STABLIZATION OF HIGH PLASTIC CLAY USING BIOMASS ASH AND GYPSUM WASTE COMPOSITE

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MY LOVING PARENTS

FOR THEIR SUPPORT, LOVE, AND ENCOURAGEMENT

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ABSTRACT

Industrial waste significantly harmed the environment and natural ecosystems at the same time that industrialization revolutionized production and living standards. Thus, in order to attain the Sustainable Development Goals (SDGs), the United Nations (UN) propose that waste be reduced, reused, or recycled worldwide. The current study focuses on the efficient reuse of biomass Ash waste and crushed gypsum waste. High plastic soils experience expansion and contraction depending on the level of water availability. Biomass ash and gypsum waste has cementations characteristics, hence these waste has the potential to be utilized for the stabilization of such soils. Understanding the impact of crushed gypsum and biomass ash on the mechanical properties of high plasticity clay is the main goal of this study. To investigate the mineralogical and morphological characteristics, microstructural investigation using XRD and XRF of materials was carried out. The binder ratio and curing time were the important variables which were examined in this study. First, Biomass Ash was used to stabilize expansive soil in order to determine the ideal Biomass Ash content based on UCS results. It was determined to be 12.5% and fixed as the study's total binder content. Crushed waste gypsum was used in place of biomass in the binder at ratios of 0:100, 25:75, 50:50, and 75:25 when adding it to the soil. The compaction, plasticity, and strength behavior of soil stabilized using composite binder (Gypsum: Biomass Ash) were investigated experimentally. In highly plastic clayey soil, it was observed that the plasticity index decreased with the addition of gypsum and biomass ash binder. After stabilization using a composite binder, shear strength and unconfined compressive strength (UCS) enhanced. Soil stabilized with biomass ash and gypsum increased by 3.38 times compared with the untreated soil. These experiments have demonstrated that the development of cementitious hydrates, which are created as a result of reaction between $CaSO_4$ and CaO from gypsum and ($CaCO_3$, SiO_2 and Al_2O_3) from biomass ash and soil, and these are responsible for the increase in strength. It is proposed to use a 25:75 gypsum to biomass ash ratio to stabilize high plastic clayey soil. This study has demonstrated the efficacy and environmental friendliness of (Gypsum: Biomass Ash) composite binder in stabilizing high plasticity clayey soil.

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LIST OF ABBREVIATIONS

AASHTO	American Association of State Highway & Transportation Official
ASTM	American Society for Testing and Materials
CBR	California Bearing Ratio
CH	High Plastic Clay
GSD	Grain Size Distribution
LL	Liquid Limit
MDD	Maximum Dry Density
OMC	Optimum Moisture Content
BA	Biomass Ash
GW	Gypsum Waste
PI	Plasticity Index
PL	Plastic Limit
UCS	Unconfined Compressive Strength
USCS	Unified Soil Classification System
XRF	X-Ray Fluorescence
XRD	X-Ray Diffraction
BBA	Biomass Bottom Ash

CHAPTER 1: INTRODUCTION

1.1 BACKGROUND

Changing one or more soil characteristics mechanically or chemically to produce an improved soil material with the appropriate engineering attributes is known as soil stabilization. To increase strength and durability soil may be stabilized [1] **.**Soil stabilized then can be used on roads, parking areas, airport and other development site where subgrade materials are not qualified for construction [2] .Different type of weak and problematic soil exist, may be chemically weak or physically, former one includes acidic soil, saline soil, and alkaline soil, later one includes expensive soil, swelling soil, dispersive soil and surface crusted soil.

Several type of stabilization techniques exist to improve engineering properties of above mentioned and like those other soils. These are mechanical stabilization, chemical stabilization, and polymer stabilization. Mechanically soil is stabilized by compacting the soil through machineries (roller). In chemical stabilization there is chemical reaction between chemical/stabilizer and soil particle compositions and formed permanent bonds between soil particles Different stabilizers utilized in chemical stabilization such as, Magnesium Chloride, Bitumen Emulsion, Cement, Lime and Fly Ash. The technique of introducing polymers to soils in order to improve their technical and physical properties is known as polymer soil stabilization. Polymers generally strengthen soils through their interactions with soil-bound particles.

Due to machinery and the industrialization of various production processes brought about by the industrial revolution, which was a significant turning point in the history of human civilization, there has been a sharp rise in development and urbanization around industrial centers. Although society's standard of living began to improve, the quality of the living environment began to deteriorate. It wasn't discovered until it started having an immediate impact on people. Now, with tonnes of waste being produced daily, industrial waste management is a problem [2].

One of method of waste management is to utilize waste as a sustainable in weak soil to stabilize and enhance its engineering properties. Different waste materials are available which could be used as soil stabilizer as fly ash, rice husk, wheat husk, biomass, gypsum, and others. In this research Gypsum, or calcium sulphate dehydrated, ($CaSO_4.2H_2O$) as a potential binder composite with biomass ash is used for stabilization of expansive soil. Gypsum is collected as a waste material, also biomass ash includes saw dusk, chips boards, etc [2].

1.2 SOURCES OF GYPSUM:

Waste gypsum is generated in three different ways, from manufacturing process, from new construction, and from remolding/demolitions. Gypsum manufacturing waste results from material that is rejected during the production of gypsum goods. Gypsum is recycled most frequently from uninstalled gypsum board leftovers left over from building construction projects. This garbage is pure and uncontaminated. Additionally, installed ceiling and boards are removed during a building's demolition or repair, creating post-consumer trash. Gypsum waste is thought to wind up in landfills at a rate of 75%, where it produces obnoxious and potentially deadly hydrogen sulphide gas. Additionally, it may release harmful sulphates into the groundwater supply [6].

Figure 1 Gypsum waste (Manufacturing)

Figure 2 Gypsum waste (New construction) Richard Thomas Lerman, 2023

Figure 3 Gypsum waste (Demolition) Richard Thomas Lerman, 2023

1.3 SOURCES OF BIOMASS ASH

Biomass Ash is obtained as a by-products from industries, like timber, agriculture, household wastes and landfills, are all feasible sources of biomass materials. The agricultural sector such as crops of olives, citrus or grapevine generates Biomass Ash. Given that the region produces a significant amount of vegetable waste (4.6 and 1.3 million tonnes of agricultural and forest biomass wastes, respectively). Energy efficiency policies have led to the discovery of a competitive source of raw material for plants that generate electricity by burning biomass [19] currently, In Andalusia, there are 18 electric biomass cogeneration facilities that use biomass-biofuel. The inorganic, noncombustible portion of biofuel left over after full combustion is known as biomass bottom ash (BBA), and it primarily consists of the mineral fraction of the original biomass [21].

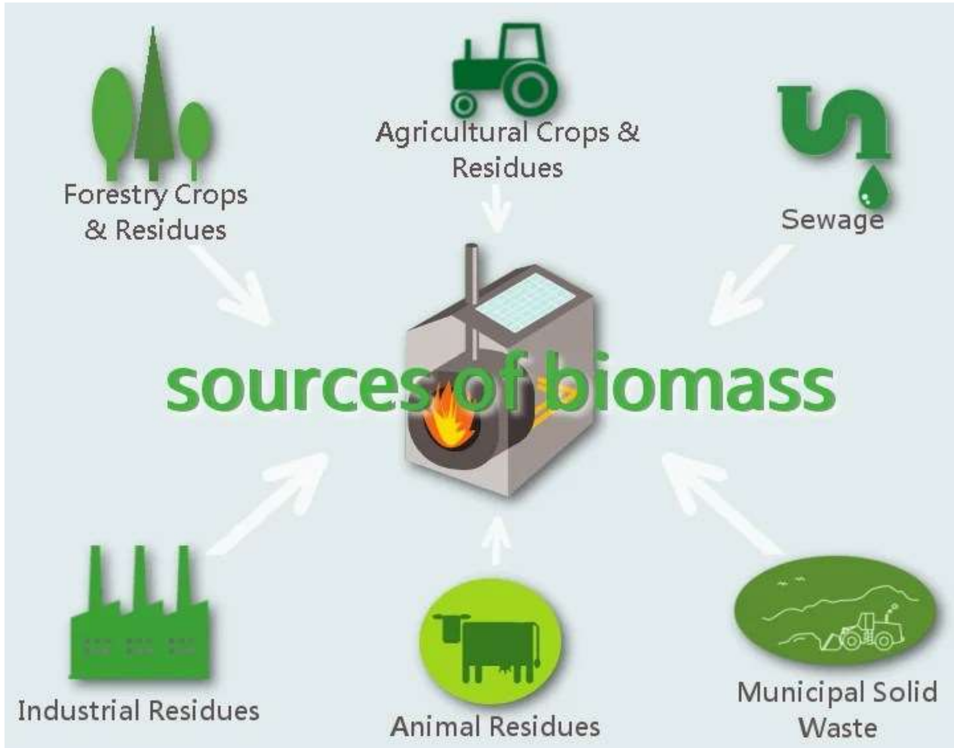

Figure 4 Sources of Biomass Ash (Salman Zafar, 2020)

1.4 PROBLEM STATEMENT:

In the past, gypsum production and also construction waste has been acceptable waste materials at landfill sites, but because of shortage of landfill space, some landfills operators and municipalities are no longer accepting gypsum waste of any kind. Additionally, when gypsum drywall is disposed of in landfills, a number of biological and chemical processes can take place that could have a negative influence on the environment, including poisonous sulphide gas. To avoid gypsum to expose to landfill, the need is to use it alternative [6]. Gypsum is non-polluting, inexpensive, fireproof, and resistant to deterioration from biological and chemical elements [5]. Because gypsum is the primary component of cementing materials, it has the potential to be utilized as one. By substituting calcium cations for sodium or other weak flocculator cations that are already present in the soil, gypsum can improve soil structure. The strength and durability of soil are seen to significantly enhance as a result of soil particle flocculation [5].

The economy of the region has historically been fueled by commodities including grapevine, citrus, and olives (AEA 2017), yet the agricultural industry produces garbage that needs to be controlled. Given the larges volume of vegetable waste produced in the area (4.6 and 1.3 million tonnes of agricultural and forest biomass wastes, respectively), by burning biomass to produce electricity have found a competitive source of raw materials for their production. The energy efficiency policies include this. [19].

There are now 18 electric biomass cogeneration units in Andalusia that burn biomass as fuel. The environment and the economy are now concerned about how industrial facilities handle and dump the ash produced by burning vegetable wastes. Callejon-Ferre et al. (2014); [20]. The large portion of minerals of the original biomass is included in biomass bottom ash (BBA), the inorganic, noncombustible portion of biofuel left over after complete combustion [21]. The physical and chemical properties of Biomass Ash depend on the operating conditions of the biomass combustion plant and the types of fuels burned [22]. That is why, BBA could result in a environmental risk, and evaluating this aspect should be necessary. [23. The amount of trash in the combination is a crucial factor when it comes to increasing the qualities of other materials in construction materials, and the dangerous potential can be reduced. Other researchers have previously assessed the potential usage of biomass ash. Other researchers have already assessed the potential for BBAs to be reused in construction materials such as road construction. [24], soil amendment, sub-base of rural paths for road embankments [22]. Ash from biomass is a pozzolanic substance. Pozzolanic materials are silicious and aluminous compounds that react with calcium hydroxide and moisture to produce cementitious materials.

1.5 AIMS AND OBJECTIVES:

The objective of stabilization is to access the possibility of using industrial waste Crushed Gypsum and Biomass in the High Plastic Clayey Soil.

To evaluate the geotechnical characteristics of High plastic clay soil by mixing Biomass Ash and Gypsum Waste composite).

i. To study Compaction behavior of Biomass Ash and Gypsum composite in high plastic clayey soil.
ii. To study Unconfined Compression Strength behavior of Biomass Ash and Gypsum composite.
iii. To Study Plasticity Behavior of Biomass Ash and Gypsum composite in High plastic clayey soil.

1.6 Organization of Thesis

This research is organized in five chapters; summary of all the chapters is discussed below:

i. Chapter 1 includes the introduction to soil stabilization, sources of Gypsum wastes, and sources of Biomass Ash, Problem statement, Aim and objectives.
ii. Chapter 2 describes the literature review of materials and process of stabilization. It also includes past studies carried out by various researchers.
iii. Chapter 3 describes the research approach taken up to achieve the goals of this study. It explains in detail the sample collections, characterization and procedures for determining optimum Biomass Ash and Gypsum wastes content.
iv. Chapter 4 presents the details and analysis of test results obtained by conducting all the tests described in Chapter 3.
v. Chapter 5 enlightens the outcomes derived from the current research as well as recommendations for the future research.

CHAPTER 2: LITERATURE RIEVEW

2.1 GENERAL

High plastic clayey soils have the potential to undergo a change in volume with the change in moisture content. These soils have the capacity to lift up, and because of the differential settlement, they could potentially destroy infrastructure. Any building built on these soils may eventually crack due to differential settlement, which is caused by moisture variations in expansive soil generating significant mass movement. For instance, a road in Sudan had a difference in settlement of up to 15% when the broad soil beneath the road became wet from precipitation penetration. [27]. The swelling and shrinkage effects of the soils on the road are represented in Figure below.

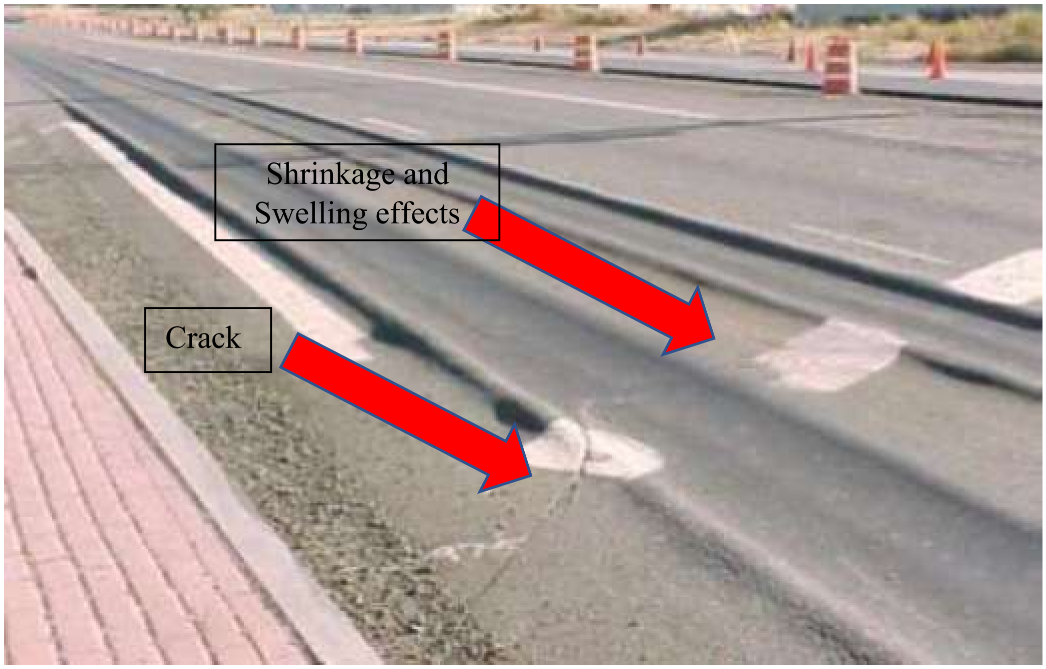

Figure 5 swelling and shrinkage effects of soil on road (Zumwari, 2015).

The clay mineral montmorillonite, which has a greater capacity to absorb water than smectite and illite, is strongly linked to the swelling potential of these soils. The main minerals that make up expansive soil are montmorillonite, illite, and smectite. The soil made of montmorillonite is typically referred to as extremely plastic soil since it expands and contracts when wet and dried. Due to the structure of expansive soil, which is similar to montmorillonite, variations in moisture content will cause the soil to expand or contract. To prevent infrastructure failures caused by their differential settlement, it is crucial to improve the performance attributes of these soils when employed as a construction material. Through soil stabilization, which can be accomplished using a variety of techniques including mechanical, chemical, and biological ones, these soils' performance characteristics can be enhanced [27].

An innovative technique for soil stabilization that is both ecologically responsible and efficient is biological soil stabilization. Several microorganisms found in the natural soil environment have the ability to generate cementations (binding material) as a result of their metabolic processes. Soil samples were subjected to a biological treatment using bacillus sphaericus to examine if it had any impact on the shear strength of swelling. As the bacterial concentration increased, shear strength surged as well. Another technique for stabilizing fragile soils is mechanical stabilization, such as compaction. The soil is stabilized using a variety of mechanical stabilization procedures, including dewatering, replacing soft soil, and compaction using various mechanical machines [28].

Chemical stabilization is a straightforward technique. Expansive soils can be stabilized chemically by adding a range of chemicals in different amounts. Chemical stabilizers are easily accessible and include natural byproducts including nutshell, bagasse ash, wheat straw ash, and rice husk. These conventional wastes must be properly disposed of in order to avoid damaging the environment. To improve the strength properties of the soils, several researchers have used bagasse ash, wheat straw ash, rice husk, lime, and other cementitious products in various combinations. Each technique has advantages and disadvantages, such as the difficulty of growing bacteria in a laboratory for biological stabilization. Mechanical stabilization comes at a higher price. Comparatively speaking, conventional chemical stabilizers are easily accessible, and using them as a reinforcing agent may also assist lower the environmental greenhouse gas load [27].

2.2 Clayey soils

Clay is a naturally occurring material created when rocks weather. According to the USCS and AASHTO categorization, clay particles are smaller than 0.002 mm; because of electrostatic forces, they adhere together despite the absence of gravitational forces. Beyond the difference in particle size, plasticity is the primary distinction between clay and silt. When clay is in contact with water, it becomes somewhat fluid; yet, when it dries, it becomes rigid and hard. When enough moisture is present, clays become sticky [30].

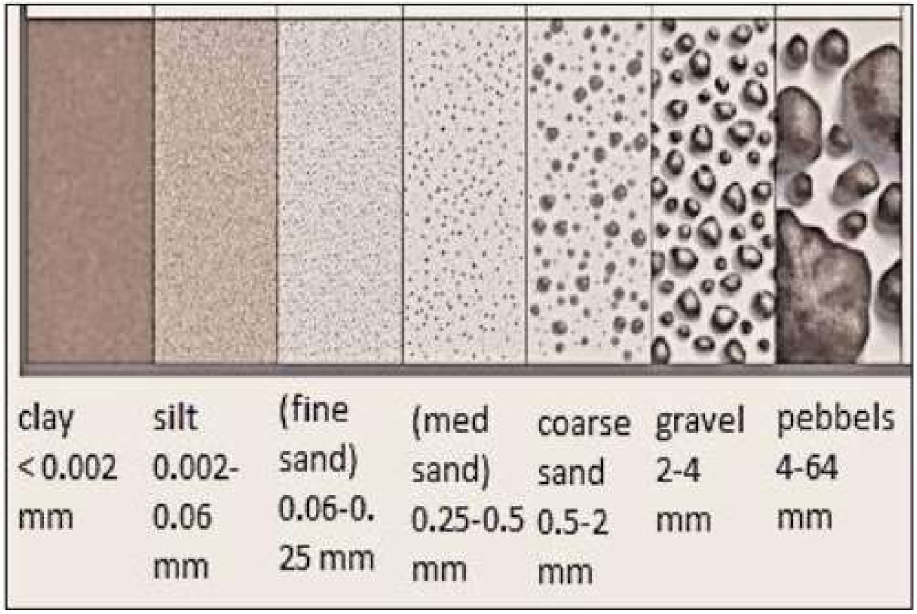

Figure 6 Classification based on particle size (Holtz and Kovacs, 1981)

Clays are divided into two classes:

Residual clay: Clay is produced in three different ways by surface weathering, which is where residual clays are discovered:

i. Chemical decomposition of rocks, such as granite, containing silica and aluminia.
ii. The solution of clayey impurities found in rocks like limestone that are insoluble and deposit as clay.
iii. Disintegration and solution of shale [8].

Clay that has been transferred or transported, also known as sedimentary clay, is clay that has been deposited in a new location that may be far from its original location as a result of erosion.

2.2.1 Structure and chemical composition of clay minerals

The characteristics that characterize the composition of clay minerals are influenced by the chemical compounds present in them, the symmetrical arrangement of atoms and ions, and the forces that keep them together. The most well-known characteristics of clay minerals are the complex silicates of different ions, including aluminum, magnesium, and iron [11]. The basic crystalline units of clay minerals can be divided into two groups based on how these ions are arranged:

a. Silicon -The silica sheet is made up of the oxygen tetrahedron, which is composed of silicon surrounded by four oxygen atoms..

b. Aluminium is surrounded by six hydroxyl units in an aluminium or magnesium octahedron, which come together to create a gibbsite sheet (if aluminium is the primary dominating atom) or a brucite sheet (if magnesium is the primary dominating atom) [11].

The silica tetrahedron and the aluminium octahedron make up the majority of the two-layer kind. The best example of the two-layer kind is kaolinite. Two layers of silicon tetrahedron and one layer of aluminium octahedron make up the three-layer kind. Expanding and nonexpanding types are further separated. Illite belongs to the non-expanding type, whereas montmorillonite belongs to the expanding type.

2.2.1.1 Kaolinite

Kaolin has a Chinese origin and is named after the "Kauling" hill in China, where it was first discovered many years ago. One unit of an aluminium octahedron and one unit of a silica tetrahedron make up the structure of kaolinite. They are primarily clay minerals with a 1:1 layer structure. Kaolinite's triclinic structure was proposed by Brindley. They have hydrogen bonding between the sheets, making them the most stable clay minerals [11].

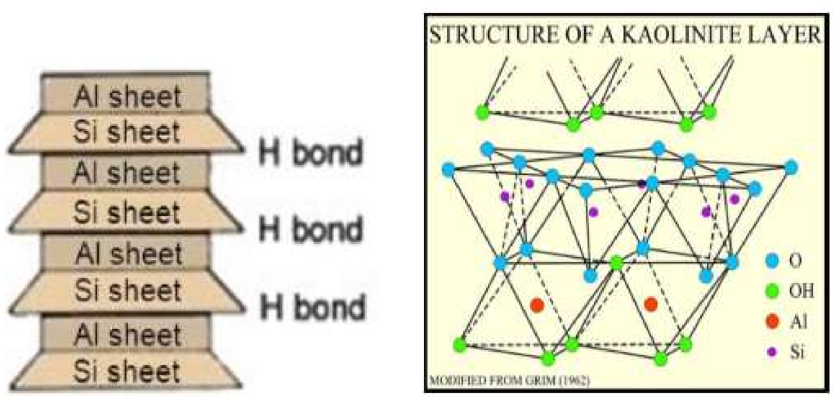

Figure 7 Hydrogen bonding + Sheet of Kaolinite (Grim, 1962)

2.2.1.2 Illite

Illite was given the name Illinois after the US state where it was found. Illite's structure is classified as a non-expanding lattice and falls within the three-layer type of crystalline structure classification. One aluminium octahedral sheet sandwiched between two silicon tetrahedral sheets makes up the structure of illite. Feldspar and felsic silicates weather to produce illite. The intermediary material between kaolinite and montmorillonite in terms of characteristics is illite. Compared to kaolinite, its hydrogen bonds are relatively weaker, whereas those with montmorillonite are relatively stronger [11].

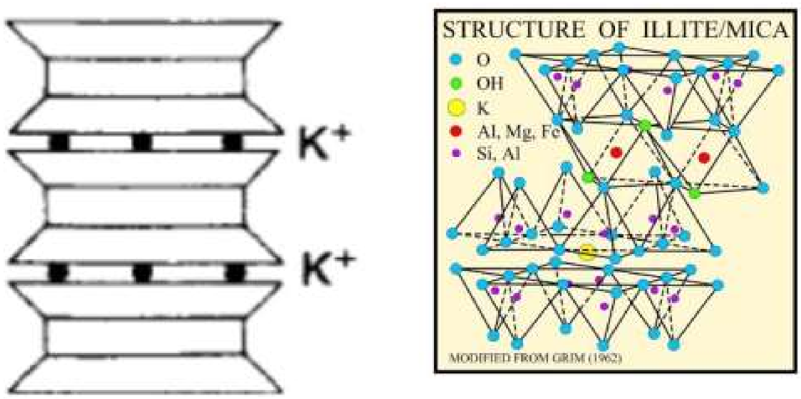

Figure 8 K bonding + Structure of Illite (Grim. 1962)

2.2.1.3 Montmorillonite

The French town of Montmorillonite is where the mineral montmorillonite gets its name. The mineral was identified as a three-layer expanding lattice crystal. It comprises of two sheets of silicon sandwiched between one aluminium octahedral sheet. Because there are weak interactions between the particles in montmorillonite, water can percolate through them and cause the lattice to expand. Van der Wall forces are the most prevalent in montmorillonite. The weathering result of the mafic silicates is montmorillonite [11].

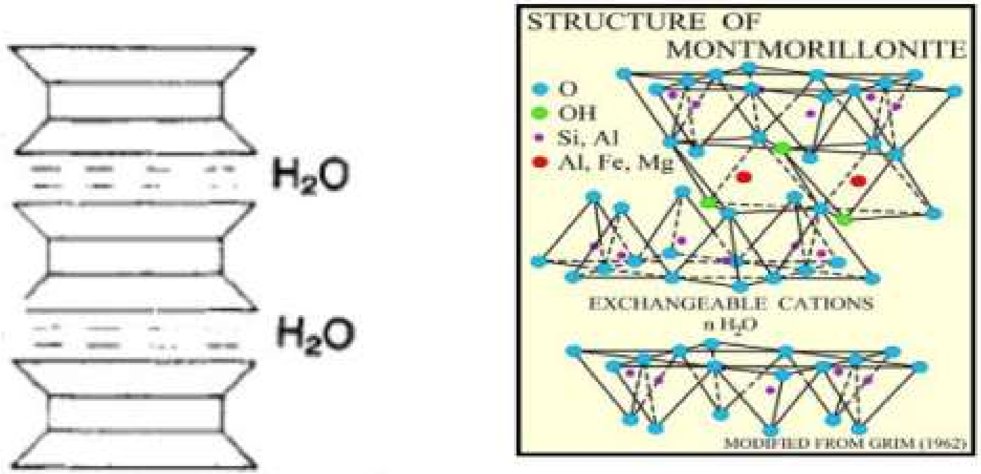

Figure 9 Bonding in Montmorillonite + Structure of Montmorillonite

2.3 Gypsum Board waste

Gypsum, or calcium sulfate dihydrate, (CaSO4l 2H2O) is the large part of drywall, or gypsum board. It is a naturally available mineral that was formed as a result of water evaporation from ancient inland seas that heavily included dissolved gypsum. A normal 20,000 gallon domestic swimming pool that is filled with seawater, for instance, will evaporate and produce around 250 pounds of gypsum. Over time, the wind's influence on surface deposits of naturally occurring gypsum rock in New Mexico's White Sands National Park changed them physically, turning them into gypsum sand that now covers a 270 square mile area [29].

On the other hand, the sulphur hot springs in Yellowstone National Park offer numerous excellent examples of how bacterial action transforms naturally existing gypsum into other sulfur-containing compounds, including elemental sulfur. Sulfate-reducing bacteria (SRB) are thought to have acted on enormous concentrations of gypsum that had previously been created by the evaporation of ancient oceans to produce the well-known large amounts of sulphur in the salt domes of Texas and Louisiana [29].

Gypsum rock is mined or quarried, then processed to make a variety of products, chief among them the plaster and wallboard produced of gypsum that are utilised in the majority of contemporary homes and workplaces in the United States and Canada.

Gypsum rock is crushed and heated to around 350 degrees F during a process called calcining in order to drive off three-fourths of the chemically combined water. For every 100 pounds of rock, gypsum contains about 21 pounds (or 10 quarts) of chemically combined water. The base for gypsum plaster, wallboard, and other gypsum products is made from the calcined gypsum (or hemihydrate) ($CaSO_4.1/2H_2O$) powder. Gypsum that has been calcined is combined with water, foam, and additives to create a slurry that is fed between endless sheets of paper on an endless belt line to create gypsum board. The calcined gypsum recrystallizes or rehydrates as the board passes down this belt line, returning to its original gypsum form, and the paper sheets solidly adhere to the rehydrated core. After being lengthened, the board is transported through dryers to eliminate any remaining free moisture [29].

2.4 Gypsum waste stabilization

2.4.1 General

Gypsum word is of Greek origin "Gypsas" meaning "plaster Gypsum is a sulphate mineral having the chemical formula CaSO4.2H2O. It is widely distributed around the world and is typically white in color. Pakistan generated 1300 thousand metric tonnes of the 258000 thousand metric tonnes of gypsum produced worldwide in 2015 (USGS Mineral Resource Programmed, 2015). Gypsum is made up of several ions and oxides. The percentage of ions and oxides in Gypsum according to (Yilmaz and Civelekoglu, 2009) are presented in table below:

Table 1 Percentage of ions and oxide in Gypsum (Yilmaz and Civelekoglu, 2009)

Ions	Percentage	Oxides	Percentage
Ca ++	23.28	CaO	32.57
H+	2.34	H_2O	20.93
S--	18.62	SO_3	46.50
O--	55.76		

2.4.2 Properties of Gypsum

Gypsum is the real source of calcium, which is a divalent cation with two electrons available for bonding and significant flocculating and replacement properties [31]. Gypsum will replace the weak cation in the soil and flocculate the soil particles, increasing the strength and angle of internal friction while lowering the soil's flexibility and swelling potential. The binding power of cations in decreasing order is shown below [30].

$$Al^{+3} \rightarrow Ca^{+2} \rightarrow Mg^{+2} \rightarrow NH_4^{+} \rightarrow K^{+} \rightarrow H^{+} \rightarrow Na^{+} \rightarrow Li^{+}$$

Table 2 Flocculation power of cations (Sumner and Naidu, 1998)

Flocculation Power of Cations			
Cations	**Charge**	**Hyd. Radii**	**Flocc. Power**
Sodium	1	0.79	1.0
Ptassium	1	0.53	1.7
Magnesium	2	1.08	27.0
Calcium	2	0.96	43.0

2.4.3 Reaction of Gypsum with Soil

Gypsum requires water to start and finish the interaction with soil. Gypsum and soil reaction is finished in the three stages listed below:

1. Cation exchange

2. Agglomeration/ Flocculation

3. Pozzolanic reaction

2.4.3.1 Cation exchange

When soil and gypsum are combined in the presence of water, calcium will take the place of the soil's sodium or hydrogen cations, which are weak cations. The following is how the reaction develops [31].

$$(H^{+} \text{ or } Na^{+})\text{-Clay} + CaSO_4.2H_2O \longrightarrow Ca\text{-Clay} + H^{+} + Na^{+} + SO_4^{-2}$$

2.4.3.2 Flocculation

Following are the completion of the cation exchange, calcium, which has a flocculation capacity 43 times greater than that of sodium, will begin to occur, resulting in much coarser soil particles than before. During the process, calcium silicate is formed, a cementitious substance that serves to enhance the characteristics of soil [31].

2.4.3.3 Pozzolanic reaction

The availability of calcium ions over the long term is necessary for pozzolanic reaction. Due to the high calcium content of gypsum, the pozzolanic reaction will last longer. The primary mechanism through which soil gains long-term strength is the pozzolanic reaction [31].

2.4.3.4 Potential of Gypsum as a Soil Stabilizer

Gypsum has been used to stabilize soil all over the world. Below are brief reviews of some of the work that was done utilising gypsum and other additions. Used Gypsum to stabilise clays that were expanding. The investigation came to the conclusion that the soil's UCS changed significantly over time. The first seven days of curing were when there was the greatest strength gain. Gypsum was used to lessen the soil's capacity to swell [29].

[34] For the stabilisation of CH and MH, phosphogypsum, fly ash, and cement were employed. The study improved the soil's flexibility, increased its OMC and decreased its MDD, dramatically raised its UCS, and produced superior results for cement-treated soil than for fly-ash-treated soil. [35] stabilised soil using phosphogypsum and leftover plastic trays. The use of the aforementioned additions resulted in an increase in OMC and a decrease in MDD, an improvement in the UCS of the soil that was notable during the first 14 days of curing, and a decrease in the capillary rise of the soil.

[32 compared the effects of lime, gypsum, MgO, RHA, fly ash, coal fly ash, coal bottom ash, steel fly ash, and aluminum filler on the soil's engineering qualities. When compared to calcium, magnesium had a greater impact on reducing swell potential. Sulfate-rich materials drastically lower the swell potential. When compared to materials with divalent cations, monovalent materials had less of an impact on soil swelling. With all of the additions utilized, UCS of the soil increases by 2-4 times RHA is a waste product made in poor nations that has a positive impact on the soil's mechanical and swelling qualities.

[33] Employed fly ash and gypsum to stabilize the peat. As the soil was cured for up to 28 days, OMC of the soil increased, MDD of the soil dropped, and UCS of the soil increased. Employed phospo-gypsum to stabilize non-plastic clay and examined its CBR value. The ideal phosphogypsum content was 21.4 percent. The usage of phosphogypsum dramatically raised UCS. The usage of phosphogypsum adequately decreased the pavement's depth.

2.4.4 Effect of Gypsum on Soil Properties

2.4.4.1 Grain size distribution (GSD)

Gypsum addition modifies the soil's GSD. The size of the soil particles rises as a result of the flocculation of the particles [29].

2.4.4.2 Atterberg limits

Depending on the soil's composition, adding gypsum may or may not increase the liquid limit. Due to flocculation and the coarseness of the soil particles, the plasticity index of the soil will decrease [34].

2.4.4.2 Density and moisture relationship

Gypsum will cause a decrease in MDD and an increase in OMC. Because gypsum powder has a smaller particle size than soil, which has a larger surface area and needs more water for lubrication, the OMC has increased. The pozzolanic reaction, which needs additional water to complete the chemical reaction, can also contribute to an increase in OMC. Due to flocculation, which makes compaction challenging, MDD will decrease. Flocculation increases the quantity of voids in the soil sample, which reduces MDD by increasing the size of the soil particles [35].

2.4.4.3 Unconfined compressive strength (UCS)

The generation of cementitious products and flocculation will result in an increase in the UCS of the gypsum-treated soils. Increased particle size and cementitious materials aid in enhancing the soil's UCS [29].

2.4.5 Uses of Gypsum

Gypsum is used in a great many products. Some of the major applications of Gypsum are as follows:

- Gypsum is used in the manufacturing of hard boards.
- Used in manufacturing of cement and Plaster of Paris.
- Used as a hardness preventer in Portland cement.
- Gypsum is used for ornamental purposes.
- Gypsum is used in making surgical and orthopedic cases.
- The primary ingredient of toothpaste.
- Used as a fertilizer in the soil.

2.5 Biomass Ash

The ash produced from burning agricultural waste has been found to help stabilize soil. Biomass Ash can be used as a filler, a binder on its own, such as glass, Portland, gypsum, or clay minerals, when it contains pozzolanic minerals, which when combined with other substances results in a pozzolanic reaction, leading to hydraulic binding when it contains active minerals, such as lime, calcium and magnesium silicate, or alumina silicates. Biomass ash has been researched for wearing course construction on both concrete and asphalt pavements. Due to its pozzolanic and hydraulic properties the bio-Biomass Ash has a high potential ash in soil stabilization for the aforementioned applications. Application of bottom ash from biomass (olive) combustion inhibits the expansion of expansive soils to the same level as treatment with lime. According to research findings, the best amendments for residual soils in terms of plasticity, compaction, strength qualities, and cost are 6-8% cement and 10-15% rice husk ash. When rice husk and sugar cane bagasse biomass ashes are used to stabilize alluvial soil, the plasticity index decreases as ash increases from 2.5% to 12.5%; the best suitable ash content for stabilization has been observed to be 7.5%. Optimum moisture content increases as the dosages of stabilizers rise, mixing rice husk ash, bagasse ash, and rice straw ash with soil increases. The California Bearing Ratio (CBR) values were also elevated by adding the same ash to clayey soil at a concentration of 20–25% [36].

Clay's compressive strength rose when rice husk and sugarcane bagasse-based mixed biomass ash and hydrated lime were utilized as an activator. Similar results are observed when bagasse ash is given to expansive soils; these are elevations in CBR, compressive strength, and maximum dry density also a reduction in swelling. As a stabilizer, sugarcane straw ash also improves the geotechnical properties of lateritic soil samples [36].

The mixture of wheat husk and sugarcane straw ash positively impacts the geotechnical characteristics of soil. Rice husk and coal fly ash admixtures in soil may increase the soil's resistance to permanent deformation. Ash from agricultural olive wastes used in biomass furnaces can also be utilized as a filler for road embankments. The least effective additive in the stabilization of marl soil, on the other hand, was found to be biomass fly ash of olive waste, suggesting that its efficacy may vary depending on the kind of soil to be treated [41].

2.6 SOIL STABILIZATION

Soil stabilization is a process in which any chemical or mechanical method is applied to enhance the engineering properties of the soil. The engineering qualities of soil, such as strength, permeability, swell potential, and compressibility, are improved via soil stabilization [42].

Different studies have been carried out by many experts to increase the mechanical and physical characteristics of soil utilizing various forms of garbage. For instance, waste plastic, fly ash, lime, cement, blast furnace slag, stone dust, recovered carpet wastes, and sewage sludge ash are all subjects of their research.

2.6.1 Soil Stabilization using cement kiln dust

Different percentage (2%, 5% 7%, 10%) of cement kiln dust was added to six type of fill clay soil. Classification tests were performed on these soils. The addition CKD resulted in increase of liquid limit, decrease in plasticity index and reduction of swell potential [6].

2.6.2 Soil Stabilization using granulated blast furnace slag and red gypsum

[37] Employed red gypsum and ground granulated blast furnace slag as a stabilising agent to stabilise peat soil. A combination of in-situ and laboratory experiments showed that the binder that was mixed was just as good at boosting peat's strength as regular Portland cement. To stabilize cohesive soil, Sewage sludge ash (SSA) and cement were used. A-6 clay was chosen as the untreated soil, and the mix ratio was 1:3. Also, SSA/cement was mixed with 0, 1, 2, and 3% of nano-AL_2O_3 to replace 15% of the clay soil. The result showed that employing 15% SSA/cement significantly increased the untreated soil's UCSs and CBR values. Also, to enhanced the treated soil in terms of both UCS and CBR values, 1% nano-Al_2O_3 addition improved using 15% SSA/cement. Also, a 1% addition of nano- Al_2O_3.

2.6.3 Soil Stabilization using Gypsum and Puddy Husk Ash

To find the engineering parameters of soil, 2% gypsum and 2%–15% paddy husk ash were added. According to the USCS and the AASHTO classification systems, the soil was categorised as Clay - Low Plasticity (CL) and as A-7-6 (10) respectively. On the original soil sample, the Proctor standard test was run, and the results showed that the ideal moisture content was 20.50% and the maximum dry density was 1,31g/cm3. The greatest value of the unconfined compression test (UCT) was achieved when 2% gypsum and 0% PHA were added to the original soil, which had a density of 1.41 kg/cm2. Gypsum boosts the soil's strength qualities [8].

2.6.4 Soil Stabilization using Gypsum and NaCl

In this paper Gypsum and NaCl were used in order to analyse the engineering qualities of the soil. To find the impacts of adding soil with various NaCl concentrations (15%, 20%, and 25%), compaction characteristics, consistency limitations, and compressive strength were measured. The addition of Gypsum and NaCl to the soil, decreased its liquid limit, plastic limit, and plasticity index. When compaction tests were performed on soil stabilized with NaCl and gypsum, the dry density of the soil increased while the ideal moisture content fell. Additionally, CBR testing was done on soil that contained the chemicals gypsum and salts as a stabilising agent, and the results revealed a higher CBR value [2].

2.6.5 Soil Stabilization using Lime and Gypsum

To check the unconfined compressive strength behavior, Lime and gypsum were added at different ration. It was declared that for all mixture ratios and periods, the effect of gypsum on compressive strength is not accurate as accurate as for the swell pressure and swell percent. Compressive strength increased seven time as compared to original value by adding 15% of lime at 90 days, while adding gypsum showed minor effect, it increased the compressive strength by 3.86 times. Also, by adding different ratios of gypsum at 7-, 28-, and 90-days compressive strength was decreased. There was no such optimum point of additive ratio for 7 days and 28 days as the strength gain increased but to stabilize the unconfined compressive strength, 12 % lime is the optimum [4].

2.6.6 Feasibility of Agricultural Biomass Fly Ash Usage for Soil Stabilization of Road Works.

As lime substitutes for soil three agricultural biomass fly ashes are utilized in this study that has been hydraulically stabilized. The goal of this study is to assess the possible use of agricultural biomass fly ash for stabilizing the soil during road construction, for subgrade and embankment reasons. The findings suggest that barley, sunflower seed shells, and wheat fly ash may be used as alternatives to lime in the stabilization of the soil during road construction. The chemical makeup of stabilized soil that incorporates biomass fly ash greatly impacts its strength qualities. By a lime/biomass fly ash binder low plasticity clay's geotechnical properties were enhanced by lowering the plasticity index, linear swelling, and raising the ideal moisture content. It is important to take into account the chemical makeup of biomass fly ash when assessing its potential use as a replacement for binder. Fly ash from biomass is added, which lowers the soaking CBR value while raising compressive strength. The chemical makeup of stabilized soil that incorporates biomass fly ash greatly influences its strength qualities [36].

2.6.7 Stabilization of expansive soils with biomass bottom ashes for an eco-efficient construction

In this study, bottom ashes from electric power plants that burn biofuels were assessed to determine whether they may be used as expansive clay stabilizers. Two goals are pursued: (1) finding a new use for waste that is typically dumped despite the waste's high potential due to its technical characteristics, and (2) enhancing the mechanical characteristics and lessening the expansive nature of the expansive clays discovered during the construction of a motorway. Based on this conceptual framework, the current investigation showed that biomass bottom ashes have the ability to stabilize expansive clays based on performance metrics like plasticity, free swelling, or soil collapse, the ideal dosage to enhance the qualities of clays was found. After that, the ashes' potential for contamination was assessed and they were labelled as hazardous waste. Expansiveness was greatly decreased after mixing with both biomass bottom ash in various amounts, the low CBR index of clay soil (1.4) was addressed when the soil was stabilised, the bearing capacity significantly enhanced with the 16% of BBAG (to a CBR of 8), [36].

CHAPTER 3: MATERIALS AND METHODOLOGY

3.1 GENERAL

This chapter illustrate the mechanism to achieve the desired properties and cover a brief description of collection of soils sample, gypsum waste, biomass ash, and preparation of remolded soil samples and the laboratory tests to determine the index properties, compaction behavior and shear strength characteristics to accomplish the intended research. Along with the accompanying ASTM standard identifiers for the tests, the procedures for standard tests have been described.

3.2 COLLECTION OF SOIL SAMPLES

Naturally available fine-grained soils (high plastic soil) were collected from Nandi Pur Punjab Pakistan. Soil sample was collected from a depth of 5ft below natural surface level and collected in polythene bags and transported to geotechnical laboratory for different types of testing to achieve the desired goals.

Figure 10 Satellite image of Nandipur, Punjab (Pakistan)

3.3 GYPSUM WASTE MATERIALS:

Gypsum waste is crushed and pass-through US sieve # 40 to use in soil sample. The study attempts to fulfil the objectives of sustainable development, which include recycling and alternative uses for waste products. Gypsum waste is readily available in Pakistan at both industry and construction sites in large quantities. Gypsum waste was gathered for this investigation from a Rawalpindi, Pakistan, from manufacturing facility. To determine the mechanical behaviour of the soil sample, crushed gypsum was combined in various ratios.

Figure 11 Gypsum waste collection site

Figure 12 Gypsum waste disposal at collection site

3.4 COLLECTION OF BIOMASS ASH:

Pakistan has a wealth of biomass resources, however these resources go beyond habitat and animal waste to include feed-stocks including agricultural stalk, straw, trash, agro-industrial bagasse, paddy husks, paddy shells, forestry and woodchips, barks and trims, and riverbank greens (M Saghir, 2019). For this study Biomass Ash was collected from Punjab oil mills located in Rawalpindi (Punjab province of Pakistan, coordinates are **33°32'30"N, 73°8'32"E**). For use in soil stabilization Biomass Ash was oven dried and pass through Sieve #40. It was then stored in polythene bags for usage.

Figure 13 Punjab Oil Mill (Biomass collection site)

Figure 14 Biomass Ash waste collected from collection site

3.5 METHODOLOGY

The research was carried out in the five phases as follow:

Phase I: (Properties of Untreated Soil)

Phase II: (Optimization of Biomass Content)

Phase III: (Optimization of Biomass with Optimum Gypsum Content)

Phase IV: (Properties of Treated Soil)

3.5.1 Phase I: (Properties of Untreated Soil)

In the first phase of the study, soil sample was collected and properties of natural soil like Atterberg limits, Specific gravity, MDD, OMC and UCS of high plastic clay soil was calculated.

3.5.1.1 Sample collection

The soil sample was collected from Nandipur, Pakistan. The sample was collected from the depth of 3 feet so that impurities can be avoided.

3.5.1.2 Geotechnical tests

A variety of laboratory tests were performed on soil samples, in order to measure different properties of expansive soil. While some soil characteristics, which depend on both the structure and content of the soil, must be assessed on samples that have been kept mostly undisturbed, other characteristics, which depend on the composition of the soil matrix, are unaffected by sample disturbance. While some soil tests measure the desired value directly, others do it by employing "index properties," which provide insightful data about the soil. Geotechnical studies were conducted to ascertain whether a mixture of biomass ash and gypsum waste might be used to stabilize expansive soil acquired from Nandipur. (Punjab).

3.5.1.3 Sieve Analysis

This test was performed in accordance to ASTM D6913 - 04(2009). The sieve analysis method was used to determine the grade of the soil sample. Sieve analysis makes use of a column of sieves. For 8 to 10 minutes, the sample was shaken in a sieve shaker. The retained weight on each sieve was divided by the final soil weight to get the percentage of soil that was kept on each sieve. A graph was drawn between the percent passing, noted on the ordinate from certain sieves, and particle size (mm), noted on the abscissa, based on the data acquired.

Figure 15 Sieve Analysis Assembly

3.5.1.4 Hydrometer analysis

A soil sample that has been run through filter #200 underwent hydrometer examination in accordance with ASTM standard D7928-16. Through hydrometer examination, the percentage of silt and clay particles was determined.

3.5.1.5 Atterberg limits

The Atterberg limit was determined using ASTM standard D4318-10. Calculations were made for the soil's LL, Plastic Limit (PL), and PI. To conduct the test, a 200 grams soil sample that passed through sieve #40 was employed. The test was run in order to classify the soil.

Figure 17 Casagrande’s apparatus

Figure 16 Plastic limit sample preparation

3.5.1.6 Specific gravity (G_s)

The specific gravity test for clayey soil was performed according to ASTM D854-14. The test was performed with the soil sample passing through sieve #16.

3.5.1.7 Standard Proctor Compaction Test

Compaction test was performed according to ASTM D698. In order to identify the optimal moisture content (OMC) at which a specific soil type will become denser and reach its maximum dry density (MDD) in the field, Proctor (1933) created a laboratory compaction test procedure. The compaction method helps to raise bulk density by eliminating air from cavities and gradually introducing more water. After passing through filter #4, a 2.5 kilograms soil sample was collected and finely powdered. Three layers of the totally mixed, water-varying amount of pulverized earth were placed within the compaction mould, and each layer was hit 25 times with a standard proctor hammer from a height of 12 inches to compact it. The experiment was carried out five times with the moisture content raised until the MDD was obtained.

Figure 18 Standard Proctor test assembly

3.5.1.8 Unconfined compressive strength

UCS of the untreated soil was calculated using ASTM standard D2166-13After being prepared, samples were cured for 7, 14, and 28 days before being evaluated. ASTM D5102-019 was followed in conducting the test. The samples were prepared for testing by curing by enclosing them in airtight plastic bags and keeping them there for the required amount of time in a 30 degree Celsius oven. The mould was 4 cm in diameter and 8 cm tall. The soil sample was completely compacted inside the mould, being careful not to over compact it.

Figure 19 UCS testing on Soil Sample

3.5.2 Phase II: Optimization of Biomass

In this phase, samples were prepared and tested by adding 5, 7.5, 10, 12.5, 15 and 20 percent of Biomass with soil.

3.5.2.1 Compaction characteristics at different percentages of Biomass

Samples were prepared by mixing soil with 5, 7.5, 10, 12.5, 15, and 20 percent of Biomass. To illustrate the relationship between moisture and density, the ASTM D698-07 standard Proctor test was carried out. With a 5.5-pound hammer, samples were compressed in three layers with 25 blows each.

3.5.2.2 UCS at different percentages of Biomass

UCS test samples were prepared at 5, 7.5, 10, 12.5, 15, and 20 percent of Biomass with soil. Two samples were created with 95 percent of OMC and MDD according to the Proctor test's previously determined results. These samples were placed in airtight bags and dried for 7 days at 30 degrees Celsius. The ideal biomass content was thought to be the amount of biomass that provided the maximum UCS value.

3.5.3 Phase III: Optimization of Biomass with Gypsum

In this phase, samples were prepared with optimum Biomass content and 25, 50, 75, and 100 percent replacement of biomass with gypsum by weight and then tested.

3.5.3.1 Compaction characteristics at different percentage of replacement of optimum biomass with gypsum

Samples were prepared with optimum Gypsum content and 25, 50, 75, and 100 percent replacement of biomass with gypsum by weight of soil. Three layers of the material were compressed with 25 blows each using a 5.5 lb. hammer that was dropped from a height of 12 inches. Each trial's moisture and density relationship was plotted.

3.5.3.2 Unconfined compressive strength at different percentage of replacement of optimum biomass with gypsum

UCS test samples were prepared at optimum Biomass content and 25, 50, 75, and 100 percent replacement of biomass with gypsum by weight of soil The samples were created using the compaction test's computed OMC and MDD at 100%. Two samples were made, baked for seven days at 30 degrees Celsius, sealed in airtight plastic bags, and then tested. The average of the two samples that produced the maximum strength was regarded as having an ideal percentage of biomass and an ideal amount of gypsum.

Figure 20 Sample failed in shear

3.5.4 Phase IV: Properties of Treated Soil

As optimum biomass content and optimum of their combination are computed. These percentages were used to calculate the Atterberg limits, standard proctor, and UCS of the treated soils, and the influence of curing on the strength was clearly visible. Curing was done for 7, 14, and 28 days. All the above-mentioned tests were performed for treated soil.

3.5.4.1 Atterberg limits of treated soil

In accordance with ASTM D4318-10, the LL, PL, and PI values for soils treated with gypsum and biomass were computed.

3.5.4.2 Compaction characteristics of treated soil

For the soil treated with the ideal ratio of biomass and gypsum, the standard Proctor test was carried out to determine the link between OMC and MDD.

3.5.4.3 Unconfined compressive strength of treated soil

Two UCS samples were made using the best possible proportions of biomass and gypsum. These samples were created using the Proctor test's computed OMC and MDD at 100%. Before testing, samples were cured in an oven for 7, 14, and 28 days at 30 degrees Celsius while being sealed in airtight plastic bags. The two specimens' average value was noted.

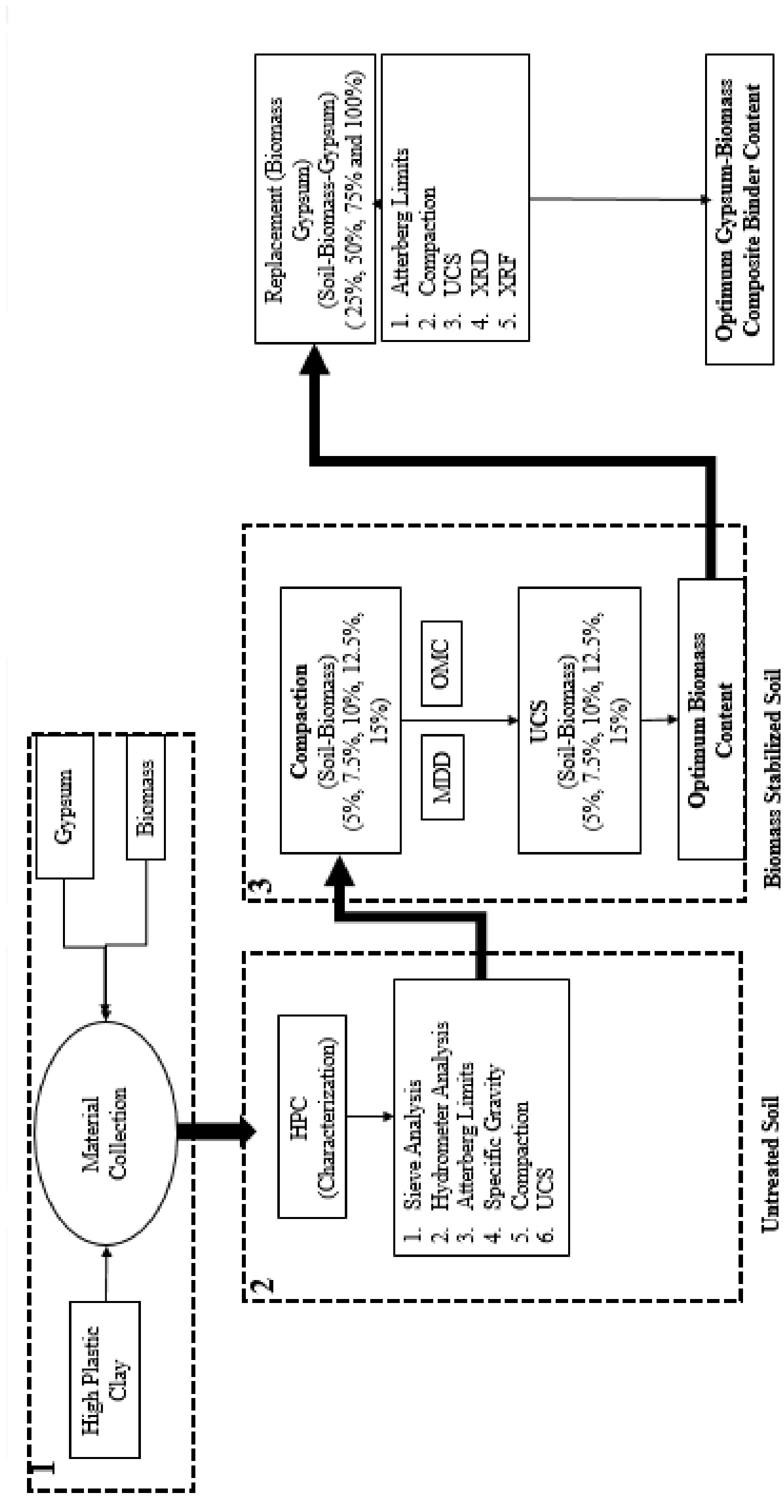

Figure 21 Flow chart of research

CHAPTER 4: RESULTS AND DISCUSSION

4.1 General

This chapter explains the results obtained, based on the testing performed to check the suitability of waste Gypsum and Biomass Ash as soil stabilizers. Theses additives are used as a stabilizers for high plastic clayey soil.

4.1.1 Scope of the work

This chapter include stabilization of high plastic soil by using crushed Gypsum and Biomass. Both the soil index properties and engineering properties are discussed in this chapter. The index properties include, specific gravity, liquid limit, plastic limit, dry density, grains size distribution, hydrometer analysis etc. while the engineering properties are shear strength, and compaction. The results of the test are discussed, with a focus, to bring out the stabilizing effect of Crushed Gypsum and Biomass Ash.

4.2 Phase I: Properties of Natural/ Untreated soil sample

4.2.1 Chemical Results

Chemical study includes XRD (X-ray Diffraction) and XRF (X-ray fluorescence). To study the mineralogy and internal structure of soil, multitude chemical tests were performed that are discussed below.

4.2.1.1 XRD Results

XRD analysis was conducted to determine the mineralogical characteristics of soil at different temperatures. It was performed on soil samples, obtained from Nandipur, Punjab (Pakistan) and on both the stabilizers.

Figure 16 identifies problematic minerals that are responsible for abnormal behavior of soil. The study soil was composed of enormous amount of kaolinite and minor amount montmorillonite as shown in Fig. 16. Kaolinite clays are classified as non-dispersive. Kaolinite has a 1:1 structure consists of alternating layers of one silica tetrahedral sheet to one alumina octahedral sheet shown in figure. Illite's structure is classified as a non-expanding lattice and falls within the three-layer type of crystalline structure classification. One aluminium octahedral sheet sandwiched between two silicon tetrahedral sheets makes up the structure of illite. Feldspar and felsic silicates weather to produce illite. Compared to kaolinite, its hydrogen bonds are relatively weaker, whereas those with montmorillonite are relatively stronger. Smectite is a layered clay mineral with a structure like a sheet. Tetrahedral and octahedral sheets make up the individual layers that make it up. The silicon (Si) atoms in the tetrahedral sheets are joined by four oxygen (O) atoms to form a tetrahedral structure. Aluminium (Al) or magnesium (Mg) atoms are joined to six hydroxyl (OH) groups to form octahedral sheets in the octahedral sheets [11].

Weak electrostatic forces and water molecules that exist between the layers of smectite hold the layers together. Smectite can experience hydration and dehydration processes in this configuration, which causes it to have swelling and contracting properties. The presence of exchangeable cations in the interlayer gaps is related to the cation exchange capacity (CEC) of smectite [11].

Contrarily, quartz is a crystalline form of silica (also known as silicon dioxide, or SiO_2). It has a linked three-dimensional framework structure made of SiO4 tetrahedra. Each silicon atom is joined to four oxygen atoms, with two tetrahedra sharing each oxygen atom. Tetrahedral structure is produced continuously by this arrangement. Numerous crystal habits, such as prismatic, hexagonal, and tabular shapes, can be seen in quartz crystals. Quartz has a very solid structure and does not easily hydrate or have strong swelling qualities like smectite. It is a non-plastic mineral that helps to maintain the soil's overall stability and mechanical qualities [11].

Quartz and smectite combined produce a heterogeneous mineralogy in high plastic clayey soils that affects the soil's behaviour. While quartz provides structural stability and affects qualities like permeability and strength, smectite contributes to the soil's flexibility and ability to hold onto water [11].

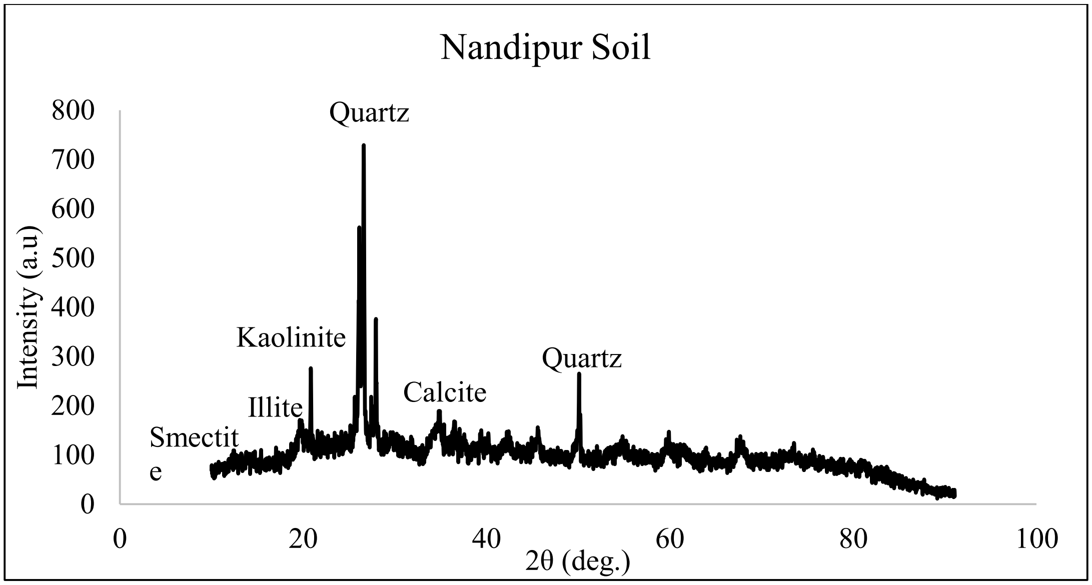

Figure 22 Soil Sample XRD Pattern

4.2.1.2 XRF Results

X-ray fluorescence (XRF) test was performed to evaluate the chemical composition of crushed gypsum and Biomass Ash. Soil composition in form of oxides is given below: Table 3 shows that soil sample has major portion of SiO2 (62.59%) and Al2O3 (19.68%), Also gypsum waste has SO3 (45.37%) and CaO (31.98%),

Table 3 XRF results of Soil sample, Gypsum waste and Biomass Ash

Chemical Composition	Nandipure soil	Gypsum	Biomass Ash
SiO_2 %	62.59	1.88	39.31
Al_2O_3 %	19.68	0.21	6.03
Fe_2O_3 %	6.32	0.17	4.04
CaO %	2.28	31.98	17.45
MgO %	2.57	0.36	3.56
K_2O %	3.18	0.05	5.01
Na_2O %	1.32	0.24	3.87
SO_3 %	0.13	45.37	7.71
Cl %	0.03	0.002	1.46

4.2.2 Grain Size Distribution (GSD)

The gradation of soil is determined via a sieve analysis test. It aids in soil classification in accordance with AASHTO and USCS. Since soil contains particles of all sizes and shapes, the sieve analysis reveals the varied percentages of gravel, sand, silt, and clay contained in the soil. The sizes and forms of the particles must be determined because they are crucial to numerous laboratory tests. On samples of untreated soil in a lab, sieve analysis was performed, following ASTM standard D422-07. For high plastic clayey soil sample, 98.135 percent sample passed through sieve #200.

Table 4 Sieve Analysis result

Sieve Number	Diameter (mm)	Soil Retained (g)	Accumulative Retain (gm)	% Mass Retain	% Passing
No. 4	4.75	0			
No. 10	2.00	0	0	0.0000	100.0000
No. 16	1.18	0	0	0.0000	100.0000
No. 20	0.85	0	0	0.0000	100.0000
No. 40	0.43	0	0	0.0000	100.0000
No. 60	0.250	0	0	0.0000	100.0000
No. 100	0.1500	2.67	2.67	0.7333	99.2667
No. 200	0.0750	4.12	6.79	1.8649	98.1351
Pan	--	357.3	364.09		

4.2.3 Hydrometer Analysis

The main purpose of hydrometer analysis in geotechnical engineering is to determine the grain size distribution of a fine-grained soil that passes through sieve #200.Results from tests using sieve analysis are unreliable for soil with fine granules. This occurs as a result of the presence of particles in fine-grained soil ranging in size from 0.075 mm to 0.0002 mm. Stock's law serves as the foundation for hydrometer analysis. All other factors being equal, the speed at which grain settles out of suspension determines the grain's form, weight, and size. The soil grains are thought to be spherical and to have the same specific gravities in the case of soil. In a suspension of dirt and water, the coarser grains will settle more quickly than the finer ones.

Hydrometer analysis was done according to ASTM standard D7928-16. The hydrometer test results showed that in the case of CH, 55.25 percent was less than 2 microns.

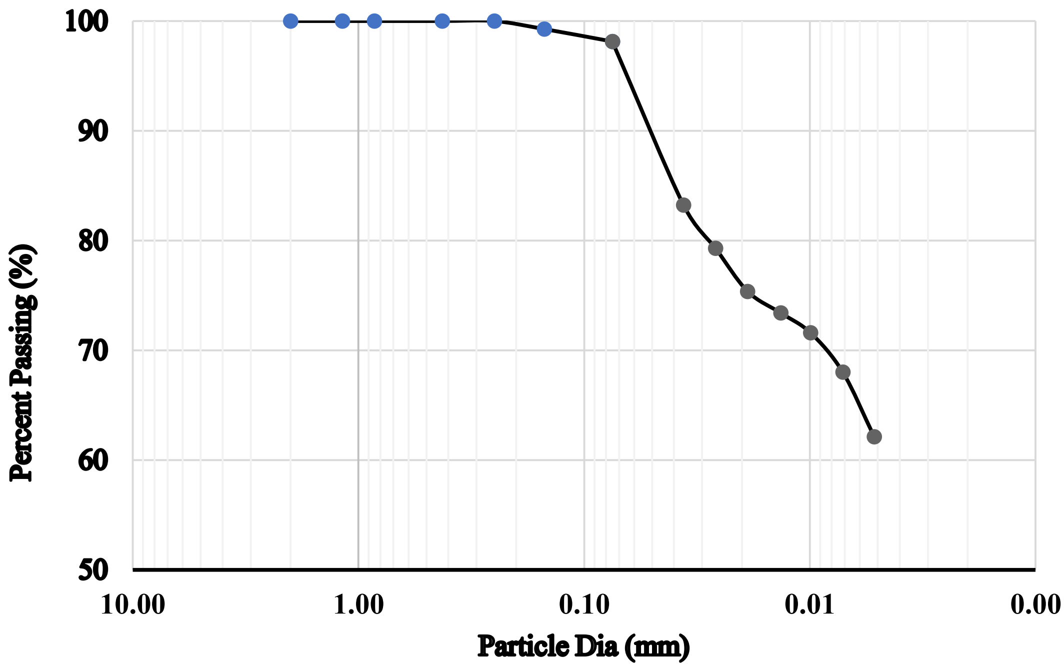

Figure 23 Sieve and Hydrometer Analysis

More than 98 percent of the soil, as shown in the Cassagrande figure, was composed of fine soil particles (75 m). According to the Unified Soil Classification System, the soil is well-graded, fine-grained, and contains inorganic clays with a high fluidity. According to the AASHTO classification system, the material is classified under the A-7-6 subgroup because more than 35% of the total sample of soil passed through sieve #200, indicating that it is unsuitable for use in large construction projects like airfields and highways.

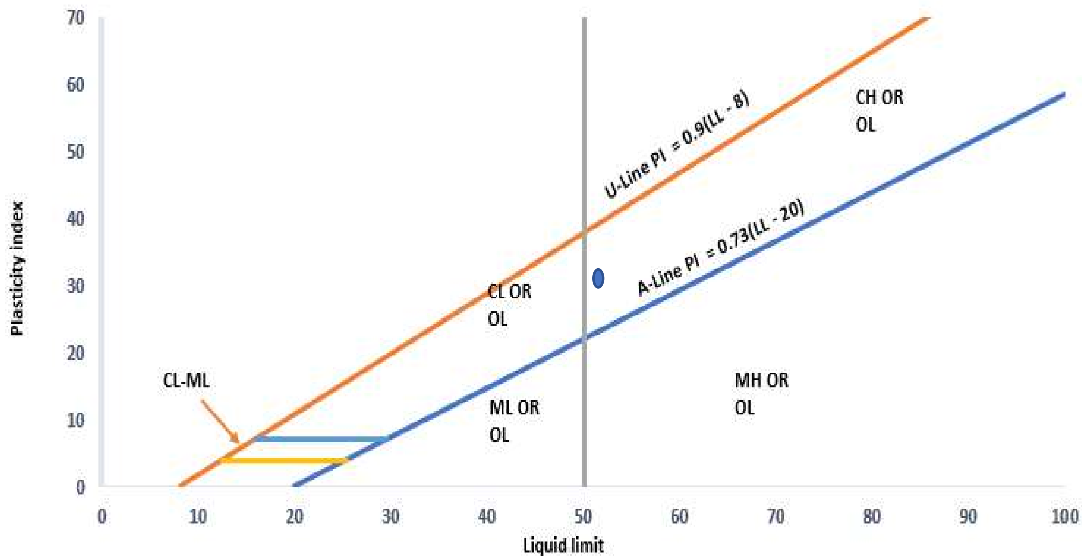

Figure 24 Soil Classification

4.2.4 Atterberg Limits of Soil

For AASHTO and the Unified Soil Classification System [USCS], Atterberg's limit serves as a generic classification for fine-grained soil. The absorbed water surrounding the particles may be the cause of soil's cohesive structure. The amount of water in the soil has a big impact on how it behaves. As a result, Atterberg's limit is established for calculating the soil's moisture content and consistency. To determine the LL of soils, Casagrande's apparatus was utilised, and 1/8" threads produced in accordance with ASTM standard D4318-10 were used for PL.

The LL for native soil was calculated to be 51%, while PL and PI were found to be 24% and 27%, respectively. The soil was categorized as "high plastic clay" by USCS, and according to the AASHTO classification system, the soil was A-7-6.

4.2.5 Specific Gravity (Gs)

Specific gravity test was performed for high plastic clayey soil using ASTM standard D854-14. The specific gravity of high plastic clayey soil was calculated to be 2.68.

4.2.6 Moisture-Density Relation of Soil

Optimum moisture content and maximum dry density of each soil sample was determined using the Standard Procter test. Also compaction is an effort to increase the density of soil particle by decreasing the voids with increasing soil water content.

For high plastic clayey soil, the values of MDD and OMC were found to be 1.69 g/cm3 and 21.27 percent, respectively. Curve of moisture-density for untreated soil is given in the figure 19.

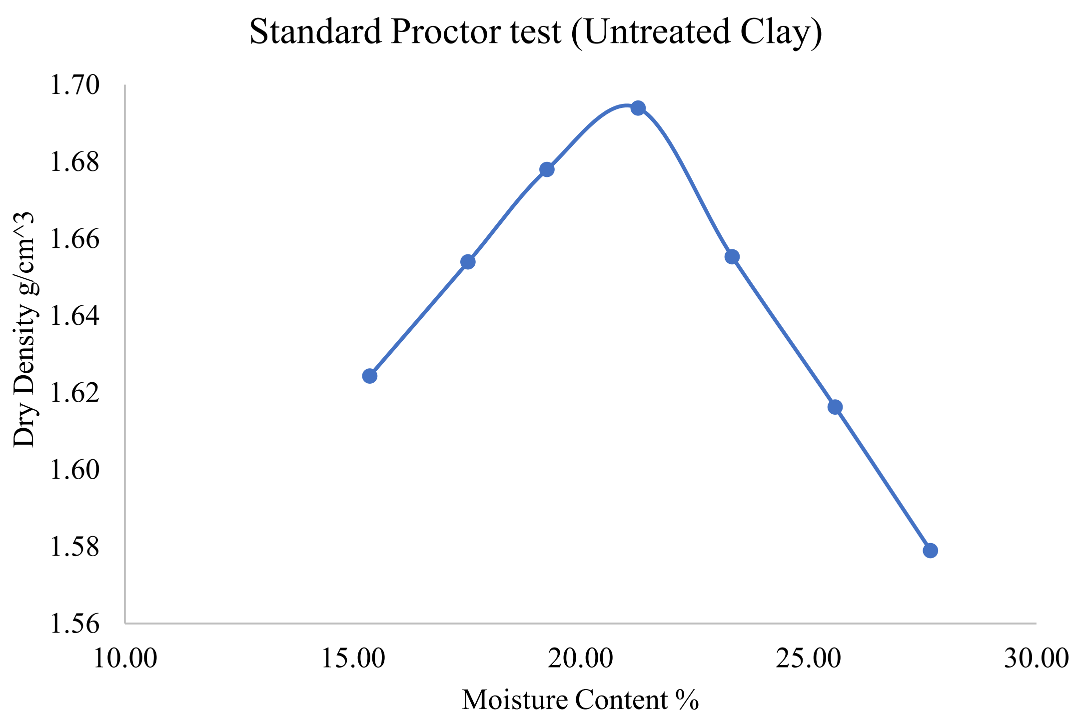

Figure 25 Standard Proctor test (Untreated Clayey sample)

4.2.7 Unconfined Compressive Strength of Soil

The UCS of high plastic clayey soil was calculated following ASTM standard D2166-13 to determine the compressive strength of a soil specimen, the unconfined compression strength test, or UCS, is carried out. This process involves compressing a cylindrical soil specimen with a height to diameter ratio of 2 to 3 at a constant velocity of 0.9 (mm/min). Both untreated and treated soil were used to assess the compressive strength in a moist condition. The soil samples were immersed in water for varying lengths of time (7, 14, and 28 days). Curing technique, curing duration, stabilizer type, and stabilizer content may all have an impact on UCS value (Guo, 2014). The UCS of high plastic clayey soil calculated as 103.1 kPa. Below table 3 shows the geotechnical properties of untreated high plastic clayey soil sample.

Table 5 Summary of Geotechnical Properties of Untreated sail sample

SUMMARY OF PROPERTIES OF NATURAL SOIL		
Liquide Limit %	53	
Plastic Limit %	24	
Plasticity index %	29	
Percent Passing Sieve #200	98.13	
Soil Type	UCS	CH
	AASHTO	A-7-6
Specific gravity of Soil	2.68	
Maximi Dry density (g/cm^3)	1.69	
Optimum moisture content %	21.27	
UCS (kPa)	103.1	

4.3 PHASE II: OPTIMIZATION OF BIOMASS CONTENT

This stage involved testing the soil under investigation with various biomass percentages to see how they affected the soil's engineering qualities. The biomass proportion that results in the highest UCS value is the ideal biomass percentage.

4.3.1 Moisture-Density Relation at Different Percentages of Biomass

Standard Proctor tests were performed by adding 5, 7.5, 10, 12.5, 15 and 20 percent of biomass by mass to untreated Soil. The result shows the decrease in max dry density with treatment of gypsum waste and Biomass Ash content with increase in optimum moisture content.

The greatest decrease in soil moisture content and dry density occurs for untreated soil with 12.5% biomass. OMC was determined as 21.27 percent with 12.5 percent biomass, and MDD as 1.69 g/cm3. Figure 17 depicts the variance of MDD and OMC with various Gypsum percentages.

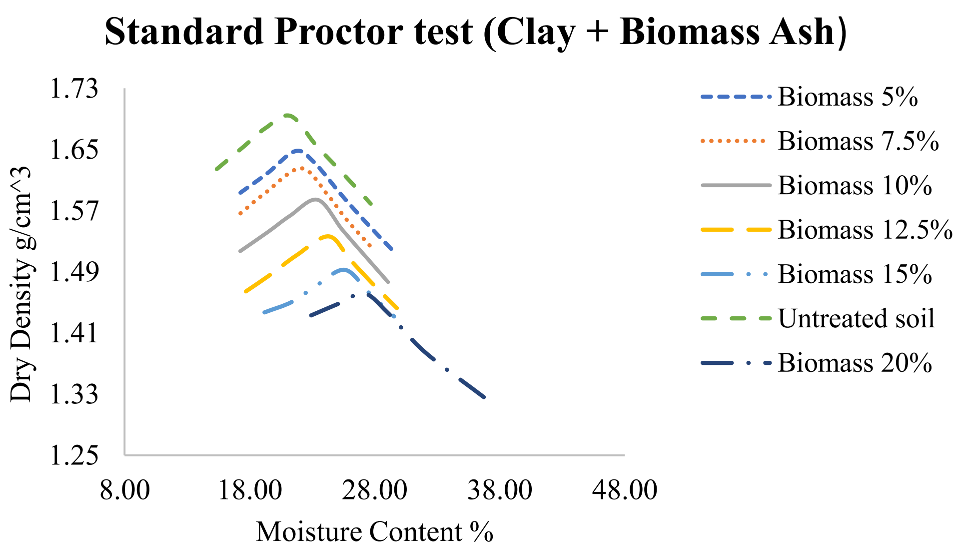

Figure 26 Standard Proctor test (Clay + Biomass Ash)

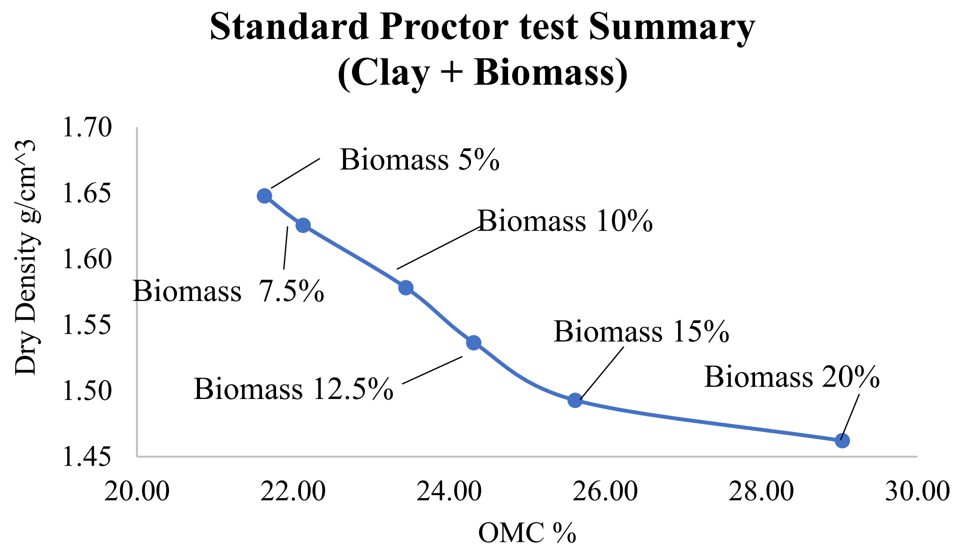

Figure 27 Relationship between OMC VS MDD

With the addition of biomass Ash in high plastic clayey soil, Maximum dry density decreases as Biomass Ash has low density in comparison to clayey soil while optimum moisture content (OMC) increases because of finer particle of Biomass Ash as compared to High plastic clayey soil.

As Biomass Ash is added to the soil, flocculation and agglomeration take place, which helps to explain why MDD has decreased. Larger soil particles will take up more space and create more voids in the soil, which will lower the soil's MDD. Because compaction becomes more challenging as soil particle size increases, the MDD of the soil likewise falls. The increase in OMC can be attributed to Biomass Ash, which is finer than soil and has a larger surface area, necessitating more water for lubrication.

4.3.2 Unconfined Compressive Strength at Different Percentages of Biomass

UCS samples were prepared at OMC and MDD obtained from compaction test. The samples were cured for 7 and 14 days and then tested for high plastic clayey soil. The optimal percentage of Biomass Ash was determined to be the percentage of Biomass that produced the highest UCS. From the testing, it was concluded that 12.5 percent of Biomass was considered as the optimum percentage, as it gives UCS of 269 kPa for 14 days of curing. The results of UCS performed for high plastic clayey soil at different percentages of Biomass are shown in the Figure 22.

The result showed that by increasing biomass content strength of soil increases that is because biomass Ash are finer particles which fills the voids present in between soil particles so it decreases voids spaces between particles and soil structure becomes dense and compact. This increase strength of overall soil structure upto optimum content (12.5%).

With further increase in Biomass Ash beyond optimum content (Biomass Ash 15%) strength is decreases that is because Biomass Ash particles are porous in nature, when porous particles replacing the soil particles, percentage of porous particles increases in whole soil matrix which causes reduction in strength of soil. Also Biomass Ash contents are waste from boiler which have impurities result in weak bonds with soil particles and this weak bonds decreases the strength of soil.

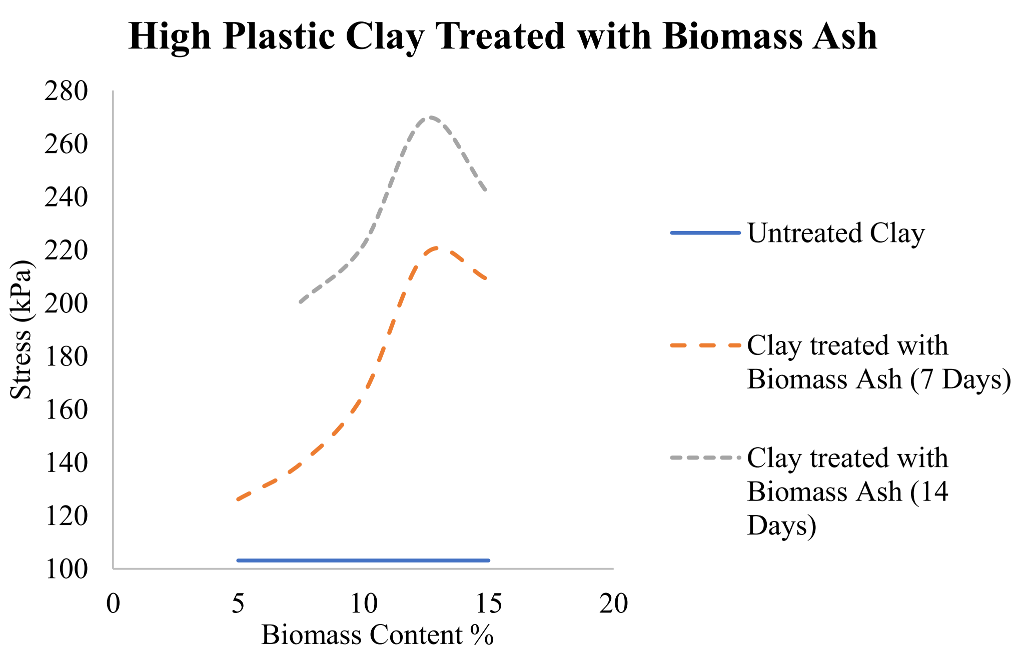

Figure 28 Relationship between Strength and Biomass content

Table 6 Soil Stress w.r.t Biomass contents and curing time

Biomass Ash	**UCS (kPa)**	
%	7 Days	14 Days
5	126.21	
7.5	139.63	200.49
10	165.51	221.72
12.5	**218.72**	**269.49**
15	208.83	241.08

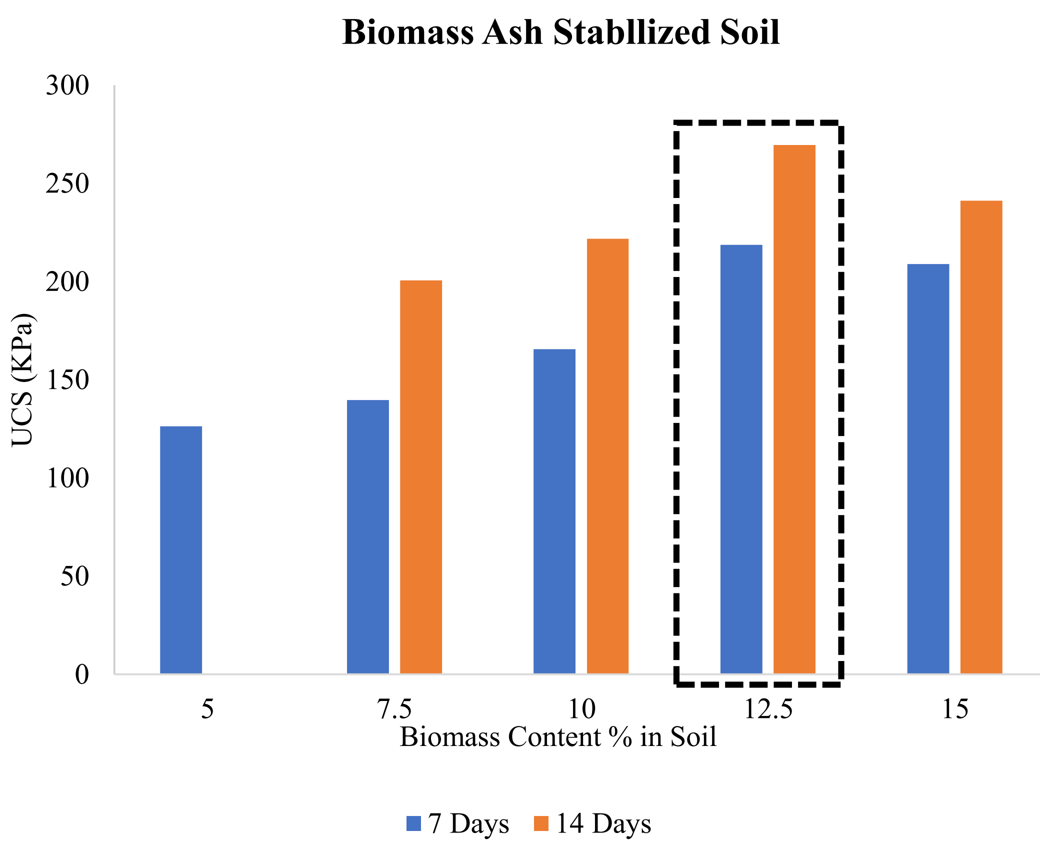

Figure 29 Biomass Ash Stabilized soil (Optimum strength)

Table 7 Summary of Optimization of Biomass

SUMMARY OF OPTIMIZATION OF BIOMASS	
Properties	12.5 Percent Biomass Ash
OMC (Percent)	24.32
MDD (g/cm^3)	1.54
UCS(kPa)	269.49

4.4 PHASE III: OPTIMIZATION OF BIOMASS WITH GYPSUM

In this phase, the engineering features of high plasticity clayey soil were investigated by substituting gypsum waste for biomass ash in soil treated with biomass. The Gypsum proportion that results in the highest UCS value is the optimum percentage.

4.4.1 Moisture-Density Relation at Different Percentages of Gypsum

For moisture density relation Standard Proctor tests were performed by replacing Biomass 25, 50, 75 and 100 percent by Gypsum by mass CH. MDD and OMC of the soil was calculated.

For soil sample optimize effect on moisture content and dry density was observed by replacing 25 percent Biomass with gypsum waste. OMC with 25 percent replacing Biomass was calculated as 23.89 % and MDD was calculated as 1.59 g/cm^3.

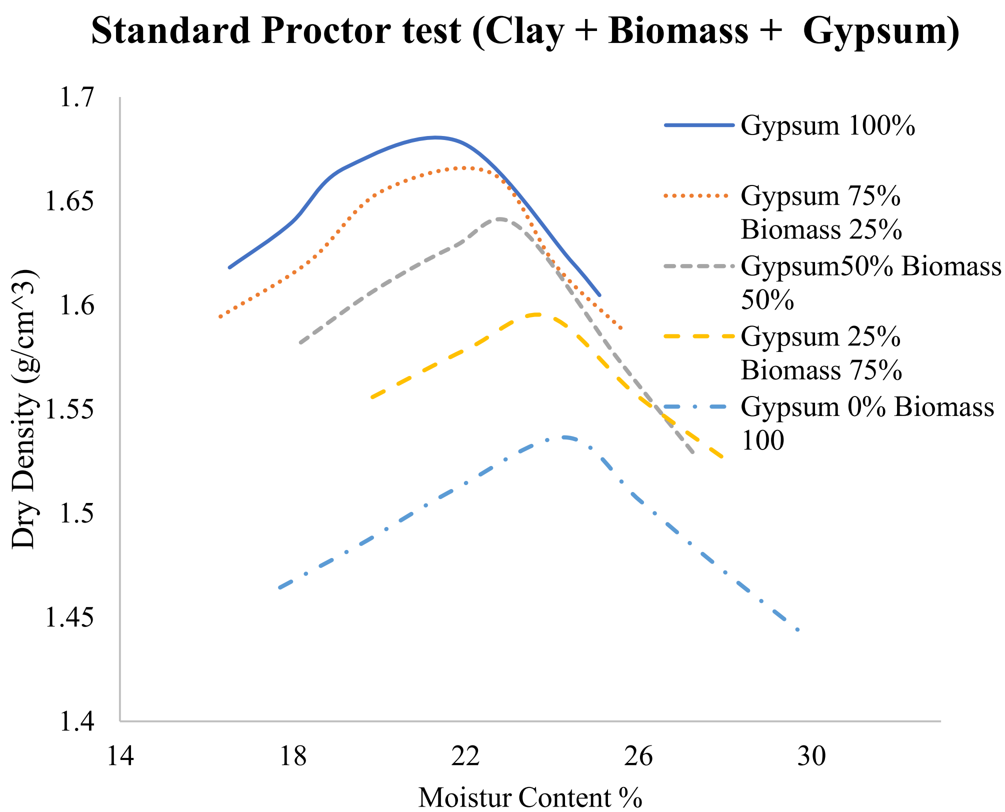

Figure 30 Standard Proctor test (Clay + Biomass + Gypsum)

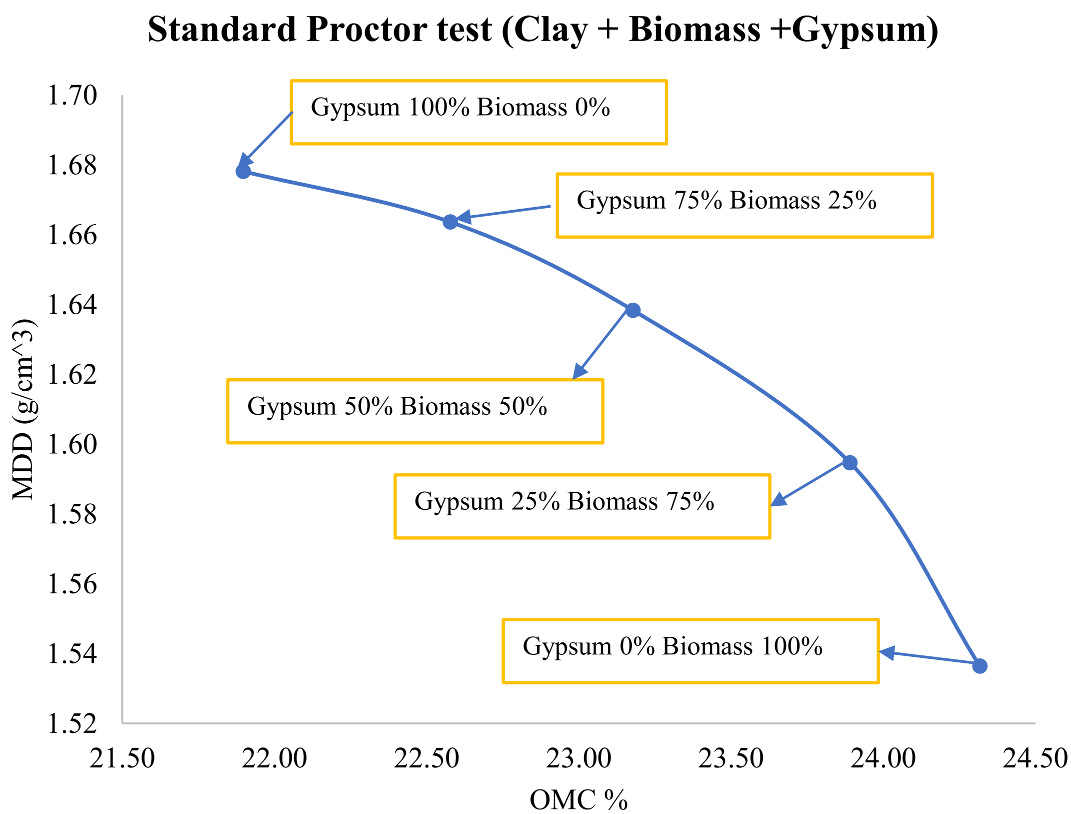

Figure 31 MDD VS OMC

There is reduction in MDD with the addition of Biomass Ash and Gypsum wastes. The reduction in MDD can be explained based on flocculation and agglomeration of the soil particles, as Biomass Ash and Gypsum waste are added to the soil. If soil particles are large, it will occupy more space, and the amount of voids in the soil will increase which will reduce the MDD of soil. The MDD of the soil also decreases because compaction becomes difficult when the size of soil particle increases. The rise in OMC can be explained on the basis that Biomass Ash is finer than soil and their surface area is greater due to which they require a greater amount of water for lubrication.

4.4.2 Unconfined Compressive Strength at Different Percentages of Waste Gypsum and Biomass Ash Composite.

UCS samples were performed by replacing Biomass 25, 50, 75 and 100 percent by Gypsum by mass with soil. Samples were created using the OMC and MDD values from the Standard Proctor test at 100%. Prior to testing, the samples were cured for 7, 14, and 28 days at 30 degrees Celsius in an oven within airtight plastic bags. For each % of gypsum, two samples were examined. The optimal percentage of gypsum and biomass was taken into consideration, and the average strength of the two samples was documented.

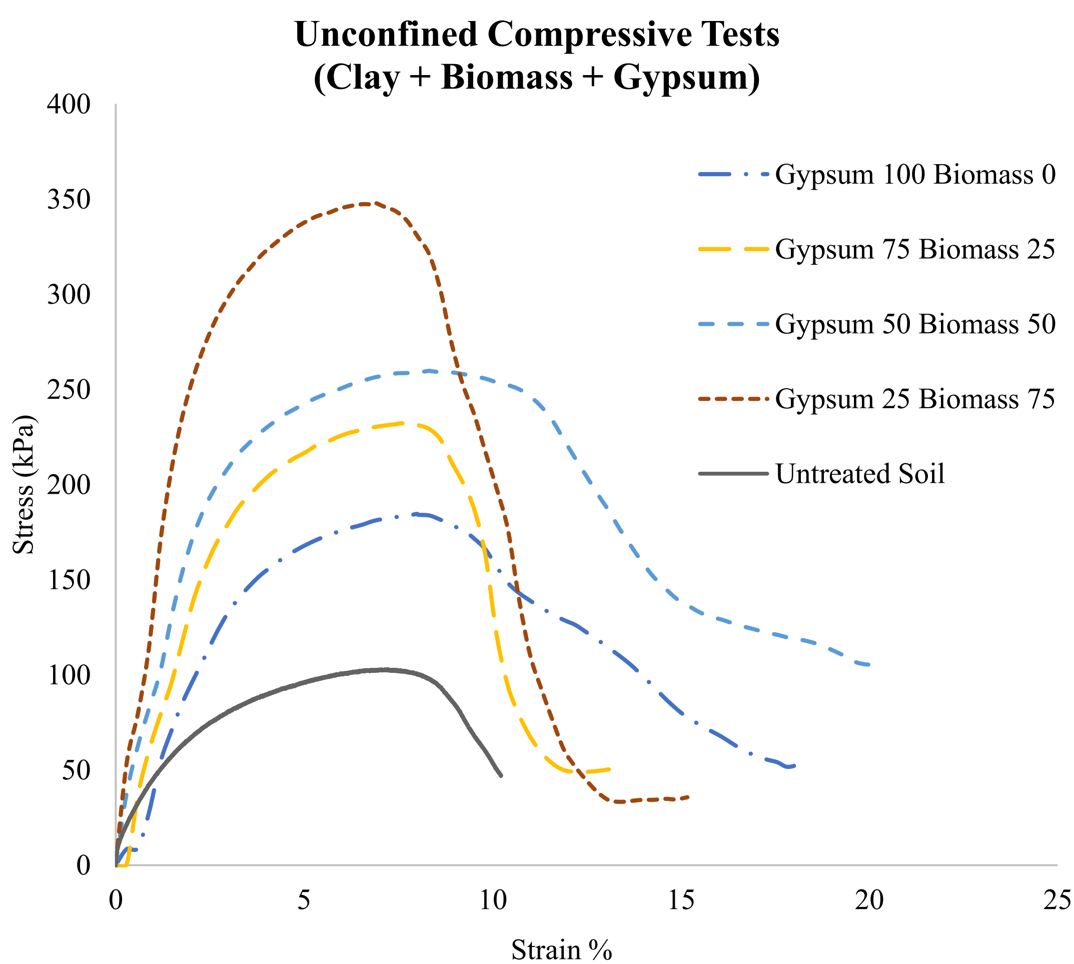

Figure 32 Unconfined Compressive test (Clay + Biomass + Gypsum)

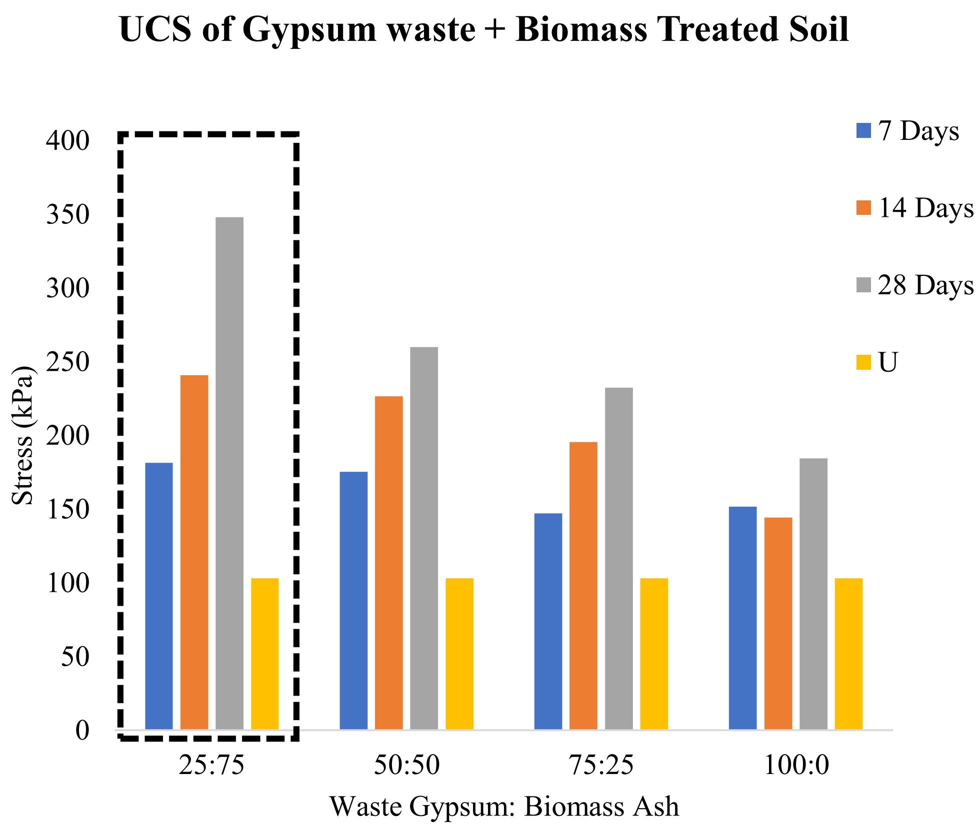

Figure 33 Biomass + Gypsum waste Optimum content for treated soil

Table 8 Gypsum waste and Biomass Ash Stabilized Soil strength w.r.t Additives content and curing time

Unconfined Compressive Strength (UCS) kPa				
Biomass Ash + Gypsum waste(% of 12.5% Biomass)	7 Days	14 Days	28 Days	Treated/Untreated
Waste Gypsum 25 Biomass 75	181.4	240.77	**348.02**	**3.38**
Waste Gypsum 50 Biomass 50	175.31	226.45	259.89	2.52
Waste Gypsum 75 Biomass 25	147.1	195.59	232.29	2.25
Waste Gypsum 100 Biomass 0	144.32	151.75	184.46	1.79

At optimum Binder Content (Waste Gypsum: Biomass ash (25:75)) peak strength (348 kPa) is 3.38 times more than untreated soil strength (103 kPa). Also Stiffness is increased in treated soil.

There is decrease in liquid limit from 51.23 % to 39.5 % , 22.89 % decrease in liquid limit of high plastic clayey soil, Also plasticity index decreases from 27.05 % to 15.56 % which 42.47 % decrease in plasticity index.

With addition of Gypsum waste and Biomass Ash, LL and PI of both the soil reduces while PL of both the soils somehow remained same. The reduction in PI is attributed with reduction of LL. The process behind reduction of LL and PI is flocculation and agglomeration which increases the silty behavior of soil. Also increase in coarseness of soil reduces the water holding capacity of soil.

CHAPTER 5: CONCLUSION ANSD RECOMMENDATION

The present study evaluated the effectiveness of Gypsum waste and Biomass Ash to stabilize the high plastic clayey soil. The treatment with both the stabilizers resulted in increase in unconfined compressive strength and reduction of plasticity. Different chemical and geotechnical tests were performed on the basis of which the following assumptions are drawn:

5.1 CONCLUSIONS

1. According to XRD test, untreated soil contains mineral kaolinite, which is problematic. Smectite-rich soils high plasticity, meaning they can easily deform and retain their shape when manipulated. When smectite absorbs water, it undergoes swelling, increasing its volume and contributing to the soil's expansive behavior. Illite-rich soils generally have lower plasticity than smectite-rich soils. This can be advantageous in some engineering applications, as lower plasticity soils tend to exhibit better shear strength and stability.

2. XRF analysis of Gypsum waste and Biomass Ash shows that Gypsum waste is used as a filler material as it has silica and alumina less than 55 %, but the Biomass Ash is acting as a pozzolanic material as it is composed of more than 55 % of silica and calcium oxide.

3. From the gradation of untreated soil, it is concluded according to USCS, soil is CH (clayey soil with High plasticity), and according to AASHTO classification it falls in A 7-6 group (clayey soil).

4. Atterberg's limits showed that with the addition of Gypsum waste and Biomass Ash the decrease in LL and PI was experienced. This result is attributed to reduction of thickness of the double layer attributable to increase electrolytic concentration.

5. There is decrease in liquid limit from 51.23 % to 39.5 % , 22.89 % decrease in liquid limit of high plastic clayey soil, Also plasticity index decreases from 27.05 % to 15.56 % which 42.47 % decrease in plasticity index.

6. The optimum percentage of Biomass Ash is 12.5 %, obtained from standard proctor test and maximum dry density at 12.5 % of Biomass Ash is 1.54 kg/m^3.

7. The optimum percentage of Biomass Ash is replaced by gypsum waste, 75:25 (Biomass: Gypsum waste) is optimum percentage of both additives giving maximum unconfined compressive strength, 3.38 times more than untreated soil at 28 days curing.

8. Unconfined Compressive Strength increases with the addition of Gypsum waste and Biomass Ash as well as with the increase curing time.

9. After the evaluation of all geotechnical characteristics, the optimum value achieved for both additives in proportions of Gypsum waste: Biomass (25: 75).

5.2 RECOMMENDATIONS

1. As both Gypsum waste and Biomass produces cementitious products so, suitability of these materials should be checked as stabilizers for granular soils and soils rich in silt.
2. CBR tests should be performed at different moisture contents to check the suitability of additives for high plastic clayey soil.
3. For future, swell percent should be study to know the effects of waste Gypsum: Biomass binder for stabilization of high plastic clayey soil.
4. These additives should be analyze for stabilization of other types of soils.
5. As with the use of Gypsum waste and Biomass Ash, the PI of the soil was reduced, which means the water retention capacity of the soil is reduced. The study should be conducted to check the effect of improvement on the permeability of the soil.

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