CAPITAL UNIVERSITY OF SCIENCE AND TECHNOLOGY, ISLAMABAD

Feasibility of Natural Fiber Reinforced Stabilized-Earth-Brick in Masonry to Promote Sustainability

by

Muhammad Zahid

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in the

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This effort is devoted to my respected and cherishing parents, who helped me through each troublesome of my life and yielded every one of the comforts of their lives for my brilliant future. This is likewise a tribute to my best teachers who guided me to go up against the troubles of presence with ingenuity and boldness, and who made me what I am today.

CERTIFICATE OF APPROVAL

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Journal Article

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Abstract

Conventional bricks are being used in masonry structures to carry building load and provide partitions. The manufacturing process of such bricks is degrading natural environment and making negative impact, which is a major concern. In this consequence, a feasible and acceptable approach toward environment friendly housing material is needed. To start with, Stabilized-Earth-Bricks (SEBs) are considered. Jute fibers (JF) are used as reinforcing agent. Local available soil and Ordinary Portland Cement (OPC) is used as raw material and stabilizing agent, respectively.

The overall aim of the research program is to evaluate the mechanical properties of Stabilized-Earth-Bricks (SEBs) masonry structures, made by local available soil, with and without natural fibers, for having sustainability. The specific goal of the research program is to determine the efficiency of jute fibers in Stabilized-Earth-Brick (SEB) masonry works, especially by using local materials for promoting sustainability. For this purpose, a series of experimental works on SEBs, made with and without natural fibers, having size of 200 mm x 100 mm x 100 mm of each brick, are carried out. Singe bricks (SB) and multiple bricks (MB) specimens are tested subjected for compressive loading, flexural loading, shear loading and water absorption properties after 28 days of manufacturing. The effect of JF, OPC and water to soil ratio (W/S) on mechanical properties of SEBs with fiber content of 1%, cement content of 8% and water content of 15%, by mass of total soil sample, are examined. Code comparisons and previous studies comparisons for compressive strength of single bricks specimens are carried out. Empirical relation between modulus of rupture (MoR) and compressive strength (CS) of single bricks specimens is developed.

It is observed that the JF significantly increase the load carrying capacity of jute fiber reinforced Stabilized-Earth-Bricks (JFRSEBs) up to 82.26% and 22.10% in SB and MB specimens, respectively, as compared with SEBs specimens. It is also found that flexural strength and shear strength is increased 100% and 67.5%, respectively, in JFRSEBs specimens in comparison with SEBs specimens. However, water absorption rate of JFRSEBs specimens is 122% higher than SEBs specimens. The results achieved minimum requirement of the code standards in JFRSEBs single bricks compression. Furthermore, empirical equation results are in good agreement with experimentally calculated values. It is recommended that the use of JF in SEBs, with different fiber and cement content, to get optimum result is still needed to be investigated.

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List of Abbreviations

ABs	Adobe bricks
ASTM	American Society for Testing and Materials
CSEBs	Compressed stabilized earth bricks
CB	Conventional brick
CO_2	Carbon dioxide
CS	Compressive strength
CSES	Cement stabilized earth specimens
CPE	Compressive absorbed pre-crack energy
CCE	Compressive cracked absorbed energy
CTE	Compressive total absorbed energy
CTI	Compressive toughness index
cm	Centimeter
FS	Flexural strength
FPE	Flexural absorbed pre-crack energy
FCE	Flexural cracked absorbed energy
FTE	Flexural total absorbed energy
FTI	Flexural toughness index
GO	Grewia Optiva
HCF	Hibiscus cannabinus fibers
JFRSEBs	Jute fiber reinforced stabilized earth bricks
JF	Jute fibers
KF	Kinaf fibers
kN	Kilo Newton
kg	Kilogram

L.L	Liquid limit
MoR	Modulus of Rupture
MDD	Maximum dry density
MPa	Mega Pascal
min	Mints
mm	Millimeter
MB	Multiple bricks
NF	Natural fibers
OPC	Ordinary Portland Cement
OMC	Optimum moisture content
PP	Pinus Poxburghii
PAB	Pressed Adobe Blocks
P.L	Plastic limit
P.I	Plasticity index
RC	Reinforced concrete
RHA	Rice husk ash
REBs	Rammed earth bricks
SEBs	Stabilized-Earth-Bricks
SB	Singe bricks
SS	Shear strength
SF	Straw fibers
SL	Sandy loam
SPE	Shear absorbed pre-crack energy
SCE	Shear cracked absorbed energy
STE	Shear total absorbed energy
STI	Shear toughness index
STM	Servo-hydraulic testing machine
SRE	Stabilized rammed earth
TI	toughness index
USCS	Unified soil classification system
W/S	Water to soil ratio

WA	Water absorption

Symbols

%	Percentage
$\triangle$	Displacement (mm)
$\triangle o$	Deflection at maximum load (mm)
e	Strain at the maximum stress (-)

Chapter 1

Introduction

1.1 Background

Food, clothes and shelters are the basic needs in todays world. Construction of own house is the dream of every individual family. Due to high wages and high material cost, the construction of building becomes expensive and cannot afford by the poor people in developing countries. The need of cost-effective technology and economical materials is the new trend in nowadays toward sustainable housing societies. Cheap housing society doesnt mean to compromise on strength and other mechanical properties but its means to use local available material and construction technology very effectively, which results durable, economical, environment friendly and requires less maintenance in house construction. It has been observed that from last few decades the uses of kiln bricks were shockingly increased. The manufacturing process of kiln bricks consists on burning in chambers, which is found responsible for the pollution of natural environment. In result, the atmosphere and ozone layer become affected. The replacement of kiln bricks in construction is a major step in order to ensuring sustainable environment. Nowadays, it is highly needed to come with economical, durable, green and readily available construction material. This reason comes with a few factors which are (a) rise in demand of the society for affordable and aesthetic houses. (b) need for promotion of use of locally available construction materials to spur economic growth. Nowadays, researchers working on modification of soil for achieving better performance, which is to be very helpful for the construction industry in economical aspect. Some of them came with the solution of conventional masonry work by using SEBs and this technique was successfully used in many developing countries. This research is based on locally available material which is to be used in SEBs, reinforced with and without natural fiber, for masonry work.

Currently, soil as a building constructional material, to produced SEBs. Compressed Stabilized-Earth-Bricks (CSEBs), rammed earth bricks (REBs), adobe bricks (ABs), mostly in masonry work, have been paid more attention due to abundantly available local soil, results cost effective and environment friendly [1-2]. However, in some cases, REBs and ABs founds lesser in load carrying capacity, compared to that of SEBs and CSEBs [3-4]. Soil as a constructional material has already been acknowledged for hundreds of years and widely used in developing countries. 30% of the world population is still using earth as a constructional material like soil bricks etc. In order to improve the mechanical properties of earth brick/blocks masonry works, stabilization technique (cement, lime, precompression etc.) were used by many researchers [5-11]. Cement stabilization technique is used widely to improve the compressive strength and other mechanical properties [12-13]. However, ayeldeen and kitazume [14] mentioned that the cement is CO_2 emissions stabilizer too.

So, fiber reinforced cement stabilization technique was kept to improve the mechanical properties of earthen bricks/blocks [3,9,15,16]. Fibers were used to enhance strength and other mechanical properties to produce SEBs. Natural fibers were being used as reinforcing and earth stabilizing agent in SEB by many researches, to enhanced physical and mechanical properties of soil samples [3,9,16]. Natural fibers have been used to improve compressive, post-cracking tensile strength, durability and reduction of shrinkage cracks for thousands of years in earth blocks [17]. Hallal et al. [18] evaluated the engineering characteristics of Stabilized-Rammed-Earth (SRE) materials by using natural fines-rich soil, combination of stabilizers (cement and lime) and hemp fibers. The addition of hemp fibers enhanced the result of modulus of rupture (MoR) and toughness index (TI). Remarkable improvement founds in first crack resistance, post cracking residual strength and energy absorption capability by incorporation of wool fiber in earthen material [19]. The contribution of adding natural fibers in earth bricks/blocks were not only improved the mechanical properties but also reduced the cement quantity which leads to CO_2 emission The overall aim of the research program is to evaluate the mechanical properties of Stabilized-Earth-Bricks (SEBs) masonry structures, made by local available soil, with and without natural fibers, for having sustainability. The specific goal of the research program is to determine the efficiency of jute fibers in Stabilized-Earth-Brick (SEB) masonry works, especially by using local materials for promoting sustainability. For this purpose, a series of experimental works on SEBs, made with and without natural fibers, having size of 200 mm x 100 mm x 100 mm of each brick, are carried out. Singe bricks (SB) and multiple bricks (MB) specimens are tested subjected for compressive loading, flexural loading, shear loading and water absorption properties after 28 days of manufacturing. The effect of JF, OPC and water to soil ratio (W/S) on mechanical properties of SEBs for fiber content of 1%, cement content of 8% and water content of 15% by mass of total soil sample were examined. Code comparison and previous studies comparison for compressive strength of single bricks specimens are carried out. Empirical relation between modulus of rupture (MoR) and compressive strength (CS) of single bricks specimens is developed.

1.2 Research Motivation and Problem Statement

Soil as a constructional material has already been acknowledged for hundreds of years and widely used in developing countries [20]. Its cheap, locally available, and widely used as constructional material in developing countries. In the upward concern of awareness about sustainable constructional material and environmental issue, SEBs are considered by many researchers that gives the interpretation of energy efficient, low cost and environment friendly construction materials, and overall impact on the sustainable development. SEBs are a comparatively new construction technique in which the soil is prepared, stabilized with binders, and provide a desire shape that looks like a residue block or brick. These bricks combine the consistency and strength of modern masonries. Some researchers have documented the use of natural fibers as reinforcing agents in SEB [3,9,16]. Natural fibers included many benefits, like low cost due to its abundance, biodegradability, and least health hazards. Therefore, the experimental research on Stabilized-Earth-Bricks for conventional masonry work with and without natural fibers is considered. Thus, the problem statement is as follows:

"For new housing societies, construction approach should focus on better mechanical properties of materials, economical, locally available, environment friendly, energy efficient, durable and earthquake resistant rather than only earthquake resistant [21]. For this to happen, a feasible and acceptable approach needs to be study for new housing societies. To start with, Stabilized-Earth-Bricks (SEBs) are considered for their mechanical properties (compressive properties, flexural properties, shear properties and water absorption properties). Local available soil and natural fibers (i.e. jute fibers) are to be explored for this purpose."

1.3 Overall Goal of the Research Program and Specific Aim of this MS Thesis

The overall aim of the research program is to evaluate the mechanical properties of Stabilized-Earth-Bricks (SEBs) masonry structures, made by local available soil, with and without natural fibers, for having sustainability.

"The specific goal of this MS thesis is to determine the efficiency of jute fibers in Stabilized-Earth-Bricks (SEBs) masonry works, especially by using local materials for promoting sustainability."

1.4 Scope of Work and Study Limitations

To achieve the specific objectives, scope of work is carried out as follow:

- Mechanical properties to be investigated are, compressive strength, strength, shear strength and water absorption of Stabilized-Earth-Bricks (SEBs) and jute fiber reinforced Stabilized-Earth-Bricks (JFRSEBs). For this purpose, a series of SEBs and JFRSEBs are made by local available soil.
- Jute fiber (JF) is used as a reinforcing agent in JFRSEBs specimens.
- Only one natural fiber with single fiber content and fiber length is used.
- Local available soil is considered to manufacture SEBs and JFRSEBs specimens.
- Cement: Sand (1:5) is used as mortar in multiple bricks (MB) specimens.
- Bond characteristic among the JF, OPC and soil of the JFRSEBs specimens is to be discussed.
- Compressive strength results of single bricks SEBs and JFRSEBs is to be compared with previous studies and standard practicing code.
- Load carrying capacity results of SEBs and JFRSEBs with minimum requirement of compressive strength of the international codes is to be compared.

1.5 Brief Methodology

In this experimental study, mechanical properties of SEBs and JFRSEBs are determined in laboratory. For mix design, the soil consists of 29% course sand, 39% fine sand, 27% silt and 5% clay are considered. Optimum moisture content and dry unit weight is obtained 12.5% and 17.16 kN/m_3. Ordinary Portland cement (OPC) of 8%, by mass of total soil sample is used. To produce JFRSEBs specimens, jute fibers (JF) having length of 5 cm and 1% content by mass of total soil sample are used. A series of specimens for SEBs and JFRSEBs having size of 200 mm x 100 mm x 100 mm are cast and tested for determination of compressive strength, flexural strength, shear strength and water absorption. Servo-hydraulic testing machine (STM) is used for determination of strength (compressive, flexural and shear) of the both, SEBs and JFRSEBs specimens.

1.6 Thesis Layout

The thesis contains six chapters. These are:

Chapter 1 includes of introduction. It explains the background of Stabilized-Earth-Bricks with and without natural fibers, research motivation and problem statement, overall or specific research aims and scope of work, brief methodology, and thesis outline.

Chapter 2 contains the literature review. It includes background, Stabilized-Earth-Bricks (SEBs) in masonry works, Stabilized-Earth-Bricks (SEBs) to promote sustainability, efficiency of fiber incorporation in Stabilized-Earth-Bricks (SEBs) for its properties improvement, jute fiber reinforced Stabilized-Earth-Bricks (JFRSEBs) in masonry works, and summary of chapter 2.

Chapter 3 combines the test methodology. It covers the background, raw materials, methods and testing procedure of Stabilized-Earth-Bricks (SEBs) and jute fiber reinforced earth bricks (JFRSEBs), and summary of chapter 3.

Chapter 4 involves the experimental result and their analysis. It defines the back ground, mechanical properties (CS, FS, and SS) and WA, and behavior of the specimens during the testing, and summary of chapter 4.

Chapter 5 contains of discussion. It comprises of background, bond characteristics among jute fibers, ordinary Portland cement (OPC) and soil, comparison with previous studies, comparison with code standards and summary of chapter 5.

Chapter 6 covers of conclusions and recommendations. Consecutive to the end of chapter 6, all the references are given.

Annexure A & B explains the details of compressive stress-strain curves of 1st specimen, 2nd specimen and averages of 1st and 2nd both single bricks and multiple bricks specimens.

Annexure C explains the details of flexural load-time curves for both 1st specimens and 2nd specimens and their average.

Annexure D explains the details of shear force-displacement curves for remaining specimens.

Chapter 2

Literature Review

2.1 Background

Soil is using as one of oldest building construction material and has been known for over 9000 years. Mud bricks masonry houses and rammed earth foundations have been discovered in Russian and Assyria dating from 8000 to 6000 BC and 5000 BC respectively [20]. In Egypt the grain stores of Ramasseum built in adobe in 1300 BC still exist; China wall was built in rammed earth over 2000 years ago. Iran, India, Nepal, Yemen all have examples of ancient cities and large buildings built in various forms of earthen construction. With earth being low-cost, environment friendly and locally available, the manufacturing of bricks made from soil (clay and silt) has been used in construction of buildings for a long time [22]. Several projects have been effectively completed using SEBs in both developed and developing countries. The benefits in this manner, using SEBs, including compressive and flexural strength, toughness and durability as compared with firebricks, while retaining significant lowest embodied energy than alternative materials. However, problems arised from the materials low tensile strength, brittle behavior, and deterioration in the presence of water [23-24].

Cheap construction materials are necessary for the development of affordable houses in Pakistan. From past few decades, conventional bricks/burnt bricks are being used in construction industries. The manufacturing process of fired bricks consists of burring the clay bricks in kiln-chambers which degrades the natural environment and the process of kiln-chambers burning is a risky stage for labor too. Supreme Court of Pakistan have declared and documented that the brick productions by using chamber-kilns are one of the major industrial emission plate form whos responsible to make degradation of natural environment [25]. Pakistan Economic Survey 2013-14 [26] reported that brick kilns were another source of pollution in many areas. The black dense smoke and other kind of emissions are also produced due to low-grade coal and old tires burning process in brick kilns. The main pollutants from these industries are particulate matter, i.e. sulphur and nitrogen oxides (which are emitted by burning fuels). The use of coal has increased by 34.3% for kilns brick in 2012-13 when compared with year 2001-02. Keeping such environmental issues, Stabilized-Earth-Bricks (SEB) is considered as an alternate of conventional/burned bricks in this research because these are low-cost to manufacture and environment friendly and having no degradation impact with respect to manufacturing process [27]. These bricks are stabilized with different nature of soils that is mixed with sand, cement or lime and natural fibers as composites. The process of SEBs consists on preparation of soil, weathering of soil, mixing of soil, adding of stabilizers and placing it in required molds. There is no burning process which make it environment friendly and lead it to energy efficient.

SEB strength (compressive and tensile) and water resistance can be improved by using hydraulic binders like cement or lime and water proofing agent like bitumen [28]. Typically, binders were used 5% to 10%, by mass of both soil and sand. However, by using stabilizing agents, the cost of material can significantly be increased. To reduce cost effect and cement content, compression technique can also be used. Compressive technique interlocks all the particles of soil by mechanically pressing the soil-bricks with appropriate mix design. Typically, compressive pressure is applied in-between 10 MPa to 20 MPa to achieve the well dense interlocked particles and impermeable SEBs. This technique surprisingly increased the compressive strength and reduced the water absorption properties of SEBs also [9].

In this chapter, a feasible use of SEBs, made with and without natural fibers is discussed in detail. It is necessary to manufacture low-cast and sustainable houses in developing countries. Thus, SEBs are considered in this research as an attractive construction material because they are low-cost, environment friendly, energy efficient and easy to manufacture. Stabilized-Earth-Bricks SEBs formed by stabilizing soil (clay, silt and sand) with cement. With earth being low-priced, friendly environmental and locally available, the manufacturing of bricks made from soil has been used in construction of buildings for a long time. Till to this time, numerous projects have been effective completed using stabilized earth in both developed and developing countries. The benefits in this manner, using SEBs, including compressive and flexural strength, toughness and durability as compared with firebricks, while retaining significant lowest embodied energy than alternative materials. However, some problems of low tensile strength, brittle behavior and continues deterioration found in the presence of water.

2.2 Stabilized Earth Bricks (SEBs) in Masonry Works

Word population of about 30-40% has made their shelters by earth bricks or blocks [4]. SEBs in masonry works are relatively new development in construction industry and have become popular material from past few decades, mostly in developing countries [29]. SEBs are made by moist soil with its deferent proportion to achieve its physical and mechanical characteristics. Additionally, it is observed that the SEBs masonry structures are relatively lower in inherent energy levels as compared with other traditional masonry materials. However, in some cases, SEBs observed deterioration in presence of water. Mechanical properties and water absorption properties can be improved by incorporation of binders like lime or cement etc. or bitumen to reduce the water absorption property. Considerably, binders in SEBs are used in-between 5 to 10%, by mass of total soil sample. However, this may affect the material cost as well as environmental impact. Ayeldeen and Kitazume [14] mentioned that the presence of cement was CO_2 emissions stabilizer too. So, considering these impacts, fiber reinforced cement stabilization technique were kept to improve the mechanical properties and to reduce the cement content of earthen bricks/blocks [3,9,15].

Mechanical properties of SEBs such as compressive, flexural and diagonal were mostly dependent on composition of soils, brick density and content of binders. The average compressive strength was recorded as 3 to 4 MPa by incorporation of 7% cement in sandy soil mix [28]. Exceeding of 10% cement in SEBs became uneconomical and unfriendly [20]. Hallal et al [18] carried out an experimental study on SEBs to know the load carrying capacity of the material. The author recorded the compressive strength of 3.82 MPa by using 8% cement binder, by mass of total soil sample. The increase of 194% was recorded in Cement Stabilized Earth Specimens (CSES) as compared with 0% cement stabilized earth specimens. Muntohar [30] investigated the mechanical properties of clay brick that was stabilized with different proportions of lime and rice husk ash (RHA) for compressive and flexural strengths. The specimen having size of 230 mm x 110 mm x 55 mm and 150 mm x 150 mm x 60 mm for compression and flexure tests, respectively, were used. The result obtained highest performance by using lime to RHS ratio of 1:1. It was also observed that water retention in specimens was taken placed by incorporation of sand. Sharma et al. [31] conducted an experimental study adobe blocks durability. The specimens were reinforced with Grewia Optiva (GO) and Pinus Poxburghii (PP) fibers. Water strength coefficient test, total absorption test, spray test, sponge water absorption test, water expansion test and wetting & drying test were carried out as per Indian Standards. It was observed that the durability of stabilized soil sample increased by 72% and 68% for fibers of GO and PP, respectively, as compared with unsterilized soil samples. Compressive strength, flexural strength and water absorption properties by some previous research are mentioned in Table 2.1. Compressive and flexural strengths were 11.6 MPa and 0.63 MPa, respectively, by using 10% cement and 2.7% salvaged stell fibers [42]. Alavez et al. [43] conducted an experimental study on Cement-Stabil-

Table 2.1: Properties of SEBs with binders and fibers (previous studies)

Refrence	**Stabilized earth bricks (SEBs)**				
	Name of stabilizer	**Fiber**	**Max Compressive Strength (MPa)**	**Max Flexural strength (MPa)**	**Water absorbed (Min) %**
Medjo et al. [42]	Cement (10%)	Salvaged stell fibers (2.7%)	11.6	0.63	-
Alavez et al. [43]	Cement (10%)	-	23.5	1.96	-
	Lime (10%)	-	16.5	1.12	-
	Lime, Bagasse ash (20%)	-	3.1	1.14	-
Hossain and Mol [44]	Cement kiln dust (20%)	-	6.01	-	7.5
	Volcanic ash (20%)	-	3.1	-	8.5
Millogo and Morel [45]	Cement (12%)	-	6.4	0.11	23.5
Millogo et al. [46]	Lime (12%)	Hibiscus cannabinus (0.8%)	3.6	0.92	19
Burroughs [47]	Cement (6%)	-	4.01	-	-
	Cement kiln dust (20%)	-	6.01	-	-
Arumala and Gondal [48]	Cement (5%)	Kenaf (5%)	1.8	-	-
Cai et al. [49]	Lime	Polypropylene fibers (0.25%)	0.88	-	-

ized-Earth-Bricks (CSEB) and Lime-Stabilized-Earth-Bricks (LSEB), to examine the compressive behavior for both, cement and lime stabilized specimens. Both cement and lime contents were 10%, by mass of total soil samples. An increase of 42% were observed in CSEB specimens, as compared to that of LSEB specimens. Millogo and Morel [45], Millago et al. [46], Burroughs [47], Arumala and Gondal [48] and Cai et al. [49] have also improved the compressive strength of the earth specimens by incorporation of cement, lime and fibers. Hossain and Mol [44] conducted water absorption test for Cement-Kiln-Dust (CKD) stabilized earth specimens. It was observed that 7.5% of water was absorbed by using 20% CKD in earth specimens.

2.3 Stabilized-Earth-Bricks to Promote Sustainability

Construction industry covered the 2nd largest industrialization platform in the world [32]. Mostly construction industry is considered on masonry structures (conventional bricks masonry and block masonry), reinforced concrete (RC) structure and steel structures. Masonry structures demand heavily construction materials like fire bricks and concrete blocks in most of the construction projects. The continued growth of the fired bricks manufacturing process is a major concern and making negative impact in degradation of natural environment [15,16,33,34]. The manufacturing process for fired bricks or kiln bricks is consisting on mixing, tempering, molding and burning of clay bricks. Burring process is carried out in kilns and their chambers for 15 to 21 days and nights. The processes of burning made pollution and negatively degraded the natural environment [15,33]. This directly affects the human health and other living bodies on the earth. Keeping the above facts, the alternative of the conventional brick (CB) is focused in this research work. SEBs are considered by many researchers that give the explanation of friendly environmental in the construction industries, and overall impact on the sustainable development [3,9,15]. Friendly environment means that the product should not emit poisonous gases, not produce air pollution during manufacturing process that can cause damage to the environment etc. Soil material is largely used in construction works for the betterment of environment due to its properties. It is also an economical and durable, by this reason soil is considering the most useable material from over the centuries.

2.4 Efficiency of Fiber Incorporation in Stabilized-Earth-Bricks (SEBs) to Improve the Properties

Fibers are used to enhance compressive strength, durability and reduction of shrinkage cracks for thousands of years in earth bricks [17]. Natural fibers have been used by many researches to enhance the physical and mechanical properties of soil samples [3,9,15]. The purpose of adding natural fiber in SEBs were not only to improve the mechanical properties but also decreased the amount of cement which were lead to CO_2 emission. Lejano [35] carried out the compression test on proto type wall made by Compressed Stabilized-Earth-Bricks (CSEBs) having size of 900 mm x 700 mm x 140 mm. A series of mix proportions were carried out to manufacture CSEBs walls. CSEBs walls made with 8% cement, 16% water to soil ratio and 0.25% of coir fiber having length of 50 mm were found the best with 33.79% increase in compression as compared to that of unreinforced fiber CSEBs walls. Mechanical properties of compressed earth blocks (CEB) reinforced with date palm fibers were carried out to examine the corresponding materials [9]. Different mix proportions were investigated. A significant improvement were observed in blocks made with 0.05% of fiber and 8% cement content, and applied pressed pressure of 10MPa. Parisi et al. [36] examine adobe bricks that were reinforced with straw fibers. Compressive and 3 point bending tests were performed. Compressive strength, tensile strength, and Youngs modulus were recorded in the range of 2.5 MPa, 0.17 MPa and 15 MPa, respectively. Sharma et al. [3] investigated grewia optivia and pinus roxbughii reinforced earth specimens. Experimental result showed that the compressive strength enhanced up to 94-200% and 73-137% by incorporation of 0.5%, 1%, 1.5% and 2% of natural fibers each Grewia Optivia (Beul) and Pinus Roxburghii (Chir Pine), stabilized with 2.5% of cement, by weight of dry soil. Millogo et al. [37] conducted an experiment on Pressed-Adobe-Blocks (PAB). The specimens were reinforced with Hibiscus-Cannabinus Fibers (HCF). The PAB were manufactured with 0.2 -0.8% of 30 mm and 60 mm lengths fibers by weight of dry density of soil specimens. The characteristics of the PABs were examined using XRD, TGA, SEM and video microscopy. It was observed that 0.2 to 0.8% of HCF with 30 mm lenght decreased the sizes of the pores in the PAB and enhancement of their mechanical properties.

Laibi et al. [38] incorporated kinaf fibers (KF) having length of 10 mm, 20 mm and 30 mm with 1.2%, by weight of total soil samples. The influence of kinaf fibers length on the mechanical property of compressed earth blocks were investigated. The experimental result expressed that compressive strength of 600 N/mm^2, 2300 N/mm^2 and 4500 N/mm^2 for the corresponding fiber length of 10 mm, 20 mm and 30 mm, respectively, were observed. Average compressive strength of soil block that were reinforced with banana fibers having length of 60 mm and 70 mm, increased by 71% and 68%, respectively, as compared to that of unreinforced compressed earth blocks [29]. Quagliarini and Lenci [39] explained how the changes occurred in workability and mechanical properties of earthen bricks were experimented. Local soil, straw fibers and coarse sand mixture were used for production of soil bricks. Desirable clay content founds between 12% and 16%, by weight of adobe bricks. Furthermore, straw fibers (SF) were observed to resist the plastic behavior and affect the breaking way of the adobe specimens. Caballero et al. [40] examined the effect of Angustifolia Haw-Agave-Bagasse-Fiber (AHABF) length in adobe bricks subjected for compressive and flexural loading. The compressive strength of fiber reinforced adobe bricks enhanced up to 33% by incorporation of 1% fiber having length of 25 mm long. These results fulfill the minimum requirement of Mexican construction regulation. At the same time, flexural strength is also recorded with enhancement of 7.01% by incorporation of fiber with same content. Ma and Gao [41] carried out a dynamic compression test on soil-cement specimens subjected to impact load. The specimens were reinforced with basalt fibers for the percentages of 0.5, 1.0 and 1.5%, by mass of total soil sample. Significant improvement was observed by incorporation of basalt fibers. At the same, it is observed the dynamic compressive strength would cause a drop in compressive strength by increasing the percentage of basalt fibers from 1.5%. Maximum compressive strength was recorded up to 5.936 MPa at fiber content of 1.5%. This increase of 7.91% was recorded in reinforced soil-cement specimens, as compared to that of unreinforced soil-cement specimens.

2.5 Jute Fiber Reinforced Stabilized Earth Bricks (JFRSEBs) in Masonry Works

To the best of author, no study has been carried out by using jute fiber reinforced Stabilized-Earth-Bricks having size of 200 mm x 100 mm x 100 mm with soil gradation of 29% course sand, 39% fine sand, 27% silt and 5% clay for masonry works. In order to provide more information regarding stabilized earth research work, the present study is conducted to elaborate the properties of local available soil reinforced with and without natural fibers to manufacture the JFRSEBs and SEBs specimens. This will cover the benefits to, regional materials can be used, which reduces cost, minimizes shipping costs for materials, and increases efficiency and sustainability. The wait-time required to obtain materials is minimal, because after the bricks are manufactured, materials are available very soon after a short drying period. The uniformity of the SEBs simplifies construction, and minimizes or eliminates the need for mortar, thus reducing both the labor and materials costs. The bricks are strong, stable, water-resistant and long-lasting. Furthermore, SEBs are energy efficient, soundproof and they do not need to use the kiln and fuel while manufacturing. Energy efficiency of JFRSEBs is the utilization of less energy to produce the alternate of the conventional bricks. Increasing energy efficiency not only allows individuals and organizations to reduce their capital and operational costs, but can also help lower fuel consumption, reduce the emission of greenhouse gases and help prevent climate change.

2.6 Summary

The need of cost-effective technology and economical materials is the new trend in this 21^{st} century. Own house is the dream of every individual family. But in developing countries, conventional bricks/burnt bricks were not in the range to afforded by the poor peoples. At the same time such huge material production degraded the natural environment. Thus, a focus has been carried out on cheap housing societies with environment friendly materials, and easily to manufacture anywhere in the world. For this purpose, local available soil, ordinary Portland cement (OPC) were experimented by many researchers with different aspects. Cheap housing society doesnt mean to compromise on strength and other mechanical properties but its means to use of local material and construction technology very effectively, it results durable, economical, environment friendly and requires less maintenance houses construction. Fibers were considered from past few decades with best possible way to increase the load bearing capacity of the Adobe bricks (AB), Stabilized-Earth-Bricks (SEBs), Compressed earth bricks (CEBs), compressed earth Stabilized-Earth-Bricks (CSEBs) etc. not only to improve the load bearing capacity but also produced the remarkable improvement in flexural strength, tensile strength, split tensile strength, shear strength and diagonal strength. Thus, therefore, Stabilized-Earth-Bricks (SEB) is considered in current research as an attractive construction material because they are low-cost, environment friendly, energy efficient and easy to manufacture. To the best of author knowledge, no study has been carried out on use of jute fiber reinforced Stabilized-Earth-Bricks with soil proportion of 29% course sand, 39% fine sand, 27% silt and 5% clay, cement and fiber content of 8% and 1% by mass of total soil sample, for masonry to improve the mechanical properties are considered.

Chapter 3

Test Methodologies

3.1 Background

Local abundantly available soil extracted from Capital University of Science and Technology, Islamabad is used for the manufacturing of SEBs. Sieve analysis is to be carried out. Natural fibers are used as a reinforcing agent. Jute fibers are considered among all natural fibers because of having good energy absorption capacity and have high tensile breaking strength. Furthermore, jute fibers are available in local market of Pakistan. For binding purpose, Ordinary Portland cement (OPC) is purchased as this is also available in local market. In this chapter, raw materials like (soil, fibers and ordinary Portland cement), methods of mixing and casting the specimens (production of bricks) and methodologies for testing are to be examined in detail.

3.2 Raw Materials

3.2.1 Soil

Soil excavated from 3-4 feet below the natural surface of earth in Capital University of Science and Technologies (CUST), Islamabad, Pakistan was used. The color of

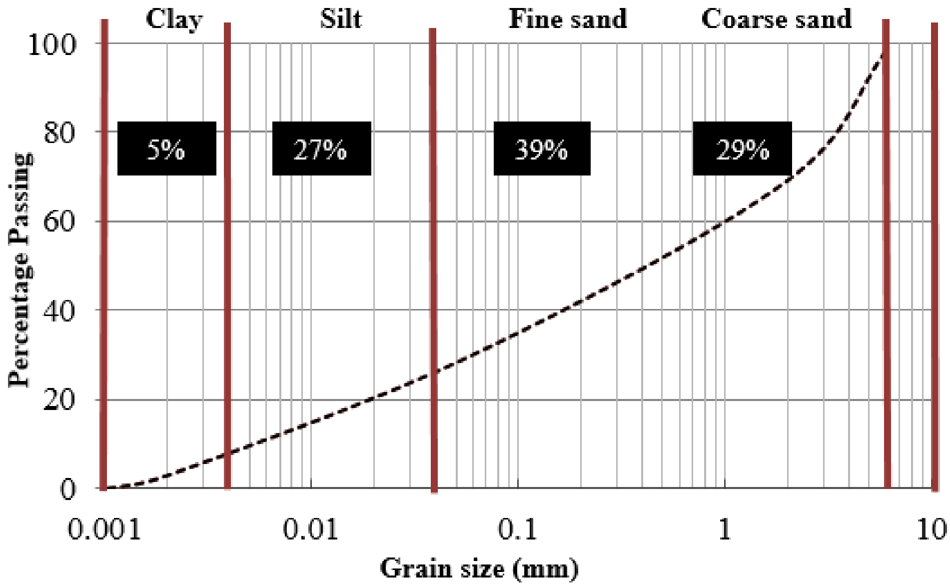

FIGURE 3.1: Gradation curve of sieve analysis

TABLE 3.1: Physical and mechanical properties of soil

Soil properties	Value
Specic gravity	2.55
Consistency limit	
Liquid limit (L.L)	36.40%
Plastic limit (P.L)	18.60%
Plasticity index (P.I)	17.8
USUC Classication	SL
Compaction study	
Optimum moisture content (OMC)	12.5 %
Maximum dry density (MDD)	17.16 kN/m^3
Grain size analysis	
Coarse Sand	29 %
Fine Sand	39 %
Silt	27 %
Clay	5 %

selected soil was naturally light brown. The debris were removed and left to open sky for weathering for 24 hours. The desired soil was sieved as per ASTM D422 [50]. Table 3.1 shows the grain size analysis and consistency limits. The percentage of course sand, fine sand, silt and clay are 29%, 39%, 27% and 5% respectively. Percentage gradation of the soil is presented in Fig 3.1. Specific gravity of the soil was achieved 2.55. The soil was classified as per unified soil classification system (USCS) and found the soil is sandy loam (SL). The optimum moisture content and dry unit weight is obtained 12.5% and 17.16 kN/m^3.

3.2.2 Fibers

Jute fibers of 50 mm in length are considered to reinforce the JFRSEBs. Jute Fibers are chosen on account of abundantly available in northern Pakistan. Properties of jute fibers are mentioned in Table 3.2. SEM micrographic and photographs of the jute fiber is shown in Fig 3.2. SEM for single hair, jute is zoomed till x35 level. The image showed that the jute fiber is consist on rough and surface which can be predicted that jute fibers will make a strong bond between soils and cement matrix. The result will directly increase in compressive and tensile strength.

Table 3.2: Properties of Jute-Fiber [51]

Behavior parameters	**Values**
Average length	50 mm
Density	1.30 g/cm^3
Diameter	0.04-0.35 mm
Tensile strength	29 312 N/mm^2
Modulus of elasticity	26.5 GPa

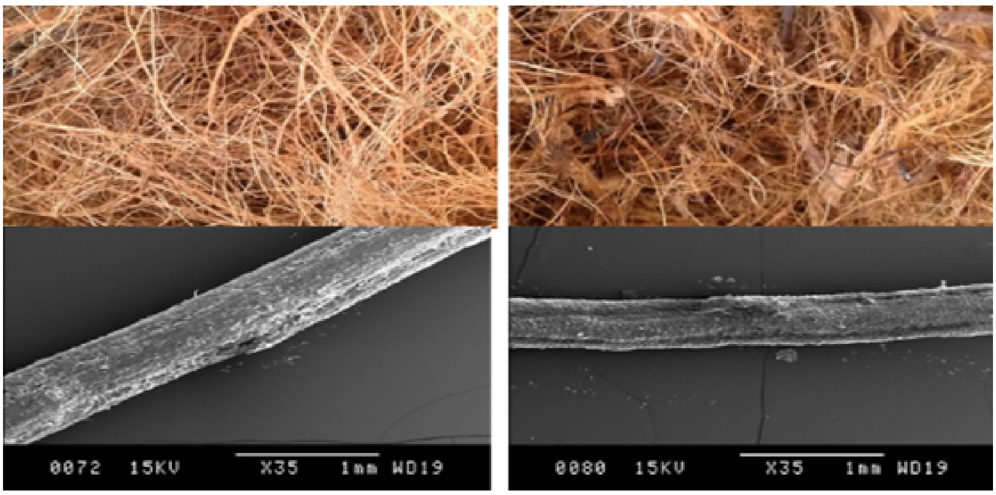

Figure 3.2: Photographs and SEM micrographs of jute fiber

3.2.3 Cement

Ordinary Portland cement (OPC) is used as a stabilizing agent in SEBs and JFRSEBs specimens. Standard physical requirements of OPC are mentioned in Table 3.3. OPC with minimum 90% of fines and compressive strength of 26 MPa is considered.

Table 3.3: Standard physical requirements of ordinary Portland cement

Cement type	Applicable test method	Value
Fineness	ASTM C204 [52]	Minimum 2,800 (cm^2 =g)
Autoclave length Change (%)	ASTM C151 [53]	Maximum 0.8
Time of setting	ASTM C191[54]	
Initial		Not less than 45 (min)
Final		Not more than 420 (min)
Air content of Mortar volume (%)	ASTM C185 [55]	Maximum 12
Compressive strength		
3 days		9 (MPa)
7 days		16 (MPa)
28 days		26 (MPa)

3.3 Methods

3.3.1 Production of Bricks

In order to evaluate the effectiveness of jute fibers in earth bricks on mechanical properties, especially to improve load carrying capacity of the masonry works, SEBs and JFRSEBs having size of 200 mm x 100 mm x100 mm are made. Local available soil extracted from the university is utilized. OPC and JF are purchased from the market. JF having length of 50 mm were used in JFRSEBs as a reinforcing agent. Many researchers used natural fibers in SEBs having length of 50 mm. Length of fibers is a point of discussion. Fibers should not be short, so that there is complete pull out from one side of fracture surface. Fibers should also not be long, so that there is balling effect during mixing. 1% JF is considered from previous studies as it gives optimum result in soil specimens [56]. Cement content and water content is used 8% and 15%, by mass of total soil respectively.

Firstly, the desired soil was well weathered for 24 hours with removal of all debris and other plantation, lumps and stones etc. In account to achieve uniform and consistent mix design. The soil was sieved and mixed in rotating mixer for homogenous mixing of the ingredients, making sure the particles are not clump together. Cement was added and the concrete mixer was allowed for three minutes rotation. After that, the required quantity of water was added in three consecutive periods each after one minute, which resulted in uniformly saturated and well-mixed composite. The prismatic molds were then filled with saturated-mixed soil in three layers, each layer compacted with temping rod for 25 blows. Same procedure was adopted for manufacturing of JFRSEBs specimens. But before adding the calculated amount of water, JF was added effectively after each three consecutive time periods of one minute. Fresh bricks were demolded after 24 hours of manufacturing and moist cured was done by using polyethylene sheets for 28 days in normal lab temperature of 20^{o}C.

3.4 Testing Procedures

Experimental programs are carried out for single bricks (SB) and multiple bricks (MB) for each, SEBs and JFRSEBs specimens. The density of both SEBs and JFRSEBs specimens are measured as per ASTM D7263-09[57]. The bricks were selected, their dimensions measured, weighted and density measured. Density observed 1985 kg/m^3 and 1797 kg/m^3 for both SEBs and JFRSEBs specimens, respectively. Table 3.4 shows the test which are performed.

Table 3.4: Intended tests to be performed

Sample		**Properties**			
		Compression Test	**Flexural Test**	**Shear Test**	**Water absorption test**
SEBs					
	Single Brick (SB)	•	•	•	•
	Multiple Bricks (MB)	•	-	-	-
JFRSEBs					
	Single Brick (SB)	•	•	•	•
	Multiple Bricks (MB)	•	-	-	-

3.4.1 Compressive Strength Test

Compression tests were performed as per ASTM C67/C67M-18 [58] to assess the load carrying capacity of single bricks (SB) and multiple bricks (MB) for each SEBs and JFRSEBs specimens. In addition, compressive strength (CS), compressive absorbed pre-crack energy (CPE), compressive cracked absorbed energy (CCE), compressive total absorbed energy (CTE), compressive toughness index (CTI) are also calculated for each, SB and MB. Test setups for compression are shown in fig 3.3(a). The tests are carried out through servo-hydraulic testing machine (STM).

According to NBC E0.30 (2003) [59], load carrying capacity of the masonry work can be determined by low height wall experimentally, to obtain the slenderness ratio (height/thick) of 3 to 4 for the minimum number of rows. Aguilar et al. [60] recommended that the slenderness coefficient of specimens remains to or in-between 3 to 5. It is further described that the minimum number of bricks/blocks should be 3 with condition to satisfy the height to length ratio (height/length) must be greater than or equal to one. Thus, considering these requirements in to the account, a series of multiple brick (MB) masonry are also made with 1:5 (cement: sand) ratio and testing for load carrying capacity.

3.4.2 Flexural Strength Test

Flexure strength test is carried in STM machine by conduction three-point bending loads as per procedure provided in ASTM C67/C67M-18 [58] for single bricks of each, SEBs and JFRSEBs. This test was performed to calculate module of rupture (MoR), flexural absorbed pre-crack energy (FPE), flexural cracked absorbed energy (FCE), flexural total absorbed energy (FTE), flexural toughness index (FTI). Test setup is shown in Fig 3.3(b).

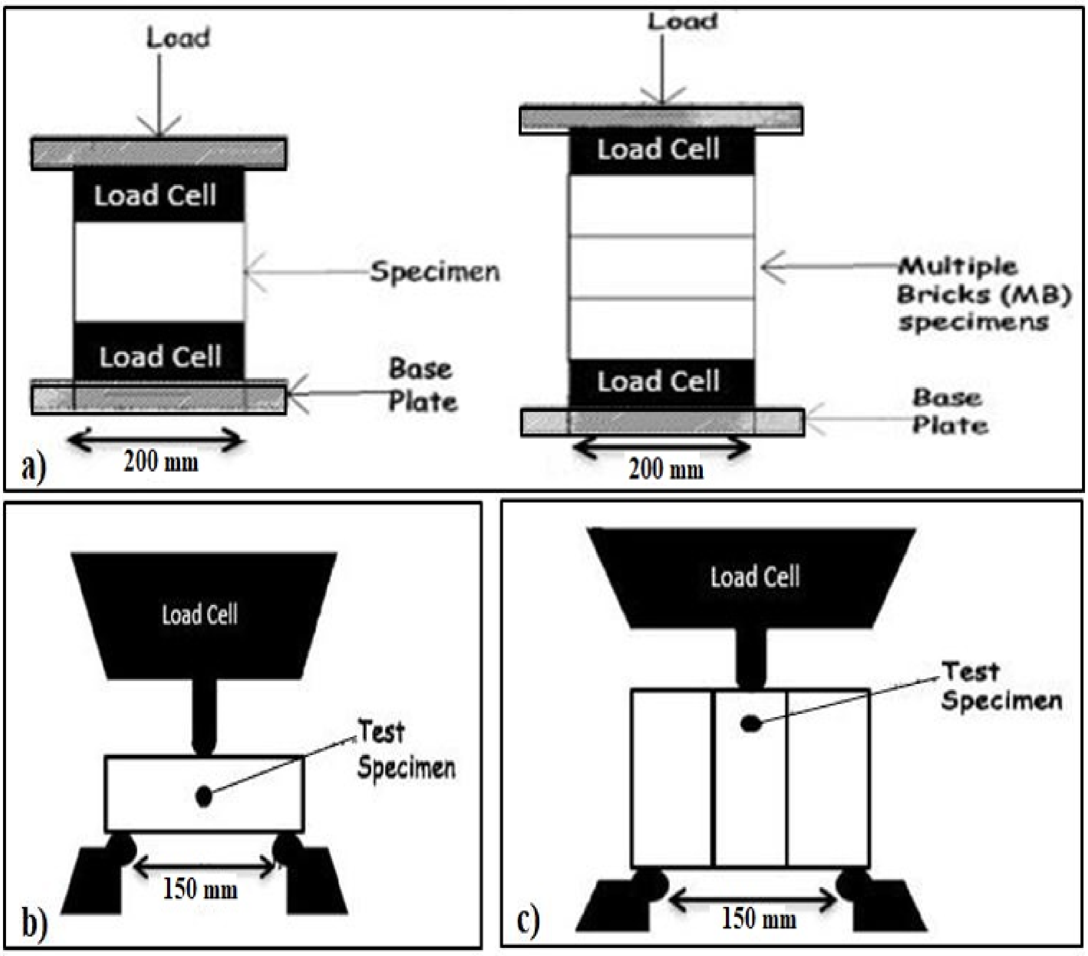

FIGURE 3.3: Test Setups for a) compressive strength b) flexural strength and c) shear strength

3.4.3 Shear Strength Test

Shear tests were performed in accordance with BS EN 1052-3 [61] in STM machine to understand the shear resistance of the multiple bricks (MB) for each, SEBs and

JFRSEBs specimens. Testing setup is shown in Fig 3.3(c). Shear strength (SS), shear absorbed pre-crack energy (SPE), shear cracked absorbed energy (SCE), shear total absorbed energy (STE) and shear toughness index (STI) is to be calculated.

3.4.4 Water Absorption Test

Water absorption (WA) of the single bricks (SB) specimens is performed through capillary action testing procedure [56] for both SEBs and JFRSEBs. Dry specimens of SEBs and JFRSEBs were first weighted and then immersed in water to a depth of 5 cm for 10 mints in constant head-water bath (fig 3.4). After immersed the specimens, specimens were then removed from the immersed tube and clean with a dry cloth for well finishing. At the end the specimens were weighted again in wet condition. The following formula is used to calculate the water amount absorbed.

$$\textbf{WA \%=((W1-W2))/W2 x 100}$$

Where WA % = absorbed water percentage
W1 = density of block after absorbed water
W2 = density of block before absorbed water

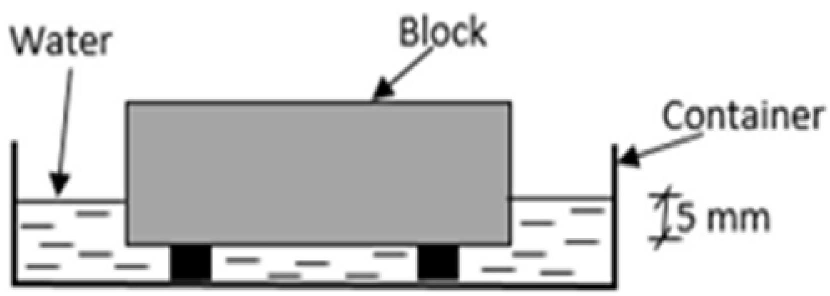

FIGURE 3.4: Schematic Set-up for Water Absorption by Capillary [56]

3.5 Summary

The proportion of natural abundantly available soil is recorded as per ASTM by using sieve analysis (course sand 29%, fine sand 39%, silt 27% and clay 5%). Water contact and cement content were added 15% and 8%, respectively, while in manufacturing stages. In addition to that, 1% fiber content (jute fibers), by mass of total soil sample, and fiber having length of 5 cm are incorporated in JFRSEBs case. A series of bricks for both, SEBs and JFRSEBs specimens are made and to be tested for compressive, flexural, shear strength and water absorption tests in chapter no 4.

Chapter 4

Test Results and Analysis

4.1 Background

Soil consists on course sand, fine sand, silt and clay at percentage of 29%, 39%, 27% and 5% respectively, are used in the production of Stabilized-Earth-Bricks (SEBs) and jute fiber reinforced Stabilized-Earth-Bricks (JFRSEBs). Ordinary Portland cement (OPC) and jute fibers (JF) at a percentage of 8% and 1%, respectively, by mass of total soil are used. This chapter will cover the results and analysis obtains after lab testing the specimens.

4.2 Compressive Properties

4.2.1 Compressive Behavior

Compressive strength, in other words load carrying capacity, is considered very important property among all others properties, especially in bricks masonry works. This research program has given emphasis on indicated property. Compressive strength property measured the performance of both SEBs and JFRSEBs specimens subjected for uniform compressive loading by STM machine. Fig 4.1(a) presented the stress-strain relation curve of SB and MB for each, SEBs and JFRSEBs specimens

First crack, crack at peak load and crack at ultimate load are shown in Fig 4.1(b). Through, the information such as location and length of cracks are exposed. First crack of SEBs and JFRSEBs is observed against SB and MB specimens are 75%, 25% and 76%, 22% of their corresponding peak load respectively.

The first crack length is measured for SEBs and JFRSEBs specimens against SB and MB of 75 mm, 45 mm and 30 mm, 44 mm, respectively (refer to extreme left column of Fig 4.1). Crack length at peak load of SEBs and JFRSEBs, measured against SB and MB specimens is 90 mm, 75 mm, respectively, and 88 mm, 90 mm, respectively, (refer to middle column of Fig 4.1). The crack lengths are further enlarged in the case of ultimate load. Length recorded for SB and MB are 95 mm, 96 mm, respectively, and 88 mm, 98 mm, respectively, for both SEBs and JFRSEBs specimens (refer to extreme right column of Fig 4.1).

Compressive strengths are observed 2.033 MPa and 3.70 MPa for single bricks (SB) compression test of SEBs and JFRSEBs specimens, respectively (Fig 4.1a). This showed that the jute fiber enhanced the compressive strength of JFRSEBs specimens up to 82.26%, as compare to that of unreinforced SEBs specimens.

Stress-strain curve of the MB small proto type specimens is shown in Fig 4.1a. Compressive strength of MB small prototype specimens is recorded 1.66 MPa and 2.027 MPa for SEBs and JFRSEBs, respectively. This showed 22.10% increase in load carrying capacity of JFRSEBs small proto type masonry walls, as to compared with SEBs small proto type masonry walls. This decrease in compressive strength is recorded due to slenderness ratio of the MB SEBs and JFRSEBs specimens, compared to that of SB SEBs and JFRSEBs specimens.

4.2.2 Compressive Strength, Compressive Pre-Crack/Post-Crack Absorbed Energies, and Compressive Toughness Index

Compressive strength (CS), compressive absorbed pre-crack energy (CPE), compressive cracked absorbed energy (CCE), compressive total absorbed energy (CTE) and compressive toughness index (CTI) are also calculated (Table 4.1). The stress measured at first crack load is considered as CPE. Stress at first crack to stress at ultimate load is considered as CCE. The total area which is to be covered beneath point of zero stress to the stress at ultimate load is considered as CTE. The ratio between CTE to CPE is known as CTI. The CPE of 0.068 MJ/m^3 and 0.413 MJ/m^3 are observed for SEBs and JFRSEBs SB specimens, respectively. In contrast to CPE of JFRSEBs SB specimens, an increase of 507% is calculated, compared to that of SEBs SB specimens. In parallel, a decrease of 47% in CTI of JFRSEBs specimens is recorded compared with SEBs specimens. CCE and CTE of JFRSEBs specimens increased up to 80% and 221% compare to that of SEBs specimens. The strain value at maximum stress of SEBs and JFRSEBs specimens are 0.062 and 0.179, respectively. The stain of JFRSEBs SB specimens having larger value as compare with strain in SEBs SB specimens. This is because of the elongation capability of JF which allows to keep hold the materials together till its breaking point and prevent the collapse as shown in Fig 4,1b(i). Comparison of CS, , CPE, CCE, CTE, and CTI for both SEBs and JFRSEBs single brick (SB) specimens are shown in Fig 4.2(a).

Subsequently, CPE, CCE, CTE and CTI are also calculated for MB small proto type specimens of each, SEBs and JFRSEBs specimens (Table 4.1). The CPE of 0.015 MJ/m^3 and 0.061 MJ/m^3 is observed for SEBs and JFRSEBs MB specimens, correspondingly. In contrast to CPE of SEBs MB specimens, an increase of 306.66% is calculated, as compared to that of JFRSEBs MB specimens. Along with, increase of 800%, 600%, and 72.13% of CCE, CTE, and CTI are observed in JFRSEBs MB specimens, compared with SEBs MB specimens. The strain value at maximum stress of SEBs and JFRSEBs specimens are recorded as 0.016 and

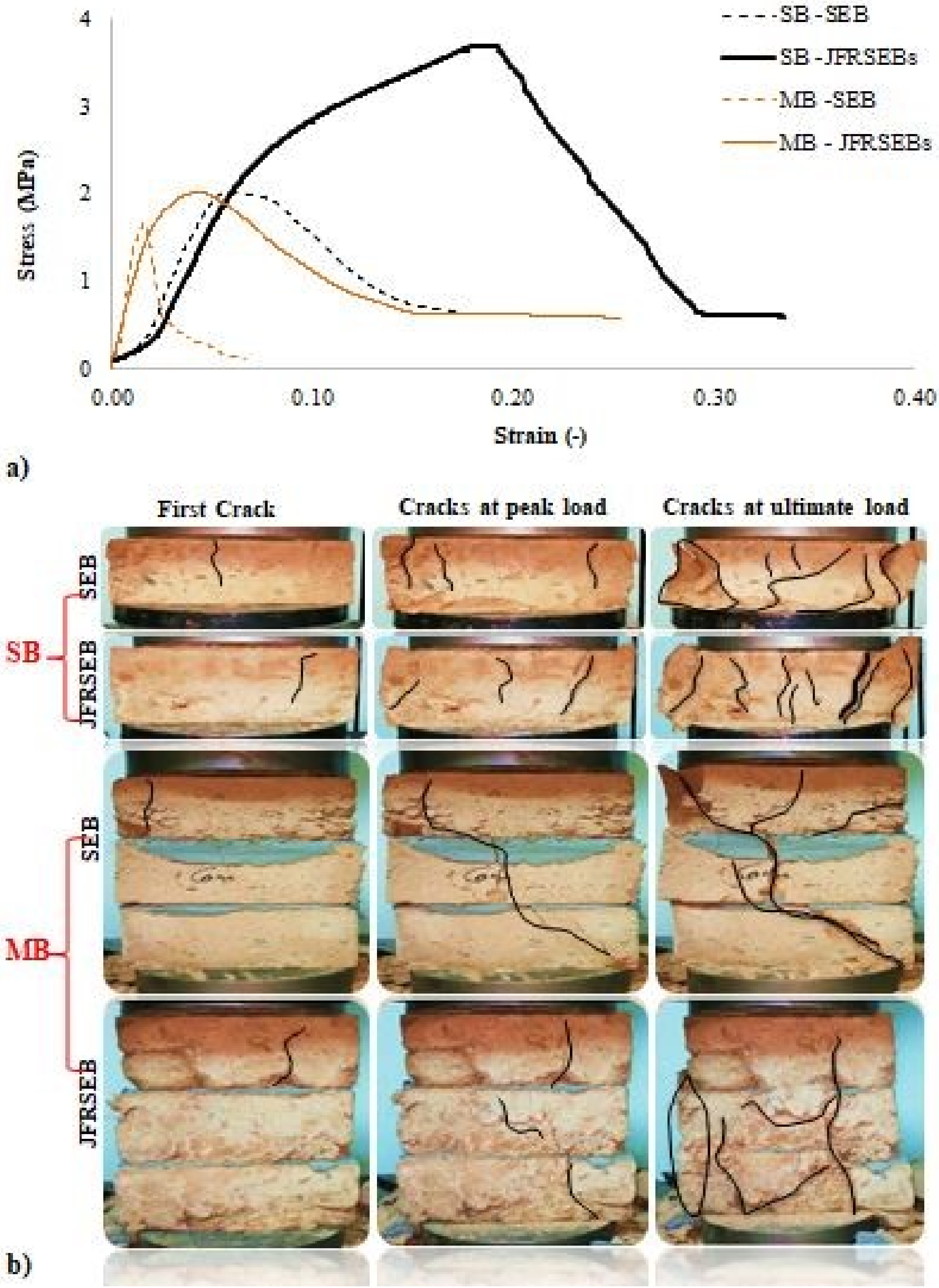

FIGURE 4.1: Compressive behavior a) Stress-Strain curve b) Crack propagation of SB and MB

0.042, respectively. The stain of JFRSEBs SB specimens having larger value of 162.5% as compare with strain in SEBs SB specimens. This is because of the elongation capability of JF which allows to keep hold the materials together till

TABLE 4.1: Compressive properties of SEBs and JFRSEBs specimens

Intended Properties	Single Bricks (SB)		Multiple Bricks (MB)	
	SEBs	**JFRSEBs**	**SEBs**	**JFRSEBs**
CS (MPa)	2.03±0.11	3.70±0.2	1.66±0.05	2.03±0.23
ε(-)	0.062±0.009	0.179±0.01	0.016±0.006	0.042±0.003
CPE (MJ/m^3)	0.068±0.003	0.413±0.34	0.015±0.01	0.061±0.06
CCE (MJ/m^3)	0.138±0.01	0.248±0.002	0.022±0.001	0.198±0.06
CTE (MJ/m^3)	0.206±0.013	0.662±0.342	0.037±0.011	0.259±0.012
CTI (-)	3.029	1.602	2.467	4.246

Note:CS = Compressive strength, ε = Strain at the maximum stress, CPE = Compressive absorbed pre-crack energy, CCE = Compressive cracked absorbed energy, CTE = Compressive total absorbed energy, CTI = Compressive toughness index.

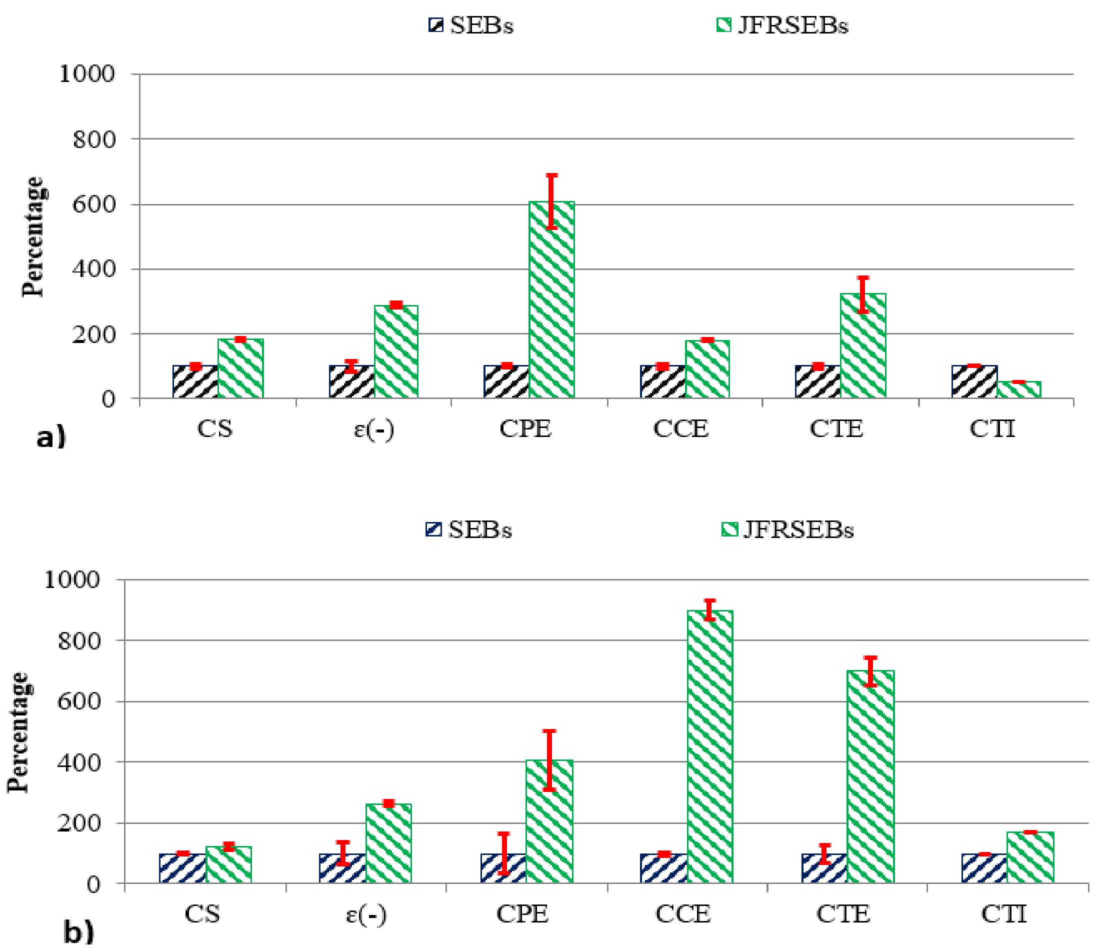

FIGURE 4.2: Comparison of CS, , CPE, CCE, CTE, and CTI for a) SB specimens and b) MB specimens

its breaking point and prevent the collapse as shown in Fig 4.1b(ii). Comparison of CS, , CPE, CCE, CTE, and CTI for both SEBs and JFRSEBs multiple brick (MB) specimens is shown in Fig 4.2(b).

4.3 Flexural Properties

4.3.1 Flexural Behavior (Three-Point Bending Behavior)

Three-point bending test is carried out on single bricks (SB) of SEBs and JFRSEBs. Fig 4.3(a) showed the load-deflection curve of the proposed specimens. Fig 4.3(b) shown the formation of the crack patterns at different loads like first crack load, crack at peak load and crack at ultimate load in SB of SEBs and JFRSEBs specimens. The first crack in SEBs SB and JFRSEBs SB specimens is observed 100% and 55%, respectively, in contradiction of their corresponding loads. The first crack length is observed about 100 mm and 55 mm in SEBs SB and JFRSEBs SB specimens, respectively. The SEBs SB specimens are collapsed and shuttered into two pieces while JFRSEBs SB specimens are held together due to JF reinforced bridging containments. The length and width of the cracks are further increased in JFRSEBs SB specimens at peak loading. In this section, length of the crack in JFRSEBs SB is observed 65 mm (refer to middle column of Fig 4.3b). At ultimate load, the crack is about to total height thick of the JFRSEBs SB specimens and approximate to collapse (refer to extreme right column of Fig 4.3b).

4.3.2 Flexure Strength, Flexural Pre-Crack/Post-Crack Absorbed Energies, and Flexural Toughness Index

MoR, FPE, FCE, FTE and FTI are calculated. MoR is considered the largest value from load-deflection curve in three-point bending test. The area which is to be covered in-between load-deflection curve up to the load at first crack is taken as to be FPE. This has been pointed out that the first crack load and peak load in case of SEBs SB specimens are same. The area which is to be covered in-between load-deflection curve from first crack load to ultimate load is known as FCE. The area which is to be covered in-between from zero loads to ultimate load is considered as FTE. The ratio between FTE to FPE is chosen as FTI. Table 4.2 shows the MoR, FPE, FCE, FTE and FTI. Compared the both materials, MoR, FPE, FCE, FTE and FTI of JFRSEBs SB specimens increased in amount of 0.005 MPa, 10.88 J, 16.2 J, 18.326 J, and 0.51 as compared to that of SEBs SB specimens. The deflection values calculated at peak load are 2 mm and 5.66 mm for both SEBs and JFRSEBs SB specimens, respectively. Thus, deflection value 183% is on higher side in JFRSEBs as compared to that on SEBs SB specimens.

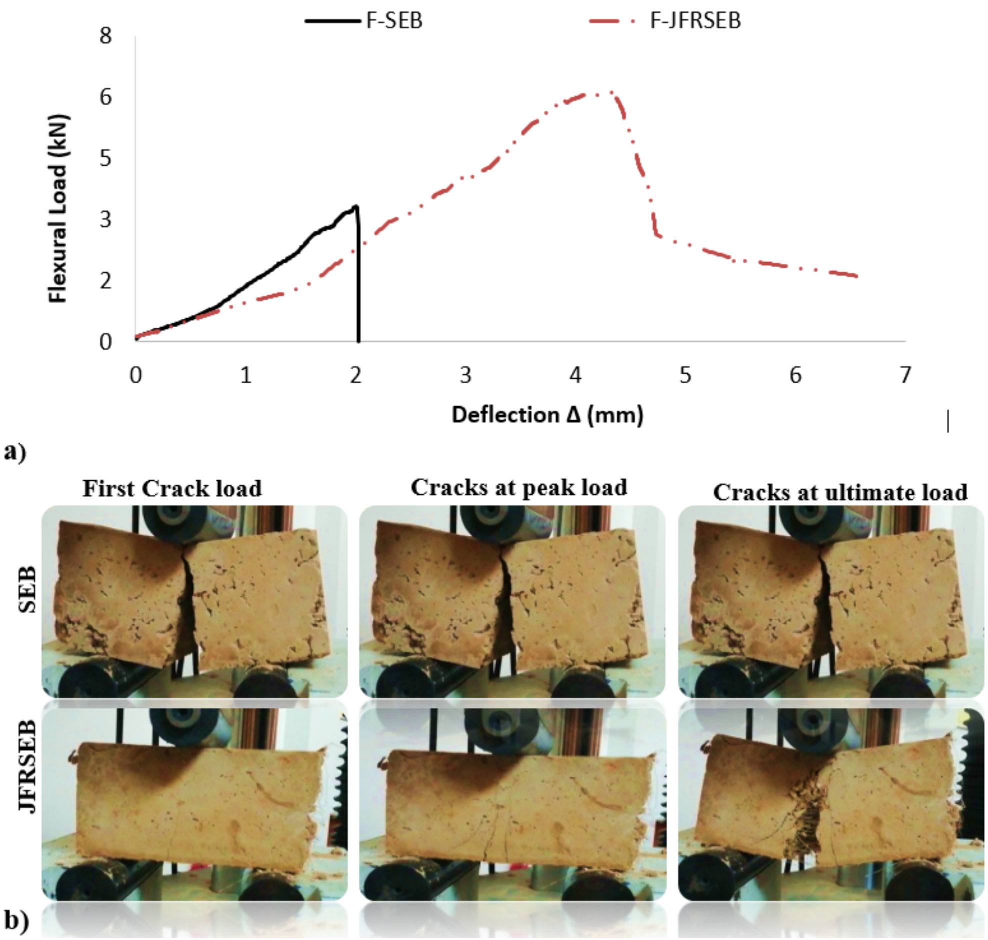

FIGURE 4.3: Flexural behavior a) Load-deflection curve b) Crack propagation of flexural specimens

Fig 4.4 showed the comparison of MoR, FPE, FCE, FTE and FTI for both the materials. The amount of MoR, FPE, FCE, FTE and FTI enhanced up to 100%, 293%, 750%, 495% and 51% in JFRSEBs specimens as compared to that of SEBs specimens. Results showed that JF can successfully improve MoR, FPE, FCE, FTE and FTI of the JFRSEBs specimens

TABLE 4.2: Flexural properties of SEBs and JFRSEBs SB specimens.

Intended Properties	**Single Bricks (SB)**	
	SEBs	**JFRSEBs**
MoR (MPa)	0.005 ± 0.001	0.01 ± 0.001
Δo(mm)	2 ± 0.06	5.7 ± 0.4
FPE (J)	3.7 ± 0.2	14.6 ± 1
FCE (J)	0 ± 0	7.5 ± 0.1
FTE (J)	3.7 ± 0.2	22.1 ± 1.1
FTI (-)	1	1.5

Note: MoR = Module of Rupture, Δo = Deflection at the maximum load, FPE = Flexural absorbed pre- crack energy, FCE = Flexural post-crack absorbed energy, FTE = Flexural total absorbed energy, FTI = Flexural toughness index.

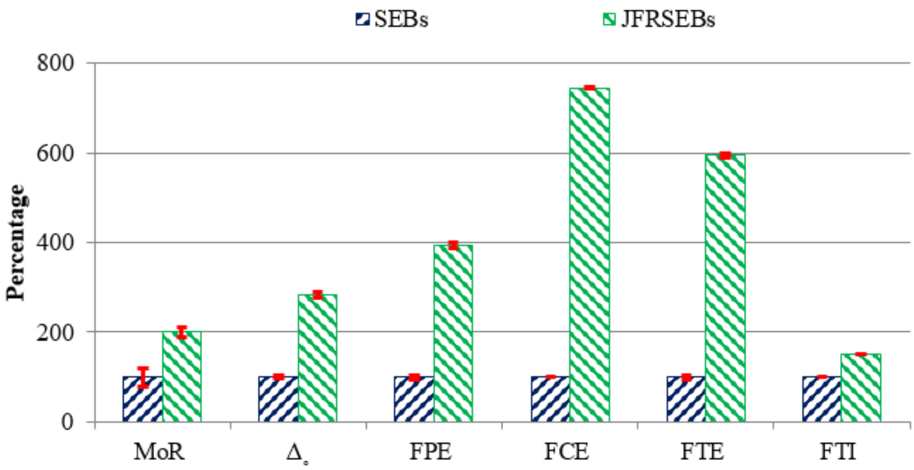

FIGURE 4.4: Comparison of MoR , o, FPE , FCE , FTE and FTI for both, SEBs and JFRSEBs single bricks (SB) specimens

4.4 Shear Properties

4.4.1 Shear Behavior

Fig. 4.5a showed the shear stress-strain curve for shear strength. Fig. 4.5b showed the formation of first crack, crack at peak load and crack at ultimate load for SB shear specimens of SEBS and JFRSEBS under shear loading. The compressive strength of mortar having cement:sand of 1:5 is reported as 8.76 MPa [4]. Refer to extreme right column of the fig 4-5b showed the first cracking pattern of SB shear specimens for both SEBs and JFRSEBs. The first crack is observed 100% and 45% in for both SEBs and JFRSEBs, respectively. The crack was recorded 300 mm in SEBs and 45 mm in JFRSEBs specimens. It is further noted that the

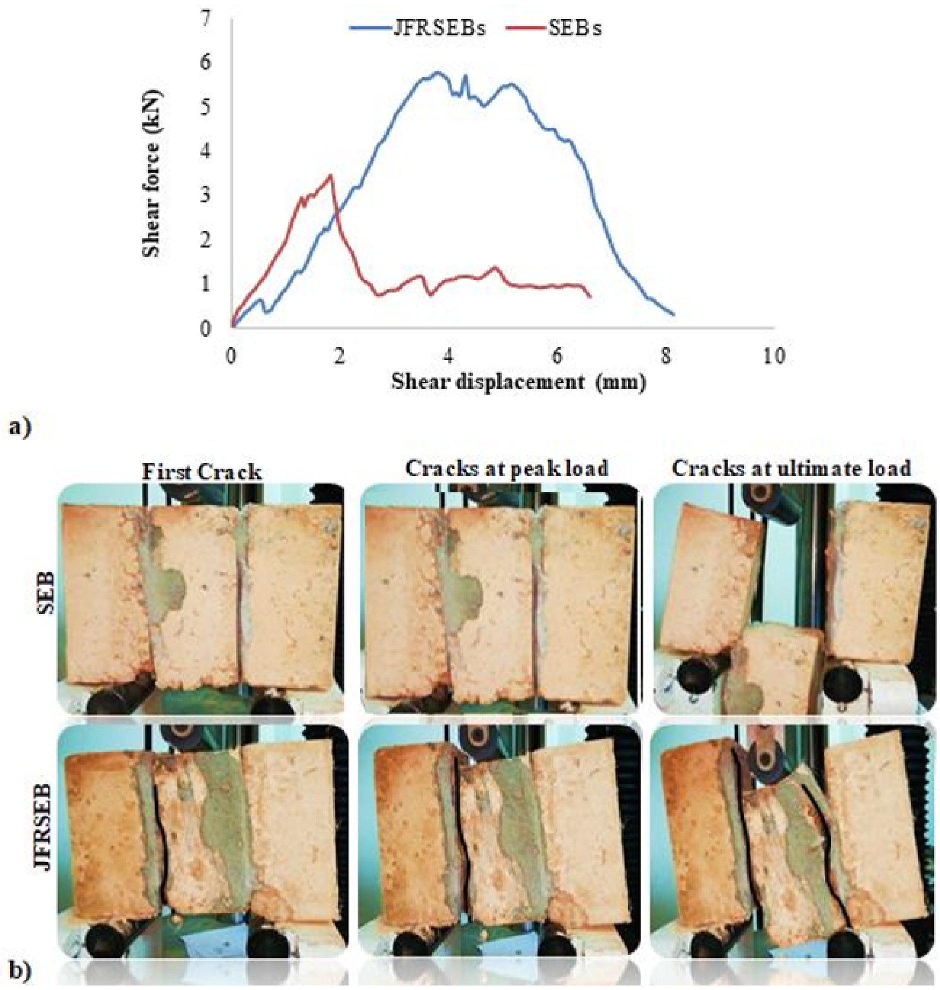

Figure 4.5: Shear behavior a) Shear stress-strain curve b) Crack propagation of shear test specimens.

SEBs specimens are split suddenly into three pieces while JFRSEBs are held together due to jute fibers. In this consequence, single brick shear displacement is recorded for corresponding loading. A sliding failure occurs along a flat plane of the sample. This is a typical example of sliding shear failure. During shear test, force is applied to specimens in a parallel direction, rather than holding it in tension. For multiple bricks masonry wall, diagonal shear test to understand diagonal shear failure is still needed to be performed. Shear test shows that JF significantly increases the shear resistance in the JFRSEBs single bricks specimens up to an optimum level 67.5%, as compared to that of SEBs single bricks specimens. At the peak load, the cracks were observed to enlarge in JFRSEBs SB specimens. The recorded cracks were found 120 mm in average length (Refer to middle column of the fig 4.5b). At ultimate load, the cracks were further enlarged up to collapsing of the specimens at both masonry points. The crack length was observed 200 mm in JFRSEBs specimens.

4.4.2 Shear Strength, Shear Pre-Crack/Post-Crack Absorbed Energies, and Shear Toughness Index

SS, SPE, SCE, STE and STI are calculated. Three-point sliding test procedure is adopted. The area which is to be covered in-between load-deflection curve up to the load at first crack is taken as to be SPE. It is observed that first crack load and peak load in case of SEBs specimens are same. The area which is to be covered in-between load-deflection curve from first crack load to ultimate load is known as SCE. The area which is to be covered in-between from zero loads to ultimate load is considered as STE. The ratio between STE to SPE is chosen as STI. Table 4.3 showed the SS, SPE, SCE, STE and STI. Compared the both materials, SS, SPE, SCE, STE and STI of JFRSEBs SB specimens increased in amount of 58 kPa, 9.42 J, 33.16 J, 42.58 J and 0.816, respectively, as compared to that of SEBs MB specimens. The displacement values calculated at peak load are 0.01 mm and 0.038 mm for both SEBs and JFRSEBs SB specimens, respectively. Thus, strain value 211% is on higher side in JFRSEBs as compare to that on SEBs MB specimens.

Fig. 4.6 showed the comparison of SS, SPE, SCE, STE and STI for both the materials. The amount of SS, SPE, SCE, STE and STI enhanced up to 67.5%, 332%, 476%, 434% and 23% in JFRSEBs specimens, respectively, as compared to that of SEBs specimens. Results showed that JF can successfully improve SS, SPE, SCE, STE and STI of the JFRSEBs specimens.

TABLE 4.3: Shear properties of SEBs and JFRSEBs MB specimens

Intended Properties	Single Bricks (SB)	
	SEBs	JFRSEBs
SS (kPa)	86 ± 10	144 ± 16
Δ (mm)	3.47 ± 0.25	10.8 ± 0.63
SPE (J)	2.83 ± 0.15	12.25 ± 0.71
SCE (J)	6.96 ± 0.42	40.12± 2.14
STE (J)	9.79 ± 0.57	52.37 ± 2.85
STI (-)	3.459	4.275

Note:SS = Shear strength, Δ = displacement at the maximum load, SPE = Shear absorbed pre-crack energy, SCE = Shear cracked absorbed energy, STE = Shear total absorbed energy, STI = Shear toughness index.

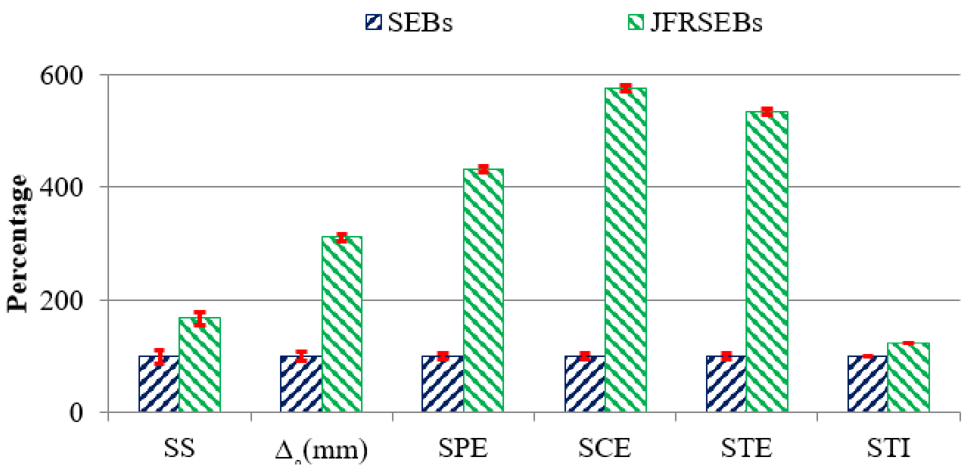

FIGURE 4.6: Comparison of SS, , SPE, SCE, STE and STI for both, SEBs and JFRSEBs Single bricks (SB) specimens

4.5 Water Absorption Property

The water taken into the pores of the specimens and is taken equal to the total mass of absorbed water of the specimens divided by the total mass of the specimens is known as water absorption (WA). Table 4.4 showed the water absorption of the both, SEBs SB specimens and JFRSEBs SB specimens. Water absorption (WA) of JFRSEBs and SEBs specimens are 22% and 10%, respectively. The value of WA enhanced 122% in JFRSEBs as compared with SEBs specimen. This effect of WA increase in JFRSEBs specimens is due to the high capillary action jute fibers (JF). This is because of cellulose surface structure and void volume, which encourages water absorption [15,16,56]. As per the IS 1077-1992 [62], WA of burnt bricks shall not be more than 20%, by dry mass of total brick. While in current study, a maximum of 22% WA is recorded in JFRSEBs specimens. This is little high. At the same time, by incorporation of jute fibers in JFRSEBs, a remarkable increase in compressive strength is achieved too. Considering the compressive strength and WA of SEBs and JFRSEBs, specimens behavior/properties can be improved by using compressed-cement-stabilized-earth technique [9]. Further, for practical application (structure made of earth brick) needs special consideration particularly for raining season.

Table 4.4: Water absorption of SEBs and JFRSEBs specimens

Sample	Water absorbed (%)
SEBs	10
JFRSEBs	22

4.6 Summary

Compressive strength properties for single bricks and multiple bricks, flexural strength, shear strength and water absorption property of each SEBs and JFRSEBs made by local available soil, OPC and jute fibers are tested for their corresponding tests. In comparison to that of SEBs decreased of density in JFRSEBs specimens are observed. Compressive strength, flexural strength and shear strength of the JFRSEBs specimens remarkable enhanced as compared with SEBs specimens. In comparison of SEBs, an enhancement of post-crack energy absorption and toughness indices are observed for JFRSEBs specimens. Furthermore, a significant increase is found in JFRSEBs specimens compared with SEBs specimens.

Chapter 5

Discussions

5.1 Background

Mechanical properties of SEBs and JFRSEBs are determined in chapter no 4. Remarkable improvement in the single bricks (SB) compression test of the JFRSEBs specimens is observed. At the same the significant improvement in multiple bricks (MB) specimens for compression and shear strengths are also observed. This chapter elaborated the bond characteristics among jute fibers, ordinary Portland cement (OPC) and soil, compression with previous studies, comparison with codes and empirical relationship between compressive strength and modulus of rupture of single brick compression specimens. The effectiveness of jute fibers (JF) with soil cement mixture is summarized.

5.2 Bond Characteristics Among Jute Fibers, Ordinary Portland Cement and Soil

SEBs specimens sudden and completely failed with propagation of single long and wider crack while on JFRSEBs specimens observed gradual failure due to jute fibers bridging and bond characteristics with soil and cement particles. These characteristics of fiber bonds and bridging depend on the dimension, surface texture, fiber type and fiber contents [63]. This scenario created the surprising increased in single bricks (SB) compressive strength. The number of fibers to matrix (soil-cement) contact points is responsible to transmit stresses in the material, which is happened in current research case. While increased in fiber content and length, reduced the compressive strength [64]. Morel et al. [65] reported that the compressive strength of SB manually pressed compressed earth bricks (CEB) were archived in the range of 2.0 to 3.0 MPa. Cement stabilization reinforced with natural fiber, as was the case in this research, exceeded 3.0 MPa in compressive strength properties.

Modules of rupture (MoR) in case of JFRSEBs SB specimens enhanced by 100%. This increased in results is due to the jute fibers bridging and bond characteristic with cement particle in soil specimens, which prevented the pulling of the fibers till its ultimate load to breakage. It is further pointed out from load-deflection curve, that the optimum strength occurred when fibers pulled-out or broken-down. This allows transmitting the flexural stress from rupture zone to the solid zone of the specimens. It can be predicted that the higher aspect ratio of the jute fibers (JF) may increase the flexural properties up to optimum limit as longer fibers in length will tends to bridge more cracks with cement particles in soil samples. This finally results to absorb more energy. Tang et al. [66] reported similar observation.

Shear strength of the specimens are measured by three-point bending test. The specimens are constructed with cement mortar with ratio of 1:5 (cement: sand). Stabilized-Earth-Bricks (SEBs) with and without jute fibers are tested in STM machine. Result showed 67.6% increase in JFRSEBs MB specimens as compared to that of SEBs MB specimens. This remarkable increase in shear strength is due the bond which created among the exposed jute fibers surfaces and cement mortar connection (refer to fig 4.5b bottom row). The cement mortar pulled the jute fibers, in result, shear behavior enhanced up to maximum level in this case. The results expressed that jute fibers can resist the literal loading in JFRSEBs masonry structure. So, the use of JFRSEBs specimens in masonry works are seems to be having good performance subjected for earthquake loading.

5.3 Comparison with Previous Studies

Comparisons of SEBs and Natural-Fiber-Reinforced-Stabilized-Earth-Bricks with previous studies are shown in Tables 5.1 and 5.2, respectively. The result showed that compressive strength of the specimens depended on the geo-tech classification of soil, cement content, water content and natural fiber content. Taallah et al. [9] conducted an experimental study on compressed cement Stabilized-Earth-Bricks (CCSEB). The modified soil gradation was used (60% silt, 10% clay, and 30% sand). Cement of 8%, by mass of total soil sample, was used as a binder. The compressive strength achieved was in the range of 11.5 MPa. At the same time, natural fiber reinforced compressed stabilized earth bricks were also cast and tested. Date palm fiber of 0.2%, by mass of total soil sample was used in fiber reinforced bricks. Only 0.5 MPa increase was observed by adding date palm fibers in compressed Stabilized-Earth-Bricks. Mostafa and Uddin [29] carried out an experimental research on Stabilized-Earth-Bricks. The soil used in the research was 84% silt, 8% clay and 8% sand. Compressive strength achieved was 3.3 MPa in this case. The same author also carried out banana fiber reinforced stabilized earth specimens. Only 0.35% of banana fibers, by mass of total soil sample, were used. 3% increase in compressive strength was observed in banana fiber reinforced Stabilized-Earth-Bricks, compared with unreinforced bricks. Segetin et al [67] achieved compressive strength of 2.2 MPa in SEBs by using soil classification of 13% silt, 9% clay and 78% sand. Furthermore, 14% increase in compressive strength was observed with incorporation of 0.8% flax fiber in the same soil specimens. In current study, local available soil consist of 27% silt, 5% clay and 67% sand is used and achieved the compressive strength of 3.705 MPa by incorporation of 1% jute fibers in SEBs. This strength is considered 82.26% increase in compressive strength of JFRSEBS specimens, compared to that of SEBs specimens.. It was observed by previous studies [9,29,67] that soil gradation was a key factor

Table 5.1: Previous study and current study comparison of SEBs single brick specimens

Previous studies	Input				CS	Size
	Cement	Silt	Clay	Sand	(MPa)	(L x B x H) mm
Taallah et al. [9]	8%	60%*	10%*	30%*	11.5	200 x 100 x 100
Mostafa and Uddin [29]	7%	84%*	8%*	8%*	3.3	120 x 120 x 90
Segetin et al. [67]	10%	20%*	3%*	77%*	2.2	250 x 120 x 100
Current Study	8%	27%**	5%**	68%**	2.0	200 x 100 x 100

* Modified content for increasing compressive strength.

** Natural content for achieving minimum code standards with small brick dimensions.

CS = Compressive strength

Table 5.2: Previous study and current study comparison of NFRSEBs single brick specimens

Previous studies	Input				CS	%age increase w.r.t SEBs	Size
	Cement + Fibers	Silt	Clay	Sand	(MPa)		(L x B x H) mm
Taallah et al. [9]	8% + 0.2% date palm fiber	60%*	10%*	30%*	12.0	12/11.5	200 x 100 x 100
Mostafa and Uddin [29]	7% + 0.35% banana fiber	84%*	8%*	8%*	3.4	3.4/3.3	120 x 120 x 90
Segetin et al. [67]	10% + 0.8% flax fiber	20%*	3%*	77%*	2.5	2.5/2.2	250 x 120 x 100
Current Study	8% + 1% jute fibers.	27%**	5%**	68%**	3.7	3.7/2.0	200 x 100 x 100

* Modified content for increasing compressive strength.

** Natural content for achieving minimum code standards with small brick dimensions.

CS = Compressive strength

to increase or decrease the compressive strength. Moreover, compressive strength could be achieved at very higher side by using compressed Stabilized-Earth-Bricks (CSEBs) technique. Thus, the compression technique interlocks all the particles of soil by mechanically pressing the soil-bricks with appropriate mix design [9]. If the bricks are stabilized with chemical binder such as cement, it will be compressed cement stabilized earth bricks (CCSEBs). Typically, compressive pressure is applied in-between 10 MPa to 20 MPa to achieve the well dense interlocked particles and impermeable stabilized earth bricks (SEBs). This technique surprisingly increased the compressive strength and reduced the water absorption properties of SEBs [9]. Thus the need of compressive technology, to stabilized soil bricks, with and without cement and jute fibers is still need to be investigated.

5.4 Minimum Requirement of Code Standards

The minimum requirement of the average compressive strength in New Mexico Earthen Building Material Code is 2.07 MPa [68]. In IS 10771992 [62], it is 3.5 MPa and in Building Code of Pakistan [69], it is 3.5 MPa. While in current study, the compressive strength achieved is 3.7 MPa in JFRSEBs specimens. Thus, it may be considered acceptable. It is further observed that the compressive strength values of SEBs SB specimens and JFRSEBs MB specimens are also acceptable when comparing with Mexico Earthen Building Code 2009 [68].

5.5 Empirical Equation Between Compressive Strength and Modulus of Rupture of Single Bricks Specimens

Empirical equation is developed with the help of experiment data (compressive and modulus of rupture) of single bricks specimens for SEBs and JFRSEBs specimens. As per ACI-318R-08 [70] section no R10.2.5, tensile strength of concrete in flexure (modulus of rupture) is a more variable property than the compressive strength and is about 10 to 15 percent of the compressive strength. Keeping the concept of ACI, a simplified equation is developed.

MoR $=\frac{1}{405^{\mathrm{F}}} * CS$ Eq 1

Where, MoR = modulus of rupture in MPa, CS = experimental calculated compressive strength of the specimens (MPa), F= 1 (flexural coefficient for SEBs specimens), F= 0.985 (flexural coefficient for JFRSEBs specimens). Table 5.3 represented the experimental and empirical values of MoR for SEBs and JFRSEBs specimens. it can be predicted that the correlation exists between MoR and compressive strength properties of the give specimens. The empirical values calculated by equation 1 for SEBs and JFRSEBs specimens are found closest to that of experimentally calculated values. The difference between experimental calculated values and empirically calculated values by equation 1 is observed 0.45% and 0.54% for SEBs and JFRSEBS specimens, respectively.

Table 5.3: Experimental and empirical values of MoR for SEBs and JFRSEBs specimens

Specimen	MoR (kPa)		
	Exp	Eq 1	Percentage error
SEBs	5	5.02	0.45%
JFRSEBs	10	10.01	0.54%

It is observed that a very miner percentage of difference is occurred among equation 1 and experimentally calculated value. The percentage error of 0.45% and 0.54%

is recorded between experimental and empirical value for SEBs and JFRSEBs, respectively.

5.6 Summary

Bond characteristic among jute fibers, ordinary Portland cement and soil were investigated. Empirical equation between compressive strength and modulus of rupture of single bricks specimens are developed and reported in this chapter. For this purpose, a series of SEBs and JFRSEBs are made and tested for their corresponding tests (discussed in chapter no 3). Surprising results observed in the case of single bricks (SB) JFRSEBs specimens in compression test. The results pointed out that the bond characteristics of jute fibers, because of their roughly surface texture, with cement and soil combination, have enhanced the corresponding strength up to 1.826 times. It is predicted that, use of jute fibers enhanced the compressive strength with minimum amount of cement content. At the same time, remarkable improvement observed in the case of flexural and shear strengths properties. Increased in shear strength is due the bond which created among the exposed jute fibers surfaces and cement mortar connection (refer to fig 4-5b bottom row). Furthermore, the empirical equation to calculate modulus of rupture of SB SEBs and JFRSEBs is developed. The comparative results expressed the negligible percentage of difference between experimentally calculated values and empirically calculated values.

Chapter 6

Conclusions and Recommendations

6.1 Conclusions

Efficiency of jute fibers (JF) Stabilized-Earth-Bricks (SEBs) made by local available soil (consist on course sand, fine sand, silt and clay) and ordinary Portland cement (OPC) are investigated in this research program. Jute fiber is considered as a reinforcing agent in jute fiber reinforced Stabilized-Earth-Bricks (JFRSEBs) cases. Compressive strength, flexural strength and shear strength of JF reinforced and unreinforced Stabilized-Earth-Bricks are examined. At the same time, density and water absorption of the both, SEBs and JFRSEBs specimens are calculated and reported. Each, SEBs and JFRSEBs are made with 29% coarse sand, 39% fine sand, 27% silt and 5% clay. 8% of cement and 1% of jute fibers are used as a binding and reinforcing agent, respectively. Fibers are used in JFRSEBs specimens only. Conclusion of the present work can be drawn as follows:

▷ Jute fiber enhanced the compressive strength of jute fiber reinforced Stabilized-Earth-Bricks (JFRSEBs) in single and multiple bricks specimens

- Up to 82% enhancement in compression test is observed in the case of JFRSEBs single bricks specimens, compared to that of SEBs single bricks specimens. An enhancement of 507%, 80% and 221%, were recorded for compressive absorbed pre-crack energy (CPE), compressive cracked absorbed energy (CCE) and compressive total absorbed energy (CTE), respectively, in JFRSEBs single brick specimens compared to that of SEBs single brick specimens. In parallel, a decrease of 47% was recorded for compressive toughness index (CTI) in JFRSEBs SB case when compared with SEBs SB specimens.

  - ◇ As compared to SEBs specimens, an increase of 122% is observed in water absorption of JFRSEBs specimens.
  - ◇ Mechanical properties of earth bricks are dependent on geo-tech classification of soil, cement content, fiber content and water content.
  - ◇ Compressive strength of JFRSEBs single bricks specimens achieved the minimum requirement of building code of Pakistan 2007, IS 10771992 and Mexico earthen building code 2009 standards.
  - ◇ An empirical equation is developed between MoR and CS of single brick specimens. Empirical values are in good agreement i-e ¡1% with experimental values.

- JFRSEBs multiple bricks (MB) specimens enhanced the load carrying capacity up to 22% compared to that of SEBs MB specimens. At the same time, the increase of 306.66%, 800%, 600% and 72% for compressive absorbed pre-crack energy (CPE), compressive cracked absorbed energy (CCE), compressive total absorbed energy (CTE) and compressive toughness index (CTI) are observed respectively, in JFRSEBs MB specimens compared to SEBs MB specimens.

▷ As compared to SEBs single bricks (SB) specimens, the increase of 100% is achieved in flexural strength of JFRSEBs SB specimens. Along with, the amount of flexural absorbed pre-crack energy (FPE), flexural cracked absorbed energy (FCE), flexural total absorbed energy (FTE) and flexural toughness index (FTI) enhanced up to 293%, 750%, 495% and 51%, respectively, in JFRSEBs SB specimens as compared to that of SEBs SB specimens.

▷ Shear strength increased up to 67% in JFRSEBs multiple bricks (MB) specimen case, compared with SEBs MB specimens. Shear absorbed pre-crack energy (SPE), shear cracked absorbed energy (SCE), shear total absorbed energy (STE) and shear toughness index (STI) improved up to 332%, 476%, 434% and 23% in JFRSEBs MB specimens as compared to that of SEBs MB specimens.

Although the conclusion presented might be specific for the specimens used in this MS thesis. It can be concluded with certainty that the local available soil consists on high fines (silt and clay) percentage can be used in Stabilized-Earth-Bricks (SEBs) if the percentage of cement decreased and the content of jute fiber 0.25-2

6.2 Recommendations

Following are the recommendations:

- Performance of proto type single bricks wall and double bricks walls with cement mortar and cement sand plaster are still needed to investigated.
- Experimental investigation of Stabilized-Earth-Bricks reinforced with other than jute fibers for their corresponding mechanical and physical properties is needed.

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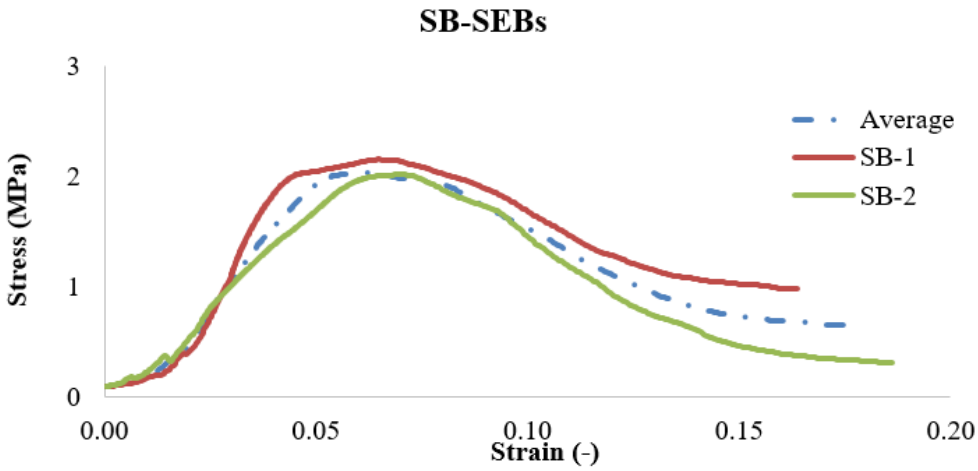
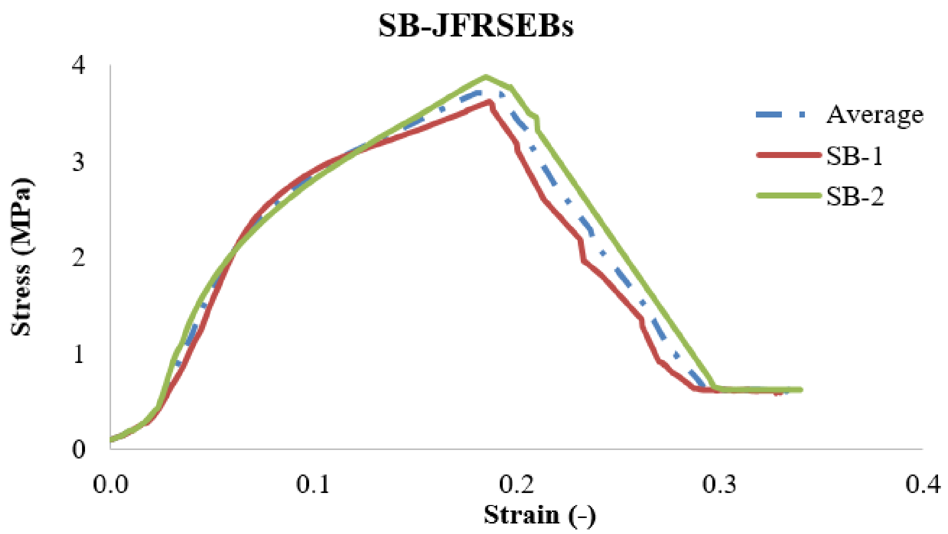
Annexure A

Compressive stress-strain curves of single bricks (SB) SEBs and JFRSEBs specimens



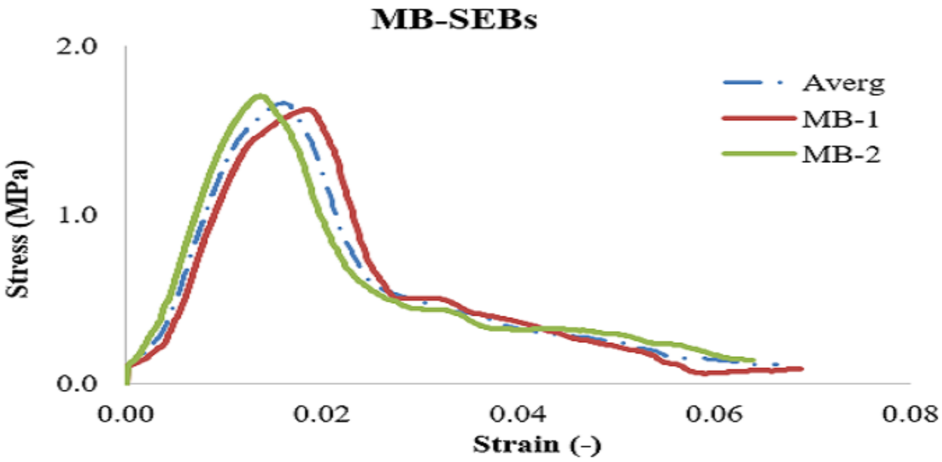
A1: Compressive stress-strain curves of single brick (SB) SEBs specimens



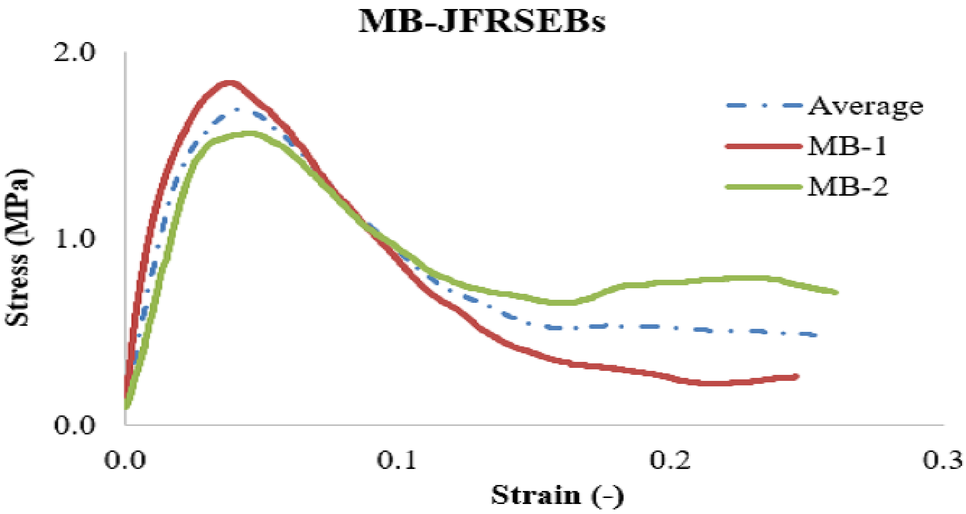
A2: Compressive stress-strain curves of single brick (SB) JFRSEBs specimens

Annexure B

Compressive stress-strain curves of multiple bricks (MB) SEBs and JFRSEBs specimens



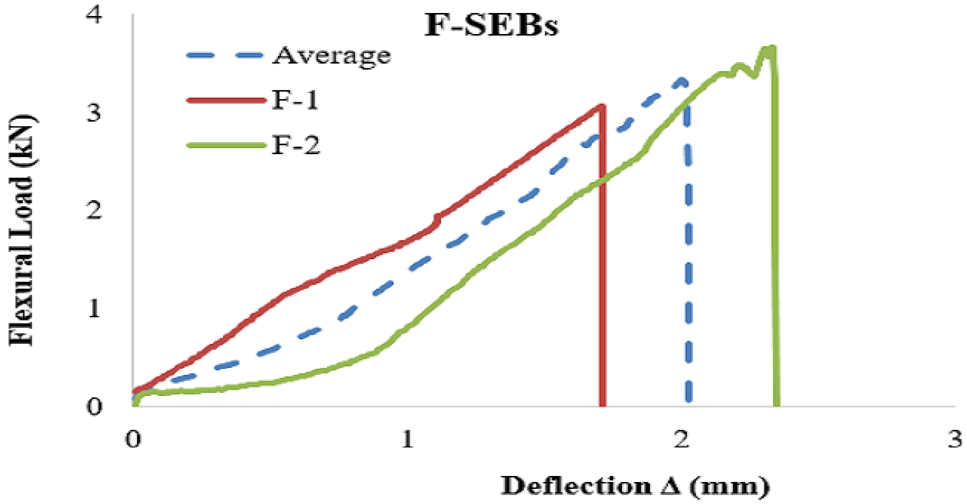
B1: Compressive stress-strain curves of multiple brick (MB) SEBs specimens



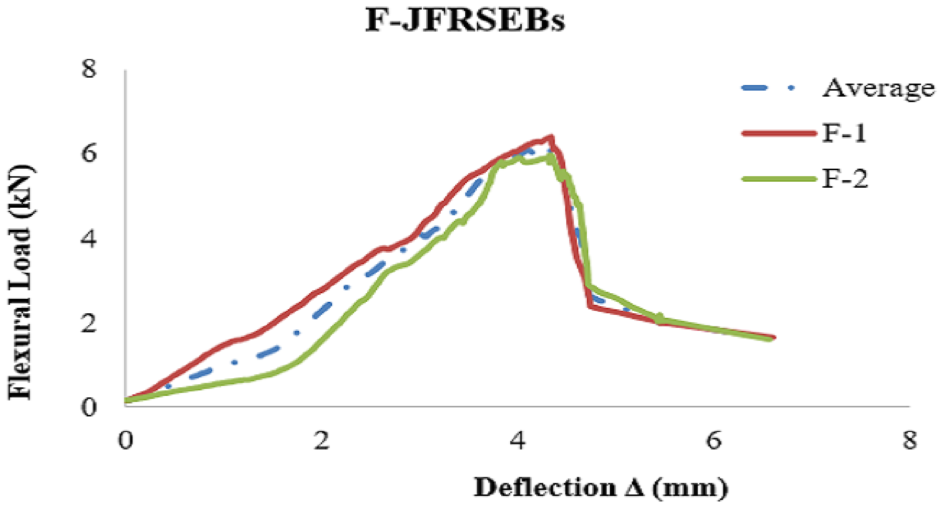
B2: Compressive stress-strain curves of multiple brick (MB) JFRSEBs specimens

Annexure C

Flexural load-deflection curves of SEBs and JFRSEBs specimens



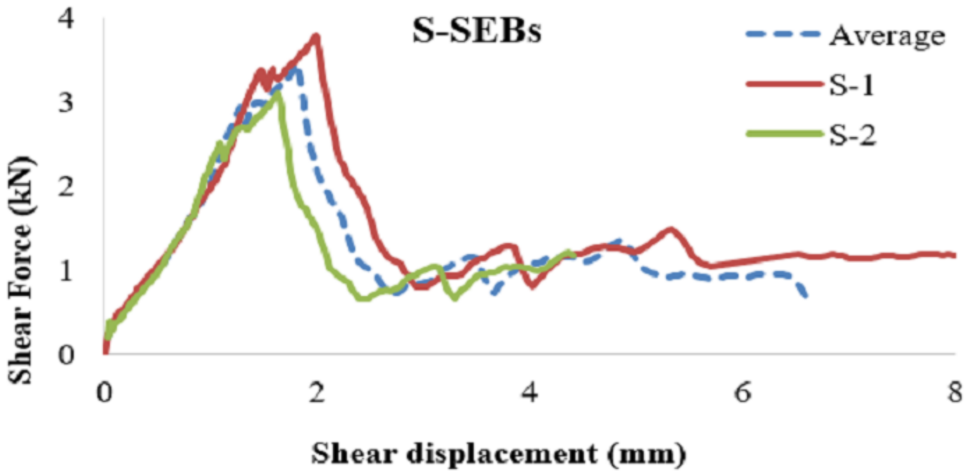
C1: Load-deflection curve of SEBs



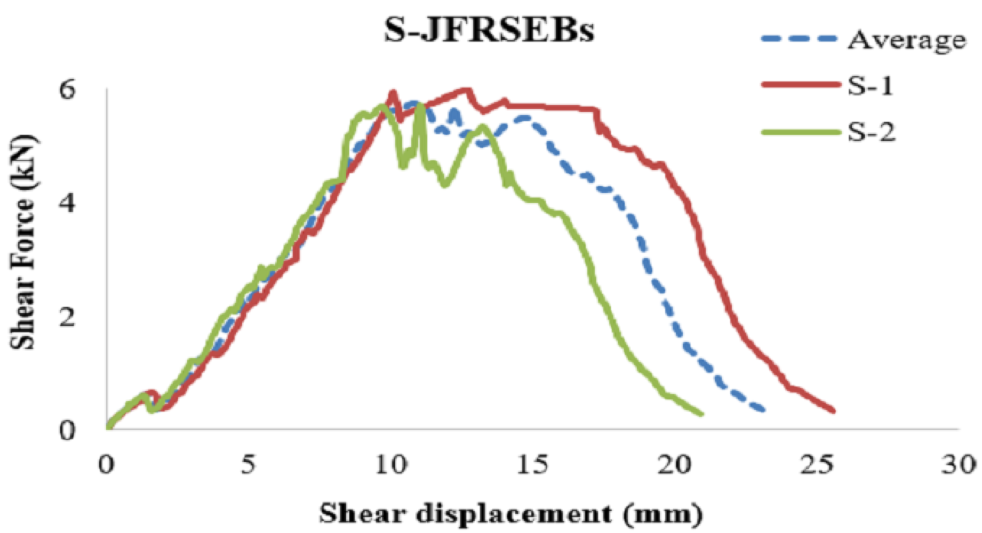
C2: Load-deflection curve of JFRSEBs

Annexure D

Shear stress-strain curves of SEBs and JFRSEBs specimens



D1:Shear force-displacement curves of SEBs specimens



D2: Shear force-displacement curves of JFRSEBs specimens