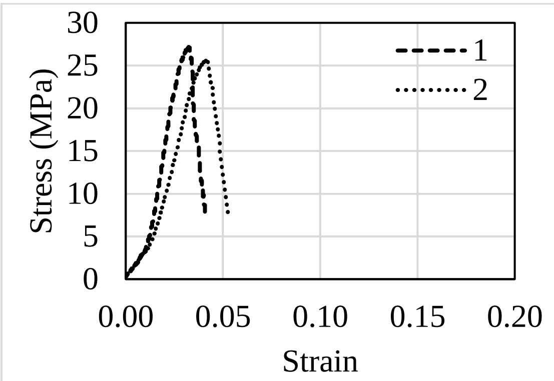
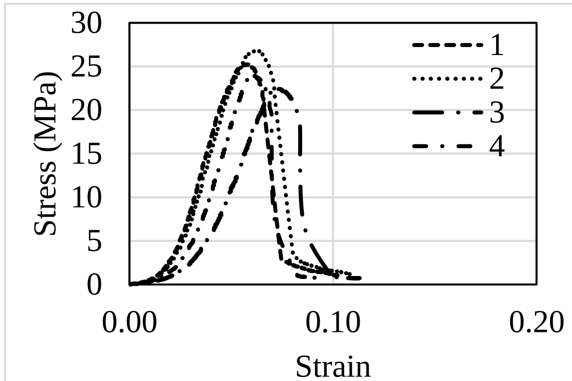
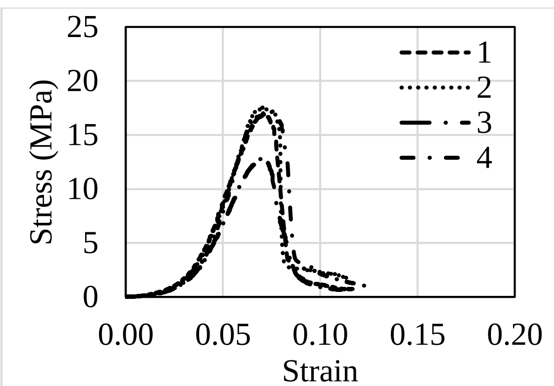


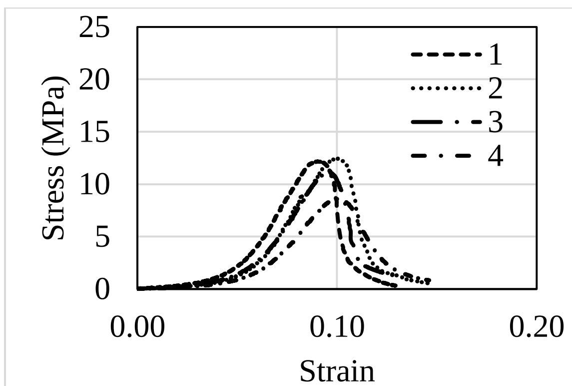
30% Fines – 7% Cement - 0.25% Fiber



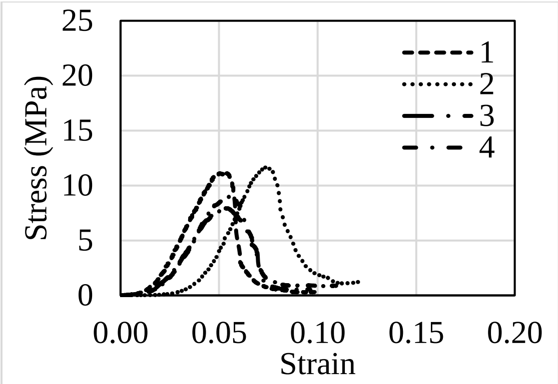
30% Fines – 7% Cement - 0.5% Fiber



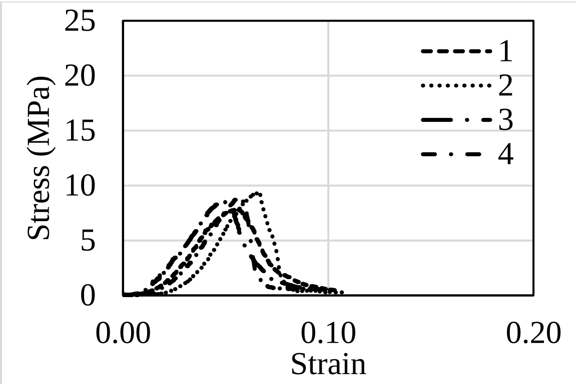
30% Fines – 7% Cement - 1% Fiber



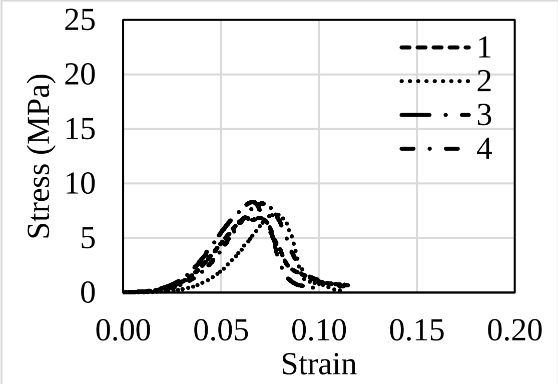
30% Fines – 7% Cement - 2% Fiber



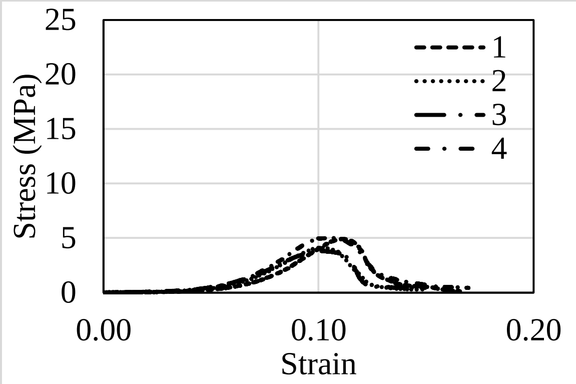
50% Fines – 3% Cement – 0.25% Fiber



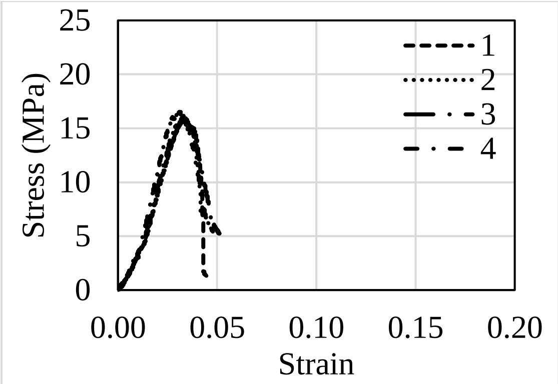
50% Fines – 3% Cement – 0.5% Fiber



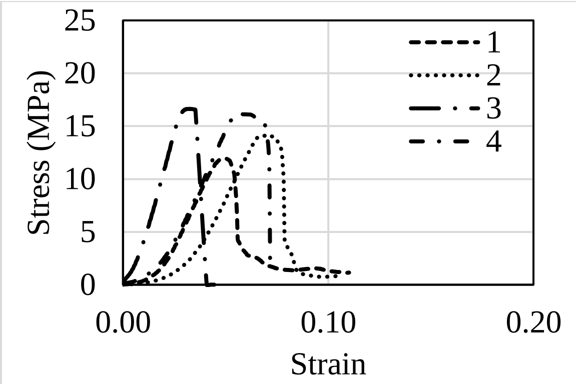
50% Fines – 3% Cement - 1% Fiber



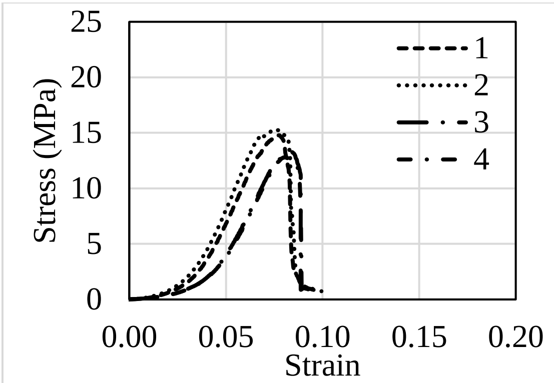
50% Fines – 3% Cement - 2% Fiber

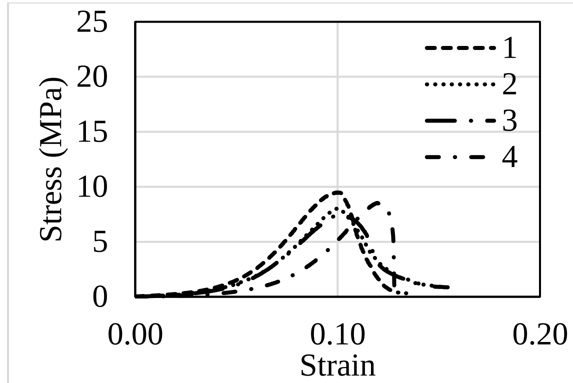


50% Fines – 5% Cement – 0.25% Fiber



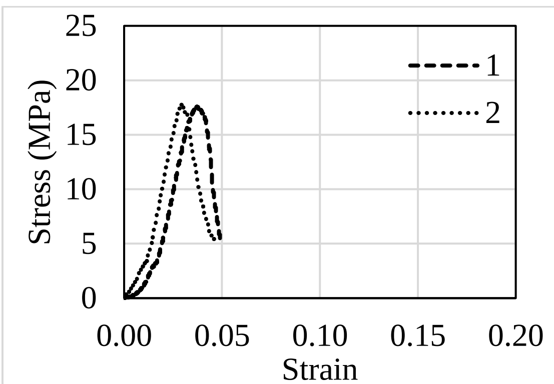
50% Fines – 5% Cement – 0.5% Fiber

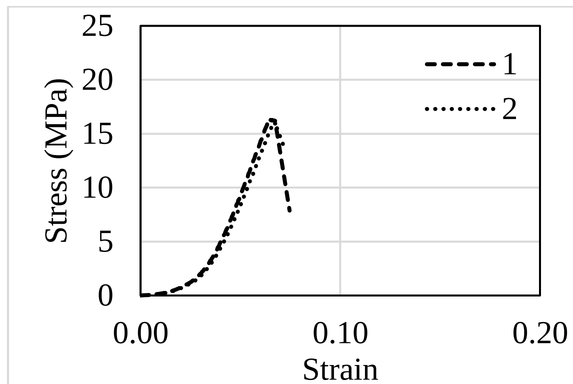




50% Fines – 5% Cement - 1% Fiber

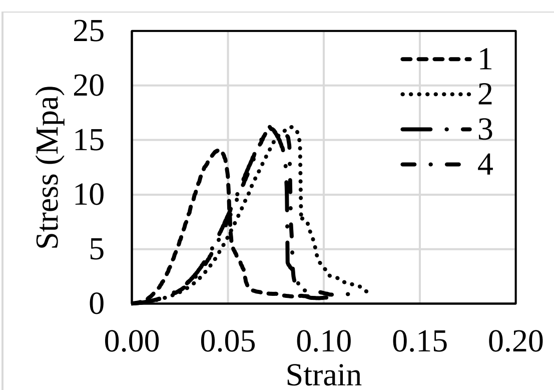
50% Fines – 5% Cement - 2% Fiber

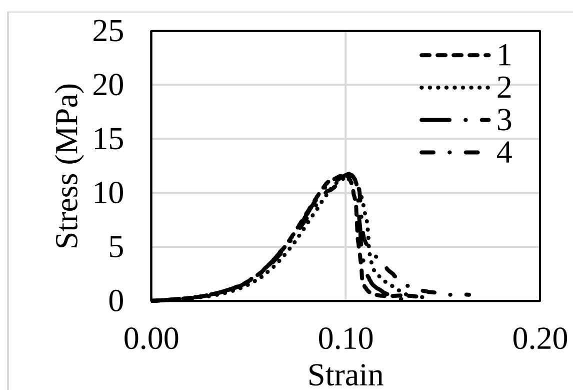




50% Fines – 7% Cement – 0.25% Fiber

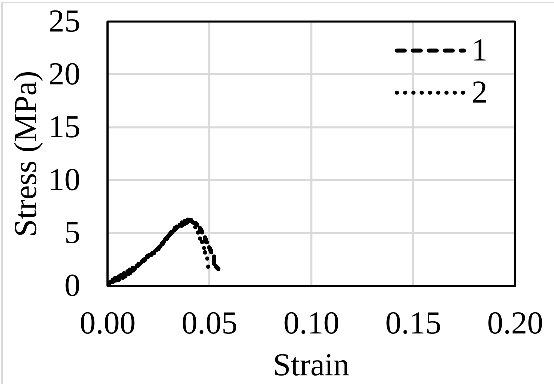
50% Fines – 7% Cement – 0.5% Fiber



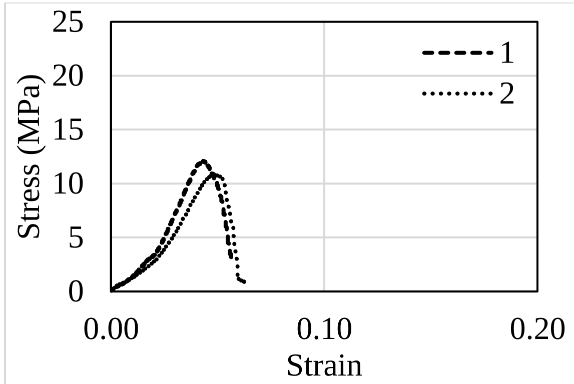


50% Fines – 7% Cement - 1% Fiber

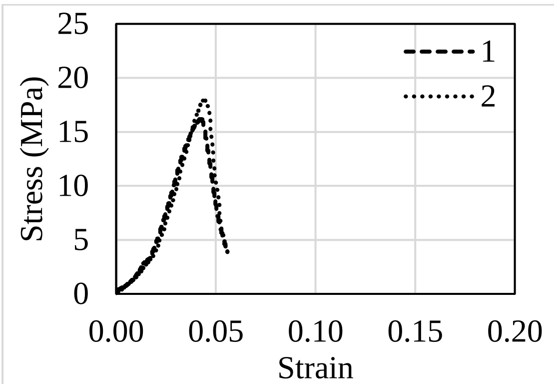
50% Fines – 7% Cement - 2% Fiber



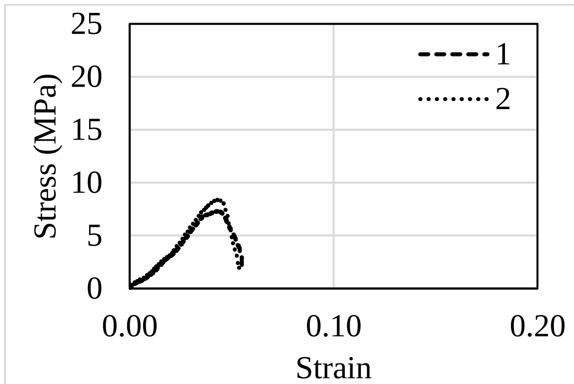
10% Fines – 3% Cement - 0% Fiber



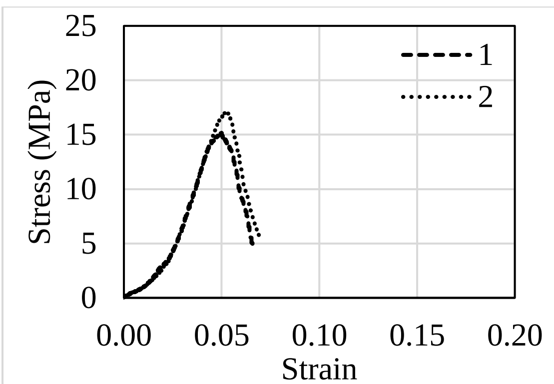
10% Fines – 5% Cement - 0% Fiber



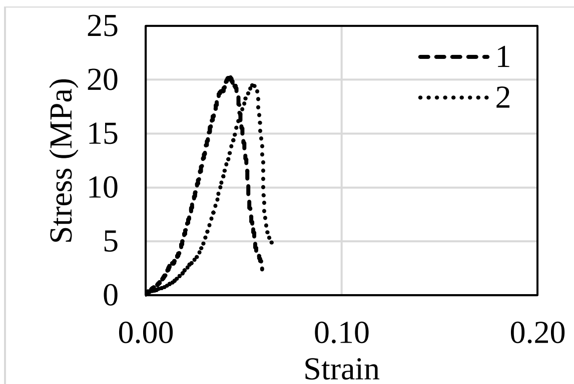
10% Fines – 7% Cement - 0% Fiber



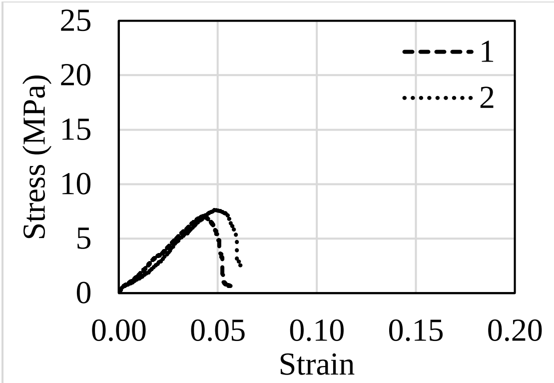
30% Fines – 3% Cement - 0% Fiber



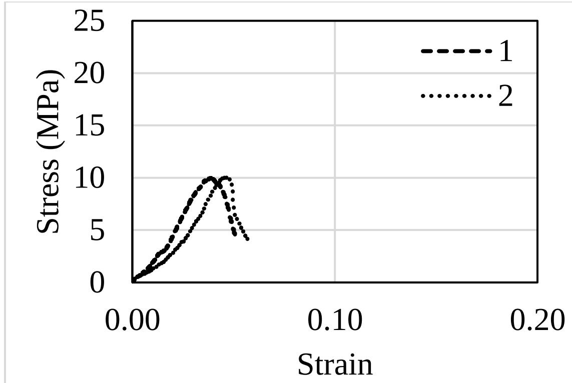
30% Fines – 5% Cement - 0% Fiber



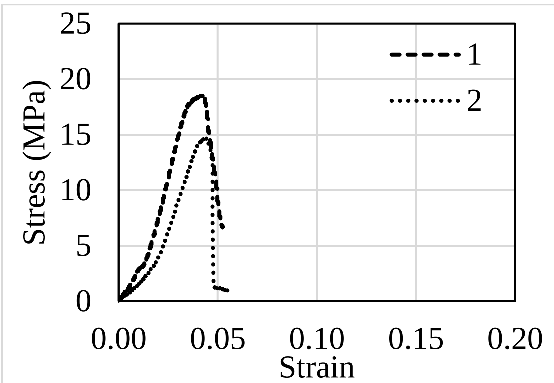
30% Fines – 7% Cement - 0% Fiber



50% Fines – 3% Cement - 0% Fiber



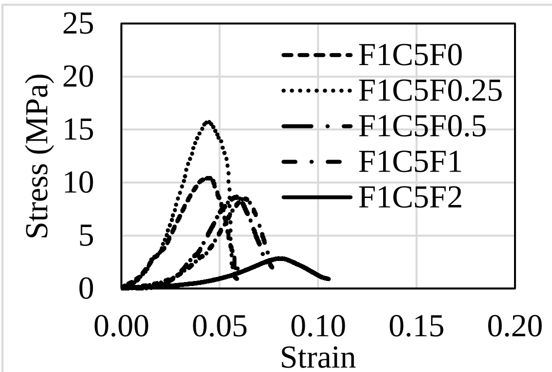
50% Fines – 5% Cement - 0% Fiber

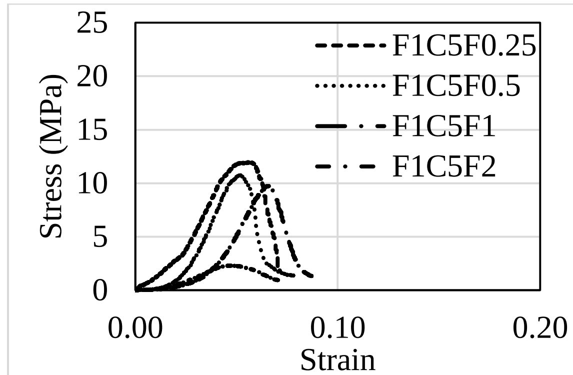


50% Fines – 7% Cement - 0% Fiber

APPENDIX E

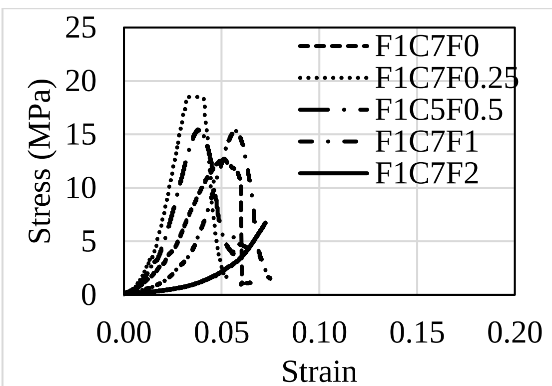
DRY COMPRESSIVE STRENGTH OF BLOCKS SUBJECTED TO WETTING AND DRYING CYCLES

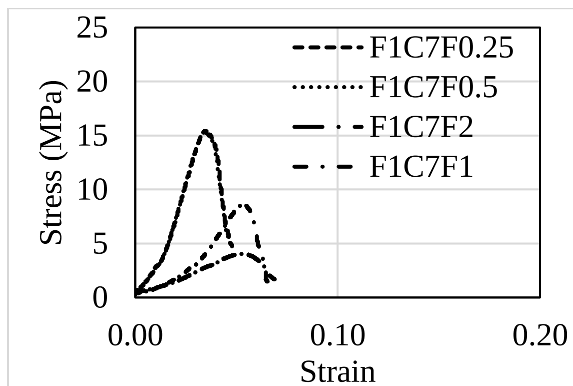




10% Fines – 5% Cement (12 Cycles)

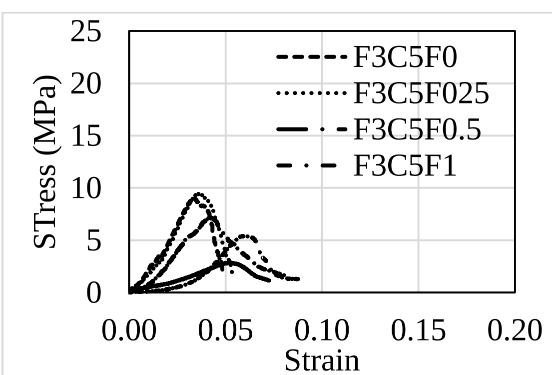
10% Fines – 5% Cement – (18 Cycles)

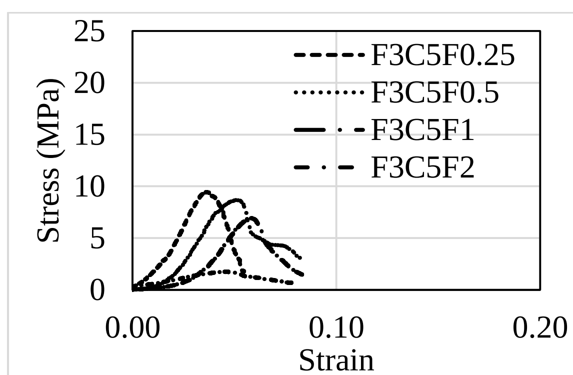




10% Fines – 7% Cement (12 Cycles)

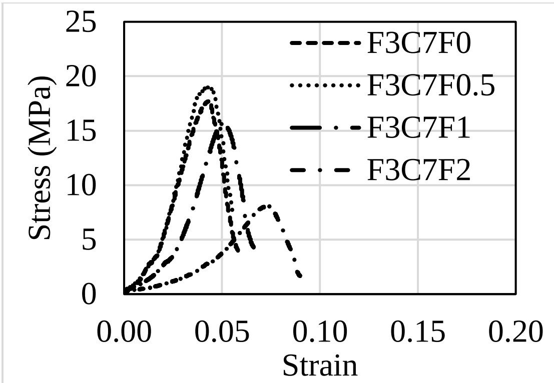
10% Fines – 7% Cement – (18 Cycles)



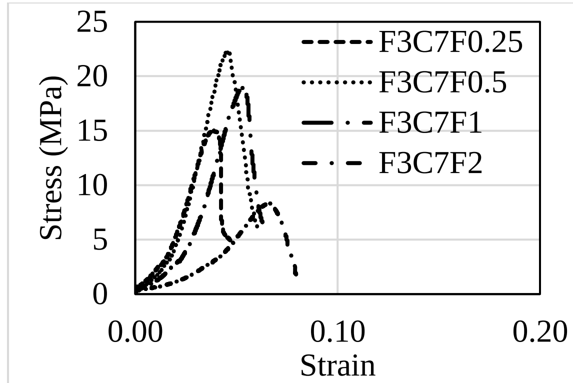


30% Fines – 5% Cement (12 Cycles)

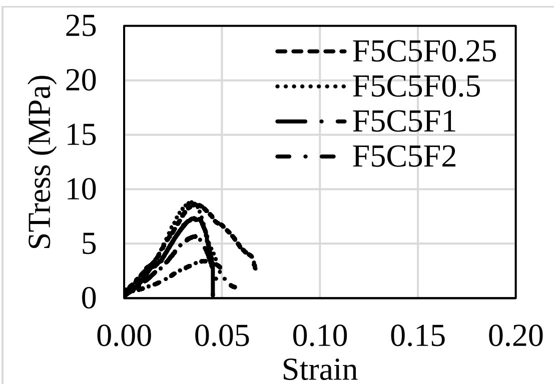
30% Fines – 5% Cement – (18 Cycles)



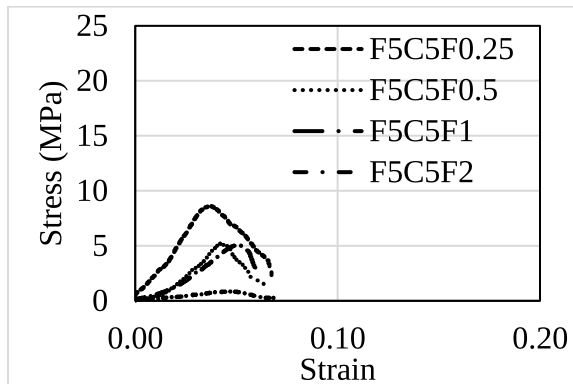
30% Fines – 7% Cement (12 Cycles)



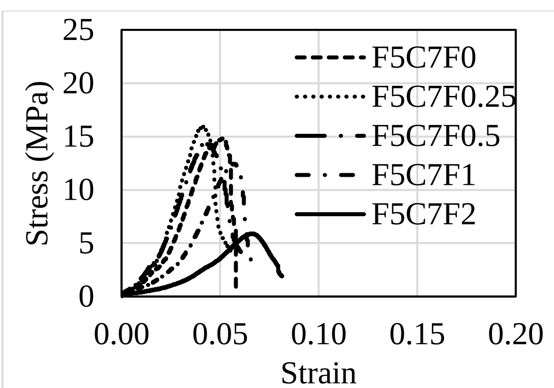
30% Fines – 7% Cement – (18 Cycles)



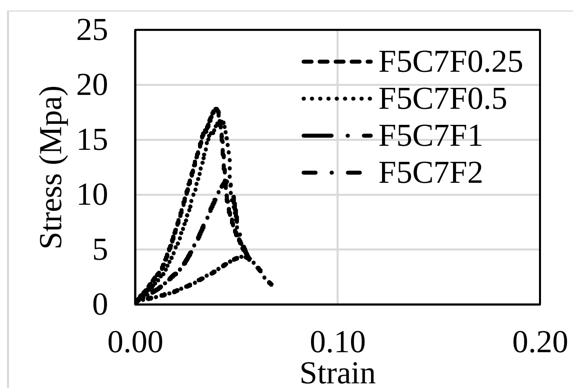
50% Fines – 5% Cement (12 Cycles)



50% Fines – 5% Cement – (18 Cycles)



50% Fines – 7% Cement (12 Cycles)



50% Fines – 7% Cement – (18 Cycles)