Use of Brine Sludge as a Construction Material

A Dissertation Submitted in Partial Fulfilment of the Requirement for the Award of the Degree of

MASTER OF ENGINEERING
IN
INFRASTRUCTURE ENGINEERING

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(A DEEMED TO BE UNIVERSITY), PATIALA, PUNJAB, 2022

DECLARATION

I, AKSHAT SIROHI, hereby declare that the thesis entitled "**Use of Brine Sludge as a Construction Material**" is an authentic record of my studies carried out as a requirement for the award of the degree of **Master of Engineering** in **Infrastructure Engineering** under the supervision of **Dr Vivek Gupta**, Assistant Professor and **Dr Tanuj Chopra**, Assistant Professor, Department of Civil Engineering, Thapar Institute of Engineering and Technology, Patiala. The matter embodied in this report has not been submitted in part or full to any other institute or university for the award of any degree.

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ACKNOWLEDGEMENT

Words are often less to reveal once deep regard for someone. With an understanding that work like this can never be the outcome of a single person, I take this opportunity to express my profound sense of gratitude and respect to all those who helped me through the duration of my work. My thesis could not have been completed without the help of many people who contributed directly or indirectly through their constructive criticism. It would not be fair on my part if I don't say a word of thanks to all those whose sincere suggestions made this period a real educative, enlightening, pleasurable and memorable one.

First of all, a special debt of gratitude is owed to my supervisor **Dr. Vivek Gupta, Assistant Professor, Department of Civil Engineering, Thapar Institute of Engineering and Technology, Patiala** for their gracious efforts and keen pursuits, which have remained a valuable asset for the successful completion of my work.

I would like to express my deepest gratitude to my mentor **Dr. Tanuj Chopra Assistant Professor Department of Civil Engineering, Thapar Institute of Engineering and Technology, Patiala** for the extensive mentoring, support, and technical guidance he provided me with throughout his tenure of this research work.

I would also like to thank to **Punjab Alkalies & Chemicals Limited (P.A.C.L.)** for providing me with the material so that my research could continue and finish on time.

I would also like to thank my parents and my friends for their constant encouragement & co-operation. Last but not least, I would like to thank God that this got completed.

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Abstract

Brine sludge is an industrial waste which comes mainly from chlor-alkali industry. There is rapid increase in the growth of chlor-alkali industries in India, currently, approximately 40 industrial units produce caustic soda with an installed production capacity of 2.27 million tonnes per year.

This increased output, results in the release of increasing amount, which causes severe environmental damage. Waste released into the environment initially enters surface and groundwater before entering the food chain, posing health risks to humans and other organisms and disrupting the overall balance of the ecology.

Efforts has been made in using the brine sludge as a construction material in the first part brine sludge is tested for use as an alternative material in subgrade by testing the CBR values of raw samples of sludge and later blending the sludge with fly ash.

In the second part brine sludge was tested for partial replacement of cement in cement concrete, for the testing compressive and flexural strength was tested for different ratio of replacement from 0 to 10 percent, results show the maximum increase in strength at 5 percent replacement.

In the third part brine sludge has been used as an alternative precursor in fly ash geopolymerized brick. The work was done in optimisation of the internal ratio of precursor, precursor to liquid, chemical to liquid. Later the bricks which had good strength were optimized of cost, which can further be reduced.

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ABBREVIATION

OMC	Optimum Moisture Content
MDD	Maximum Dry Density
CBR	California bearing ratio
XRF	X-ray fluorescence
XRD	X-ray diffraction technique
SEM	Scanning Electron Microscope
S/S	Solidification/stabilization
UCS	Unconfined Compressive Strength
WTS	Water Treatment Sludge
SSA	Sewage Sludge Ash
w/c	Water Content
FA	Fly Ash
IS	Indian Standard
TCLP	Toxicity Characteristic Leaching Procedure

Chapter 1
Introduction

1.1 General

The rapid growth of industries in India in the recent years is the striking feature of nation's economic development. The other side of industrialization has been the serious damage to the surrounding environment due to the wastes and pollutants generated from the industries. Various chemical, mining, steel, fertilizer, paper, and pulp industries generate huge amounts of wastes out of their production processes. The uncontrolled dumping of these wastes causes irreparable damage to the surface and ground water, air, and soil and has become a matter of serious concern for the protection of environment. Thus, the utilization/recycling of these waste materials are quite desirable for the sustainable development of the economy and for ensuring a clean and safe environment. Attempts have been made earlier to utilize various industrial wastes as an alternative material in the construction industry.

The modern construction industry is a multi-billion dollar industry, and the production and getting of raw materials for construction purposes is on a worldwide scale. Environmental factors are also becoming a dominating world topic concerning the availability and sustainability of particular materials and the extraction of bulk of these are needed for the human habitat. In respect of minimizing the use of natural resources as construction materials, alternate construction materials or partial replacement with suitable waste material can be done to safeguard the natural resources and to utilize the waste and industrial by-products.

Natural resources must be wisely used because they are finite. This will assist in preventing environmental degradation and preserving the ecosystem for use by future generations. Recycling and using industrial waste, whose disposal would otherwise be a significant challenge, can help in preserving the ecosystem. Utilizing natural resources can let the concrete industry expand more quickly while keeping the use of cement and other commodities under control. Any material that produced by industrial activity and is rendered unusable during a production process, such as that of factories, mills, and mines, is referred to as industrial waste.

Brine sludge is a by-product of the chlor-alkali manufacturing industry which is produced during the electrolysis of brine during the production of chlorine and caustic soda. In India, approximately 40 units produce caustic soda with an installed production capacity of 2.27 million tonnes per year.

Brine is a concentrated solution of salt in water. It can be any solution of a salt in water e.g., potassium chloride brine. It can occur either naturally or as by-product of industry. Generally, by-products from industries have more than twice the concentration of salts than that of natural brine solutions. Natural brines occur underground, in salt lakes, or as seawater and are commercially important sources of salts, such as chlorides and sulfates of magnesium and potassium.

The brine sludge generated must be disposed of or should be used in production of different material or product so that it doesn't affect the environment and doesn't take much land of the industries in which it produced so that the land could be used for other production purposes.

Chlor-alkali manufacturing industry sector mainly cover three types of industries such as

- Caustic soda industries
- Soda ash industries
- PVC industries.

Out of these, caustic soda industries produce caustic soda lye, hydrochloric acid, liquid chlorine, sodium hypochlorite, and hydrogen gas as their main products. The Caustic soda industry procure the raw salt and make the brine solution by dissolving in water. The salt mainly contains sodium chloride with some impurities of Calcium, magnesium, sulphate and moisture.

In particular, the industrial washery and super washery salt mainly contains sodium chloride (NaCl), calcium chloride ($CaCl_2$), calcium sulphate ($CaSO_4$), magnesium chloride ($MgCl_2$), magnesium sulphate ($MgSO_4$), iron, sand and earthen particles. The produced brine solution undergoes through different purification process to get ultrapure form of brine solution. Barium carbonate ($BaCO_3$) is used to remove sulphates of salt from brine solution. Soda ash (Na_2CO_3) is used to remove calcium of salt from brine solution. Sodium Bisulphite ($NaHSO_3$) is used to remove free chlorine from brine solution. α-cellulose is used to remove suspended impurities from brine solution. Flocculating agents are used for settling down the suspended impurities from brine solution. This ultrapure form of brine solution is electrolyzed and different products are obtained through membrane technology.

The waste generated from the above process is called Brine Sludge.

A few decades back, mercury-based production process was used which get redundant due to this environment friendly membrane technology. Still, this membrane technology produces a huge amount of sludge i.e., brine sludge whose disposal is the main concern of these chlor-alkali industries now-a-days.

Currently, the brine sludge produced is categorized as hazardous waste as per the HW(M&H)

Rules notified by the Government.(Gandhi, 2010) So, the industries are advised to store such wastes in lined pits inside their premises.

The filled sludge pit is capped with good soil to limit the environmental interaction. Along with the land-fill cost, such a huge infrastructure creates an economic burden on the industry that creates a need of utilizing the brine sludge in a constructive way.

1.2 Different types of Sludge

There are different types of sludge which are generated from different industries some of them are listed below with process through which they are generated and their constituents.

a) **Brine Sludge** – It a sludge which is generated in chlor-alkali industries by the electrolysis of Brine solution mostly it contains CaO (58.95%), MgO (37.41%), SrO (0.92%), SiO_2 (1.44%), Fe_2O_3 (0.78%), Al_2O_3 (0.36%), Na_2O (0.14%)

b) **Lime Sludge –** It is a sludge which is produced from the lime calcining process. Lime sludge is composed mainly of calcium (51.48%), silica (8.30%), and aluminium (3.24%), Iron, magnesium, and sulfur each make up less than 3% by weight, while zinc, chromium, selenium, lead, cadmium, barium, and silver collectively make up less than 0.01% of the total composition.

c) **Textile Sludge -** Textile sludge is an inevitable by-product of Textile wastewater treatment process. Textile sludge consists of a cluster of organic and inorganic complex with high concentrations of heavy metals such as Fe, Cu, Cd, Zn, Cr etc.

1.3 Industrial process of Brine purification and Brine Sludge generation

1.3.1 Brine Purification

Brine by Chlor-Alkali process is prepared by dissolving salt in the water. Brine solution goes through electrolysis in plant, and purified in two stages. Primary purification removes impurities like calcium, magnesium, sulphate, iron, silica etc. to ppm level. Secondary purification is required to make brine suitable for the ion exchange membrane Chlor-alkali process.

1.3.2 Primary Brine Purification

Brine Purification section consists of salt handling system, brine saturator, reactor clarifier, clarified brine tank and associated facilities. This process includes brine saturation, chemicals dosage, reaction and sedimentation. The purpose of this process is to re-saturate the return brine with raw salt and to remove impurities from the saturated raw brine.

a) The return brine is fed from the top of the brine saturator and saturated with salt. The salt is continuously supplied to the top of the saturator by a belt conveyor system.

b) The saturated raw brine overflows from the brine saturator and flows into reactor. Chemicals such as barium carbonate, sodium carbonate, caustic soda are fed to reactor.

c) Calcium, magnesium and other multivalent cations and sulphate anions in the raw brine react with these chemicals reacts & flocks are settled & drained while the brine is held in the reactor.

d) pH of the brine is controlled by the addition of caustic-soda to the brine. Then the brine overflows from the reactor into the brine clarifier. Flocculent is fed to the brine line entering the clarifier.

e) Suspended solids in the brine are removed by settling in the clarifier provided with water seal & insulated from the sides. The brine, thus clarified, flows into clarified brine tank over the weir of clarifier & is pumped out and recirculated to the brine system before reactor for better clarification. Slurry is periodically measured for better control.

f) The slurry is sent to Secondary Brine purification section by clarified brine pump.

1.3.3 Secondary Brine Purification

a) Secondary Brine Purification Section consists of Brine Filters and Ion Exchange Resin Columns.

b) The clarified brine is filtered through the filter and flows into filtered Brine tank.
c) Suspended solids caught on the filter element surface are blown down to Filter Slurry Pit.
d) Filter Slurry in the pit is sent to vacuum drum filter (VDF) where most of the brine is recovered and fed back to Return Brine Tank.
e) Ion Exchange Resin Column packed with special Ion Exchange resin is operated and controlled automatically from control room. This specially developed Ion exchange resin can remove multivalent cations harmful to the Ion exchange membrane.
f) The brine thus purified is fed to Electrolyser and electrolysis is conducted.
g) The slurry left after the recovery of brine from vacuum drum filter is then transported to be disposed and that slurry is Brine Sludge.

1.4 Environmental Issues Related to Brine Sludge

The major environmental problems and challenges posed by this industrial sector are related to the disposal of brine sludge. It contains toxic materials that precipitate from the brine, which during the course of time might get leached out, thereby affecting ecosystem adversely. The industries require large percentage of land space in nearby vicinity so that Brine sludge can be dumped on the land, alternatively some companies dispose their industrial waste in incinerators which raise concerns about major land and air pollution problems. So, it is required that we find alternate solutions for disposal or use of brine sludge, for ecologically safe disposal by stabilizing the leachable impurities which may harm the environment.

1.5 Possibility of use brine sludge in construction

One possible solution can be using brine sludge as a construction material, i.e., using brine sludge as a partial replacement of cement; it could also be used as a construction material by mixing a certain amount of cement, fly ash and brine sludge; brine sludge can also be used in a geopolymeric matrix as it helps in stabilizing/immobilizing hazardous and toxic material in its matrix if they are leaching out into the water table.

The geopolymerization of brine sludge converts it into non-toxic material, which is confirmed by leachability studies. The utilization of brine sludge in making geopolymeric (cement-free) paver blocks and bricks as construction materials could serve as an attractive approach to solve its disposal issue.

Brine sludge can be used as an alternative precursor blended with fly ash in geopolymer bricks. This will also use the geopolymeric matrix to stabilizing/immobilizing hazardous and toxic material in its matrix if they are leaching out into the environment.

Another possible solution could be using the brine sludge to stabilize the soft soil to make it suitable to be used in subgrade which could be done by testing blend of different materials with brine sludge and soil, and testing for suitability of stabilized soil to be used as subgrade soil. After stabilization of soil, it should first be checked for leaching, if the hard metals which gets leached out from the stabilized soil are under the limit.

1.6 Aims and Objectives of the thesis

The primary aim of the study are as follows:

1. To conduct an extensive study on the feasibility analysis of brine sludge as a construction material.
2. To reduce the negative impact of brine sludge on environment and promoting harmless utilization of brine sludge as a construction material.

The primary objectives to achieve above aim are as follows:

1. To use brine sludge as a partial replacement of cement in cement concrete with varying percentage of replacement of cement (i.e., 0%, 2.5%, 5%, 7.5%, 10%) and checking for compressive strength and flexural strength.
2. To use brine sludge as a subgrade material by checking the OMC, MDD and CBR values of raw samples of brine sludge and samples of brine sludge blended with fly ash at different ratios (i.e., 10% and 20%).
3. To use brine sludge as an alternative precursor in geopolymer bricks by optimisation of internal precursor ratio, precursor to total liquid ratio, internal chemical ratio, chemical to water ratio.

1.7 Organization of the thesis

Chapter 1 provides an introduction to the analysis of the research work. The significance of the research, aims and objective of the investigation and the layout of the thesis.

Chapter 2 provides a literature review which provides in depth knowledge of the existing field of research.

Chapter 3 describes the materials and methods

Chapter 4 summarizes the results and discussion on the experimental investigation

Chapter 5 presents detailed summary of the work, conclusions and scope for further research.

The references are presented at the end of the thesis.

Chapter 2
Literature Review

2.1 Introduction

In this chapter, a literature review related to brine sludge generation strength, durability, characterization and its utilization in construction has been carried out. Work on making paver blocks from brine sludge has been done, work on development of geopolymerized brine sludge has been done through which geopolymeric gel is made to improve interfacial binding of conventional geopolymeric matrix using jute and glass fiber as reinforcement with further helps in making toxic hazardous materials non leachable.

2.2 Brine Sludge Generation

Brine Sludge is generated as waste by two industries mainly by chlor-alkali and paper industry, in chlor-alkali industry it is generated by the electrolysis of Brine solution to produce Caustic Lye. A few decades back, mercury-based production process was used which get redundant due to this environment friendly membrane technology.

Regardless of the type of technology adopted for chlorine and caustic soda production (membrane cells, asbestos diaphragm, or mercury cell), salt is used as raw material and needs treatment before electrolysis.

During the salt treatment, the Chlor-alkali industry generates large amounts of brine sludge. That industrial waste is generated in large amounts and usually it is disposed into industrial landfills.(Izidoro et al., 2021a)

2.3 Characterization of Brine Sludge

Characterization of brine sludge was completed, and it was discovered that brine sludge contains elements such as Ca, Si, Na, Mg, Al, Cl, and Fe. The XRD results confirm the crystalline nature of the compounds, and the main compounds in brine sludge samples are calcium carbonate, sodium chloride, magnesium hydroxide, and quartz.(Izidoro et al., 2021)

2.4 Discussion of papers related to Brine Sludge

Garg & Pundir (2014): In this article work on characterization and influence of Brine Sludge on the properties of cement-fly ash sludge and on utilization of brine sludge in making paver blocks and bricks has been done and conclusion has been made that brine sludge up to 35% and 25% can be used for making paver blocks and bricks, respectively.

Shukla et al. (2015) : In this article work on recovery of Barium Sulphate from Brine Sludge has been done, and it was discovered that Brine Sludge have 40% barium sulphate ($BaSO_4$) which have good economic value. The barium sulphate was 93% pure and was separated by simple chemical separation method which could be used in several industries.

Izidoro et al. (2021) : In this article work have been done on characterization of Brine Sludge and its application for non-structural and structural construction materials.

The feasibility of utilization of brine sludge wastes for the preparation of value-added materials are investigated. 2 samples of brine sludge were used for characterization in terms of chemical and physical composition, particle size distribution, X-ray diffraction (XRD), Fourier Transform Infrared Spectroscopy (FTIR), and thermal analysis (DTA/TG). Presence of elements like Ca, Si, Na, Mg, Al, Cl and Fe was found. The XRD results confirmed the crystalline nature of compounds and so they concluded that the main compounds in brine sludge samples were calcium carbonate, sodium chloride, magnesium hydroxide, and quartz.

It was concluded that brine sludge samples have favourable characteristics to be used as limestone filler and binder alternative to Portland cement in nonstructural construction materials, also it was concluded that incorporation of brine sludge in geopolymeric materials is another possible use in sustainable construction material products.

Verma et al. (2017): In this article geopolymerized brine sludge was developed as it leads to the formation of enhanced geopolymeric gel which helps in further improving the interfacial binding of conventional geopolymeric matrix using jute and glass fiber as reinforcement and also helps in making toxic hazardous martial non leachable. interfacial binding is improved with the help of advanced geopolymeric matrix because of formation of additional C-S-H gel along with Na-S-H gel of conventional geopolymeric matrix in the geopolymeric brine sludge. The simultaneous presence of desired components and constituents in the single matrix of geo polymeric brine sludge led to the enhanced homogeneity among the reinforcement and matrix. Closed mould fabrication system was used for making advance composites of geopolymerized brine sludge. Hand layup manual technique was used once without any fiber reinforcement, once with jute fiber reinforcement and once with glass fiber reinforcement of dimensions 12 in. x 12 in. x 6 in. There were three different kinds of advance composites (AC) developed and their morphologies were examined and other mechanical properties like tensile strength, flexural strength, impact strength, abrasion resistance were also tested.

According to the results fiber reinforced advance composites had better mechanical properties as that of non-fiber reinforced advance composites

The result indicated mechanical properties of advance composites (AC) in increasing order:

Non-fiber reinforced AC < Jute fiber reinforced AC < Glass fiber reinforced AC.(Verma et al., 2017)

Pingle et al. (2018) : In this article work has been done on using the brine sludge in cement concrete. This research was done because production of cement is not good for environment as production of cement increases the greenhouse gases and need of cement is increasing also millions of tons of solid wastes are produced in India every year one of them is Brine Sludge obtained as waste by goods from paper industry. Brine sludge was used as partial replacement of cement, so by using brine sludge as a partial replacement of cement the cost of making concrete will be reduced as brine sludge is very cheaply available as compared to cement also the problem of disposal of brine sludge will also be solved which will free a lot of land space to be used for the industries for different purposes.

The partial replacement of cement at different percentage of brine sludge was studied i.e. 3%, 5%, 7%, 10% and 12% in conventional concrete of M30 and M40 grade. The compressive strength at 7 days and 28 days were observed, it was found out that up to 7% of cement replacement the compressive strength increased, and then decreased and at 10% cement replacement the compressive strength was same as conventional concrete. It was concluded that 7 % cement replacement with brine sludge is the optimum replacement.(Pingle et al., 2018)

Masilela et al. (2018): In this article the work has been done on avoiding the disposal of industrial brine sludge waste from chlor-alkali plants by utilizing it as a sorbent in wet flue gas desulfurization. To determine the dissolution kinetics of industrial brine sludge waste the she shrinkage core model was used, which is a vital step in wet flue gas desulfurization. The effects of solid-to-liquid ratio (m/v), temperature, pH, particle size, and stirring speed on the conversion and dissolution rate constant were determined. The pH, particle size, and solid-to-liquid ratio were found to be inversely proportional to the conversion and dissolution rate, while temperature, concentration of acid, and stirring speed are directly proportional to the conversion and dissolution rate. x-ray fluorescence (XRF), x-ray diffraction (XRD), and scanning electron microscopy (SEM) were used for the characterization of sorbents before and after dissolution. The rate-controlling step was found to be the product layer diffusion model.

It was concluded that industrial brine sludge waste can be used as an alternative sorbent in wet flue gas desulfurization which can reduce the need of land space required be industries for the disposal of brine sludge. This study also concludes that sorbent can contain 91% of calcium carbonate and small amount of sulfate, magnesium, and other elements. The sorbent made can be used to reduce the amount of sulfur dioxide in the atmosphere and a by-product gypsum is obtained which can further be used as a plaster ingredient.(Masilela et al., 2018)

Verma and Amritphale (2018): In this article work has been done on developing a non-toxic geopolymeric material from brine sludge from chloral alkali industry and fly ash. This article discusses about the utilization of brine sludge in making geopolymeric paver blocks and bricks and its effect in the engineering properties of these products. Water absorption and porosity of geopolymeric brine sludge binders was studied for the estimation of strength and durability of the binders, it was concluded that the geopolymeric paver blocks does not leach which ascribed to the chemical binding of toxic elements cement-free geopolymeric matrix. Further The toxic characteristic leaching procedure (TCLP) test was performed to evaluate the immobilization and stabilization of metal ions present in the geo polymerized product. A comparison between raw brine sludge and geopolymerized brine sludge paver block for leaching was made after 28 days of curing and it was found out that the concentration of leached metals is below detection limit of the limits specified in India standard, and thus, results clearly confirmed that metal ions are chemically bound and retain into the geopolymeric material structure.

Leachability studies of raw brine sludge and geopolymerized brine sludge (cement-free) paver blocks were as follows:

Table 2. 1 Leachability studies of raw brine sludge and geopolymerized brine sludge (cement-free) paver blocks

Sr. no.	Name of metal ions	Concentration of metal ions (mg/L)		IS 10500-2012 discharge limit of metal ions at inland surface water (mg/L)
		Raw brine sludge	Geopolymerized brine sludge paver blocks	
1	Chromium	290	2.70	3.1
2	Copper	260	2.50	3.0
3	Vanadium	100	0.17	0.2
4	Zinc	370	4.70	5.0

Chen et al. (2019): In this article work has been done on utilization of brine sludge in controlled low strength material which have begun to apply in a lot of countries because they can be distributed randomly in complex sites. The brine sludge from chlor-alkali industry, was used to replace the composition in CLSM for resource application. The mix composition of brine sludge replaced only the fine aggregates or all of the aggregates. Ball drop test was done to determine the penetration resistance and flexibility at fast deformation of the CLSM to accept loads prior and the bearing capacity at different ages were measured by the compressive strength test. It was observed that replacement of fine aggregates satisfied the rule of CLSM. X-ray fluorescence (XRF) to determine the chemical ingredient of the brine sludge and the mineralogy was analysed by X-ray diffraction technique (XRD) which are as follows:

Table 2. 2 The chemical composition and physical properties of brine sludge

S. no.	Properties	Brine Sludge
	Physical Properties	
1	Color	light grey
2	Specific gravity	2.63
3	Natural water content %	36.21
4	pH	10.55
	Chemical Composition %	
1	CaO	58.95

2	MgO	37.41
3	SrO	0.92
4	SiO_2	1.44
5	Fe_2O_3	0.78
6	Al_2O_3	0.36
7	Na_2O	0.14

Twidwell and Thompson (2001) : In this article work is done on Recovering and Recycling Hg from Chlor-Alkali Plant Wastewater Sludge. hydrometallurgical process for treating mercury- bearing wastes and by-products is called **REMERC**. This process is able to recover more than 98% of mercury from waste materials. Hydrometallurgical reactors and solid/liquid-separation devices are required for the process. The REMERC process is based on leaching mercury and mercury compounds in an oxidizing chloride-bearing environment (hypochlorite) with subsequent recovery of mercury from the leach solution via either cementation on iron or by aqueous-phase electrolysis.

Verma et al. (2018): In this article work has been done on making non-toxic X-ray Radiation Shielding Glass Possessing Barium, Boron Substituted Kornerupine Crystallites in the Glassy Matrix as traditionally lead based radiation shielding glasses are used in X-ray room of the purpose of radiation shielding. But production and recycling of lead containing glass causes health hazards so work is done on making non-toxic radiation shielding glasses which could be used in X-ray rooms and in can be used as radiation shielding glass in different places. Oxide of alkali and alkaline earth metals are the major constituents of glass and same are present in brine sludge which is a waste generated from chloral alkali industries, enabling synergistic chemical reaction among other raw materials namely fly ash (FA) and Borax (B_2O_3), have been chemically formulated and designed for Developing shielding Kornerupine crystallites embedded in the developed lead free homogenous shielding glass by a novel process (The patent application has been filed in India Ref. No. 0059NF2016). Shielding glasses with composition xBS:(80-X) B_2O_3:20 FA, where (x = 35, 40, 45, 50 wt%) have been prepared using melt process followed by annealing method. Sophisticated instrumental techniques were used for the characterization of shielding glass such as FESEM, EDS XRD, IR and TG/DSC and SEM for identifying shielding crystallites embedded in the developed glassy matrix. The

X-ray attenuation test of the developed glass was done which showed that this glass can be used for shielding in X-ray room and have various other shielding application.

Chen and Lin (2009): In this article work has been done on incinerated sewage sludge ash (ISSA) which is mixed with cement in fixed ratio of 4:1 to work as a stabilizer to improve strength of soft, cohesive, subgrade soil. The ISSA/cement is used as admixture and mixed with cohesive soil to make soil samples in five different ratio by weight i.e. 0%, 2%, 4%, 8%, 16%. Different tests were done to identify the effects of admixture on soil properties such as tests of the pH value, Atterberg limits, compaction, California bearing ratio (CBR), unconfined compressive strength, and triaxial compression test.

Unconfined compressive strength of specimens with the ISSA/cement addition was improved to approximately 3–7 times better than that of the untreated soil.

- Swelling behavior was also effectively reduced as much as 10–60% for those samples.
- The ISSA/cement additive improved the CBR values by up to 30 times that of untreated soil.

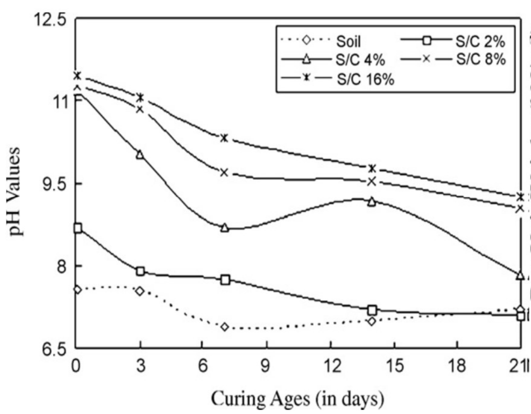

Figure 2. 1 The relationship between pH values and curing ages for cohesive soil with different amounts of ISSA/cement added.

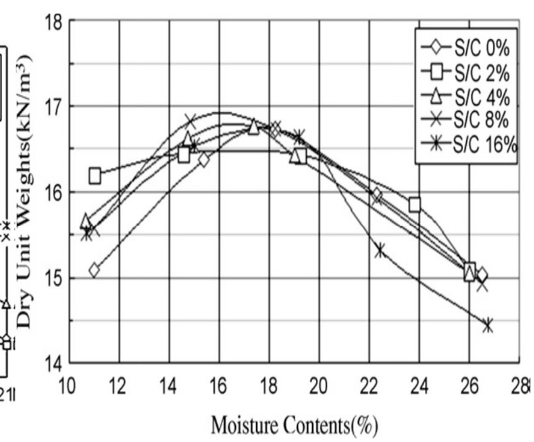

Figure 2. 2 Effects of the ISSA/cement admixture on the properties of the soil after compaction.

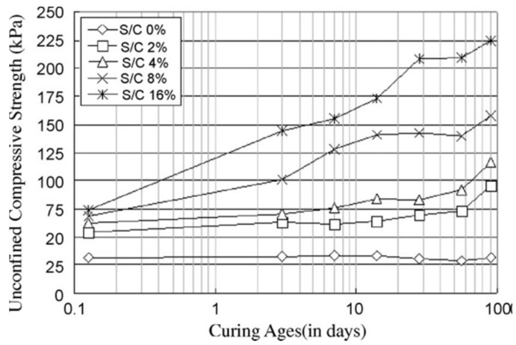

Figure 2. 3 The relationship between ISSA/cement and the unconfined compressive strength of specimens at different curing ages.

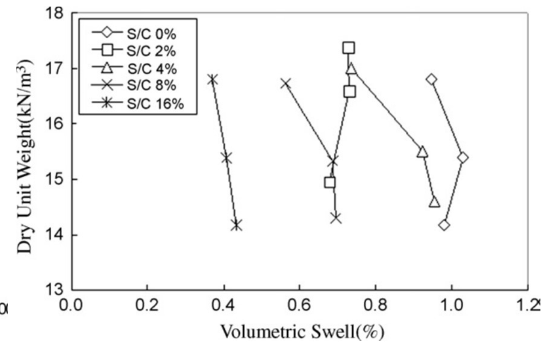

Figure 2. 4 The relationship between volumetric swelling and dry unit weight for the ISSA/cement soil specimens.

Zhang et al. (2018): In this article work has been done on electroplating sludge which may pose serious threat to human health and environment if not treated correctly. The mechanical properties and environmental risks of the cement-coal fly ash solidified sludge were investigated. Portland cement and coal fly ash were used to solidify/stabilize the sludge. The stabilized/solidified sludge samples were tested for mechanical properties, leaching, and microcosmic test after curing for 7, 14, and 28 days.

The test results on compressive strength are as follows:

- Compressive strength increased with the increase of cement content.
- Compressive strength increased with the increase of curing time.
- Compressive strength increased with the increase of cement replacement by coal fly ash.
- Compressive strength decreased with the increase of water content.

The most impactful factor on compressive strength was water content because it was observed that compressive strength decreased by 87.1% as the water content increased from 0% to 10%. Leaching tests were done on stabilized sample and it was observed that leaching of heavy metals was under standard limit and the test was done according to USEPA TCLP method (method no: 1311).

The test results show that electroplating sludge might be used in soil subgrade and problem of its disposal can be solved.

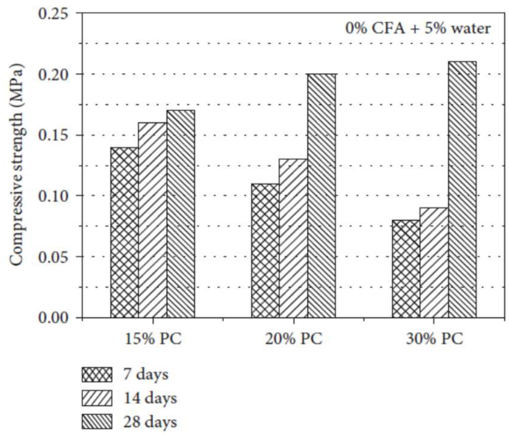

Figure 2. 5 Compressive strength of solidified sludge with different amounts of PC.

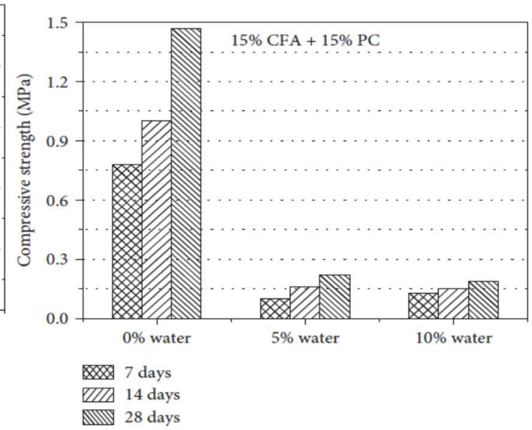

Figure 2. 6 Compressive strength of solidified sludge with different water contents.

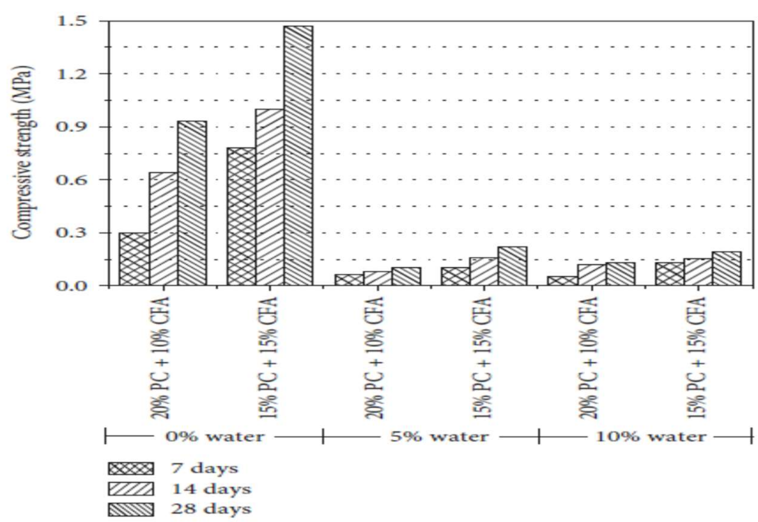

Figure 2. 7 Compressive strength of solidified sludge with different contents of CFA

Cheng et al. (2020) : In this article work has been done on disposal of textile sludge via laboratory and field tests. Solidification/stabilization (S/S) technology and skeleton construction method are introduced to investigate the application of S/S sludge for subgrade material. Solidification/stabilization (S/S) is used to increase the strength of soil and prevent the leaching of heavy metals in the textile sludge. Skeleton construction method aims to decrease the liquid-solid ratio in mixture to reduce the binder dosage and save binder cost.

the differences in unconfined compressive strength (UCS) to explore the optimal mixture were investigated in lab between binders and skeleton material. It was found out that that UCS of binder-sludge is below 100 kPa and enhanced more than 400 kPa after adding gypsum and skeleton material.

The unconfined compressive strength was significantly improved by skeleton soil material with high plasticity index and low moisture content.

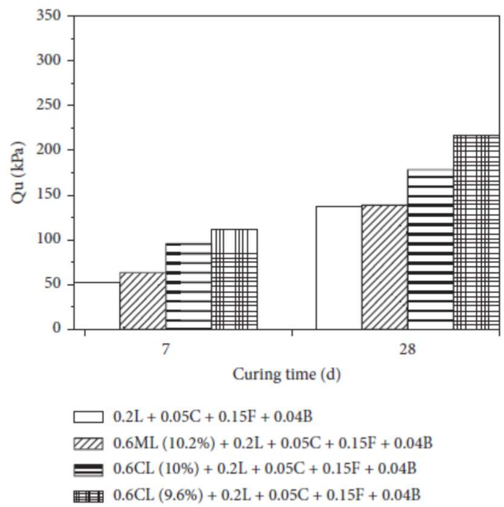

Figure 2. 8 Strength of S/S specimens constructed by skeleton material skeleton materials (ML, CL, and CH) with approximate moisture content.

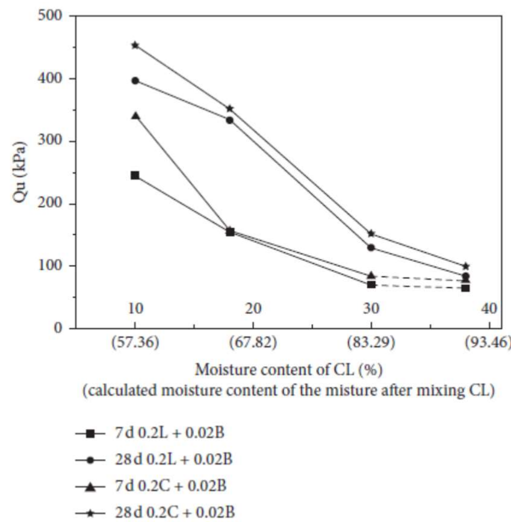

Figure 2. 9 Strength of S/S specimens constructed by skeleton material different moisture contents of the CL.

Iqbal et al. (2020) : In this work has been done on compaction characteristics and the California bearing ratio (CBR) of water treatment sludge (WTS) blended with clay brick aggregates for the road subgrade application. Clay brick (CB) and recycled clay brick (RCB) aggregates of three different particle sizes were prepared from Raw and waste clay bricks from Vietnam.

water treatment sludge (WTS) of 2mm passing sieve was blended with clay brick (CB)/recycled clay brick (RCB) aggregates at different proportion and CBR and MDD test were done and the results showed that MDD was only dependent on mixing proportion of WTS and CB/RCB and increased linearly with increase in amount of CB/RCB.

The WTS blended with coarse and graded fractions with a range of 60 ≤ f ≤ 80% showed a significant improvement in CBR (>100%).

So it can be concluded that WTS blended with CB/RCB can be used in subgrade.

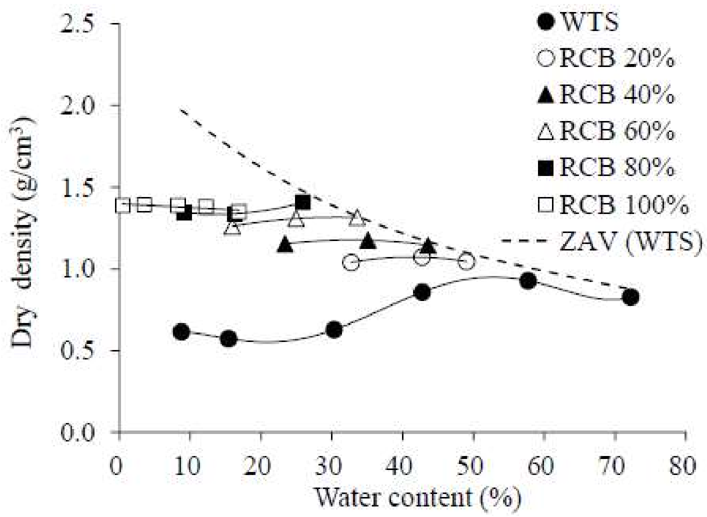

Figure 2. 10 Compaction curves of WTS blended with RCB aggregate (Fine 2–10 mm)

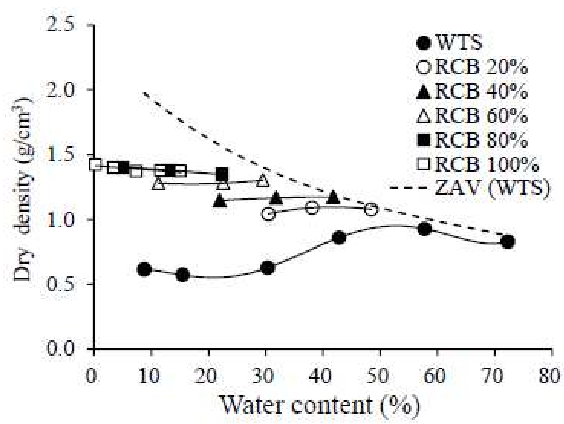

Figure 2. 11 Compaction curves of WTS blended with RCB aggregate (Coarse 10–30)

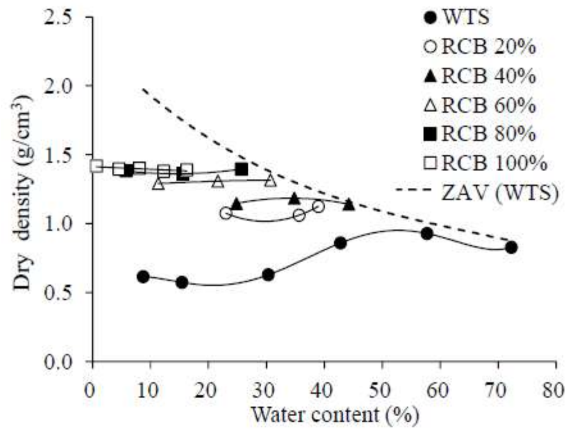

Figure 2. 12 Compaction curves of WTS blended with RCB aggregate (Graded 2–30 mm)

Xiaodan et al. (2020) : In this article work has been done on development of curing agent of sludge. Cement was used as major curing agent, and carried out experiment on sludge solidified as subgrade filling. Experiments were carried out to analyze the effect of addition of curing agent on moisture content, unconfined compressive strength and CBR value of subgrade filling. The results indicated that cement, fly ash, offscum could improve the sludge strength but fly ash did not have a great effect on reducing the moisture content. The excessive use of fly ash caused the lamellar structure of solidified sludge.

Khalid et al. (2015) : In this article work has been done on stabilization of soil using waste paper sludge (WPSA). The soft soil was stabilized WPSA and tests were conducted to determine the following:

- Compressive Strength
- Total Shear Strength
- Effective Shear Strength

The microstructure of soft soil and stabilized soft soil was investigated to evaluate the role of WPSA to the strength of stabilized soft soil. Class-C of WPSA was used to stabilized the soft soil. Firstly, maximum compressive strength and optimum percentages of WPSA mixture was determined then the total shear strength and effective shear strength of soft soil stabilized with optimum percentage of WPSA was determined. Scanning electron microscopic test (SEM) was done to understand the effect of WPSA on strength of stabilized soft soil by microstructure testing.

Three main tests involved were:

- unconfined compression test to determine the compressive strength
- consolidated undrained test to determine the total shear strength
- consolidated drained test to determine the effective shear strength

The results indicated that addition of 10 % WPSA were giving the highest compressive strength about 737 kPa which is about 2.2 times of unstabilized soft soil, and improved the total strength and effective strength to stabilize the soft soil due to the crystal formation from the pozzolanic reaction.

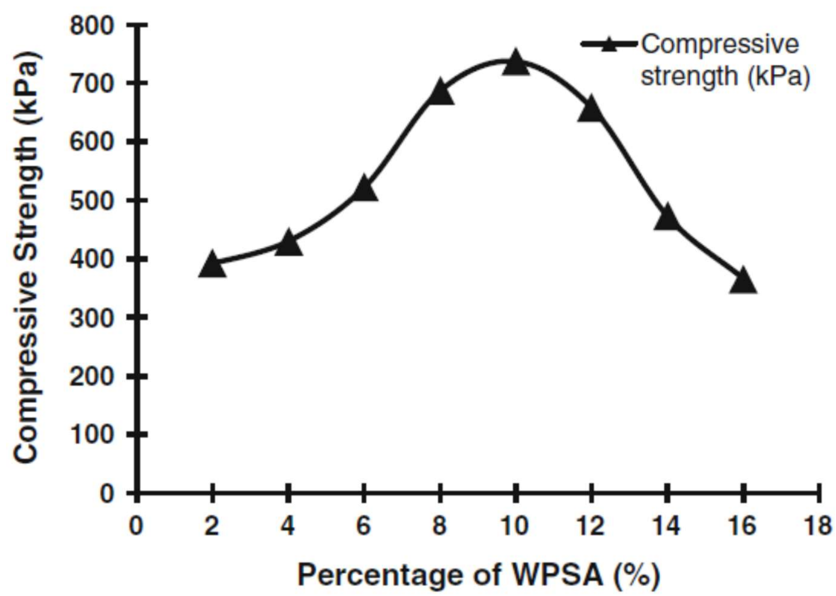

Figure 2. 13 Compressive strength v/s percentage of WPSA

Lin et al. (2016) : In this article work has been done on stabilization and improving the strength of the soft cohesive subgrade soil. The properties of soft cohesive soil were improved by blending the soil with a mixture of sewage sludge ash (SSA) and cement. Nano-SiO_2 was also blended in addition with SSA and cement.

Four different mix ratios of SSA and cement (1:1, 2:1, 3:1, and 4:1) were used as stabilizers and added at a fixed 15% of the soil weight to improve the strength of soft cohesive soil.

Experiments, including Atterberg limit measurements, compaction tests, unconfined compressive strength (UCS) tests, and scanning electron microscopy, were performed to investigate the effect of of 2 % nano-SiO_2.

Microstructure analyses from XRD and SEM indicate that the addition of 2 % nano-SiO_2 accelerated the production of calcium hydroxide and CSH gel.

Results of the tests showed that a mixture of SSA and cement can improve the engineering properties of soft subgrade soil and were as follows:

- UCS that was 6.5–8.4 times better over 28 days.
- CBR value that was 61–97 higher.

Furthermore, the addition of nano-SiO_2 enhanced the engineering properties after adding various SSA/cement ratios as follows:

- UCS was 30–47 kPa higher over 28 days.
- CBR values that were 3–9 higher.

It was concluded that nano-SiO_2 should be added to soil treated with an SSA/cement ratio of 3:1.

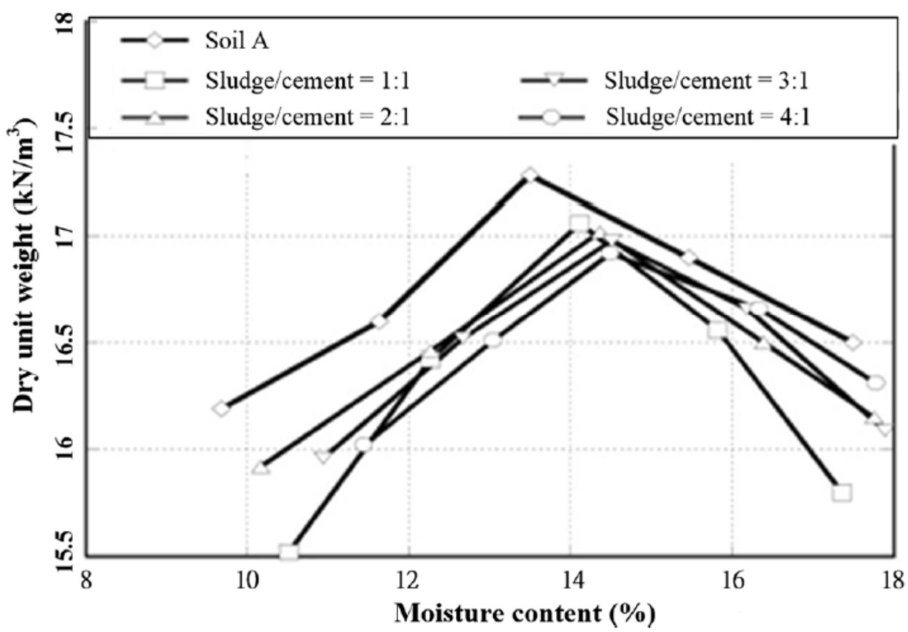

Figure 2. 14 Results for the OMC and maximum dry unit weight obtained from the compaction tests for soil mixed with various SSA/cement ratios

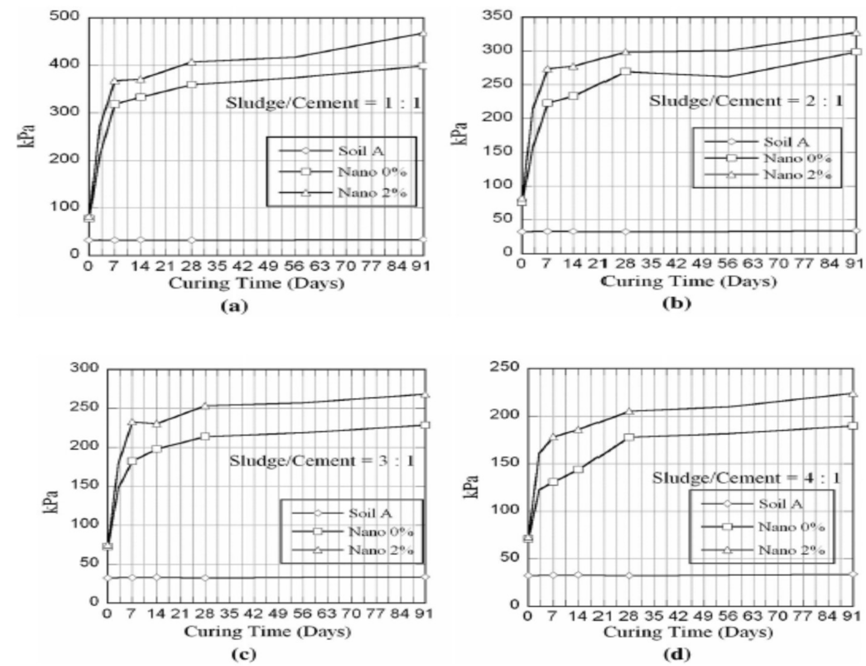

Figure 2. 15 Relationship between the UCSs of treated soil specimens at different curing ages with various ratios of SSA/ cement (a) 1:1, (b) 2:1, (c) 3:1, and (d) 4:1 with or without 2 % nanoSiO2 added

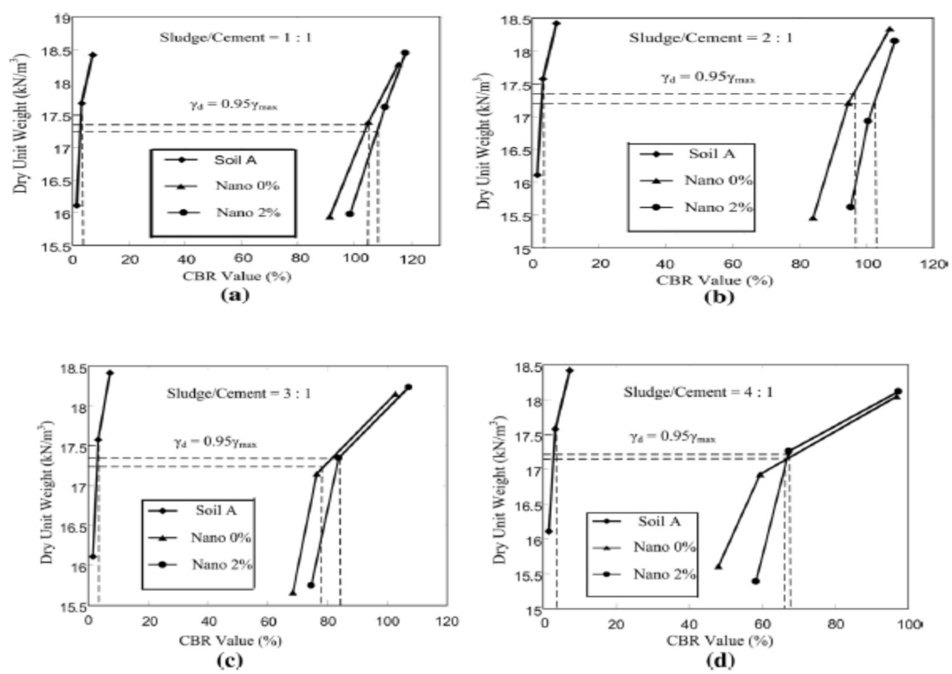

Figure 2. 16 Relationships between CBR values of treated soil specimens at different curing ages and various SSA/cement ratios (a) 1:1, (b) 2:1, (c) 3:1, and (d) 4:1 with or without 2 % nano-SiO2 added

Lisbona et al. (2012) : In this article work has been done on use of calcined paper sludge (CPS) in the stabilization of soils. The mixture of CPS and a mixture of CPS and cement (C) was used to stabilize the soil. The blending ratio (by weight) of the CPS:C mixture was taken as 1:1, 1:3.

Firstly, laboratory tests were done which includes determination of bearing capacity of stabilized soil, after that field tests were done which involved in situ stabilization of 250 m of subgrade using dry-mix methods. The densities of the subgrade were measured in the field following compaction and deflections at 7 days. The change in the unconfined compressive strength (UCS) was measure over the period of 90 days.

The test results concluded that optimal mechanical behavior of the stabilized soil at CPS:C ratios of approximately 1:3.

Table 2. 3 Effectiveness of the Binders to Ensure Strength as a Function of the CPS : Cement Blending Ratio

Test Specimen	Blending ratio CPS:cement	% CPS in dosage	Dosage (%) (%CPS + % cement)	UCS[a] (MPa)/ dosage (%)
SS1	1:0	100	3	0.67
SS2	1:0	100	5	0.66
SS3	1:1	50	4	1.08
SS4	1:1	50	6	0.83
SS5	0:1	0	3	1.50
SS6	0:1	0	3	1.47
SS7	1:3	25	4	1.40
SS8	1:1	50	4	1.05

UCS at 7 days.

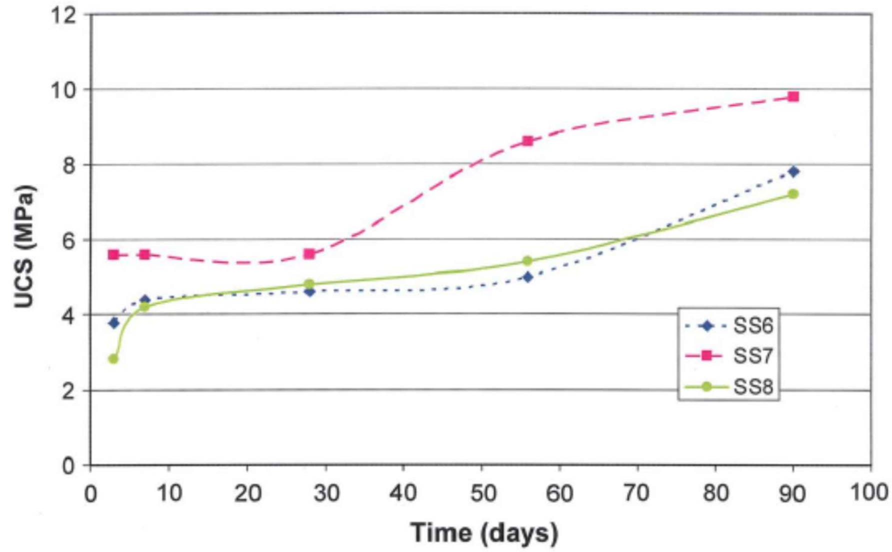

Figure 2. 17 Evolution of unconfined compression strength over time

Luo et al. (2012) : In this article work has been done on stabilization of soft soil with a mixture of incinerated sewage sludge ash (SSA) and cement as a soil stabilizer. The mix ratio of SSA and cement was fixed at 3:1 and A-6 clay was selected as untreated soil, 15% of the clay soil was replaced with SSA/cement which was kept fixed and four different volumes (0%, 1%, 2%, 3%) of nano-Al_2O_3 were mixed with the treated soil as an additive.

Test were conducted to investigate the following properties of the treated soil and compare:

- Compaction
- pH values
- Atterberg limits
- Unconfined compressive strength (UCS)
- Swell potential
- California bearing ratio (CBR)
- Permeability

The results indicated that use of 15% SSA/cement can improve both UCS and CBR value of untreated soil. Which could be further more improved by the addition of nano-Al_2O_3.

The swell potential was effectively reduced by the use of 15% SSA/cement as compared with untreated soil, further more addition of nano-Al_2O_3 reduced the swell potential even more.

It was concluded that 15% of SSA/cement replacement could effectively stabilize A-6 clay soil, and addition of 1% of nano-Al_2O_3 is the optimum amount.

Sabat (2012): In this article effects of bagasse ash and lime sludge on compaction characteristics, unconfined compressive strength (UCS), soaked California bearing ratio (CBR) and swelling pressure of an expansive soil have been discussed.

Different amount of bagasse ash (0 to 16 percent by dry weight of soil in 4 steps) and lime sludge (0 to 20 percent by dry weight of soil in 4 steps) were blended with untreated soil.

Following tests were conducted on each sample after it was cured for 7 days in a humidity chamber at 32ºC temperature and 97% humidity:

- Standard Proctor compaction tests
- UCS tests
- Soaked CBR tests
- Swelling pressure tests (conducted on some selected samples)

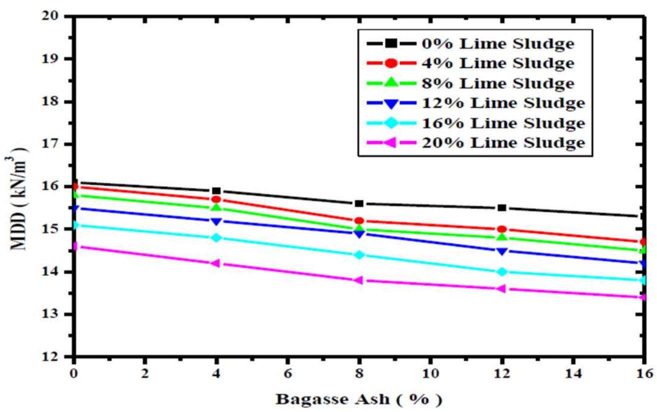

Figure 2. 18 Variation of MDD with percentage of Bagasse ash and Lime sludge

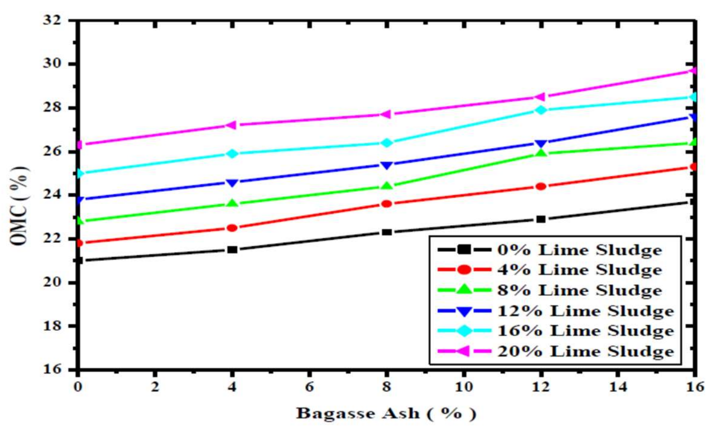

Figure 2. 19 Variation of OMC with percentage of Bagasse ash and Lime sludge

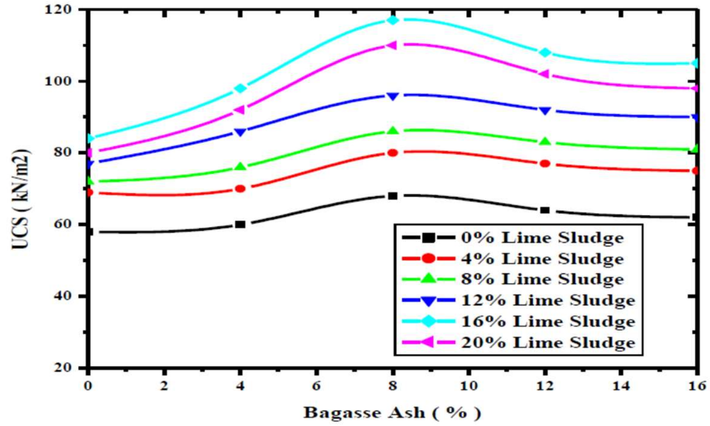

Figure 2. 20 Variation of UCS with percentage of Bagasse ash and Lime sludge

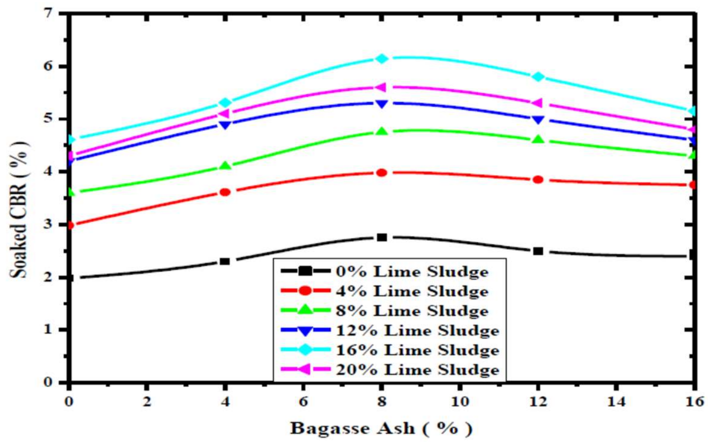

Figure 2. 21 Variation of Soaked CBR with percentage of Bagasse ash and Lime sludge

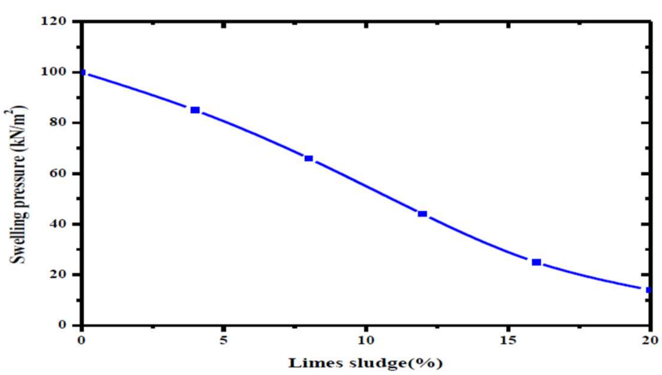

Figure 2. 22 Variation of swelling pressure of 8% Bagasse ash stabilized expansive soil with percentage of lime sludge

From the results and graphs following conclusions were made:

- Increasing the percentage of addition of bagasse ash, the MDD of soil goes on decreasing.
- Increasing the percentage of addition of bagasse ash, the OMC of soil goes on increasing.
- UCS of soil goes on increasing, up to 8% addition of bagasse ash, further addition of bagasse ash decreases the UCS of the soil.
- Soaked CBR of soil goes on increasing, up to 8% addition of bagasse ash, further addition of bagasse ash decreases the UCS of the soil.

Suthar & Aggarwal (2018) : In this article work has been done on stabilization of Class F pond ash with lime (2%, 4%, 6% and 8% by weight) alone and with lime sludge (5%, 10% and 15% by weight). X-ray diffraction (XRD) scanning electron micrograph (SEM) tests were also performed to identify the possible formation of crystalline phases after stabilization. The effects of lime sludge on the unsoaked and soaked bearing ratios of pond ash with different lime contents, after 7 d, 28 d and 45 d of curing, were observed. The test results indicated that up to 4% of lime content, bearing ratio increased rapidly and 4% lime content was taken as optimum content of lime. On adding more than 4% of lime bearing ratio was increasing but at slow rate.

Leachate analysis of stabilized ash was performed using toxicity characteristic leaching procedure (TCLP-1311) method. The leaching of toxic elements Zn, Cu, Cd, Ni and Cr was reduced.

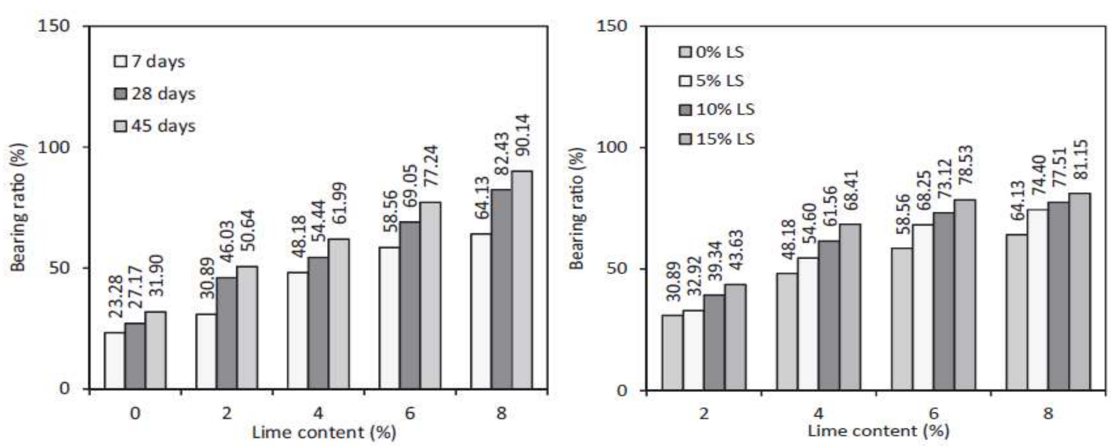

Figure 2. 23 Bearing ratio of lime-stabilized pond ash at 7 days, 28 days and 45 days of curing period (Unsoaked test)

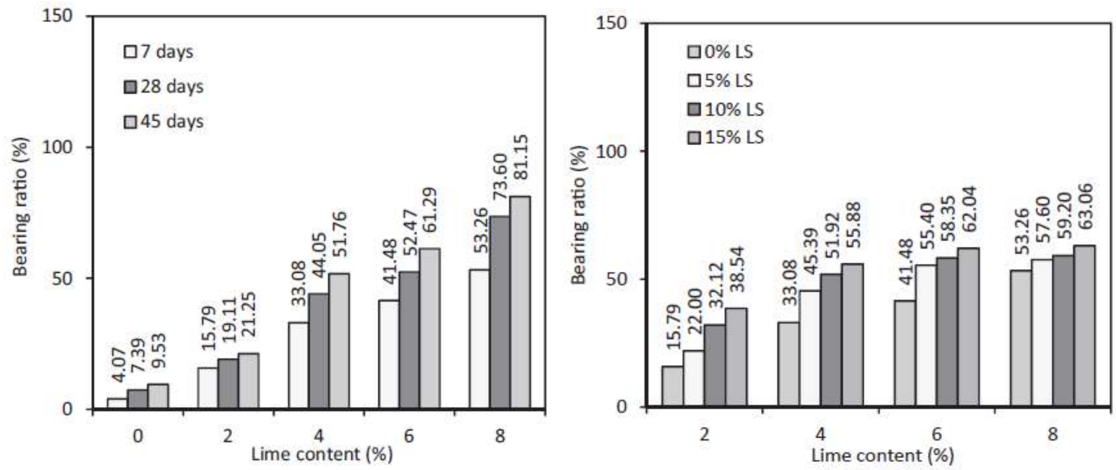

Figure 2. 24 Bearing ratio of lime-stabilized pond ash at 7 days, 28 days and 45 days of curing period (Soaked test)

Phanikumar & Ramanjaneya Raju (2020) : In this article work has been done on chemical stabilization of expansive soils by use of chemical reagents which have been effective in stabilizing expansive soils and improving their characteristics like Lime, cement, CaCl2, fly ash, pond ash, and other chemical reagents and effect of addition of lime sludge on the index properties of expansive clays was also investigated. The properties of stabilized expansive soil were investigated by measuring Liquid Limit (LL), Plasticity Index (PI), Free Swell Index (FSI), other engineering properties, compaction characteristics, stress-strain behaviours at different curing periods and CBRs. The lime sludge was blended in different proportions with the expansive soil and index and engineering properties were observed.

The results showed that on addition of lime sludge the compacted density was improved satisfactorily, all the lime sludge clay blends were added with 10% cement and all the properties mentioned above were studied and it was found out that, on addition of 10% cement LL, PI and FSI were reduced and compacted density was increased, strength and CBR also increased.

Property of material used in this study:

- Expansive soil
    - Natural water content 8%
    - Liquid Limit (LL) 84%

- Plasticity Index (PI) 58%
- Free Swell Index (FSI) 125%
- Maximum Dry Density (MDD) 13.27 kN/m^3
- Optimum Moisture Content (OMC) 29.83%

- Lime Sludge used was in powdered form and was in air dried state.
- Cement used was Ordinary Portland Cement (OPC)

Tests performed in this study:

- Liquid Limit Test
- Plasticity Index Test
- Free Swell Index Test
- Proctor Compaction Test (OMC, MDD)
- Unconfined Compressive Strength Test
- California Bearing Ratio

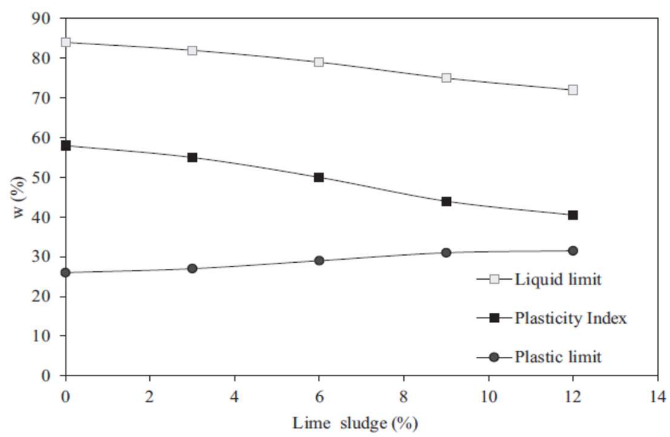

Figure 2. 25 Effect of lime sludge content on index properties of expansive clay

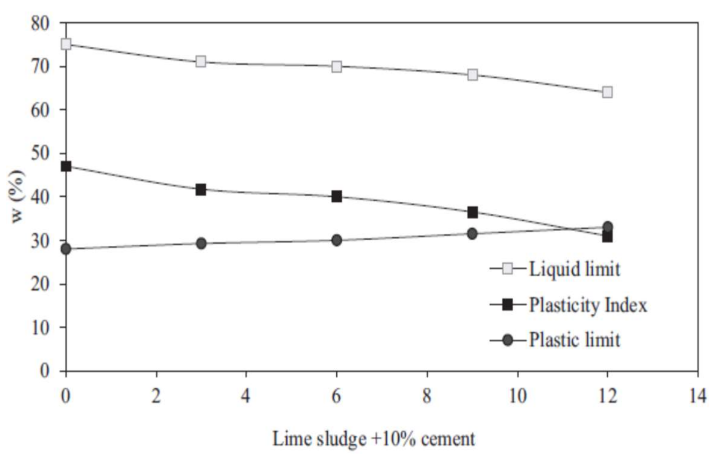

Figure 2. 26 Effect of 10% cement content on index properties of lime sludge treated expansive clay

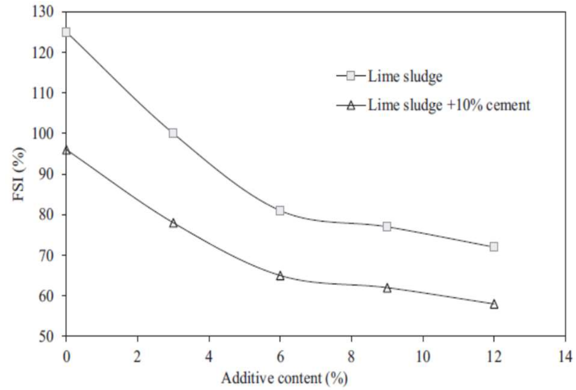

Figure 2. 27 Effect of additives on FSI of expansive clay

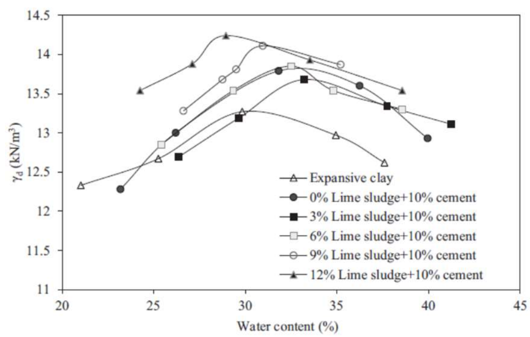

Figure 2. 28 Effect of 10% cement content on compaction characteristics of lime sludge treated expansive clay

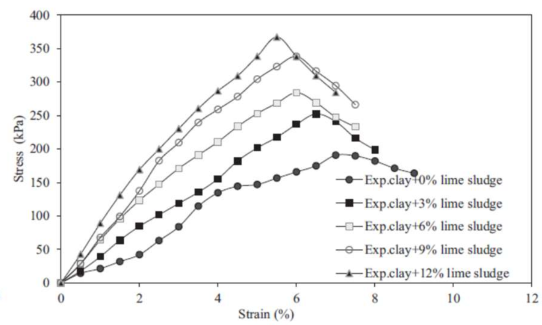

Figure 2. 29 Stress-strain characteristics of expansive clay alone and expansive clay blended with varying lime sludge content (7 days curing)

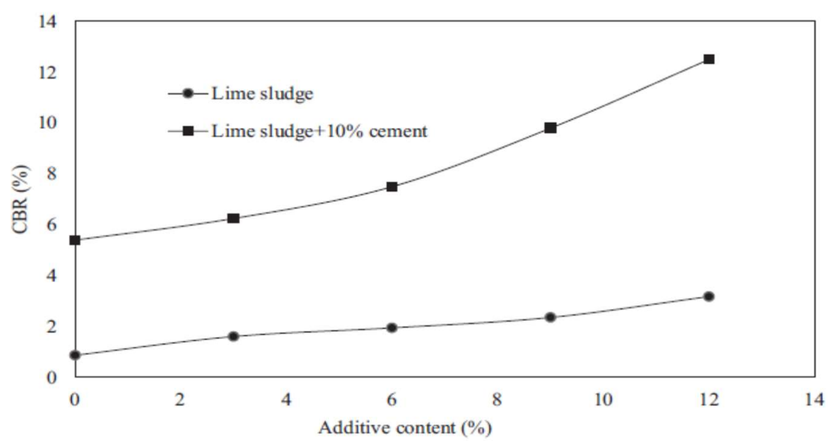

Figure 2. 30 Effect of additives on soaked CBR

Burra et al. (2019) : In this study work has been done on investigation of utilization of lime sludge which is a waste from water treatment plant and polypropylene fiber, Its effects on Unconfined Compressive Strength and shrinkage behaviour of commercially available kaolinite clay are observed.

Fiber and Lime Sludge are added at different quantity and there effects were observed on Unconfined Compressive Strength and shrinkage behaviour. Different composition of fiber were taken as 0%, 0.5%, 1.0%, and 1.5% and composition of lime sludge was taken as 2%, 4%, 6%, and 8%. The percentage added was taken in accordance with the dry weight of kaolinite (EPK clay). Proctor tests were done for different combinations and their OMC and MDD were determined and then the sample were prepared for Unconfined Compressive Strength test.

The test results indicated that addition of fibers and lime sludge results in significant influence on engineering properties with curing period.

The UCS test results indicated that UCS increases with increase in:

- Lime sludge content initially and then slightly decreases.
- Curing period
- Fiber content

It was also observed that shrinkage potential reduces with increase in lime sludge content.

Based on Scanning electron microscopy (SEM) analysis it was concluded that addition of fiber created a physical interaction between the fiber and the EPK clay. Whereas, the use of lime sludge induced a chemical reaction between the EPK clay and the lime sludge which changed the soil fabric significantly.

Material used in this study:

- EPK Clay it is a classified as silt with high plasticity with specific gravity of 2.61.
- Polypropylene fiber - The fibers used in this study were Forta Mighty Mono 100% virgin homopolymer propylene monofilament fibrous reinforcement. It offers long term durability, increased impact resistance and reduce settlement shrinkage. The specific gravity of the fibers was determined to be 0.91. The length of fibers used was 6.35 mm.
- Lime Sludge from a water treatment facility, Lime sludge sample was crushed and mixed prior to its use to obtain more uniform sample. The pH of the lime sludge was 9.10. The

percentages of fine sand, silt, and clay size fraction particles were 12.5, 76.5, and 11, respectively. The specific gravity of the lime sludge was measured to be 2.47.

Tests performed in this study:

- Physical Properties Test
    - Shrinkage Strain Test
- Engineering Properties Test
    - Standard Proctor test
    - Unconfined Compressive Strength (UCS) test
    - Scanning Electron Microscope (SEM) Test

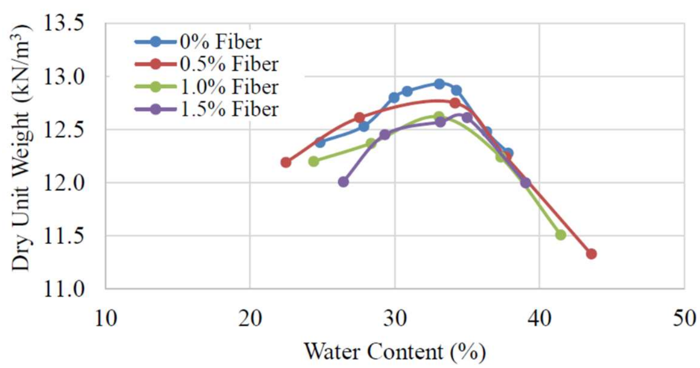

Figure 2. 31 Compaction curve of EPK with various percentages of fiber

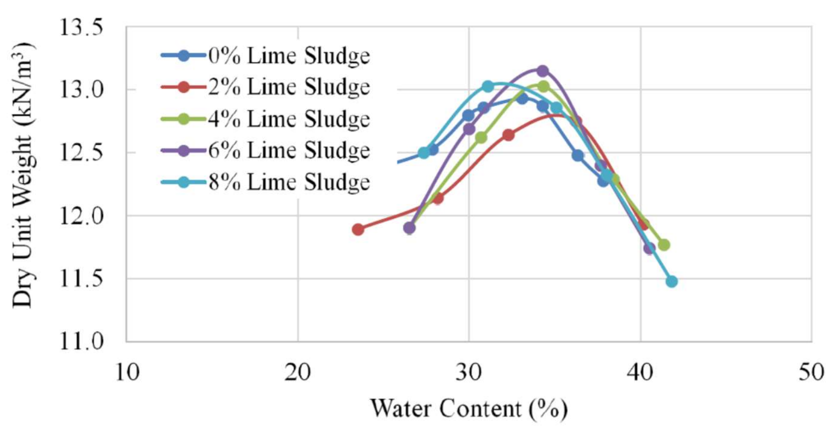

Figure 2. 32 Compaction curve of EPK with various percentages of lime sludge

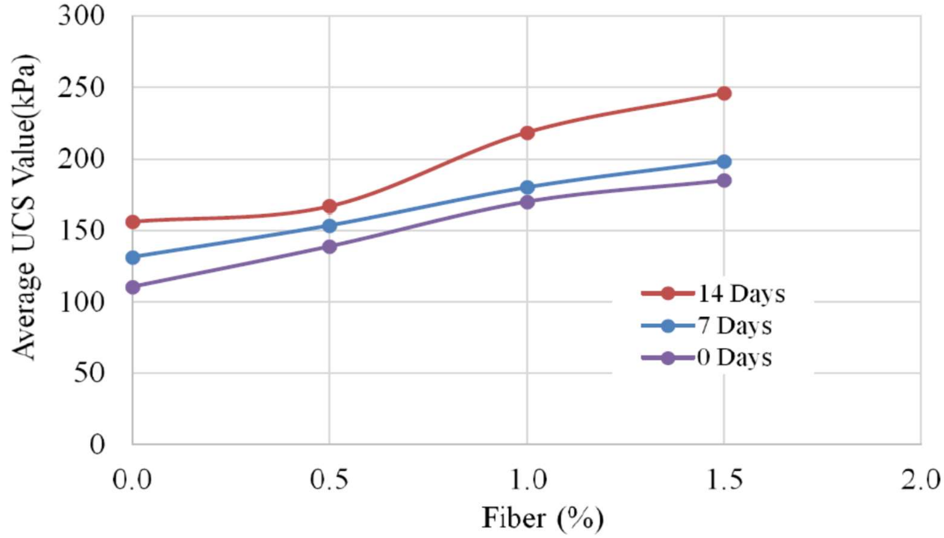

Figure 2. 33 UCS values of EPK clay with Different Fiber percentages after 0, 7 and 14 days curing periods

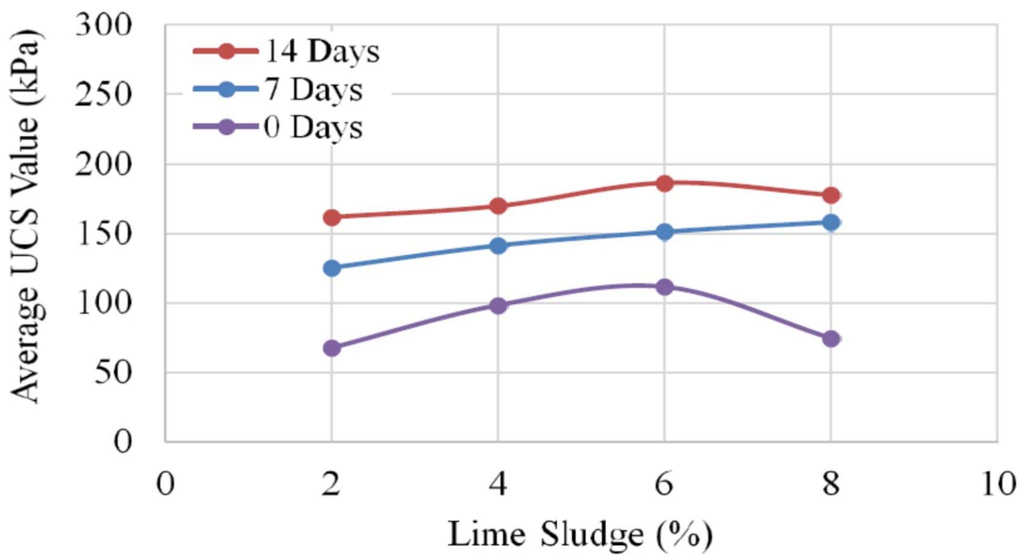

Figure 2. 34 UCS values of EPK clay with Different Lime Sludge percentages for 0,7and 14 days curing periods

Chittoo & Sutherland (2013) : In this article work has been done on investigation of the shear behaviour of unmodified and modified clay to determine the potential of using lime-iron sludge as a soil modifier. Different quantity of lime iron sludge, moisture content, and vertical normal stresses were examined, for that standard test method for direct shear test of soil under consolidated shear condition (ASTM D3080) was performed using a direct shear machine (ELE International T206). Tests were conducted in shear box of 5 cm x 5 cm in plane and 4.2 cm depth, shearing rate was kept at 0.001 cm/s.

Shear stresses were obtained up to a horizontal displacement of 1.2 cm to observe the post failure behaviour. The test results concluded that optimum dose of lime-iron sludge to be mixed is 3% with optimum moisture content of 20%. By using 3% lime-iron sludge and 20% moisture content an improvement of 20% increase in shear stress together with a rise in cohesion of 155% can be achieved.

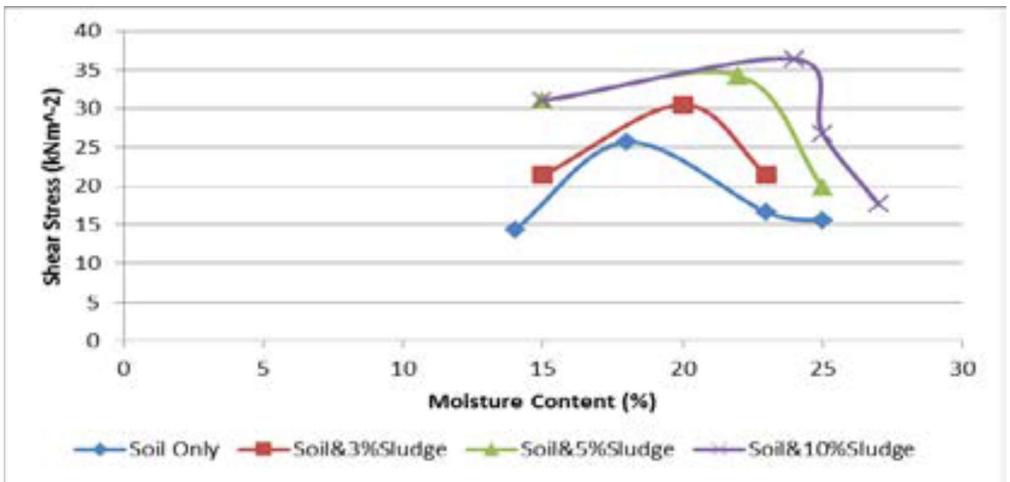

Figure 2. 35 Effect Of Moisture Content On The Shear Stress Of Inorganic Clay For Different Lime-Iron Sludge Concentrations

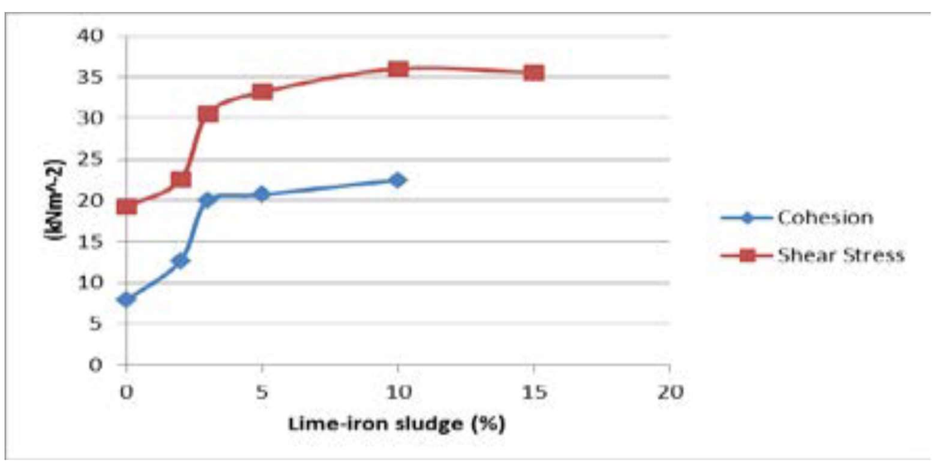

Figure 2. 36 Effect of Lime-Iron Sludge on the Shear Stress and Cohesion of an Inorganic Clay

AI-Sharif and Attom (2014) : In this article work has been done on use of burned sludge ash as a soil stabilizing agent. The sludge ash was obtained from a public wastewater treatment plant, and it was burned at 550ºC. The burned sludge was mixed with three different types of clayey soil at different percent by the dry weight of the soil. Different tests were done on sample treated with burned sludge which are as follows:

- Atterberg's limits test
- Unconfined compressive strength test
- Standard proctor test
- Swelling pressure test

The test results concluded that addition of 7.5 % of the burned sludge ash increases the unconfined compressive strength and maximum dry density and decreases the swelling pressure and the swell potential of the soil. On addition more than that decreases both the maximum dry density and the unconfined compressive strength, thus it was concluded that on adding more than 7.5% of burned sludge decreases the stabilization of soil, so 7.5% of addition of burned sludge ash by dry weight of the soil is the optimum percentage of mixture and burned sludge ash can be used as a promising material for soil stabilization.

Table 2. 4 Physical properties of the used soil

	Soil 1	Soil 2	Soil 3
Atterberg's limits			
Liquid limit (%)	79	69	47
Plastic limit (%)	26	27	23
Plasticity Index (%)	55	42	24
Maximum dry unit weight (kN/m^3)	13.8	14.6	15.6
Optimum moisture content (%)	34	27	21
Grain size distributions			
Sand (%)	11	15	26
Silt (%)	25	32	30
Clay (%)	64	53	44
Activity (%)	86	60	55
Specific gravity Gs	2.7	2.66	2.56
Mineralogical composition			
Kaolinite (%)	18.2	26.6	29.3

Illite (%)	33.2	25.3	37.7
Montmorillonite (%)	14.1	11.0	7.6
Chlorite (%)	16.3	13.1	6.2

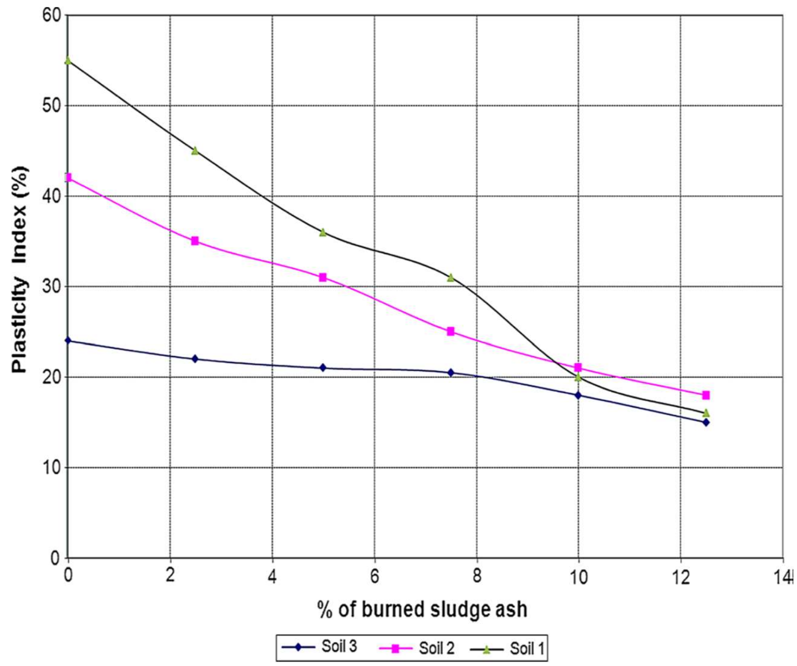

Figure 2. 37 Effect of burned sludge ash on the plasticity index of soils

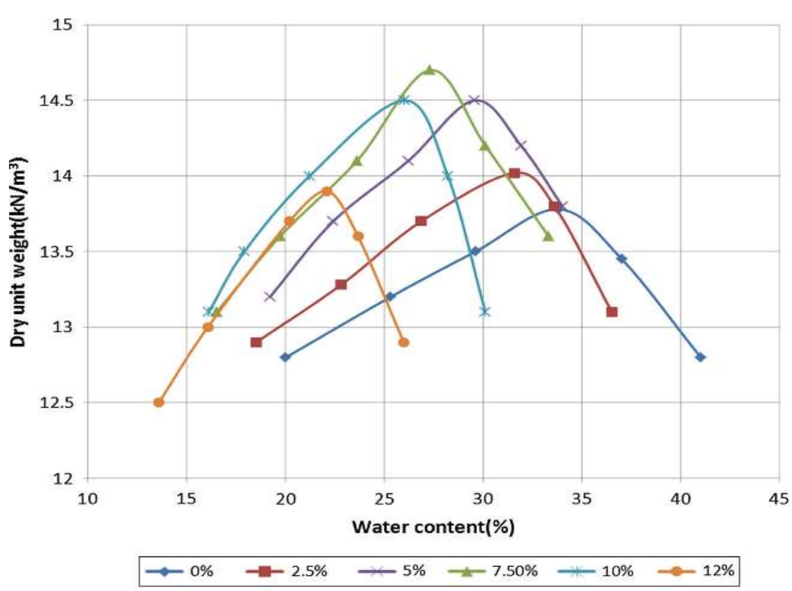

Figure 2. 38 Water content vs. dry unit weight at different percentages of burned sludge ash for soil 1

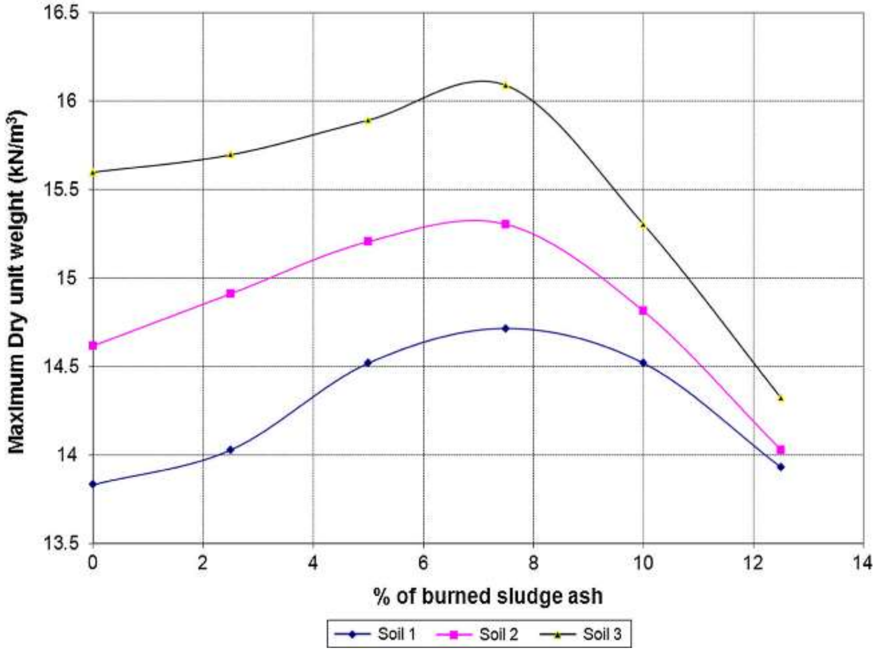

Figure 2. 39 Effect of burned sludge ash on the maximum dry unit weight of soils

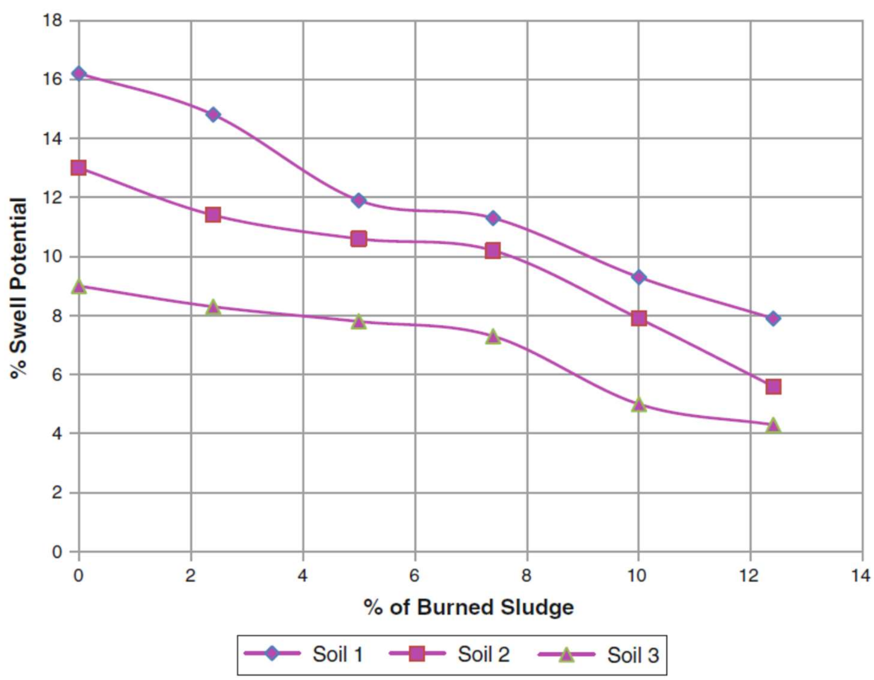

Figure 2. 40 Effect of burned sludge addition on swell potential of the soil

Coban & Cetin (2018) : In this article work has been done on use of lime sludge as an alternative stabilizer to increase its use for soil stabilization. For these 2 different combinations were made and tested one with only lime sludge, and second one with lime sludge and class C fly ash to stabilize silty soil.

Tests performed:

- Atterberg limits test
- Unconfined Compression (UC) test
- Freeze-thaw (F-T) test

The UC test results of the specimens cured up to 90 days showed that the use of lime sludge alone increased the strength of the silty soil. Besides, the UC test results of the 7-day cured specimens pointed out that lime sludge can be mixed with class C fly ash to provide a further increase in the strength of the silty soil. However, the UC test results performed after the F-T tests showed that there was no considerable benefit of using lime sludge either alone or with class C fly ash to increase the durability of the silty soil.

Norouzian et al. (2018) : In this article work has been done on use of sewage sludge ash (SSA) as an additive for clay. The mechanism of sewage sludge ash (SSA) and hydrated lime (HL) was studied by testing its effects on clay samples.

The SSA was taken in different contents i.e. - 0, 5, 10, 15% abbreviated as S0, S5, S10, S15.

Hydrated Lime was also taken in different contents i.e. – 0, 1, 3, 5% abbreviated as L0, L1, L3, L5. The ratio was taken by dry weight of the additive to the dry weight of the soil.

Total 288 samples were prepaired for testing with different proportion of SSA, HL and clay samples and unconfined compressive strength (UCS) tests were done on those samples in saturated and unsaturated condition, and coefficient of softening was calculated by the formula.

$k_s = f_{sat} / f_d$

where,

f_{sat} = unconfined compressive strength in saturated condition

f_d = unconfined compressive strength in unsaturated condition

k_s = coefficient of softening

Based on the existing criteria, if the material has a coefficient of softening less than 0.8, the material should not be placed in the vicinity of moisture.

The results of the coefficient of softening indicated that by adding SSA and hydrated lime to clay soil simultaneously, the stabilized clay soils can be applied in the moist and saturated condition. According to the results, the samples of SSA contents 0% with hydrated lime 5% and SSA contents 10% with hydrated lime 5% can be placed in the vicinity of moisture.

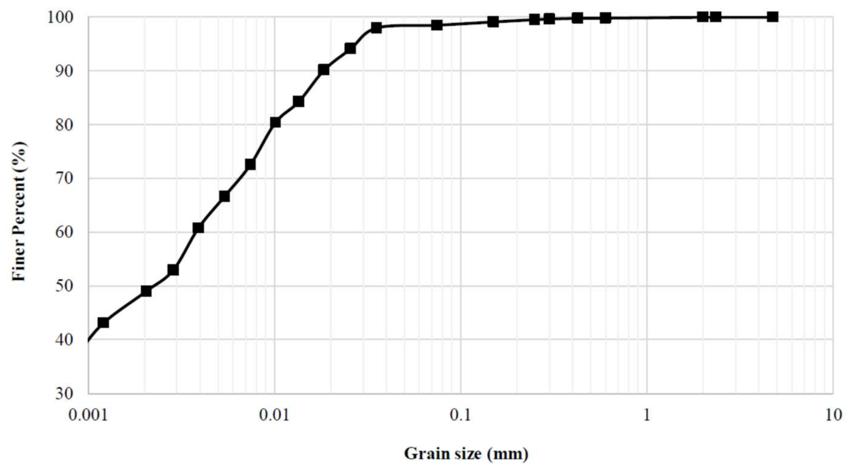

Figure 2. 41 Particle Size Distribution of untreated clay soil

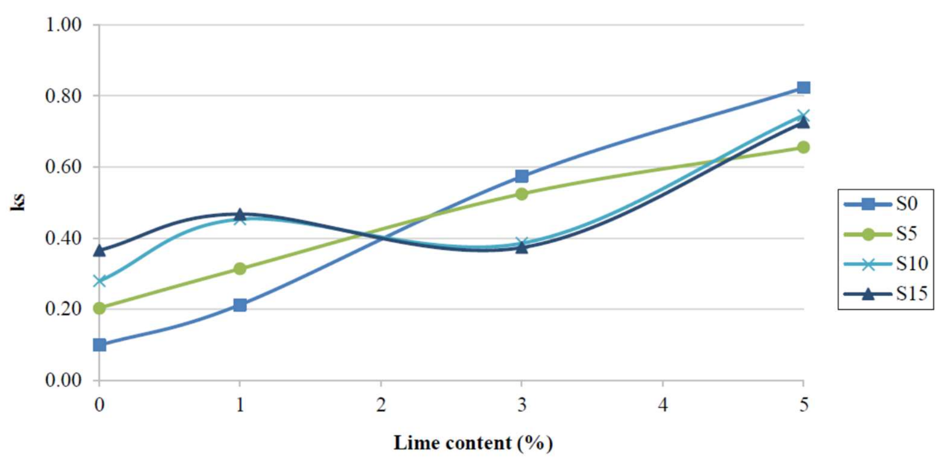

Figure 2. 42 Effect of burned sludge addition on swell potential of the soil

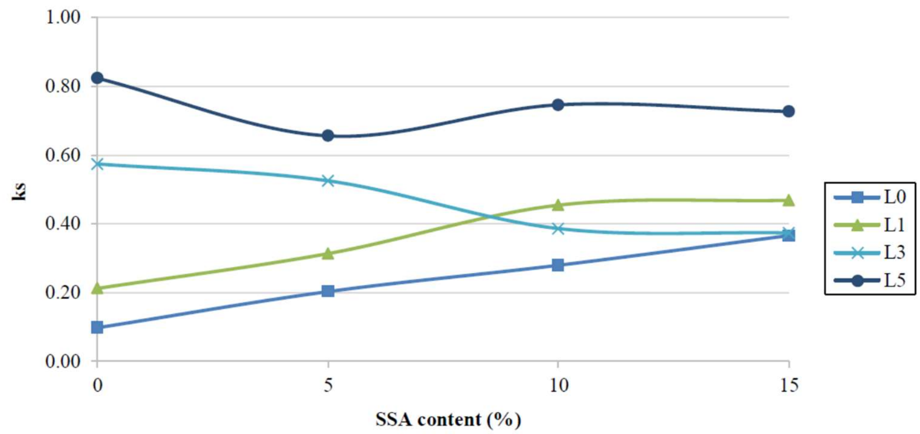

Figure 2. 43 Effect of SSA on coefficient of softening of 7-day samples

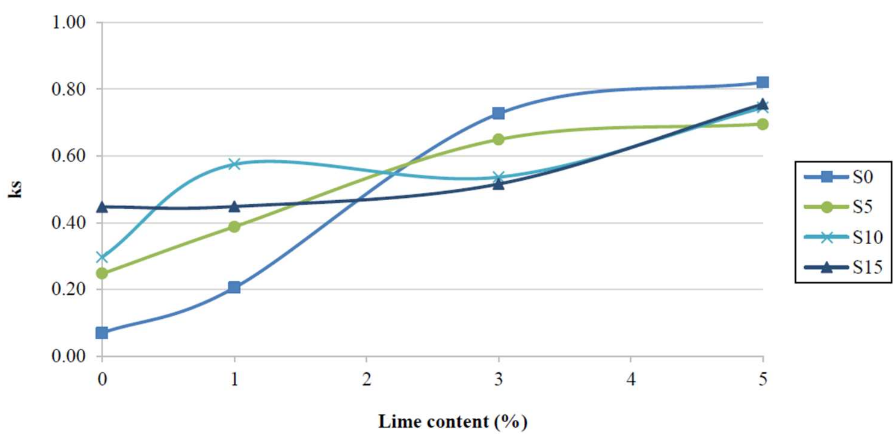

Figure 2. 44 Effect of lime on the coefficient of softening of 14-day samples

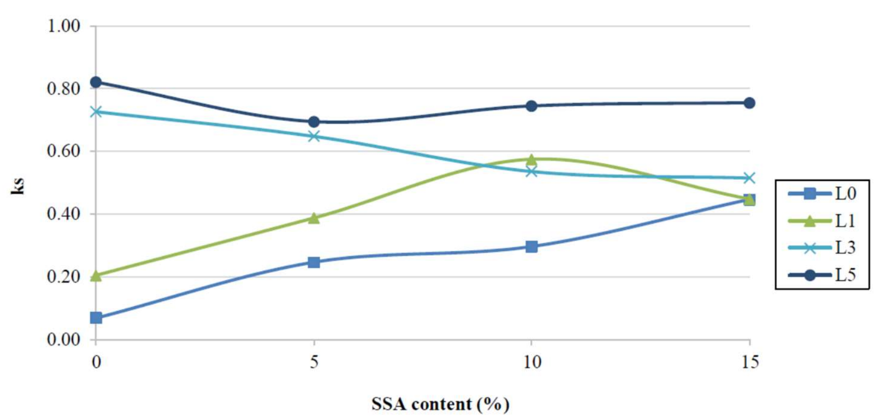

Figure 2. 45 Effect of SSA on coefficient of softening of 14-day samples

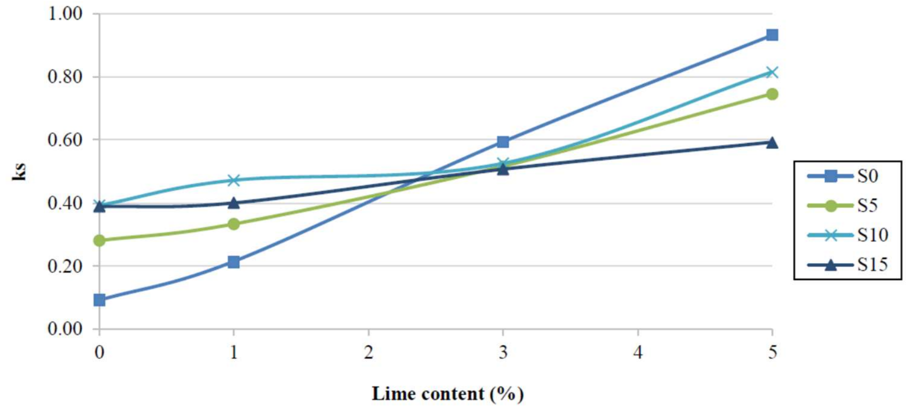

Figure 2. 46 Effect of lime on the coefficient of softening of 28-day samples

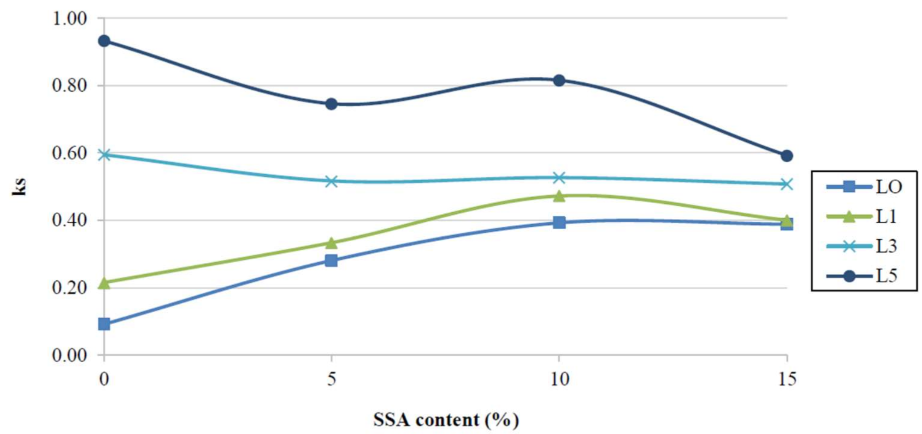

Figure 2. 47 Effect of SSA on coefficient of softening of 28-day samples

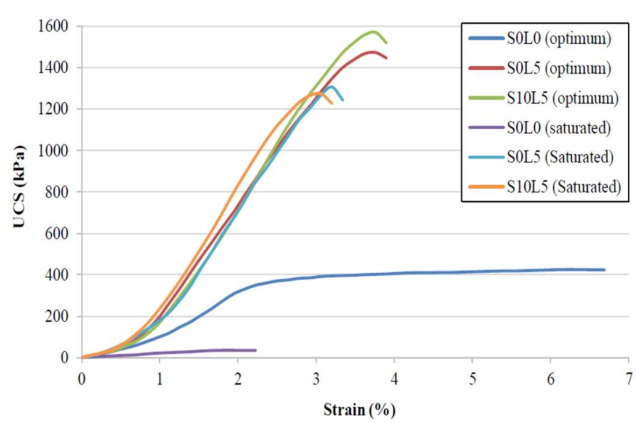

Figure 2. 48 The stress–strain curve of S0L0, S0L5 and S10L5 samples for a 28- day curing time in saturation condition and optimum moisture content condition

Based on the results following assumptions were made:

- The amount water absorption decreased with curing time, increased with SSA content and decreased with lime content.
- The addition of sewage sludge ash and lime to clay soil, increases the coefficient of softening of the soil.
- Using SSA and lime simultaneously increased the coefficient of softening. Curing time leads to an increase in coefficient of softening for both SSA (except the sample stabilized by 15% SSA) and HL stabilization.

It can be concluded that pozzolanic reaction is a time-dependent process and with increasing curing time, the greater amounts of lime and sewage sludge ash participate in the pozzolanic reactions. The most significant influence on the coefficient of softening happened to be from a 28 day test specimen corresponding to the addition of 5% HL, 0% SSA and 5% HL, 10% SSA.

- The samples of S0L5 and S10L5 can be placed in the vicinity of moisture.
- The results show that although adding water caused a reduction in strength.
- Saturation condition has a low failure strain compared to optimum moisture content condition.
- The initial slope of the stress-strain curves was increased by adding SSA and HL to the soil which shows increase in stiffness of the untreated soil.

Chapter 3

Materials and Methodology

In the present thesis, brine sludge has been explored to use as an alternative subgrade material, to use as an alternative cementitious material in cement concrete and to use as an alternative precursor for geopolymer bricks. The sludge has been explored as subgrade material in isolation as well as in different combination with fly ash. In cement concrete, different proportions of sludge have been investigated for partial replacement of cement. The sludge has been explored as an alternative precursor, blended with fly ash in geopolymer bricks.

3.1 Materials

Following materials have been used in the experimental work throughout the study.

3.1.1 Cement

The cement used for the experimental work is Ordinary Portland Cement (OPC), grade 43, make Ultratech, which comes with a trade name as "ULTRATECH OPC 43". It satisfies the requirement of OPC 43 grade cement according to IS:269-2015. The physical properties of OPC 43 cement used in our study are shown in table 2.5 below.

Table 2. 5 Physical properties of OPC 43 cement

S. No.	Characteristic	Test Result	Requirement
i)	Normal Consistency	30%	-
ii)	Setting time: a) Initial, min, Min b) Final, min, Max	 72 min 305 min	 30 min 600 min
iii)	Fineness	4.7%	-
iv)	Specific Gravity	3.1	-
v)	Compressive strength, MPa a) 72 ± 1 h, Min b) 168 ± 2 h, Min c) 672 ± 4 h, Min Max	 24.07 33.43 42.89 -	 23 33 43 58

3.1.2 Fly Ash

The fly ash use in this study was acquired locally from a fly ash brick manufacturer, the physical and chemical properties of fly ash are shown in table 3.1 below and figure 3.1 shows the fly ash used in this study.

Figure 3. 1 Fly Ash

Table 3. 1 Physical properties of Fly Ash

Properties	Value
Class	F
Colour	Grey
Specific gravity	**2.14**

Table 3. 2 Chemical properties of Fly Ash

Properties	Value
Loss on ignition	1.2%
SiO_2	59.37
Al_2O_3	27.94
Fe_2O_3	3.68
CaO	3.12
MgO	1.57
SO_3	0.085

3.1.3 Coarse aggregate

Crushed stone aggregates (locally available) of size 20 mm and 10 mm are used throughout the experiment study. The particle size distribution of 10 mm and particle size distribution of 20 mm and physical properties of coarse aggregates are given in Table 3.3, Table 3.4 and Table 3.5 respectively.

Particle size was done according to Indian Standard Code 383-1970 Clause 4.1

Table 3. 3 Sieve analysis of 10 mm coarse aggregate

IS Sieve Designation	Weight retained (g)	Percent weight retained	Cumulative percent of weight retained	Cumulative percent of weight passing	Limit of percentage passing IS : 383
12.5 mm	0	0.0	0.0	100.0	100
10 mm	680	13.6	13.6	86.4	85 to 100
4.75 mm	3738	74.8	88.4	11.6	0 to 20
2.36 mm	342	6.8	95.2	4.8	0 to 5
Pan	240	4.8	100.0	0.0	-
Total	**5000**				

Table 3. 4 Sieve analysis of 20 mm coarse aggregate

IS Sieve Designation	Weight retained (kg)	Percent weight retained	Cumulative percent of weight retained	Cumulative percent of weight passing	Limit of percentage passing IS : 383
40 mm	0.00	0.0	0.0	100.0	100
20 mm	0.386	3.9	3.9	96.1	85 to 100
10 mm	7.768	77.7	81.5	18.5	0 to 20
4.75 mm	1.420	14.2	95.7	4.3	0 to 5
Pan	0.426	4.3	100.0	0.0	-
Total	**10**				

Table 3. 5 Physical properties of coarse aggregates

Characteristics	10 mm Coarse Aggregate	20 mm Coarse Aggregate
Specific Gravity	2.69	2.79
Water Absorption	0.17%	0.38%

3.1.4 Natural fine aggregate

Sand was used as fine aggregate which was procured locally. The particle size distribution (sieve analysis) was done and is shown in Table 3.6 below and other physical properties of sand are presented in Table 3.7. To remove any unwanted particles that have size greater than 4.75 mm sieving was done through 4.75 mm sieve.

Table 3. 6 Sieve analysis of fine aggregates

I.S. Sieve Designation	weight retained (g)	Percent weight retained	cumulative percent of weight retained	cumulative percent of weight passing	Requirement of percentage passing for zone II by IS : 383
10 mm	0	0.0	0.0	100.0	100
4.75 mm	14	1.4	1.4	98.6	90-100
2.36 mm	9	0.9	2.3	97.7	75-100
1.18 mm	388	38.8	41.1	58.9	55-90
600 micron	167	16.7	57.8	42.2	35-59
300 micron	266	26.6	84.4	15.6	8-30
150 micron	130	13.0	97.4	2.6	0-10
pan	26	2.6	-	-	
Total	1000				

Sand was tested as per Indian Standard Specifications IS : 383-1970. On the basis of particle size distribution, the fine aggregates fall under zone II of IS : 383-1970 clause 4.3.

The sand satisfies the grading requirements of zone II of IS : 383-1970, Hence it is a Zone-II Fine Aggregate.

The specific gravity of fine aggregate was measured using pycnometer shown in Indian Standard Code 2386 (part III) – 1963. The sample was placed in a try and filled with distilled water. Soon after immersion, air entrapped in or bubbles on the surface of the aggregate were removed by gentle agitation with a rod. The sample was left to remain immersed for 24 hours. After 24 hours the water was drained from the sample and the surface dry condition was made. The saturated and surface-dry sample was weighed as W1.

The sample was the filled in the pycnometer and then it is filled with water, to remove any trapped air pycnometer was rotated on its side while covering the hole in the apex with finger and filled with distilled water and weight is noted down as W2. All the aggregates were then transferred to tray and the pycnometer is then again filled with distilled water and weighed as

W3. The water absorption along with specific gravity was calculated by drying this sample in oven at 110^0C for 24 hours and noted down the weight as W4.

Specific gravity = W4/ [W1 - (W2 – W3)]

Water absorption = [100 x (W1 – W4)]/W4

where,

W1 = weight of saturated surface dry sample, g

W2 = weight of pycnometer containing sample and filled with water, g

W3 = weight of pycnometer filled with water, g

W4 = weight of oven dried sample, g

Table 3. 7 Physical properties of fine aggregate

S.No.	Characteristics	Value/ Type
i)	Specific gravity	2.65
ii)	Water Absorption	1.6%
iii)	Grading zone	Zone II

3.1.5 Manufactured fine aggregate

Manufactured fine aggregate or stone dust was used for the purpose of making bricks. Specific gravity and water absorption was determined which comes out to be 2.66 and 2.96% respectively.

3.1.6 Brine sludge

Brine sludge is a by-product of the chlor-alkali manufacturing industry which is produced during the electrolysis of brine.

Specific Gravity = 2.72

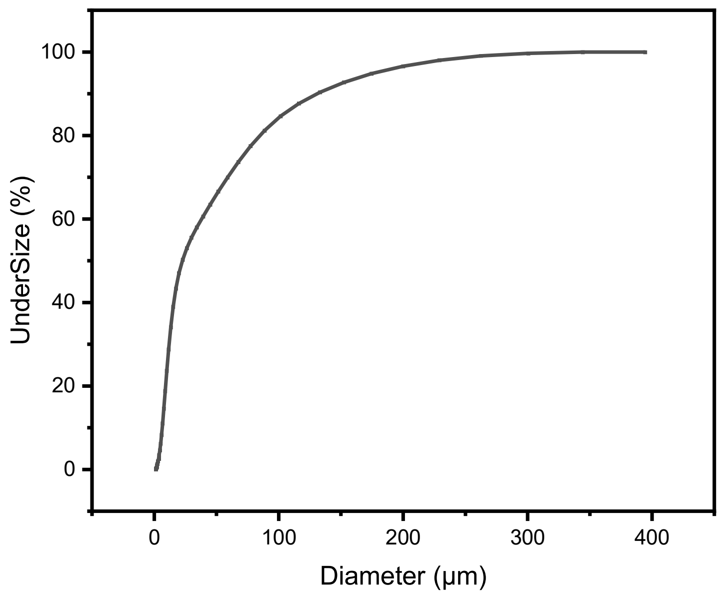

Figure 3. 2 Particle size distribution of brine sludge (F - I)

Particle Size Distribution of brine sludge

Median Size : 22.59890(μm)

Mean Size : 49.80172(μm)

Std.Dev : 57.9458(μm)

3.1.7 Caustic Soda Lye

Sodium hydroxide solution of concentration 47.5 ± 0.2 % was used for the purpose of this study. It has the following synonyms Liquid Caustic Soda, Soda Lye, Lye Solution, Sodium Hydroxide. Table 3.8 below shows the properties of Caustic Soda Lye.

Table 3. 8 Properties of Caustic Soda Lye

Appearance	Clear, colourless liquid
Nature	Strong base
Odour	Unpleasant
Solubility in water	Completely soluble
Density	710 kg/m^3

Caustic soda lye should be stored in a tightly closed container in a designated area with adequate ventilation, away from acids. Caustic soda lye is corrosive in nature. For safety wear all the necessary personal protective equipment (PPE). Ensure adequate ventilation. Prevent breathing of mist or vapours. Prevent contact with skin, eyes and clothing.

3.1.8 Sodium silicate solution

Sodium silicate solution of grade 52 was used for the purpose of study. The properties of sodium silicate are shown in table 3.9 below.

Table 3. 9 Properties of Sodium silicate

Appearance	Liquid
Color	Cloudy
Odor	Odorless
Solubility in Water	Completely soluble

3.1.9 Water

Water is a major component of concrete mix. Water is very important for mixing because in the chemical reaction along with the cement it actively participates, it is also Important for the purpose of curing. The quality and quantity of water should be looked into very carefully because water helps to achieve the strength by forming cement gel, so it is advised that the water should be free from organic matter, silt, oil, sugar and other impurities so it is advised to use potable water for the purpose of mixing and curing. Same is used in this research.

3.1.10 Admixture

The admixture used in this study is Auramix 400, it is a high performance superplasticiser intended for applications where high water reduction and long workability retention are required.

Table 3. 10 Properties of Auramix 400

Appearance	:	Light yellow coloured liquid
pH	:	Minimum 6.0
Volumetric mass @ 20^0 C	:	1.09 kg/litre

For safety Auramix 400 does not fall into the hazard classifications of current regulations. However, it should not be swallowed or allowed to come into contact with skin and eyes. Suitable protective gloves and goggles should be worn. Splashes on the skin should be removed with water. In case of contact with eyes rinse immediately with plenty of water and seek medical advice. If swallowed seek medical attention immediately - do not induce vomiting.

3.2 Methodology

3.2.1 Brine sludge as an alternative subgrade material

A total of four sludge samples were investigated out of which two are weathered sludge samples and two are un-weathered sludge.

All the four sludge samples were tested for optimum moisture content and maximum dry density. A total of four samples have been prepared, one for each sludge sample. The sludge samples were named as F-I, F-II, F-III and F-IV. Further, sludge sample F-I (one from the group of weathered sludge samples) and F-III (one from the group of un-weathered sludge samples) have been blended with fly ash and explored for optimum moisture content and maximum dry density.

A total of two replacement levels of fly ash have been tested while investigating the blends of sludge and fly ash as subgrade material. 20% fly ash and 40% fly ash by weight was incorporated in respective blended samples.

The mix 80% F-I + 20% fly ash is named as 80F-I - 20FA. Similarly, other mixes are named as 60F-I - 40FA, 80F-III - 20FA, 60F-III - 40FA. A total of 8 samples were investigated, 04 samples for raw sludge and 04 samples for fly ash blended sludge.

California bearing ratio (CBR) test was done at optimum moisture content for all the eight samples discussed above. For each mix, soaked and unsoaked CBR test was performed separately at respective optimum moisture content.

Therefore, a total of 16 CBR tests have been performed including 08 soaked CBR tests and 08 unsoaked CBR tests.

Table 3. 11 Brine Sludge and Fly Ash blends naming

Brine Sludge type and quantity in mix	Fly Ash quantity in mix	Name of mix
F-I 80%	20%	80F-I - 20FA
F-I 60%	40%	60F-I - 40FA
F-III 80%	20%	80F-III - 20FA
F-III 60%	40%	60F-III - 40FA

3.2.1.1 Optimum moisture content and maximum dry density determination

For optimum moisture content and maximum dry density, proctor test was done on each sample according to IS : 2720 (Part VII) - 1980 for which about 2200 gram sample passing through 4.75 mm sieve was taken, The mould, with a capacity of 1000 cm^3 and a baseplate attached was weighed. The mould was placed on a solid base which in our case was marble floor and the moist sample was compacted into the mould, with the extension attached, in three layers. Each layer was approximately taken in equal mass and 25 blows were given to each layer by a rammer of weight 2.6 kg which is dropped from a height of 310 mm above the sample, it was ensured that blows are distributed uniformly over the surface of each layer. It was ensured that the tube of rammer was clean from sample to ensure the free fall. It was tried that the sample filled in mould is just enough that not more than 6 mm of sample is there to struck off when the extension of mould is removed. After the extension is removed, the compacted soil was levelled to the top of mould by straightedge. After that mould was weighed with soil.

The sample was then removed from the mould and paced in the mixing tray while small amount of sample was taken from the sample in mould for the determination of water content, The method for determination of water content is discussed below in section 3.2.1.2.

The remainder of the specimen was broken up and then mixed with the remainder of the original sample, Suitable increment of water were added successively and mixed into the sample, and the above procedure was repeated for each increment of water added. The total number of determinations made were such that optimum moisture content, at which the maximum dry density occurs in the range of wated added.

Figure 3. 3 Proctor Mould

From the above procedure following data can be interpreted at each water content level:

- Bulk density
- Dry density

Bulk density (γ_m g/ml) : Bulk density shall be determined from the equation 1 below

$$\gamma_m = \frac{m_2 - m_1}{V_m} \qquad \text{Equation 1}$$

where,

m_1 - mass in g of mould and base;

m_2= mass in g of mould, base and soil; and

V_m - volume in ml of mould.

Dry density (γ_d g/ml) : Dry density shall be determined from the equation 2 below

$$\gamma_d = \frac{100\gamma_m}{100 + w} \qquad \text{Equation 2}$$

where,

w = moisture content of soil in percent

3.2.1.2 For determination of water content (w)

Determination of water content for each sample was done according to IS: 2720 (Part II)- 1975, The container with lid was cleaned for each sample whose moisture content had to be determined, the empty dry weight of container with lid was wayed, after that sample was placed into the container and sample was crumbled. The weight of the container with lid and sample filled was measured. The sample was left for 24 hours at about temperature of 110 ± 5º with lid removed inside the oven. After 24 hours the sample was taken out from the oven and lid was replaced. The container was then weighed with lid and dry sample inside it. The water content is determined from the equation 3 below

$$w = \frac{W_2 - W_3}{W_3 - W_1} \text{ x } 100 \qquad \text{Equation 3}$$

where,

w = water content in percent,

W_2 = mass of container with lid with wet soil in g,

W_3 = mass of container with lid with dry soil in g, and

W_1 = mass of container with lid in g.

3.2.1.3 Determination of California Bearing Ratio (CBR)

CBR tests were done on each sample at their respective optimum moisture content which was calculated prior to the CBR test. The sample was tested for CBR in soaked and unsoaked condition.

3.2.1.3.1 Soaked CBR

The material used in the remoulded specimen was sieved through 19-mm IS Sieve. 5kg of sample was taken and the sample was mixed with water up to their respective optimum moisture content before compaction. The mould with the extension collar attached was clamped to the base plate. The spacer disc was inserted over the base plate and a disc of coarse filter paper was placed on the top of the spacer disc and the collar is attached over the mould. The moist sample was compacted over the spacer disc in the mould in 5 layers in accordance with the light compaction to the 150 mm diameter mould specified in IS : 2720 (Part 8) – 1983.

The extension collar was removed and the compacted soil was carefully trimmed even with the top of the mould by means of a straightedge. The base plate and the spacer disc shall was removed, and the mass of the mould and the compacted soil specimen recorded. A disc of coarse filter paper shall be placed on the base plate, the mould and the compacted soil was inverted and the perforated base plate clamped to the mould with the compacted soil in contact with the filter paper.

The sample from the remaining material was taken for moisture content and its water content was determined as discussed in section 3.2.1.2.

A filter paper was placed over the specimen and the adjustable stem and perforated plate was placed on the compacted soil specimen in the mould. Weights to produce a surcharge equal to the weight of base material and pavement to the nearest 2.5 kg was placed on the compact soil specimen. The whole mould and weights was immersed in a tank of water allowing free access of water to the top and bottom of the specimen. This set-up shall be kept undisturbed for 96 hours (4 days) in water maintaining a constant water level. After 4 days the setup is taken out from the water and free water collected in the mould was removed and the specimen was allowed to drain downwards for 15 minutes. It was taken care that sample surface is not disturbed during the removal of the water. The weights, the perforated plate and the top filter paper was removed and the mould with the soaked soil sample was weighed.

The mould containing the specimen, with the base plate in position but the top face exposed, was placed on the lower plate of the CBR testing machine. The surcharge weight equal to that used during the soaking period. To prevent upheaval of soil into the hole of the surcharge weights, 2.5 kg annular weight was placed on the soil surface prior to seating the penetration plunger. The load and deformation gauges was set to zero (In other words, the initial load applied to the plunger shall be considered as zero when determining the load penetration relation). Load was applied to the plunger into the sample at the rate of 1.25 mm per minute. Reading of the load was taken at penetrations of 0.5, 1.0, 1.5, 2.0, 2.5, 4.0, 5.0, 7.S, 10.0 and 12.5 mm.

The load penetration curve is plotted. This curve is usually convex upwards although the initial portion of the curve may be convex downwards due to surface irregularities. A correction is then applied by drawing a tangent to the point of greatest slope and then transposing the axis of the load so that zero penetration is taken as the point where the tangent cuts the axis of penetration. The corrected load-penetration curve would then consist of the tangent from the new origin to the point of tangency on the re-sited curve and then the curve itself.

California Bearing Ratio : The CBR values are calculated for penetrations of 2.5 and 5 mm. Corresponding to the penetration value at which the CBR values is desired, corrected load value shall is taken from the load penetration curve and the CBR calculated as follows:

$$\text{California Bearing Ratio} = \frac{P_T}{P_S} \text{ x } 100 \qquad \text{Equation 4}$$

3.2.1.3.2 Unsoaked CBR

The material used in the remoulded specimen was sieved through 19-mm IS Sieve. 5kg of sample was taken and the sample was mixed with water up to their respective optimum moisture content before compaction. The mould with the extension collar attached was clamped to the base plate. The spacer disc was inserted over the base plate and a disc of coarse filter paper was placed on the top of the spacer disc and the collar is attached over the mould. The moist sample was compacted over the spacer disc in the mould in 3 layers in accordance with the light compaction to the 150 mm diameter mould specified in IS : 2720 (Part 8) – 1983.

The extension collar was removed and the compacted soil was carefully trimmed even with the top of the mould by means of a straightedge. The base plate and the spacer disc shall was removed, and the mass of the mould and the compacted soil specimen recorded. A disc of coarse filter paper shall be placed on the base plate, the mould and the compacted soil was inverted and the perforated base plate clamped to the mould with the compacted soil in contact with the filter paper.

The sample from the remaining material was taken for moisture content and its water content was determined as discussed in section 3.2.1.2.

A filter paper was placed over the specimen and the adjustable stem and perforated plate was placed on the compacted soil specimen in the mould. Weights to produce a surcharge equal to the weight of base material and pavement to the nearest 2.5 kg was placed on the compact soil specimen.

The mould containing the specimen, with the base plate in position but the top face exposed, was placed on the lower plate of the CBR testing machine. The surcharge weight is used, to prevent upheaval of soil into the hole of the surcharge weights, 2.5 kg annular weight was placed on the soil surface prior to seating the penetration plunger. The load and deformation gauges was set to zero. Load was applied to the plunger into the sample at the rate of 1.25 mm per minute. Reading of the load was taken at penetrations of 0.5, 1.0, 1.5, 2.0, 2.5, 4.0, 5.0, 7.S, 10.0 and 12.5 mm.

The load penetration curve is plotted. This curve is usually convex upwards although the initial portion of the curve may be convex downwards due to surface irregularities. A correction is then applied by drawing a tangent to the point of greatest slope and then transposing the axis of the load so that zero penetration is taken as the point where the tangent cuts the axis of penetration. The corrected load-penetration curve would then consist of the tangent from the new origin to the point of tangency on the re-sited curve and then the curve itself.

California Bearing Ratio : The CBR values are calculated for penetrations of 2.5 and 5 mm. Corresponding to the penetration value at which the CBR values is desired, corrected load value shall is taken from the load penetration curve and the CBR calculated as follows:

$$\text{California Bearing Ratio} \quad = \frac{P_T}{P_S} \text{ x } 100 \qquad \text{Equation 5}$$

3.2.2 Brine sludge as partial replacement for cement in cement concrete

Concrete mixes were prepared using Cement, fine aggregate, coarse aggregate, water and superplasticizer.

The replacement of brine sludge was made by volume of cement. The replacement levels were varied from 0% - 10% with a shift of 2.5%. First as control specimen with 0% replacement and four others at 2.5%, 5%, 7.5% and 10%, with specimen ID as follows A0, A1, A2, A3 and A4. The mix proportions have been shown in Table 3.12 below.

Table 3. 12 Concrete mixes proportion by replacing the Cement with Brine Sludge

Mix	Brine Sludge (%)	Cement (kg/m^3)	Brine Sludge (kg/m^3)	Coarse aggregate (kg/m^3)	Fine aggregate (kg/m^3)	Water (kg/m^3)	Chemical admixture (%)
A0	0.0	400	0	1200.63	674.58	182	0.70%
A1	2.5	390	8.77	1200.63	674.58	182	0.70%
A2	5.0	380	17.55	1200.63	674.58	182	0.70%
A3	7.5	370	26.32	1200.63	674.58	182	0.70%
A4	10.0	360	35.10	1200.63	674.58	182	0.70%

A total of 30 cubic specimen of 150 mm size were prepared for compressive strength tests. 03 cubes for each mix and a total of 15 cubes were tested for 7 days compressive strength. Similarly, 03 cubes for each mix and a total of 15 cubes were tested for 28 days compressive strength.

A total of 30 beam specimen of 150 mm x 150 mm x 700 mm size were prepared for flexural strength tests. 03 beam specimen for each mix and a total of 15 beam specimen were tested for 7 days flexural strength. Similarly, 03 beam specimen for each mix and a total of 15 beam specimen were tested for 28 days flexural strength.

Procedure for preparation of samples was as follows :

- All the materials were kept at room temperature.
- 6 cube of side 150 mm moulds and 6 beam of dimensions 150 mm x 150 mm x 700 mm moulds were cleaned for each sample, it was ensured that all bolts of the moulds are fully tight and a thin film of oil was applied inside the moulds so that the casted material doesn’t stick to the mould and the demoulding of the moulds can be done easily.
- The moulds were placed empty on vibration table so that vibration can be applied when the moulds are filled with concrete mix.
- The materials were weighed according to the requirement of the mix design.
- The dry materials were placed into the concrete mixer and the lid of the concrete mixer was closed and concrete mixer was then run and the dry materials were mixed properly so that all the materials get blended together perfectly.

- Required amount of admixture was mixed in water, then the water was poured into the concrete mixer where the blended materials are placed, it was taken at most care that the least amount of water touches the concrete mixer surface directly while pouring the water in the blended materials.
- The concrete mixer lid is then closed and the concrete mixer is then rotated till the concrete becomes homogeneous.
- The concrete mix is taken out from the concrete mixer and placed into the empty moulds on the vibration table, the moulds are filled in 3 layers, after each layer is placed vibration is applied, it was made sure that the concrete doesn't bleed out.
- The filled moulds are then left for 24 hours to harden after that demoulding of moulds is done and casted concrete is named with permanent marker.
- The cubes and beams were then placed in filled water tank and left for ageing i.e. 3 cubes and 3 beams from each sample were aged for 7 days and 3 cubes and 3 beams from each sample were aged to 28 days.

Testing procedure of cubes :

- After their ageing cubes were taken out from the water and tested immediately while they are still in the wet condition.
- Surface water and grit was wiped off the specimens.

Placing the cube specimen into the Compression Testing Machine-

- The bearing surfaces of the testing machine was wiped clean and any loose sand or other material was removed from the surfaces of the specimen which will come in contact with the compression platens.
- the specimen was placed in the compression testing machine in such a manner that the load will be applied to opposite sides of the cubes as cast, i.e., not to the top and bottom.
- The axis of the specimen was carefully aligned with the centre of thrust of the spherically seated platen.
- The load was applied without shock and increased continuously at a rate of approximately 140 kg/sq cm/min (228.822 kN/m^2/s) which comes out to be about 5 kN/s for 150 mm cube, until the resistance of the specimen to the increasing load breaks down and no greater load can be sustained.
- The maximum load applied to the specimen was recorded.

Testing procedure of beams :

- After their ageing beams were taken out from the water and tested immediately while they are still in the wet condition.
- Surface water and grit was wiped off the specimens.

Placing the cube specimen into the Flexural Testing Machine

- The bed of the testing machine is provided with two steel rollers, of diameter 38 mm on which the specimen was supported, and these rollers were mounted that the distance from centre to centre of 600 mm.
- The load was applied through two similar rollers, mounted at the third point of the supporting span, that is spaced at 200 mm centre to centre.
- The specimen was placed in the machine in such a manner that the is applied to the uppermost surface as cast in the mould, along two lines spaced 200 mm.
- The axis of the specimen was carefully aligned with the axis of the loading device.
- The load shall be applied without shock and increasing continuously at a rate such that the extreme fibre stress increases at approximately 7 kg/sq cm/min. i.e., at a rate of loading of 400 kg/min for 150 mm x 150 mm x 700 mm beam specimen.
- The load shall be increased until the specimen fails, and the maximum load applied to the specimen during the test shall be recorded and the distance between fracture line and point of loading is measured.

3.2.3 Brine sludge as an alternative precursor, blended with fly ash in geopolymer bricks

Materials used for the preparation of bricks are Brine Sludge, Fly Ash, Stone Dust, Caustic lye (Sodium Hydroxide), Sodium Silicate and water.

Preparation of bricks :

A total of 11 different samples of bricks were made where Fly Ash and Brine Sludge were taken as precursor. Stone dust was used in double the amount of total weight of precursors for each mix. The mix was prepared according to the table 3.13 below and was blended dry in the tray, when mix was properly blended liquid was poured into the mix and was mixed until there are no lumps left so that liquid was mixed evenly into the mix. When the liquid is properly mixed in the mix, the material is placed into the brick mould and then compressed with the arrangement in the brick mould so that the material takes the shape of brick.

Table 3. 13 Mix proportions of Bricks

Brick Code	Sludge	Fly Ash	Stone dust	NaOH	Na_2SiO_3	water	Total Liquid	Total chemical
S1	517	517	2067	300	300	0	600	600
S2	310	723	2067	310	310	0	620	620
S3	723	310	2067	310	310	0	620	620
S4	723	310	2067	300	300	100	700	600
S5	723	310	2067	240	360	100	700	600
S6	723	310	2067	233	467	0	700	700
S7	723	310	2067	200	500	0	700	700
S9	723	310	2067	350	350	0	700	700
S10	723	310	2067	280	420	0	700	700
S11	723	310	2067	200	400	100	700	600
S12	723	310	2067	171	428	100	699	599

Figure 3. 4 Geopolymer bricks with brine sludge and fly ash as precursor

Table 3. 14 Ratio of mix proportion of bricks

sample ID	Total Precursor (Sludge +Fly Ash)	Total Material	ratio 1 (precursor to total liquid)	ratio 2 (precursor to total chemical)	ratio 3 (Na_2SiO_3 : NaOH)	Ratio of Dilution (Chemical : water)
S1	1033	3100	1 : 0.58	1 : 0.58	1 : 1	1 : 0
S2	1033	3100	1 : 0.6	1 : 0.6	1 : 1	1 : 0
S3	1033	3100	1 : 0.6	1 : 0.6	1 : 1	1 : 0
S4	1033	3100	1 : 0.68	1 : 0.58	1 : 1	1 : 0.17
S5	1033	3100	1 : 0.68	1 : 0.58	1 : 0.67	1 : 0.17
S6	1033	3100	1 : 0.68	1 : 0.68	1 : 0.5	1 : 0
S7	1033	3100	1 : 0.68	1 : 0.68	1 : 0.4	1 : 0
S9	1033	3100	1 : 0.68	1 : 0.68	1 : 1	1 : 0
S10	1033	3100	1 : 0.68	1 : 0.68	1 : 0.67	1 : 0
S11	1033	3100	1 : 0.68	1 : 0.58	1 : 0.5	1 : 0.17
S12	1033	3100	1 : 0.68	1 : 0.58	1 : 0.4	1 : 0.17

Firstly, optimisation of density and compressive strength of brick mix was done with respect to the internal ratio of precursor i.e., ratio of brine sludge to fly ash. After the optimisation of internal ratio of precursor, the ratio of precursor to total liquid was optimised, while keeping previously optimised ratio fixed, the ratio between chemicals i.e., Sodium Silicate and Sodium Hydroxide was optimised. While keeping the chemical ratio constant the dilution was done and a comparison was made between non diluted sample and diluted sample.

Chapter 4

Results and Discussion

The results are discussed in three different sections. In the first section, the results related to use of brine sludge as an alternative subgrade material are discussed. The sludge has been explored as subgrade material in isolation as well as in different combination with fly ash. The optimum moisture content, maximum dry density and California bearing ratio test results are discussed. In the second section, the results related to use the brine sludge as an alternative cementitious material in cement concrete are discussed. In cement concrete, different proportions of sludge have been investigated for partial replacement of cement. The compressive strength and flexural strength results are discussed. In the third section, results related to use the brine sludge as an alternative precursor, blended with fly ash in geopolymer bricks. The sludge has been explored as an alternative precursor, blended with fly ash in geopolymer bricks. The dimensional test, density and compressive strength test results are discussed.

4.1 Brine sludge as partial replacement for cement in cement concrete

A total of 05 different concrete mixes were prepared by replacing cement with the brine sludge by volume where 0% replacement is control sample and then 2.5%, 5%, 7.5% and 10%. Then they were tested for compressive and flexural strength.

4.1.1 Compressive Strength test

Six cubes (150mm) from each batch of concrete mix were casted and cured for 7 and 28 days in order to determine compressive strength of concrete. Table 4.1 shows the average compressive strength of different mix combinations tested at 7 and 28 days.

Figure 4. 1 Cubes of dimensions 150 mm x 150 mm x 150 mm for compression testing

Figure 4. 2 Cube in Compression Testing machine

Table 4. 1 Compressive strength results of cement concrete cubes at 7 days

Mix	% Brine Sludge (By vol% of cement)	Compressive strength (MPa) 7 days				
		Cube 1	Cube 2	Cube 3	Average	Standard Deviation
A0	0.0	21.129	20.987	19.853	20.656	0.699
A1	2.5	21.991	21.529	21.818	21.779	0.234
A2	5.0	24.938	25.302	25.164	25.135	0.184
A3	7.5	20.076	20.782	20.444	20.434	0.353
A4	10.0	17.311	22.347	20.453	20.037	2.543

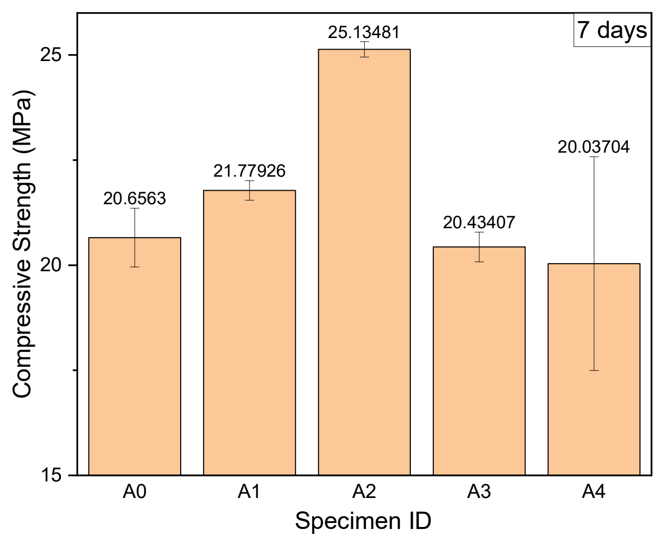

Figure 4. 3 - 7 days Compressive strength vs percent replacement of Cement with Brine Sludge

Strength of concrete reached to 25.135 MPa at 5% cement replacement with Brine Sludge. At 7.5% the compressive strength of concrete is 20.434 MPa which nearly same to that of conventional concrete i.e., 20.656 MPa the compressive strength decreases further when 10% cement was replaced. So, on comparing results it is clear that 5% replacement of cement with brine sludge is optimum replacement for 7 days strength.

Table 4. 2 Compressive strength results of cement concrete cubes at 28 days

Mix	% Brine Sludge (By vol% of cement)	Compressive strength (MPa) 28 days				
		Cube 1	Cube 2	Cube 3	Average	Standard Deviation
A0	0.00	24.458	22.911	24.738	24.036	0.984
A1	2.50	24.413	23.391	24.907	24.237	0.773
A2	5.00	37.227	36.631	36.973	36.944	0.299
A3	7.50	33.467	30.951	28.204	30.874	2.632
A4	10.00	33.76	32.587	30.551	32.299	1.624

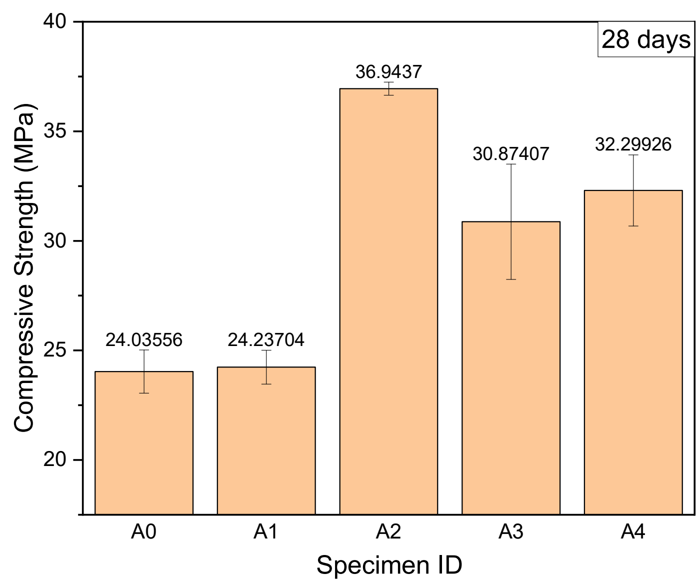

Figure 4. 4 - 28 days Compressive strength vs percent replacement of Cement with Brine Sludge

Strength of concrete reached to 36.94 MPa at 5% cement replacement with Brine Sludge. At 7.5% the compressive strength of concrete is 30.87 MPa which is more than that of conventional concrete also at 10% replacement strength of concrete is more than that of conventional concrete. So, on comparing results it is clear that 5% replacement of cement with brine sludge is optimum replacement for 28 days strength also.

Table 4. 3 Compressive strength results of cement concrete cubes at different ages

Mix	% Brine Sludge (By vol% of cement)	Average Compressive strength of cube (MPa) 7 days	Average Compressive strength of cube (MPa) 28 days
A0	0.00	20.6563	24.03556
A1	2.50	21.77926	24.23704
A2	5.00	25.13481	36.9437
A3	7.50	20.43407	30.87407
A4	10.00	20.03704	32.29926

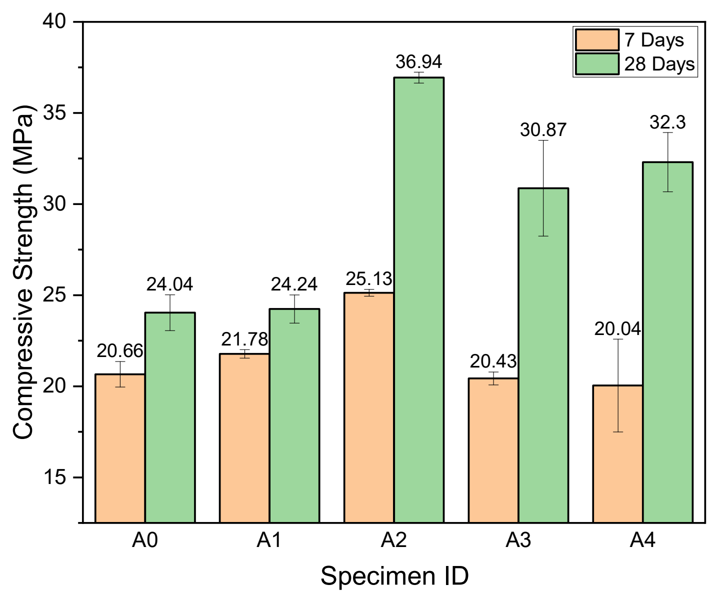

Figure 4. 5 - 7 days & 28 days Compressive strength vs percent replacement of Cement with Brine Sludge

From the above Fig. 3.9 it can be observed that compressive strength of control sample (0% replacement) is 20.66 MPa for 7 days curing and is 24.04 MPa for 28 days curing, compressive strength increases up to 25.13 MPa for 7 days curing and 36.94 MPa for 28 days curing at 5 percent replacement. It can also be observed that there is significant difference in strength of cement concrete between 7 days and 28 days curing after 5 percent replacement of brine sludge.

Table 4.4 below shows the percentage variation in compressive Strength of Concrete with partial replacement of Cement with Brine Sludge Specimens at different ages of curing.

Table 4. 4 Percent variation in compressive strength of Concrete with partial replacement of Cement with Brine Sludge at 7 days and 28 days curing

Specimen ID	Compressive Strength of Specimen (MPa)			
	7 days	**% Variation**	**28 days**	**% Variation**
A0	20.66	Reference	24.04	Reference
A1	21.78	5.436	24.24	0.838
A2	25.13	21.681	36.94	53.704
A3	20.43	-1.076	30.87	28.452
A4	20.04	-2.998	32.30	34.381

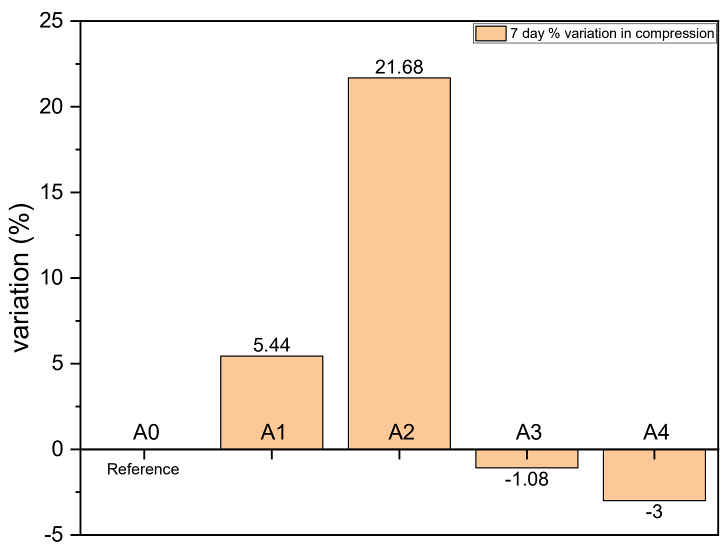

Figure 4. 6 Percent variation in compressive strength of Concrete with partial replacement of Cement with Brine Sludge at 7 days curing

From the Fig. 3.10 above it can be seen that 7 days compressive strength increases as the cement is replaced with brine sludge up to A2 i.e., up to 21.68% and then decreases only 1.08% at A3 and 3% at A4.

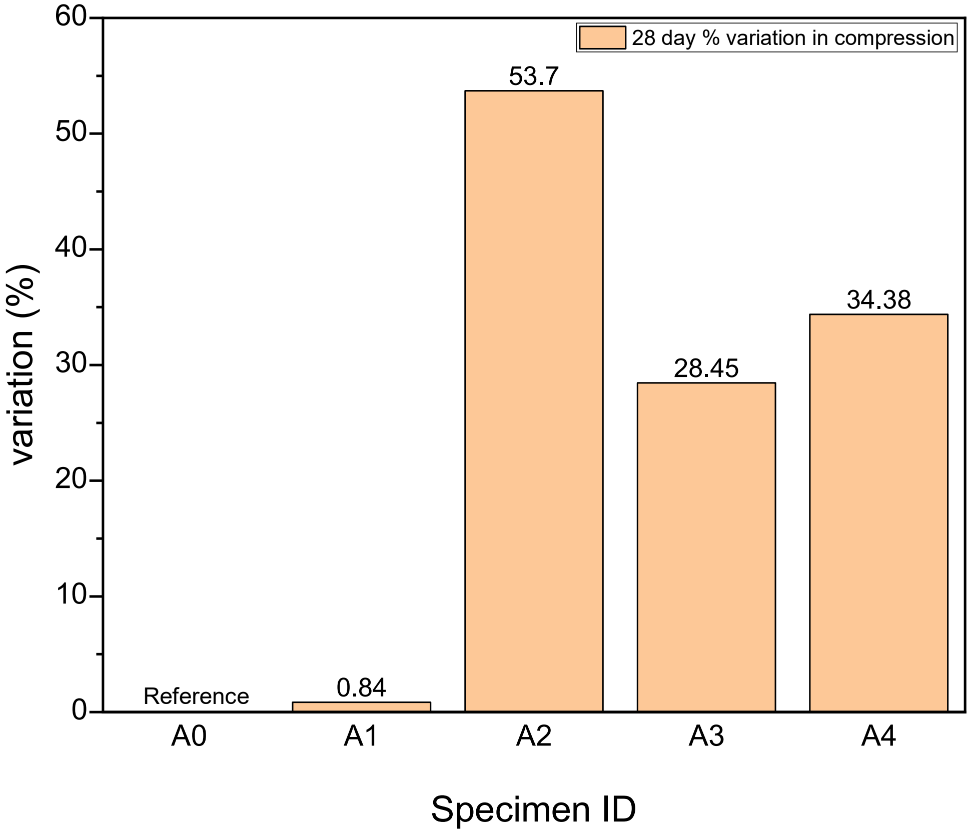

Figure 4. 7 Percent variation in compressive strength of Concrete with partial replacement of Cement with Brine Sludge at 28 days curing

From the Fig. 3.11 above it can be seen that 28 days compressive strength increases as the cement is replaced with brine sludge up to A2 i.e., up to 53.7% and then at A3 decreases in comparison with A2 and again increases at A4 but always stayed more then control i.e., A0, The strength increased up to 53.7% at most for 28 days curing.

The compressive strength for 7 days increases more as compared to 28 days at A1, then on increasing the replacement the compressive strength for 28 increases more than that of 7 days and does not get less then reference while for 7 days compressive strength at A3 and A4 gets less than reference, so it can be concluded that in initial days brine sludge at A3 and A4 decreases the compressive strength but after 28 days the compressive strength is more than that of reference.

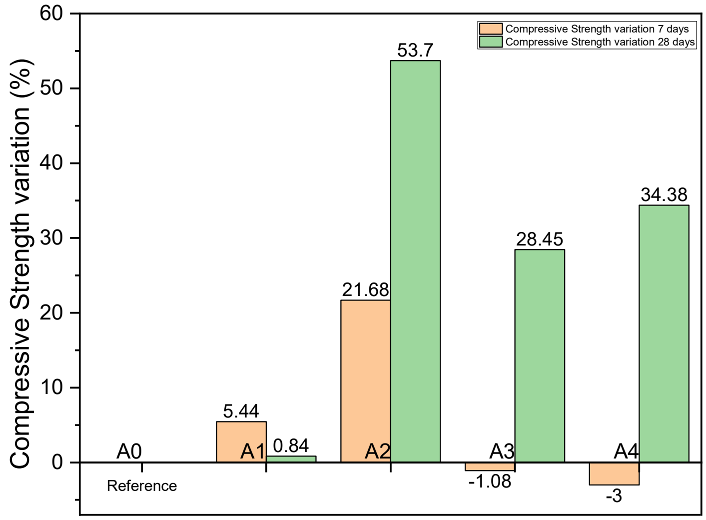

Figure 4. 8 Percent variation in compressive strength of Concrete with partial replacement of Cement with Brine Sludge at 7 and 28 days curing

4.1.2 Flexural Strength test

Six beams (150 mm x 150 mm x 700 mm) from each batch of concrete mix were casted and cured for 7 and 28 days in order to determine flexural strength of concrete. Table 4.5 shows the average flexural strength of different mix combinations tested at 7 and 28 days.

Figure 4. 9 Beams of dimensions 150 mm x 150 mm x 700 mm for flexure testing

Figure 4. 10 Beam in Flexural Testing machine

Table 4. 5 Flexure strength of beam

Mix	% Brine Sludge (By vol% of cement)	Average Flexural strength of cube (MPa) 7 days	Average Flexural strength of cube (MPa) 28 days
A0	0.0	1.920	2.750
A1	2.5	2.034	2.359
A2	5.0	2.110	3.004
A3	7.5	2.158	2.967
A4	10.0	2.189	2.952

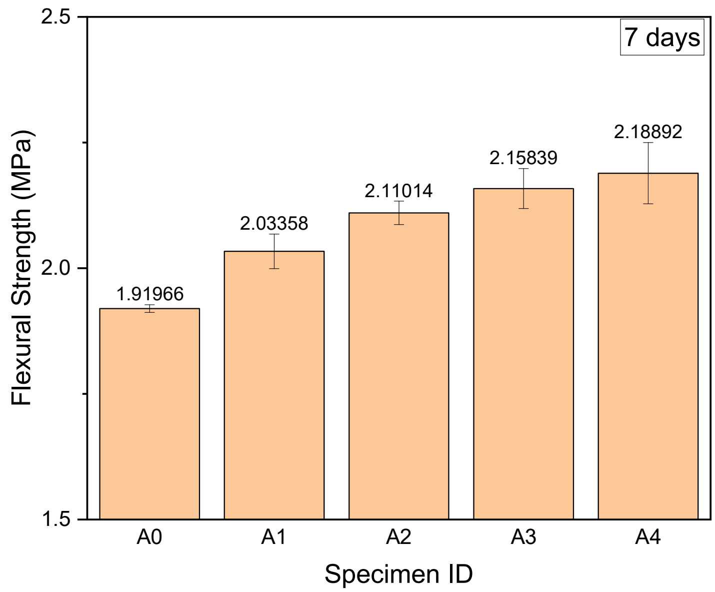

Figure 4. 11 - 7 days Flexural strength vs percent replacement of Cement with Brine Sludge

From the Fig. 3.15 above it is clear that 7 days flexural strength with the increase of percentage of replacement of cement with the brine sludge. The tests were conducted up to 10 % replacement up to which the flexural strength increases for 7 days curing.

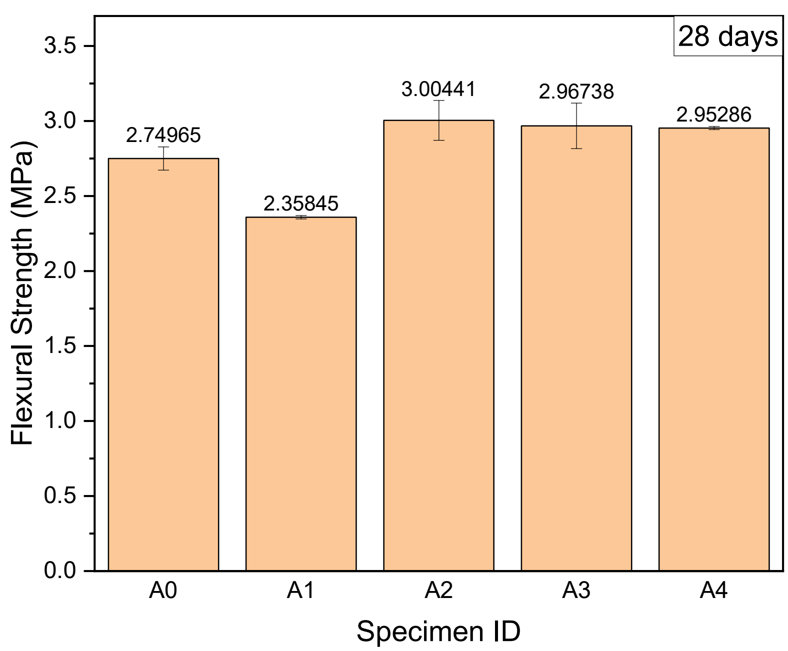

Figure 4. 12 - 28 days Flexural strength vs percent replacement of Cement with Brine Sludge

From the Fig. 3.16 above it is clear that the flexural strength first decreases with the increase in replacement of cement with brine sludge then reaches to a maximum value at 5% replacement and then again decreases, stays more than control sample.

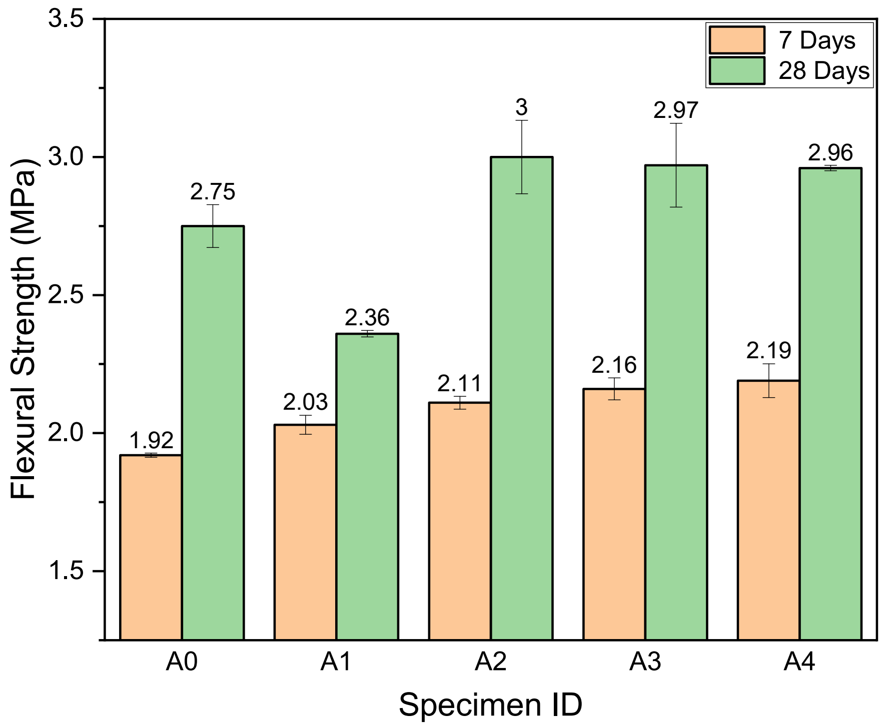

Figure 4. 13 - 7 days & 28 days Flexural strength vs percent replacement of Cement with Brine Sludge

From the Fig. 3.17 above it is clear that the flexural strength for 7 days curing kept on increasing almost uniformly up to A4 (10% replacement) replacement of cement with brine sludge, while for 28 days the flexural strength initially decreases at A1(2.5% replacement) and at A2(5% replacement) it increases and then start decreasing with a very small amount but even at A4 (10% replacement) the Flexural strength was more than that of control sample, while for 7 days it was increasing with a small amount.

Table 4.6 below shows the percentage variation in Flexural Strength of Concrete with partial replacement of Cement with Brine Sludge Specimens at different ages of curing.

Table 4. 6 Percent variation in Flexural strength of Concrete with partial replacement of Cement with Brine Sludge at 7 days and 28 days curing

Specimen ID	Compressive Strength of Specimen (MPa)			
	7 days	% variation	28 days	% variation
A0	1.919664	Reference	2.7496546	Reference
A1	2.033579	5.934	2.3584488	-14.227
A2	2.110142	9.922	3.0044057	9.265
A3	2.158394	12.436	2.9673802	7.918
A4	2.188917	14.026	2.9528581	7.390

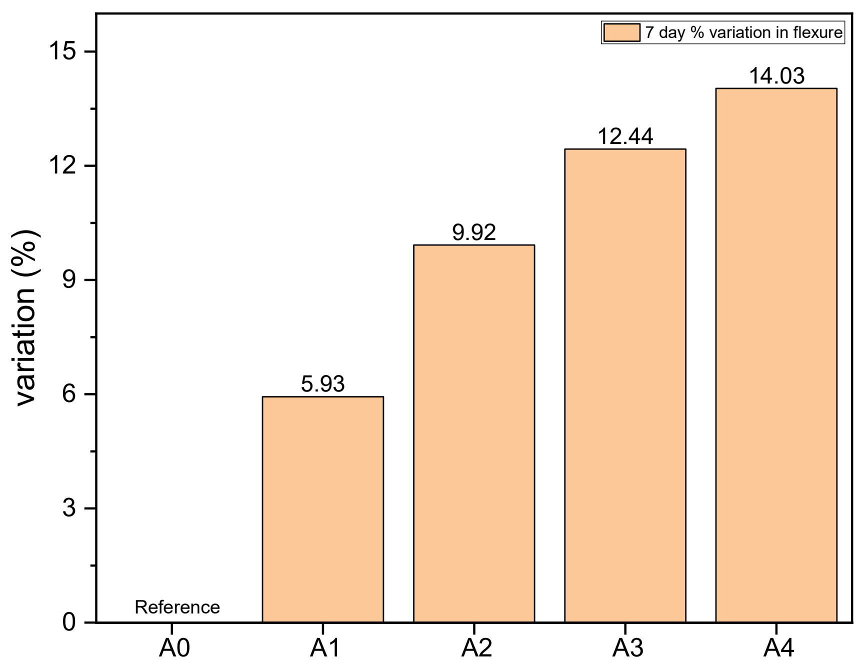

Figure 4. 14 Percent variation in Flexural strength of Concrete with partial replacement of Cement with Brine Sludge at 7 days curing

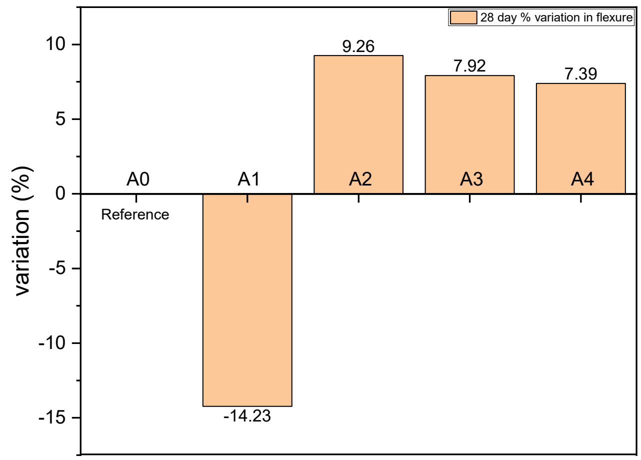

Figure 4. 15 Percent variation in Flexural strength of Concrete with partial replacement of Cement with Brine Sludge at 28 days curing

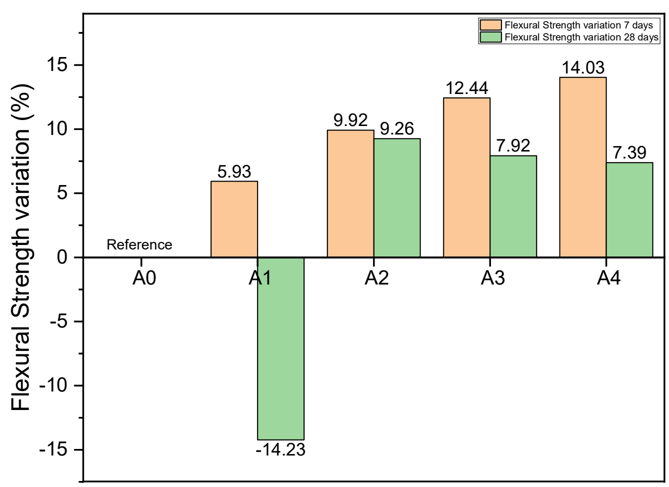

Figure 4. 16 Percent variation in Flexural strength of Concrete with partial replacement of Cement with Brine Sludge at 7 and 28 days curing

From the Fig. 3.18, 3.19 and 3.20 above it can be seen that at A1 (2.5% replacement) for 7 days curing the flexural strength increases up to 5.93 %that of plane cement concrete and increases up to 14.03 % for 7 days curing. While for 28 days curing the flexural strength decreases to 14.23% at A1 (2.5% replacement) and then kept on increasing up to the replacement done in test i.e., 10% replacement of cement with brine sludge.

4.2 Use of Brine Sludge in Subgrade

OMC MDD was done according to the method discussed above, at that OMC of each sample soaked and unsoaked C.B.R. test was done first on raw sample then on fly ash blended sample.

4.2.1 OMC MDD of Raw Sample of Brine Sludge

4.2.1.1 OMC MDD of F-I

Proctor test was performed on F-I sample of brine sludge with light compaction, For the test empty weight of mould, weight of mould with soil, volume of mould, crucible weight, weight of crucible with soil and weight of crucible with dry soil was readings were noted down as shown in table 4.7 below.

These readings were used for the calculation of weight of soil in mould, bulk density, water content and dry density. Fig. 3.21 was plotted between Water Content and Dry density, the maximum point up to which graph reaches in y axis gives the value of maximum dry density which in case of F-I is 1.58 (g/ml) and x-axis coordinate corresponding to that point gives the value of optimum moisture content which is 19.32 %.

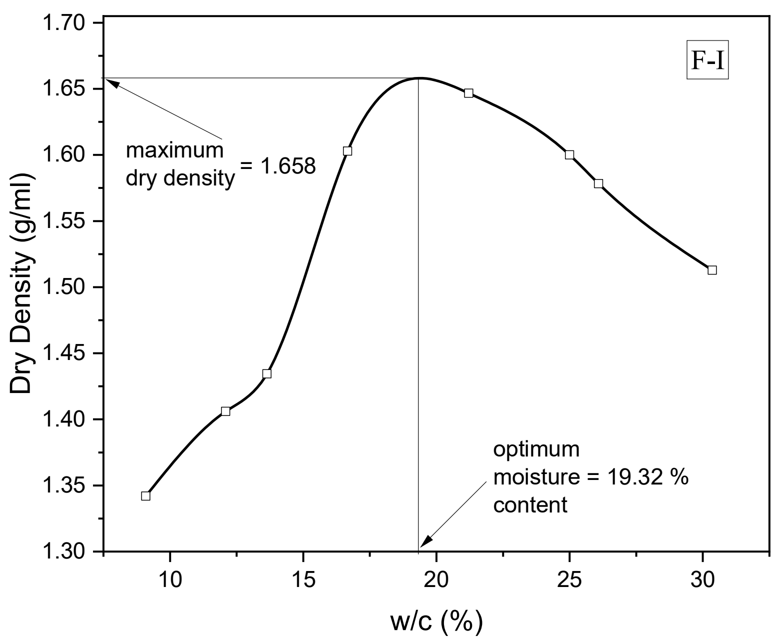

Figure 4. 17 Water content vs Dry Density of F-I Brine Sludge sample

Table 4. 7 Readings and Calculations results of proctor test on F-I Brine Sludge

S.No	Weight of empty mould(g)	Mould + soil (g)	weight of soil in mould (g)	vol. of mould (ml)	bulk density (g/ml)	crucible weight (g)	weight of wet soil+ crucible (g)	weight of dry soil + crucible (g)	w/c %	Dry Density (g/ml)
1	5920	7384	1464	1000	1.464	28	100	94	9.09	1.34
2	5920	7496	1576	1000	1.576	24	126	115	12.09	1.41
3	5920	7550	1630	1000	1.63	30	130	118	13.64	1.43
4	5920	7790	1870	1000	1.87	26	124	110	16.67	1.60
5	5920	7916	1996	1000	1.996	30	110	96	21.21	1.65
6	5920	7920	2000	1000	2	26	136	114	25.00	1.60
7	5920	7910	1990	1000	1.99	24	140	116	26.09	1.58
8	5920	7892	1972	1000	1.972	30	176	142	30.36	1.51

4.2.1.2 OMC MDD of F-II

Proctor test was performed on F-II sample of brine sludge with light compaction, For the test empty weight of mould, weight of mould with soil, volume of mould, crucible weight, of crucible with soil and weight of crucible with dry soil was readings were noted down as shown in table 4.8 below.

These readings were used for the calculation of weight of soil in mould, bulk density, water content and dry density.

Fig. 3.22 was plotted between Water Content and Dry density, the maximum point up to which graph reaches in y axis gives the value of maximum dry density which in case of F-II is 1.643 (g/ml) and x-axis coordinate corresponding to that point gives the value of optimum moisture content which is 25.03 %.

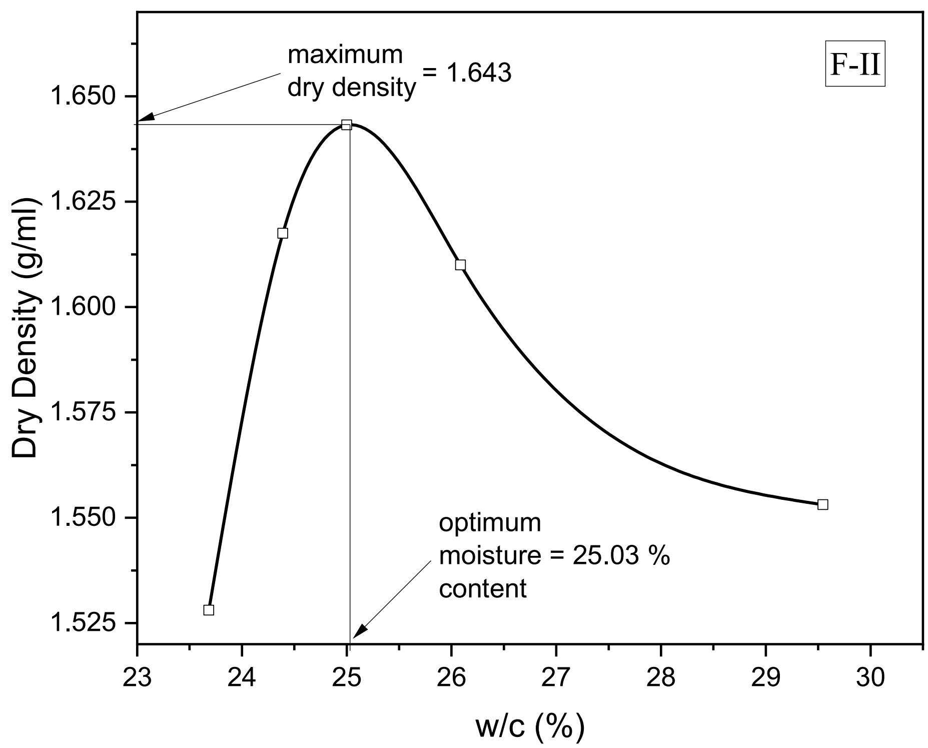

Figure 4. 18 Water content vs Dry Density of F-II Brine Sludge sample

Table 4. 8 Readings and Calculations results of proctor test on F-II Brine Sludge

S.No	Weight of empty mould(g)	mould + soil (g)	weight of soil in mould (g)	vol. of mould (ml)	wet density (bulk density) (g/ml)	crucible weight (g)	weight of wet soil+ crucible (g)	weight of dry soil + crucible (g)	w/c %	Dry Density (g/ml)
1	4302	6192	1890	1000	1.89	30	124	106	23.68	1.53
2	4302	6314	2012	1000	2.01	32	134	114	24.39	1.62
3	4302	6356	2054	1000	2.05	26	116	98	25.00	1.64
4	4302	6332	2030	1000	2.03	28	144	120	26.09	1.61
5	4302	6314	2012	1000	2.01	26	140	114	29.55	1.55

4.2.1.3 OMC MDD of F-III

Proctor test was performed on F-III sample of brine sludge with light compaction, For the test empty weight of mould, weight of mould with soil, volume of mould, crucible weight, of crucible with soil and weight of crucible with dry soil was readings were noted down as shown in table 4.9 below.

These readings were used for the calculation of weight of soil in mould, bulk density, water content and dry density.

Fig. 3.23 was plotted between Water Content and Dry density, the maximum point up to which graph reaches in y axis gives the value of maximum dry density which in case of F-III is 1.741 (g/ml) and x-axis coordinate corresponding to that point gives the value of optimum moisture content which is 21.6 %.

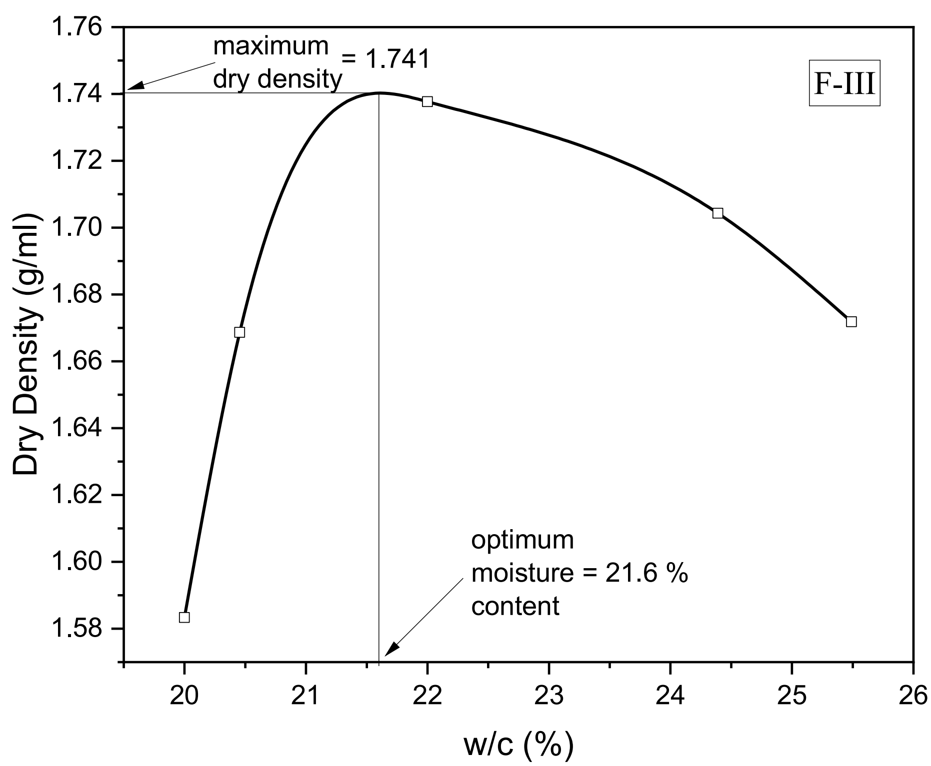

Figure 4. 19 Water content vs Dry Density of F-III Brine Sludge sample

Table 4. 9 Readings and Calculations results of proctor test on F-III Brine Sludge

S.No	Weight of empty mould(g)	mould + soil (g)	weight of soil in mould (g)	vol. of mould (ml)	wet density (bulk density) (g/ml)	crucible weight (g)	weight of wet soil+ crucible (g)	weight of dry soil + crucible (g)	w/c %	Dry Density (g/ml)
1	4290	6190	1900	1000	1.90	30	150	130	20.00	1.58
2	4290	6300	2010	1000	2.01	32	138	120	20.45	1.67
3	4290	6410	2120	1000	2.12	28	150	128	22.00	1.74
4	4290	6410	2120	1000	2.12	28	130	110	24.39	1.70
5	4290	6388	2098	1000	2.10	26	154	128	25.49	1.67

4.2.1.4 OMC MDD of F-IV

Proctor test was performed on F-IV sample of brine sludge with light compaction, For the test empty weight of mould, weight of mould with soil, volume of mould, crucible weight, of crucible with soil and weight of crucible with dry soil was readings were noted down as shown in table 4.10 below.

These readings were used for the calculation of weight of soil in mould, bulk density, water content and dry density.

Fig. 3.24 was plotted between Water Content and Dry density, the maximum point up to which graph reaches in y axis gives the value of maximum dry density which in case of F-IV is 1.773 (g/ml) and x-axis coordinate corresponding to that point gives the value of optimum moisture content which is 21.1 %.

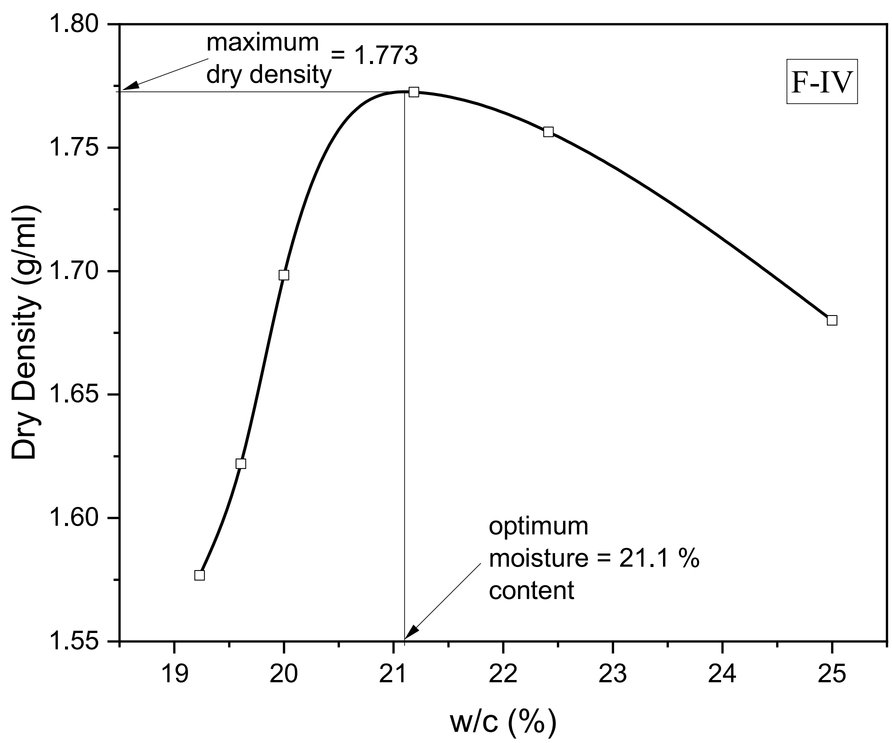

Figure 4. 20 Water content vs Dry Density of F-IV Brine Sludge sample

Table 4. 10 Readings and Calculations results of proctor test on F-IV Brine Sludge

S.No	Weight of empty mould(g)	mould + soil (g)	weight of soil in mould (g)	vol. of mould (ml)	wet density (bulk density) (g/ml)	crucible weight (g)	weight of wet soil+ crucible (g)	weight of dry soil + crucible (g)	w/c %	Dry Density (g/ml)
1	4290	6170	1880	1000	1.880	26	150	130	19.23	1.58
2	4290	6230	1940	1000	1.940	22	144	124	19.61	1.62
3	4290	6328	2038	1000	2.038	24	168	144	20.00	1.70
4	4290	6438	2148	1000	2.148	24	167	142	21.19	1.77
5	4290	6440	2150	1000	2.150	24	166	140	22.41	1.76
6	4290	6390	2100	1000	2.100	16	96	80	25.00	1.68

4.2.1.5 Comparison between Maximum Dry Density (MDD) of different raw Brine Sludge samples

A comparison can made between F-I, F-II, F-III and F-IV on Maximum dry density which was calculated above in section 4.2.1. A Fig. 3.25 is plotted below which shows the MDD of different brine sludge samples.

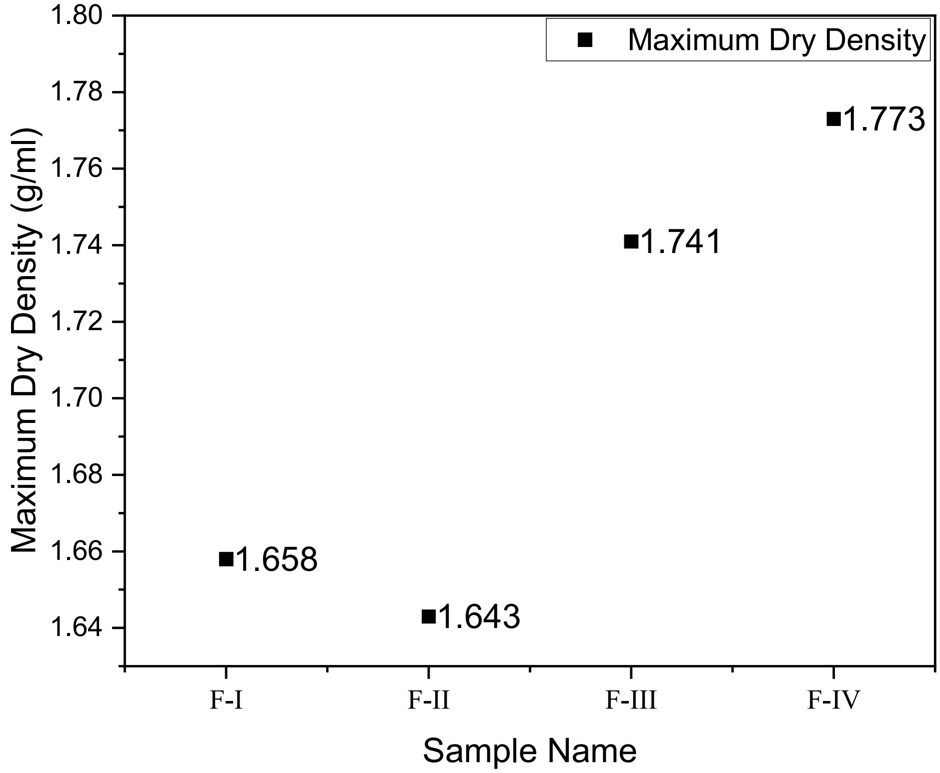

Figure 4. 21 Comparison of MDD between different Brine Sludge samples

The MDD for F-I sample comes out to be 1.658 g/ml, which then decreases for F-II sample up to 1.643 g/ml and for F-III increases up to 1.741 g/ml and for F-IV reaches the maximum of 1.773 g/ml.

It can be stated that weathered brine sludge samples i.e., F-I and F-II have low maximum dry density then the un-weathered brine sludge samples F-III and F-IV.

4.2.2 California bearing ratio of Raw Sample of Brine Sludge

4.2.2.1 Unsoaked California Bearing Ratio

Unsoaked CBR test of F-I

Unsoaked California bearing ratio test was performed on F-I sample of Brine Sludge using light compaction and load was noted against penetration at points shown in table 4.11 below. The load reading from CBR testing machine comes out in kN it was converted into kg/cm^2.

Table 4. 11 Penetration and its corresponding Load of F-I sample of Brine Sludge for Unsoaked CBR

displacement (mm)	load (kN)	load (kg)	load (kg/cm2)
0.5	0.27	27.53233	1.401646
1	0.37	37.72949	1.920774
1.5	0.5	50.9858	2.595641
2	0.62	63.22239	3.218595
2.5	0.73	74.43927	3.789635
4	1.05	107.0702	5.450846
5	1.22	124.4054	6.333363
7.5	1.7	173.3517	8.825179
10	2.11	215.1601	10.9536
12.5	2.51	255.9487	13.03012

Graph was plotted between displacement (mm) and load (kg/cm^2) as shown in figure 4.22 below and from the graph it was clear that there is no need for the correction for load, so CBR will now be calculated for 2.5 mm and 5 mm penetration i.e., no shift of origin is required.

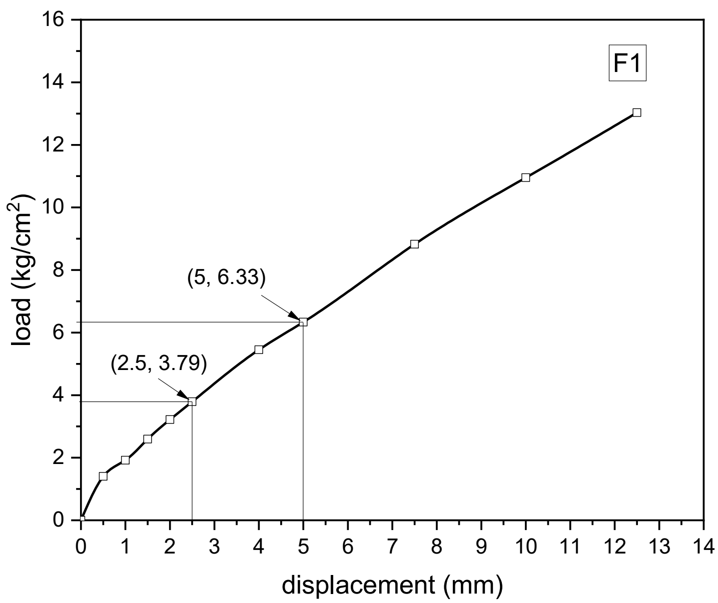

Figure 4. 22 Load vs Penetration curve of F-I Brine Sludge sample

CBR at 2.5 mm penetration = $\frac{load\ (kg/cm^2)}{70} \times 100$

$= \frac{3.789}{70} \times 100$

= 5.414 %

CBR at 5 mm penetration = $\frac{load\ (kg/cm^2)}{105} \times 100$

$= \frac{6.333}{105} \times 100$

= 6.032 %

Grater CBR is considered so CBR of F-I Brine Sludge comes out to be 6.032%

Unsoaked CBR test of F-II

Unsoaked California bearing ratio test was performed on F-II sample of Brine Sludge using light compaction and load was noted against penetration at points shown in table 4.12 below. The load reading from CBR testing machine comes out in kN it was converted into kg/cm^2.

Table 4. 12 Penetration and its corresponding Load of F-II sample of Brine Sludge for Unsoaked CBR

displacement (mm)	load (kN)	load (kg)	load (kg/cm2)
0.5	0.23	23.4535	1.193995
1	0.3	30.5915	1.557384
1.5	0.36	36.7098	1.868861
2	0.43	43.8478	2.232251
2.5	0.49	49.9661	2.543728
4	0.65	66.2815	3.374333
5	0.75	76.4787	3.893461
7.5	0.98	99.9322	5.087456
10	1.21	123.3856	6.281451
12.5	1.41	143.7800	7.319707

Graph was plotted between displacement (mm) and load (kg/cm^2) as shown in figure 4.23 below and from the graph it was clear that there is no need for the correction for load, so CBR will now be calculated for 2.5 mm and 5 mm penetration i.e., no shift of origin is required.

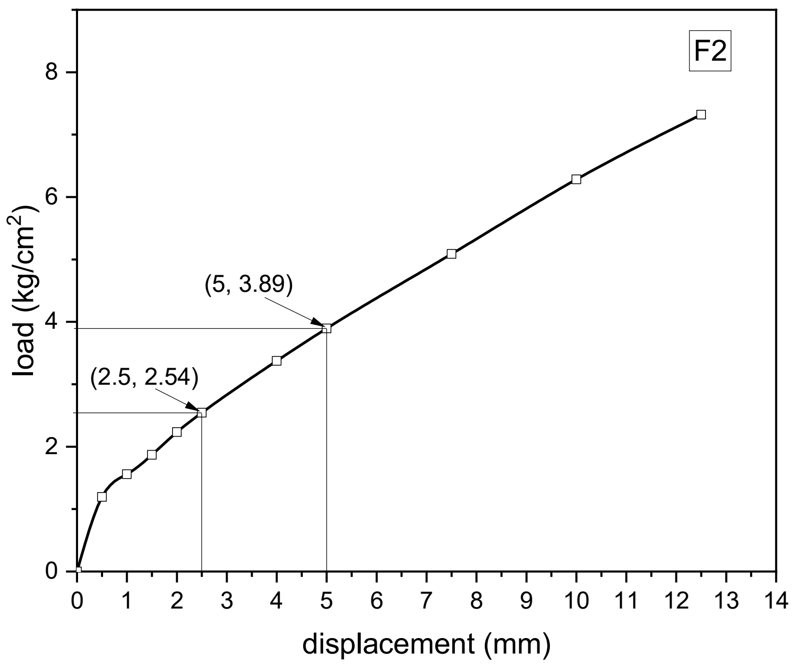

Figure 4. 23 Load vs Penetration curve of F-II Brine Sludge sample

CBR at 2.5 mm penetration = $\frac{load\ (kg/cm^2)}{70} \times 100$

$= \frac{2.54}{70} \times 100$

= 3.633 %

CBR at 5 mm penetration = $\frac{load\ (kg/cm^2)}{105} \times 100$

$= \frac{3.89}{105} \times 100$

= 3.708 %

Grater CBR is considered so CBR of F-II Brine Sludge comes out to be 3.708%

Unsoaked CBR test of F-III

Unsoaked California bearing ratio test was performed on F-III sample of Brine Sludge using light compaction and load was noted against penetration at points shown in table 4.13 below. The load reading from CBR testing machine comes out in kN it was converted into kg/cm^2.

Table 4. 13 Penetration and its corresponding Load of F-III sample of Brine Sludge for Unsoaked CBR

displacement (mm)	load (kN)	load (kg)	load (kg/cm^2)
0.5	0.08	8.15772804	0.415303
1	0.16	16.31545608	0.830605
1.5	0.27	27.53233214	1.401646
2	0.43	43.84778822	2.232251
2.5	0.57	58.12381229	2.95903
4	0.98	99.93216849	5.087456
5	1.19	121.3462046	6.177625
7.5	1.57	160.0954128	8.150312
10	1.83	186.6080289	9.500045
12.5	2.03	207.002349	10.5383

Graph was plotted between displacement (mm) and load (kg/cm^2) as shown in figure 4.24 below and in the graph it is clear that there is need for the correction for load, because the initial portion of the curve is concave upwards, which needs to be corrected, for correction tangent is drawn at the point on upward concave curve where the slope is maximum, the origin is shifted to the point where the tangent touches the displacement axis, in our case tangent touches the displacement axis at 0.364 mm displacement.

So CBR will now be calculated for (2.5+0.364) mm and (5+0.364) mm penetration.

CBR at (2.5+0.364) mm penetration will be treated as 2.5 mm penetration CBR and CBR at (5+0.364) mm penetration will be treated as 5 mm penetration CBR.

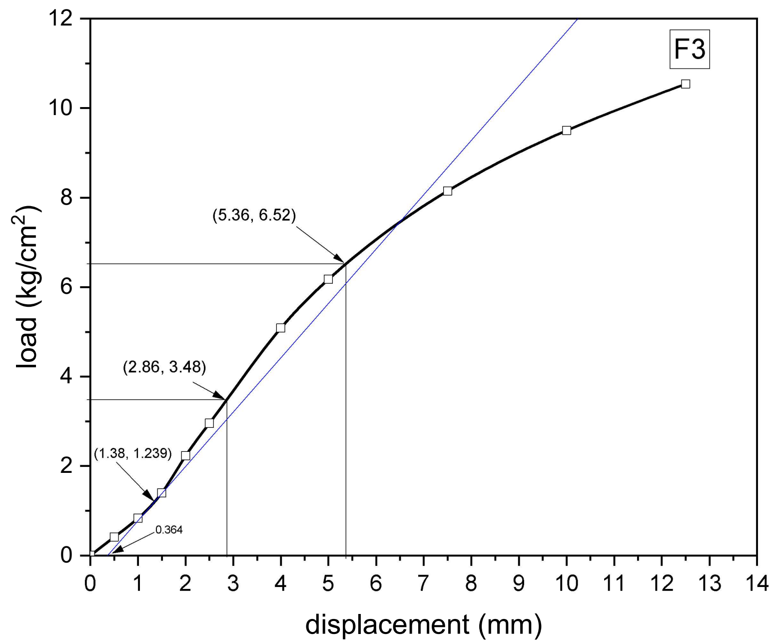

Figure 4. 24 Load vs Penetration curve of Unsoaked F-III Brine Sludge sample

Load corresponding to (2.5+0.364) penetration =3.48 kg/cm^2

Corrected load at 2.5 mm penetration = 3.48 kg/cm^2

Load corresponding to (5+0.364) penetration =6.52 kg/cm^2

Corrected load at 5 mm penetration = 6.52 kg/cm^2

$$\text{CBR at 2.5 mm penetration} = \frac{load\ (kg/cm^2)}{70} \times 100$$

$$= \frac{3.48}{70} \times 100$$

$$= 4.97\ \%$$

$$\text{CBR at 5 mm penetration} = \frac{load\ (kg/cm^2)}{105} \times 100$$

$$= \frac{6.52}{105} \times 100$$

$$= 6.21\ \%$$

Grater CBR is considered so CBR of F-III Brine Sludge comes out to be 6.21%

Unsoaked CBR test of F-IV

Unsoaked California bearing ratio test was performed on F-IV sample of Brine Sludge using light compaction and load was noted against penetration at points shown in table 4.14 below. The load reading from CBR testing machine comes out in kN it was converted into kg/cm^2.

Table 4. 14 Penetration and its corresponding Load of F-IV sample of Brine Sludge for Unsoaked CBR

displacement (mm)	load (kN)	load (kg)	load (kg/cm2)
0.5	0.08	8.15772804	0.41530
1	0.13	13.25630807	0.67487
1.5	0.2	20.3943201	1.03826
2	0.27	27.53233214	1.40165
2.5	0.34	34.67034417	1.76504
4	0.55	56.08438028	2.85520
5	0.7	71.38012035	3.63390
7.5	1.04	106.0504645	5.39893
10	1.37	139.7010927	7.11206
12.5	1.67	170.2925728	8.66944

Graph was plotted between displacement (mm) and load (kg/cm^2) as shown in figure 4.25 below and from the graph it was clear that there is no need for the correction for load, so CBR will now be calculated for 2.5 mm and 5 mm penetration i.e., no shift of origin is required.

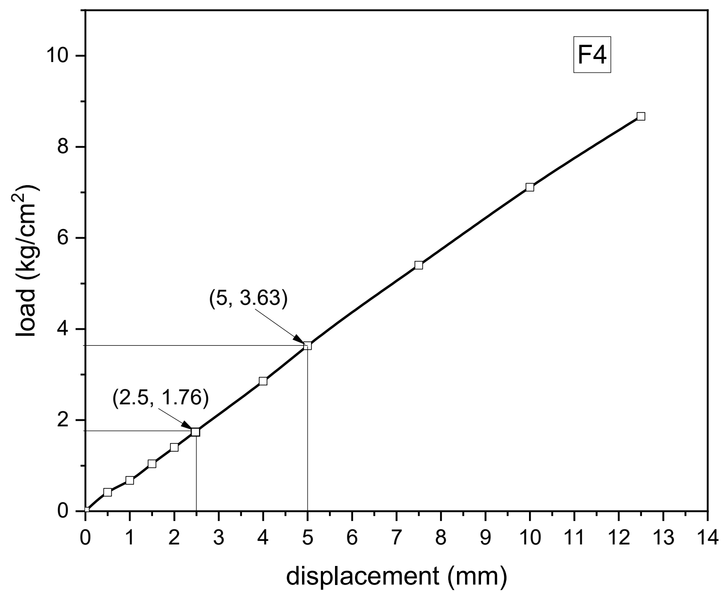

Figure 4. 25 Load vs Penetration curve of Unsoaked F-IV Brine Sludge sample

CBR at 2.5 mm penetration = $\frac{load\ (kg/cm^2)}{70} \times 100$

$= \frac{1.76}{70} \times 100$

= 2.52 %

CBR at 5 mm penetration = $\frac{load\ (kg/cm^2)}{105} \times 100$

$= \frac{3.63}{105} \times 100$

= 3.46 %

Grater CBR is considered so CBR of F-IV Brine Sludge comes out to be 3.46 %

4.2.2.2 SOAKED California Bearing Ratio

Soaked CBR test on F-I

Soaked California bearing ratio test was performed on F-I sample of Brine Sludge using light compaction and load was noted against penetration at points shown in table 4.15. The load reading from CBR testing machine comes out in kN it was converted into kg/cm^2.

Table 4. 15 Penetration and its corresponding Load of F-I sample of Brine Sludge for Soaked CBR

displacement (mm)	load (kN)	load (kg)	load (kg/cm2)
0.5	0.1	10.19716	0.519128
1	0.17	17.33517	0.882518
1.5	0.22	22.43375	1.142082
2	0.28	28.55205	1.453559
2.5	0.36	36.70978	1.868861
4	0.6	61.18296	3.114769
5	0.77	78.51813	3.997287
7.5	1.26	128.4842	6.541015
10	1.75	178.4503	9.084743
12.5	2.21	225.3572	11.47273

Graph was plotted between displacement (mm) and load (kg/cm^2) as shown in figure 4.26 below and from the graph it was clear that there is no need for the correction for load, so CBR will now be calculated for 2.5 mm and 5 mm penetration i.e., no shift of origin is required.

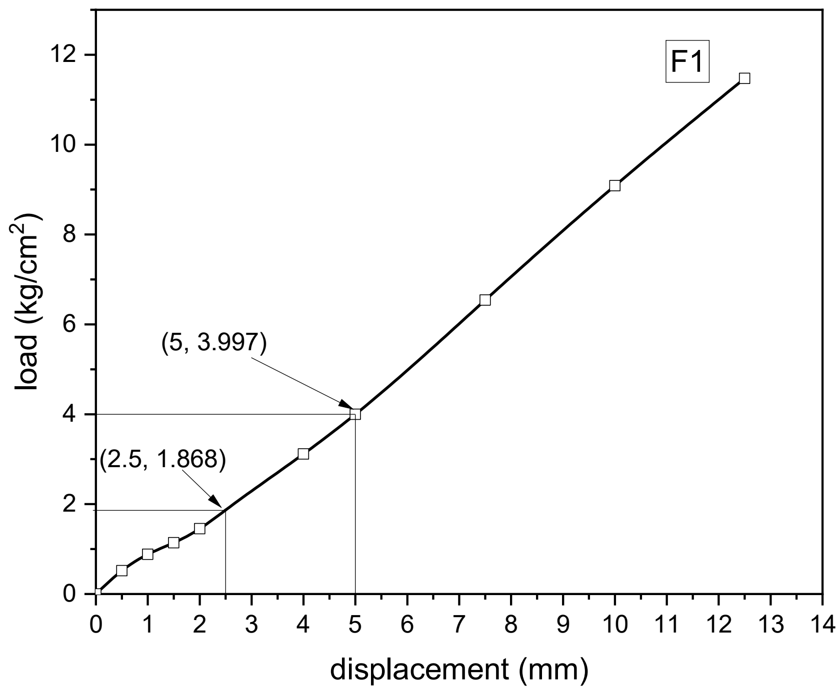

Figure 4. 26 Load vs Penetration curve of Soaked F-I Brine Sludge sample

CBR at 2.5 mm penetration = $\frac{load\ (kg/cm^2)}{70} \times 100$

$= \frac{1.868}{70} \times 100$

= 2.67 %

CBR at 5 mm penetration = $\frac{load\ (kg/cm^2)}{105} \times 100$

$= \frac{3.997}{105} \times 100$

= 3.81 %

Grater CBR is considered so CBR of F-I Brine Sludge comes out to be 3.81 %

Soaked CBR test on F-II

Soaked California bearing ratio test was performed on F-II sample of Brine Sludge using light compaction and load was noted against penetration at points shown in table 4.16. The load reading from CBR testing machine comes out in kN it was converted into kg/cm^2.

Table 4. 16 Penetration and its corresponding Load of F-II sample of Brine Sludge for Soaked CBR

displacement (mm)	load (kN)	load (kg)	load (kg/cm2)
0.5	0.05	5.098	0.260
1	0.09	9.177	0.467
1.5	0.12	12.236	0.623
2	0.16	16.315	0.831
2.5	0.2	20.394	1.038
4	0.35	35.690	1.817
5	0.45	45.887	2.336
7.5	0.73	74.439	3.790
10	1.01	102.991	5.243
12.5	1.3	132.563	6.749

Graph was plotted between displacement (mm) and load (kg/cm^2) as shown in figure 4.27 below and from the graph it was clear that there is no need for the correction for load, so CBR will now be calculated for 2.5 mm and 5 mm penetration i.e., no shift of origin is required.

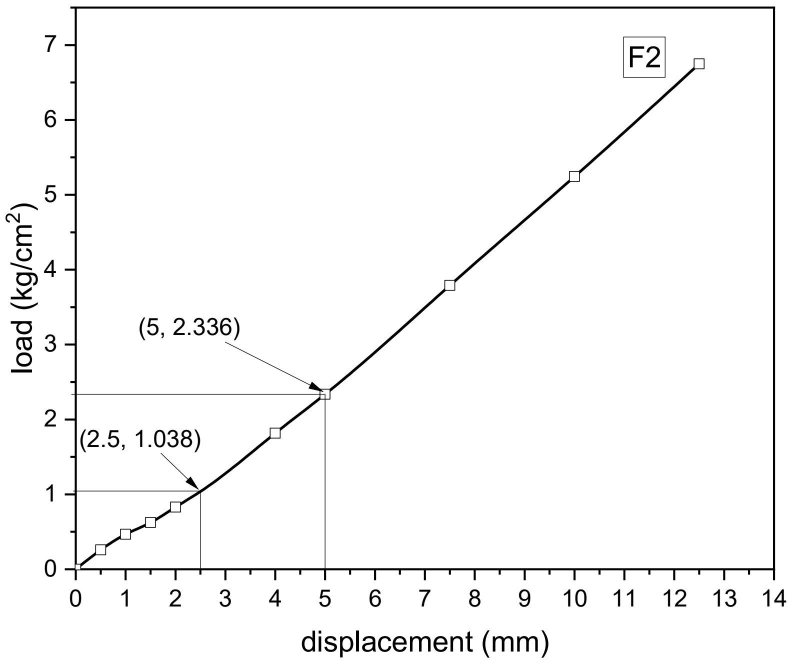

Figure 4. 27 Load vs Penetration curve of Soaked F-II Brine Sludge sample

CBR at 2.5 mm penetration = $\dfrac{load\ (kg/cm^2)}{70} \times 100$

$= \dfrac{1.038}{70} \times 100$

$= 1.48\ \%$

CBR at 5 mm penetration = $\dfrac{load\ (kg/cm^2)}{105} \times 100$

$= \dfrac{2.336}{105} \times 100$

$= 2.22\ \%$

Grater CBR is considered so CBR of F-II Brine Sludge comes out to be 2.22 %

Soaked CBR test on F-III

Soaked California bearing ratio test was performed on F-III sample of Brine Sludge using light compaction and load was noted against penetration at points shown in table 4.17 below. The load reading from CBR testing machine comes out in kN it was converted into kg/cm^2.

Table 4. 17 Penetration and its corresponding Load of F-III sample of Brine Sludge for Soaked CBR

displacement (mm)	load (kN)	load (kg)	load (kg/cm2)
0.5	0.05	5.09858	0.259564
1	0.07	7.138012	0.36339
1.5	0.09	9.177444	0.467215
2	0.1	10.19716	0.519128
2.5	0.11	11.21688	0.571041
4	0.16	16.31546	0.830605
5	0.19	19.3746	0.986343
7.5	0.25	25.4929	1.29782
10	0.32	32.63091	1.66121
12.5	0.37	37.72949	1.920774

Graph was plotted between displacement (mm) and load (kg/cm^2) as shown in figure 4.28 below and from the graph it was clear that there is no need for the correction for load, so CBR will now be calculated for 2.5 mm and 5 mm penetration i.e., no shift of origin is required.

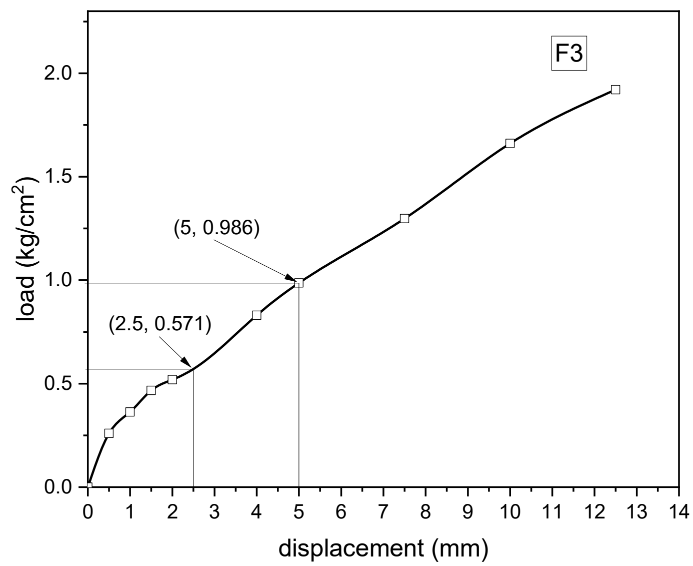

Figure 4. 28 Load vs Penetration curve of Soaked F-III Brine Sludge sample

CBR at 2.5 mm penetration = $\frac{load\ (kg/cm^2)}{70} \times 100$

$= \frac{0.571}{70} \times 100$

= 0.816 %

CBR at 5 mm penetration = $\frac{load\ (kg/cm^2)}{105} \times 100$

$= \frac{0.986}{105} \times 100$

= 0.939 %

Grater CBR is considered so CBR of F-III Brine Sludge comes out to be 0.939 %

Soaked CBR test on F-IV

Soaked California bearing ratio test was performed on F-IV sample of Brine Sludge using light compaction and load was noted against penetration at points shown in table 4.18 below. The load reading from CBR testing machine comes out in kN it was converted into kg/cm^2.

Table 4. 18 Penetration and its corresponding Load of F-IV sample of Brine Sludge for Soaked CBR

displacement (mm)	load (kN)	load (kg)	load (kg/cm2)
0.5	0.05	5.09858	0.259564
1	0.07	7.138012	0.36339
1.5	0.09	9.177444	0.467215
2	0.11	11.21688	0.571041
2.5	0.12	12.23659	0.622954
4	0.19	19.3746	0.986343
5	0.23	23.45347	1.193995
7.5	0.34	34.67034	1.765036
10	0.44	44.8675	2.284164
12.5	0.55	56.08438	2.855205

Graph was plotted between displacement (mm) and load (kg/cm^2) as shown in figure 4.29 below and from the graph it was clear that there is no need for the correction for load, so CBR will now be calculated for 2.5 mm and 5 mm penetration i.e., no shift of origin is required.

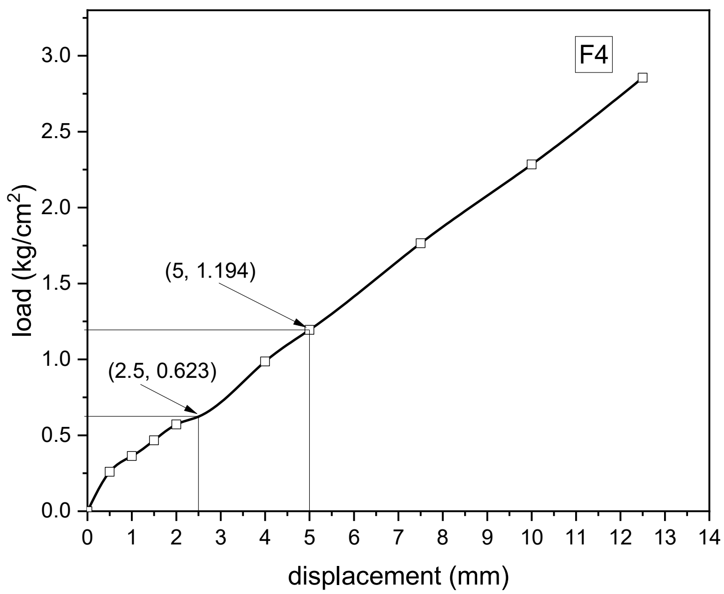

Figure 4. 29 Load vs Penetration curve of Soaked F-IV Brine Sludge sample

CBR at 2.5 mm penetration = $\frac{load\ (kg/cm^2)}{70} \times 100$

$= \frac{0.623}{70} \times 100$

= 0.889 %

CBR at 5 mm penetration = $\frac{load\ (kg/cm^2)}{105} \times 100$

$= \frac{1.194}{105} \times 100$

= 1.137 %

Grater CBR is considered so CBR of F-IV Brine Sludge comes out to be 1.137 %

4.2.3 OMC MDD of Fly Ash mixed Brine Sludge

4.2.3.1 OMC MDD of Fly Ash mixed F-I

Sample 80F-I – 20FA (80% F-I Brine Sludge 20 % Fly Ash)

Proctor test was performed on F-I of brine sludge and Fly Ash blend sample with light compaction where the blending ratio was taken as 4:1 (Brine Sludge : Fly Ash), in percentage it is 80% Brine Sludge and 20 % Fly Ash it is named as 80F-I – 20FA. For the test empty weight of mould, weight of mould with soil, volume of mould, crucible weight, of crucible with soil and weight of crucible with dry soil was readings were noted down as shown in table 4.19 below. These readings were used for the calculation of weight of soil in mould, bulk density, water content and dry density.

Fig. 3.34 was plotted between Water Content and Dry density, the maximum point up to which graph reaches in y axis gives the value of maximum dry density which in case of 80F-I – 20FA is 1.769 (g/ml) and x-axis coordinate corresponding to that point gives the value of optimum moisture content which is 14.15 %.

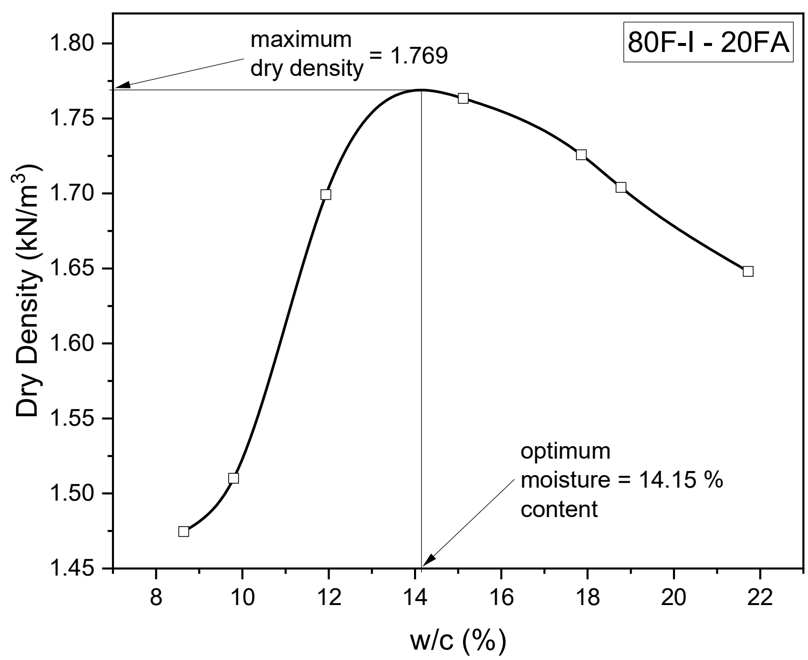

Figure 4. 30 Water content vs Dry Density of 80F-I – 20FA

Table 4. 19 Readings and Calculations results of proctor test on 80F-I - 20FA

S.No	Weight of empty mould(g)	mould+soil (g)	weight of soil in mould (g)	vol. of mould (cc)	wet density (bulk density) (g/cc)	crucible weight (g)	weight of wet soil+ crucible (g)	weight of dry soil + crucible (g)	w/c %	Dry Density (kN/m3)
1	5900	7502	1602	1000	1.602	28	160	149.5	8.64	1.47
2	5900	7558	1658	1000	1.658	30	160	148.4	9.80	1.51
3	5900	7802	1902	1000	1.902	24	160	145.5	11.93	1.70
4	5900	7930	2030	1000	2.03	26	160	142.4	15.12	1.76
5	5900	7934	2034	1000	2.034	28	160	140	17.86	1.73
6	5900	7924	2024	1000	2.024	24	160	138.5	18.78	1.70
7	5900	7906	2006	1000	2.006	30	160	136.8	21.72	1.65

Sample 60F-I – 40FA (60% F-I Brine Sludge 40 % Fly Ash)

Proctor test was performed on F-I of brine sludge and Fly Ash blend sample with light compaction where the blending ratio was taken as 3:2 (Brine Sludge : Fly Ash), in percentage it is 60% Brine Sludge and 40 % Fly Ash it is named as 60F-I – 40FA. For the test empty weight of mould, weight of mould with soil, volume of mould, crucible weight, of crucible with soil and weight of crucible with dry soil was readings were noted down as shown in table 4.20 below.

These readings were used for the calculation of weight of soil in mould, bulk density, water content and dry density.

Fig. 3.35 was plotted between Water Content and Dry density, the maximum point up to which graph reaches in y axis gives the value of maximum dry density which in case of 60F-I – 40FA is 1.789 (g/ml) and x-axis coordinate corresponding to that point gives the value of optimum moisture content which is 18.6 %.

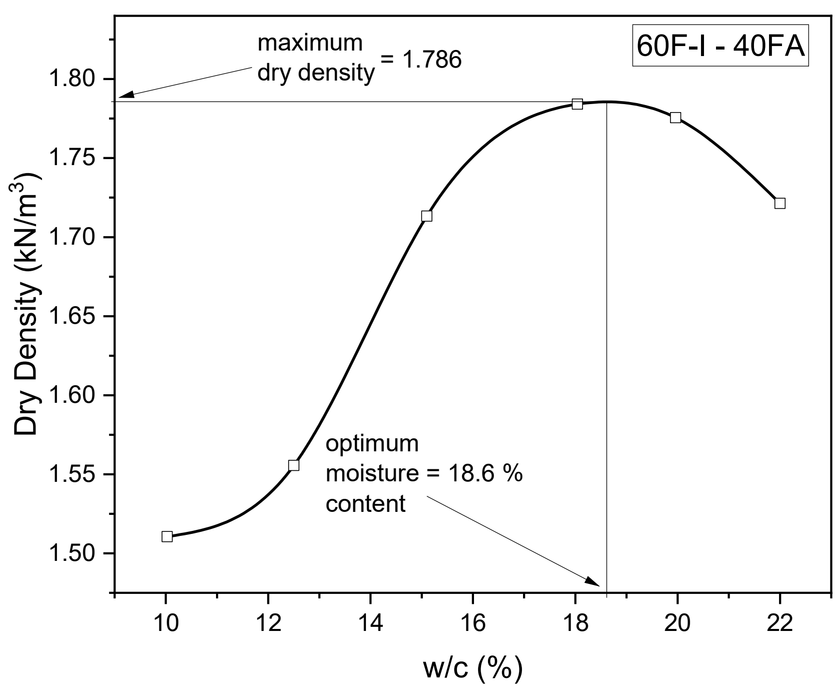

Figure 4. 31 Water content vs Dry Density of 60F-I – 40FA

Table 4. 20 Readings and Calculations results of proctor test on 60F-I - 40FA

S.No	Weight of empty mould(g)	mould+soil (g)	weight of soil in mould (g)	vol. of mould (cc)	wet density (bulk density) (g/cc)	crucible weight (g)	weight of wet soil+ crucible (g)	weight of dry soil + crucible (g)	w/c %	Dry Density (kN/m3)
1	5900	7562	1662	1000	1.662	26	150	138.7	10.03	1.51
2	5900	7650	1750	1000	1.75	24	150	136	12.50	1.56
3	5900	7872	1972	1000	1.972	25	150	133.6	15.10	1.71
4	5900	8006	2106	1000	2.106	27	150	131.2	18.04	1.78
5	5900	8030	2130	1000	2.13	25	150	129.2	19.96	1.78
6	5900	8000	2100	1000	2.1	28	150	128	22.00	1.72

4.2.3.2 OMC MDD of Fly Ash mixed F-III

Sample 80F-III – 20FA (80% F-III Brine Sludge 20 % Fly Ash)

Proctor test was performed on F-III of brine sludge and Fly Ash blend sample with light compaction where the blending ratio was taken as 4:1 (Brine Sludge : Fly Ash), in percentage it is 80% Brine Sludge and 20 % Fly Ash it is named as 80F-III – 20FA. For the test empty weight of mould, weight of mould with soil, volume of mould, crucible weight, of crucible with soil and weight of crucible with dry soil was readings were noted down as shown in table 4.21 below.

These readings were used for the calculation of weight of soil in mould, bulk density, water content and dry density.

Fig. 3.36 was plotted between Water Content and Dry density, the maximum point up to which graph reaches in y axis gives the value of maximum dry density which in case of 80F-III – 20FA is 1.878 (g/ml) and x-axis coordinate corresponding to that point gives the value of optimum moisture content which is 15.42 %

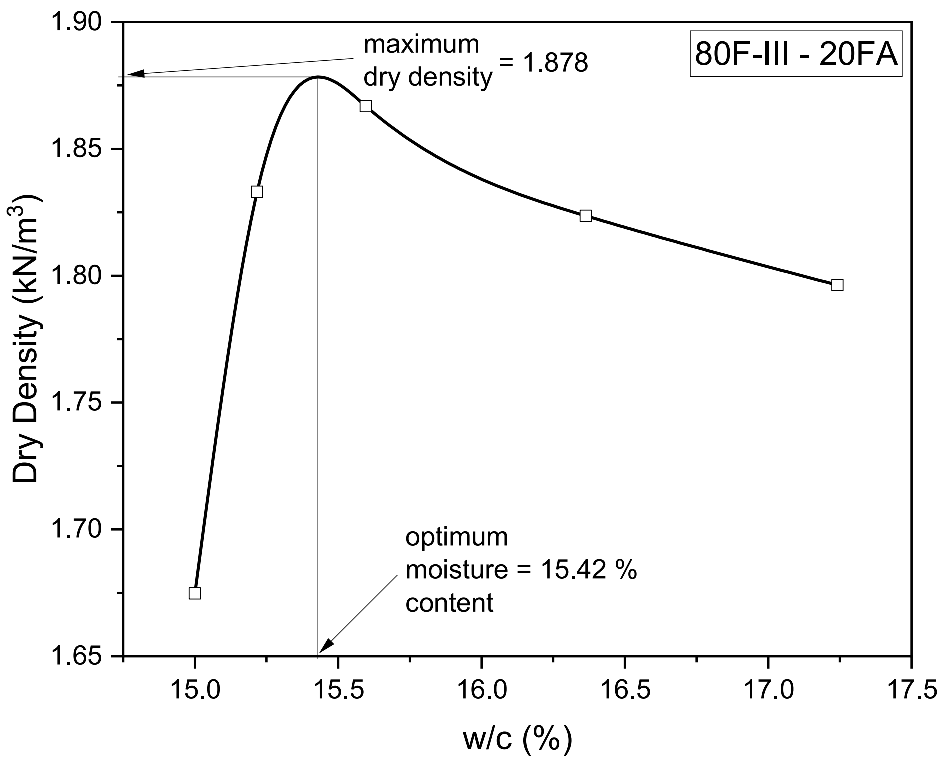

Figure 4. 32 Water content vs Dry Density of 80F-III – 20FA

Table 4. 21 Readings and Calculations results of proctor test on 80F-III - 20FA

S.No	Weight of empty mould(g)	mould+soil (g)	weight of soil in mould (g)	vol. of mould (cc)	wet density (bulk density) (g/cc)	crucible weight (g)	weight of wet soil+ crucible (g)	weight of dry soil + crucible (g)	w/c %	Dry Density (kN/m3)
1	5898	7824	1926	1000	1.926	0	92	80	15.00	1.67
2	5898	8010	2112	1000	2.112	0	106	92	15.22	1.83
3	5898	8056	2158	1000	2.158	0	126	109	15.60	1.87
4	5898	8020	2122	1000	2.122	0	128	110	16.36	1.82
5	5898	8004	2106	1000	2.106	0	136	116	17.24	1.80

Sample 60F-III – 40FA (60% F-III Brine Sludge 40 % Fly Ash)

Proctor test was performed on F-III of brine sludge and Fly Ash blend sample with light compaction where the blending ratio was taken as 3:2 (Brine Sludge : Fly Ash), in percentage it is 60% Brine Sludge and 40 % Fly Ash it is named as 60F-III – 40FA. For the test empty weight of mould, weight of mould with soil, volume of mould, crucible weight, of crucible with soil and weight of crucible with dry soil was readings were noted down as shown in table 4.22 below.

These readings were used for the calculation of weight of soil in mould, bulk density, water content and dry density.

Fig. 3.37 was plotted between Water Content and Dry density, the maximum point up to which graph reaches in y axis gives the value of maximum dry density which in case of 60F-III – 40FA is 1.881 (g/ml) and x-axis coordinate corresponding to that point gives the value of optimum moisture content which is 15.58 %

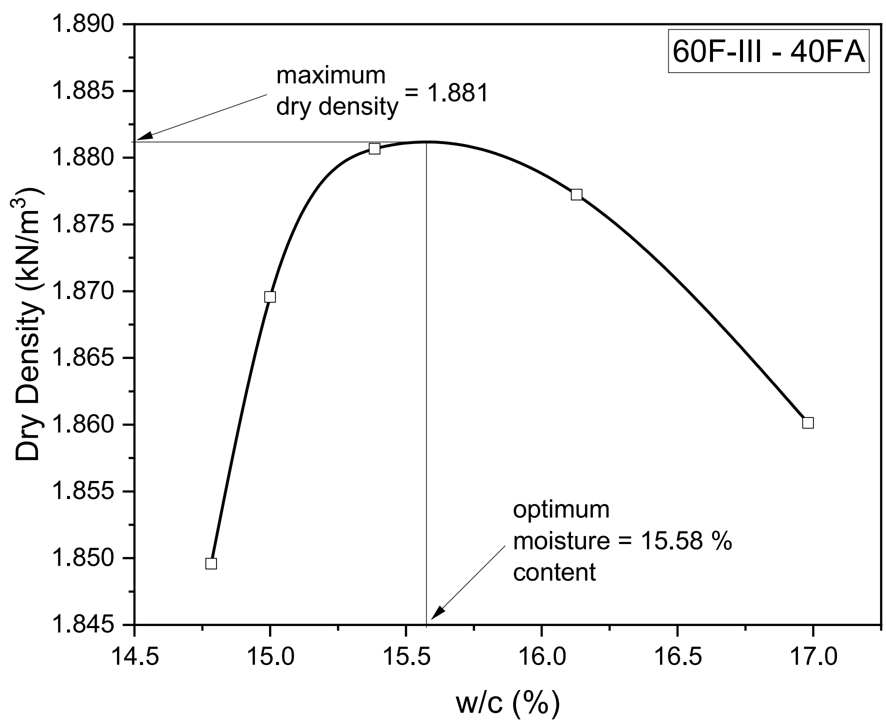

Figure 4. 33 Water content vs Dry Density of 60F-III – 40FA

Table 4. 22 Readings and Calculations results of proctor test on 60F-III - 40FA

S.No	Weight of empty mould(g)	mould+soil (g)	weight of soil in mould (g)	vol. of mould (cc)	wet density (bulk density) (g/cc)	crucible weight (g)	weight of wet soil+ crucible (g)	weight of dry soil + crucible (g)	w/c %	Dry Density (kN/m3)
1	5900	8023	2123	1000	2.123	0	132	115	14.7826	1.8496
2	5900	8050	2150	1000	2.15	0	92	80	15.0000	1.8696
3	5900	8070	2170	1000	2.17	0	150	130	15.3846	1.8807
4	5900	8080	2180	1000	2.18	0	144	124	16.1290	1.8772
5	5900	8076	2176	1000	2.176	0	124	106	16.9811	1.8601

4.2.4 CBR of Fly Ash mixed Brine Sludge

4.2.4.1 Unsoaked CBR of Fly Ash mixed Brine Sludge

Unsoaked CBR test of Fly Ash mixed F-I

Sample 80F-I – 20FA (80% F-I Brine Sludge 20 % Fly Ash)

Unsoaked California bearing ratio test was performed F-I of brine sludge and Fly Ash blend sample with light compaction where the blending ratio was taken as 4:1 (Brine Sludge : Fly Ash), in percentage it is 80% Brine Sludge and 20 % Fly Ash it is named as 80F-I – 20FA and load was noted against penetration at points shown in table 4.23 below. The load reading from CBR testing machine comes out in kN it was converted into kg/cm^2.

Table 4. 23 Penetration and its corresponding Load of 80F-I – 20FA for Unsoaked CBR

displacement (mm)	load (kN)	load (kg)	load kg/cm2
0.5	0.29	29.57	1.51
1	0.39	39.77	2.02
1.5	0.53	54.04	2.75
2	0.66	67.30	3.43
2.5	0.78	79.54	4.05
4	1.12	114.21	5.81
5	1.3	132.56	6.75
7.5	1.81	184.57	9.40
10	2.25	229.44	11.68
12.5	2.68	273.28	13.91

Graph was plotted between displacement (mm) and load (kg/cm^2) as shown in figure 4.34 below and from the graph it was clear that there is no need for the correction for load, so CBR will now be calculated for 2.5 mm and 5 mm penetration i.e., no shift of origin is required.

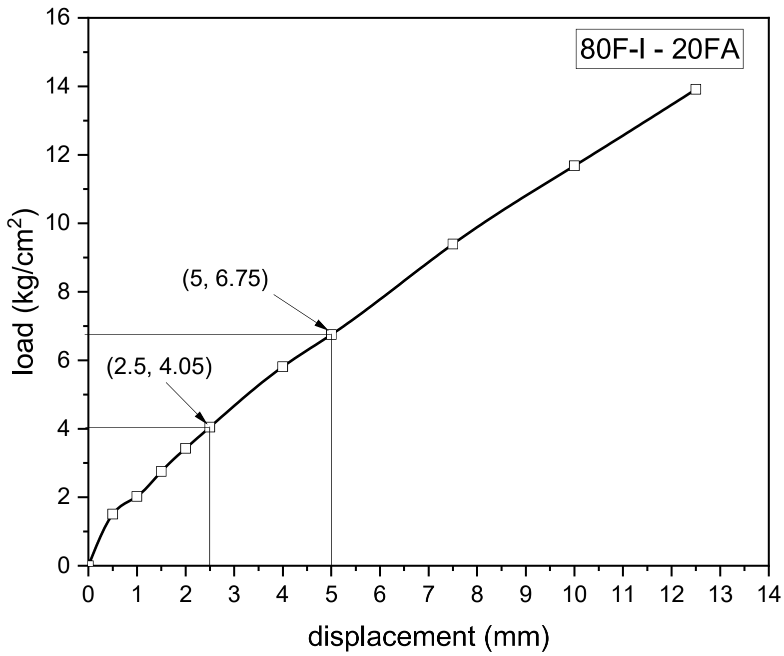

Figure 4. 34 Load vs Penetration curve of Unsoaked 80F-I – 20FA

CBR at 2.5 mm penetration = $\frac{load\ (kg/cm^2)}{70} \times 100$

$= \frac{4.05}{70} \times 100$

= 5.784 %

CBR at 5 mm penetration = $\frac{load\ (kg/cm^2)}{105} \times 100$

$= \frac{6.75}{105} \times 100$

= 6.427 %

Grater CBR is considered so CBR of 80F-I – 20FA comes out to be 6.427%

Sample 60F-I – 40FA (60% F-I Brine Sludge 40 % Fly Ash)

Unsoaked California bearing ratio test was performed F-I of brine sludge and Fly Ash blend sample with light compaction where the blending ratio was taken as 3:4 (Brine Sludge : Fly Ash), in percentage it is 60% Brine Sludge and 40 % Fly Ash it is named as 60F-I – 40FA and load was noted against penetration at points shown in table 4.24 below.

The load reading from CBR testing machine comes out in kN it was converted into kg/cm^2.

Table 4. 24 Penetration and its corresponding Load of 60F-I – 40FA for Unsoaked CBR

displacement (mm)	load (kN)	load (kg)	load kg/cm2
0.5	0.357435	36.45	1.86
1	0.500409	51.03	2.60
1.5	0.643383	65.61	3.34
2	0.71487	72.90	3.71
2.5	0.786357	80.19	4.08
4	1.106683	112.85	5.75
5	1.314186	134.01	6.82
7.5	1.729192	176.33	8.98
10	2.213366	225.70	11.49
12.5	2.559204	260.97	13.29

Graph was plotted between displacement (mm) and load (kg/cm^2) as shown in figure 4.35 below and from the graph it was clear that there is no need for the correction for load, so CBR will now be calculated for 2.5 mm and 5 mm penetration i.e., no shift of origin is required.

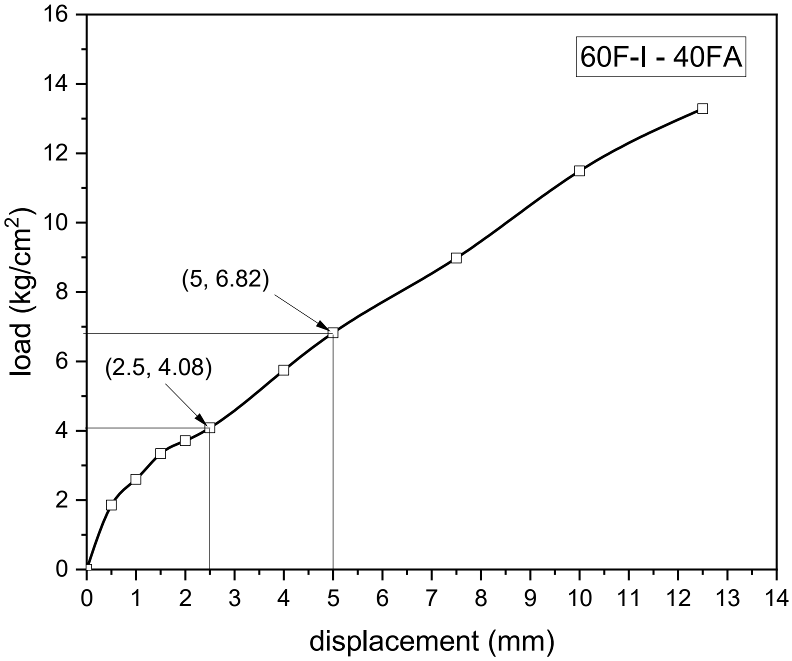

Figure 4. 35 Load vs Penetration curve of Unsoaked 60F-I – 40FA

CBR at 2.5 mm penetration = $\frac{load\ (kg/cm^2)}{70} \times 100$

$= \frac{4.08}{70} \times 100$

= 5.832 %

CBR at 5 mm penetration = $\frac{load\ (kg/cm^2)}{105} \times 100$

$= \frac{6.82}{105} \times 100$

= 6.497 %

Grater CBR is considered so CBR of 60F-I – 40FA comes out to be 6.497%

Unsoaked CBR test of Fly Ash mixed F-III

Sample 80F-III – 20FA (80% F-III Brine Sludge 20 % Fly Ash)

Unsoaked California bearing ratio test was performed F-III of brine sludge and Fly Ash blend sample with light compaction where the blending ratio was taken as 4:1 (Brine Sludge : Fly Ash), in percentage it is 80% Brine Sludge and 20 % Fly Ash it is named as 80F-III – 20FA and load was noted against penetration at points shown in table 4.25 below.

The load reading from CBR testing machine comes out in kN it was converted into kg/cm^2.

Table 4. 25 Penetration and its corresponding Load of 80F-III – 20FA for Unsoaked CBR

displacement (mm)	load (kN)	load (kg)	load kg/cm2
0.5	0.10	10.20	0.52
1	0.20	20.39	1.04
1.5	0.33	33.65	1.71
2	0.53	54.04	2.75
2.5	0.71	72.40	3.69
4	1.11	113.19	5.76
5	1.35	137.66	7.01
7.5	1.78	181.51	9.24
10	2.07	211.08	10.75
12.5	2.30	234.53	11.94

Graph was plotted between displacement (mm) and load (kg/cm^2) as shown in figure 4.36 below and from the graph it was clear that there is no need for the correction for load, so CBR will now be calculated for 2.5 mm and 5 mm penetration i.e., no shift of origin is required.

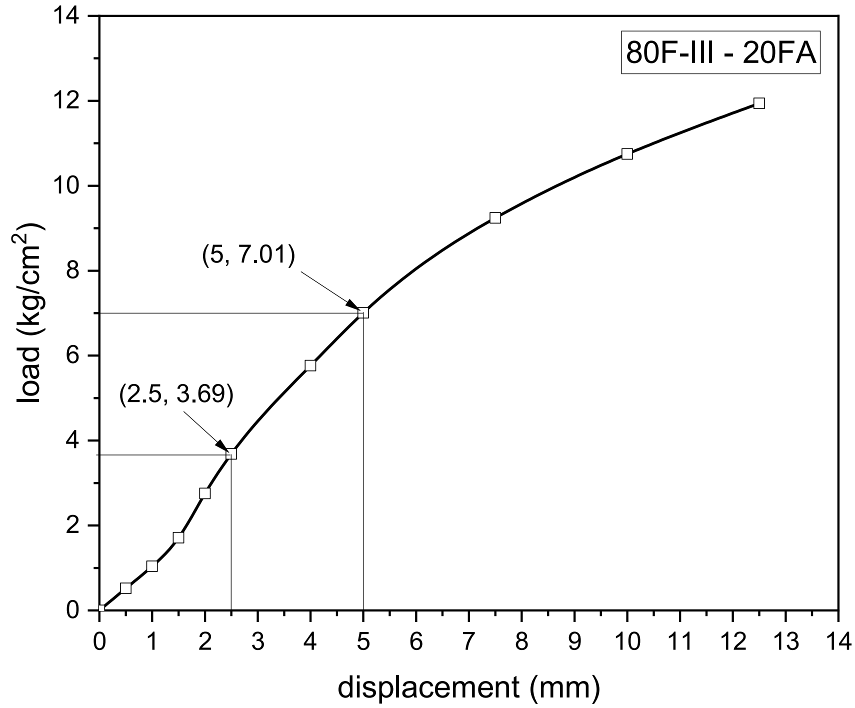

Figure 4. 36 Load vs Penetration curve of Unsoaked 80F-III – 20FA

CBR at 2.5 mm penetration = $\frac{load\ (kg/cm^2)}{70} \times 100$

$= \frac{3.69}{70} \times 100$

= 5.27 %

CBR at 5 mm penetration = $\frac{load\ (kg/cm^2)}{105} \times 100$

$= \frac{7.01}{105} \times 100$

= 6.67 %

Grater CBR is considered so CBR of 80F-III – 20FA comes out to be 6.67%

Sample 60F-III – 40FA (60% F-III Brine Sludge 40 % Fly Ash)

Unsoaked California bearing ratio test was performed F-III of brine sludge and Fly Ash blend sample with light compaction where the blending ratio was taken as 3:2 (Brine Sludge : Fly Ash), in percentage it is 60% Brine Sludge and 40 % Fly Ash it is named as 60F-III – 40FA and load was noted against penetration at points shown in table 4.26 below.

The load reading from CBR testing machine comes out in kN it was converted into kg/cm^2.

Table 4. 26 Penetration and its corresponding Load of 60F-III – 40FA for Unsoaked CBR

displacement (mm)	load (kN)	load (kg)	load kg/cm2
0.5	0.13	13.26	0.67
1	0.26	26.51	1.35
1.5	0.4	40.79	2.08
2	0.58	59.14	3.01
2.5	0.72	73.42	3.74
4	1.12	114.21	5.81
5	1.36	138.68	7.06
7.5	1.79	182.53	9.29
10	2.09	213.12	10.85
12.5	2.31	235.55	11.99

Graph was plotted between displacement (mm) and load (kg/cm^2) as shown in figure 4.37 below and from the graph it was clear that there is no need for the correction for load, so CBR will now be calculated for 2.5 mm and 5 mm penetration i.e., no shift of origin is required.

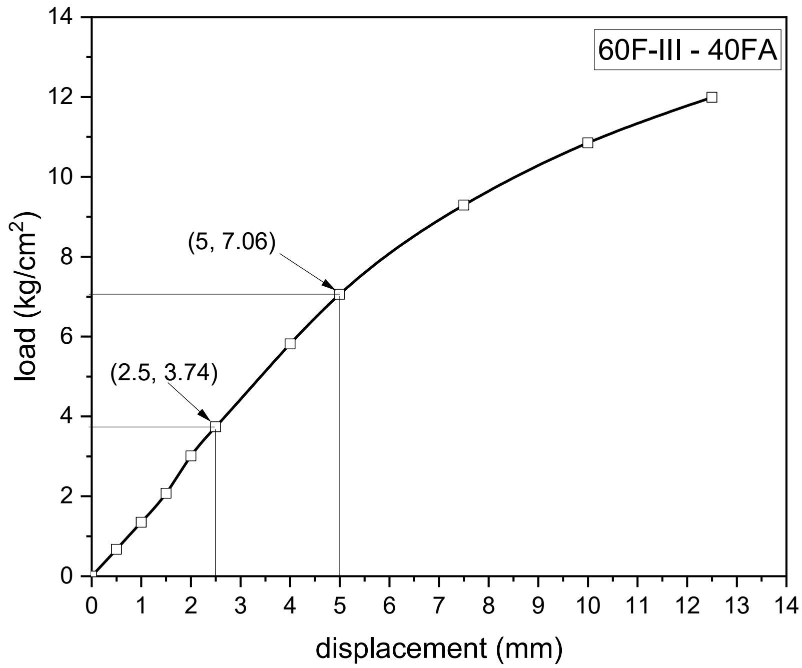

Figure 4. 37 Load vs Penetration curve of Unsoaked 60F-III – 40FA

CBR at 2.5 mm penetration $= \frac{load\ (kg/cm^2)}{70} \times 100$

$= \frac{3.74}{70} \times 100$

$= 5.34\ \%$

CBR at 5 mm penetration $= \frac{load\ (kg/cm^2)}{105} \times 100$

$= \frac{7.06}{105} \times 100$

$= 6.72\ \%$

Grater CBR is considered so CBR of 60F-III – 40FA comes out to be 6.72%

4.2.4.2 Soaked CBR of Fly Ash mixed Brine Sludge

Soaked CBR test of Fly Ash mixed F-I

Sample 80F-I – 20FA (80% F-I Brine Sludge 20 % Fly Ash)

Soaked California bearing ratio test was performed F-I of brine sludge and Fly Ash blend sample with light compaction where the blending ratio was taken as 4:1 (Brine Sludge : Fly Ash), in percentage it is 80% Brine Sludge and 20 % Fly Ash it is named as 80F-I – 20FA and load was noted against penetration at points shown in table 4.27 below. The load reading from CBR testing machine comes out in kN it was converted into kg/cm^2.

Table 4. 27 Penetration and its corresponding Load of 80F-I – 20FA for Soaked CBR

displacement (mm)	load (kN)	load (kg)	load (kg/cm2)
0.5	0.17	17.34	0.88
1	0.23	23.45	1.19
1.5	0.32	32.63	1.66
2	0.39	39.77	2.02
2.5	0.47	47.93	2.44
4	0.67	68.32	3.48
5	0.78	79.54	4.05
7.5	1.08	110.13	5.61
10	1.34	136.64	6.96
12.5	1.49	151.94	7.74

Graph was plotted between displacement (mm) and load (kg/cm^2) as shown in figure 4.38 below and from the graph it was clear that there is no need for the correction for load, so CBR will now be calculated for 2.5 mm and 5 mm penetration i.e., no shift of origin is required.

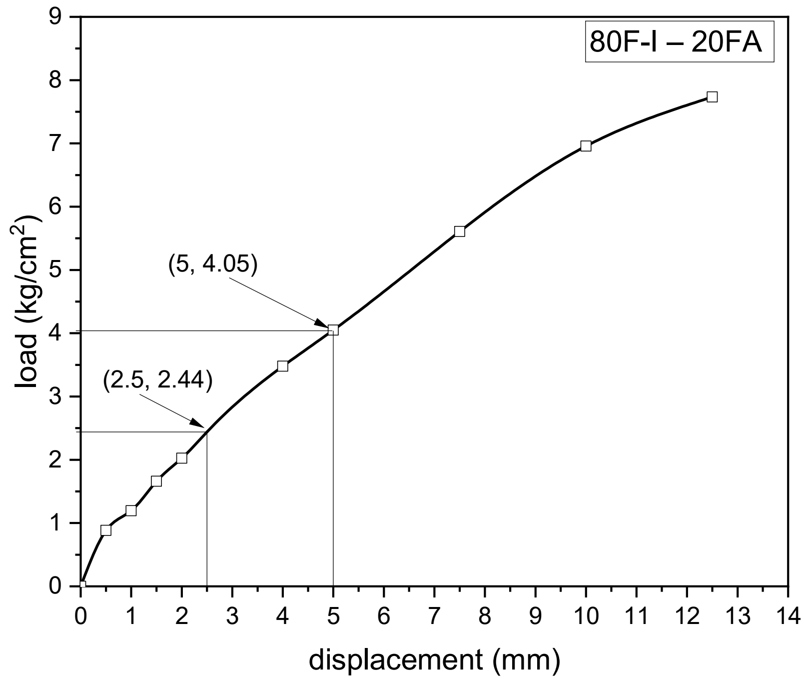

Figure 4. 38 Load vs Penetration curve of Soaked 80F-I – 20FA

CBR at 2.5 mm penetration = $\frac{load\ (kg/cm^2)}{70} \times 100$

$= \frac{2.44}{70} \times 100$

= 3.485 %

CBR at 5 mm penetration = $\frac{load\ (kg/cm^2)}{105} \times 100$

$= \frac{4.05}{105} \times 100$

= 3.856 %

Grater CBR is considered so CBR of 80F-I – 20FA comes out to be 3.856%

Sample 60F-I – 40FA (60% F-I Brine Sludge 40 % Fly Ash)

Soaked California bearing ratio test was performed F-I of brine sludge and Fly Ash blend sample with light compaction where the blending ratio was taken as 3:4 (Brine Sludge : Fly Ash), in percentage it is 60% Brine Sludge and 40 % Fly Ash it is named as 60F-I – 40FA and load was noted against penetration at points shown in table 4.28 below.

The load reading from CBR testing machine comes out in kN it was converted into kg/cm^2.

Table 4. 28 Penetration and its corresponding Load of 60F-I – 40FA for Soaked CBR

displacement (mm)	load (kN)	load (kg)	load (kg/cm2)
0.5	0.14	14.28	0.73
1	0.19	19.37	0.99
1.5	0.24	24.47	1.25
2	0.27	27.53	1.40
2.5	0.3	30.59	1.56
4	0.42	42.83	2.18
5	0.5	50.99	2.60
7.5	0.66	67.30	3.43
10	0.84	85.66	4.36
12.5	0.97	98.91	5.04

Graph was plotted between displacement (mm) and load (kg/cm^2) as shown in figure 4.39 below and from the graph it was clear that there is no need for the correction for load, so CBR will now be calculated for 2.5 mm and 5 mm penetration i.e., no shift of origin is required.

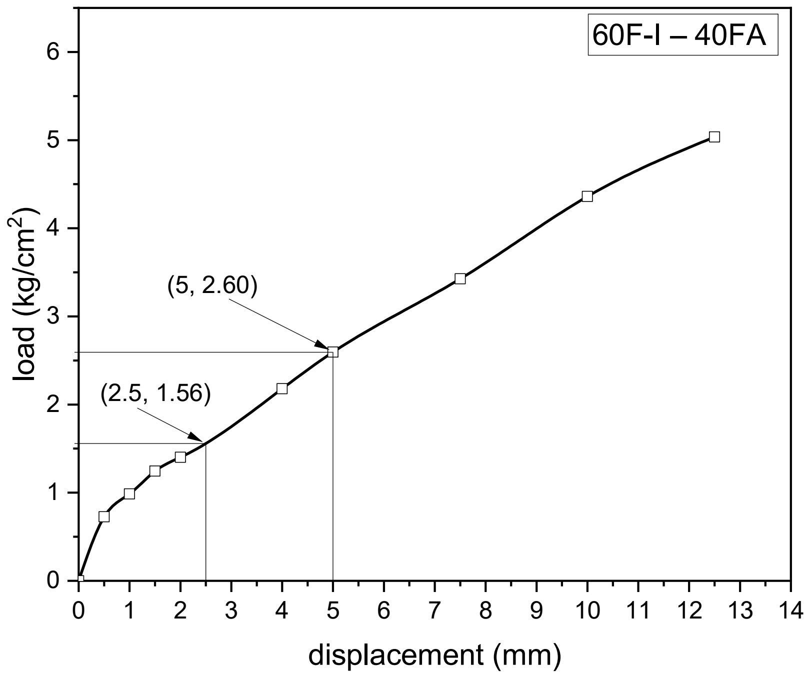

Figure 4. 39 Load vs Penetration curve of Soaked 60F-I – 40FA

CBR at 2.5 mm penetration = $\frac{load\ (kg/cm^2)}{70} \times 100$

$= \frac{1.56}{70} \times 100$

= 2.22 %

CBR at 5 mm penetration = $\frac{load\ (kg/cm^2)}{105} \times 100$

$= \frac{2.60}{105} \times 100$

= 2.47 %

Grater CBR is considered so CBR of 60F-I – 40FA comes out to be 2.47 %

Soaked CBR test of Fly Ash mixed F-III

Sample 80F-III – 20FA (80% F-III Brine Sludge 20 % Fly Ash)

Soaked California bearing ratio test was performed F-III of brine sludge and Fly Ash blend sample with light compaction where the blending ratio was taken as 4:1 (Brine Sludge : Fly Ash), in percentage it is 80% Brine Sludge and 20 % Fly Ash it is named as 80F-III – 20FA and load was noted against penetration at points shown in table 4.29 below. The load reading from CBR testing machine comes out in kN it was converted into kg/cm^2.

Table 4. 29 Penetration and its corresponding Load of 80F-III – 20FA for Soaked CBR

displacement (mm)	load (kN)	load (kg)	load (kg/cm2)
0.5	0.07	7.14	0.36
1	0.13	13.26	0.67
1.5	0.23	23.45	1.19
2	0.35	35.69	1.82
2.5	0.42	42.83	2.18
4	0.66	67.30	3.43
5	0.81	82.60	4.20
7.5	1.06	108.09	5.50
10	1.24	126.44	6.44
12.5	1.37	139.70	7.11

Graph was plotted between displacement (mm) and load (kg/cm^2) as shown in figure 4.40 below and from the graph it was clear that there is no need for the correction for load, so CBR will now be calculated for 2.5 mm and 5 mm penetration i.e., no shift of origin is required.

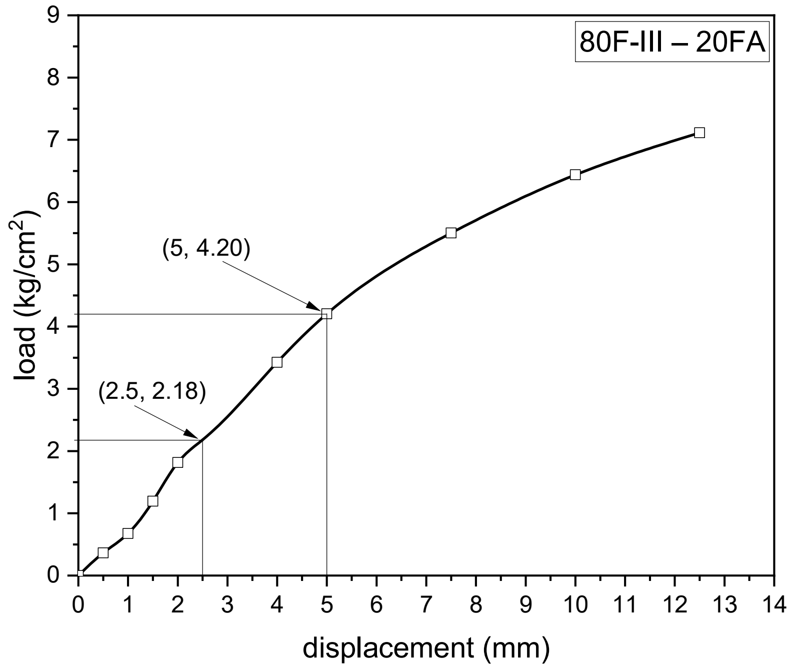

Figure 4. 40 Load vs Penetration curve of Soaked 80F-III – 20FA

CBR at 2.5 mm penetration = $\frac{load\ (kg/cm^2)}{70} \times 100$

$= \frac{2.18}{70} \times 100$

= 3.11 %

CBR at 5 mm penetration = $\frac{load\ (kg/cm^2)}{105} \times 100$

$= \frac{4.20}{105} \times 100$

= 4.00 %

Grater CBR is considered so CBR of 80F-III – 20FA comes out to be 4.00 %

Sample 60F-III – 40FA (60% F-III Brine Sludge 40 % Fly Ash)

Soaked California bearing ratio test was performed F-III of brine sludge and Fly Ash blend sample with light compaction where the blending ratio was taken as 3:2 (Brine Sludge : Fly Ash), in percentage it is 60% Brine Sludge and 40 % Fly Ash it is named as 60F-III – 40FA and load was noted against penetration at points shown in table 4.30 below.

The load reading from CBR testing machine comes out in kN it was converted into kg/cm^2.

Table 4. 30 Penetration and its corresponding Load of 60F-III – 40FA for Soaked CBR

displacement (mm)	load (kN)	load (kg)	load (kg/cm2)
0.5	0.05	5.10	0.26
1	0.1	10.20	0.52
1.5	0.15	15.30	0.78
2	0.22	22.43	1.14
2.5	0.27	27.53	1.40
4	0.43	43.85	2.23
5	0.52	53.03	2.70
7.5	0.68	69.34	3.53
10	0.9	91.77	4.67
12.5	1.03	105.03	5.35

Graph was plotted between displacement (mm) and load (kg/cm^2) as shown in figure 4.41 below and from the graph it was clear that there is no need for the correction for load, so CBR will now be calculated for 2.5 mm and 5 mm penetration i.e., no shift of origin is required.

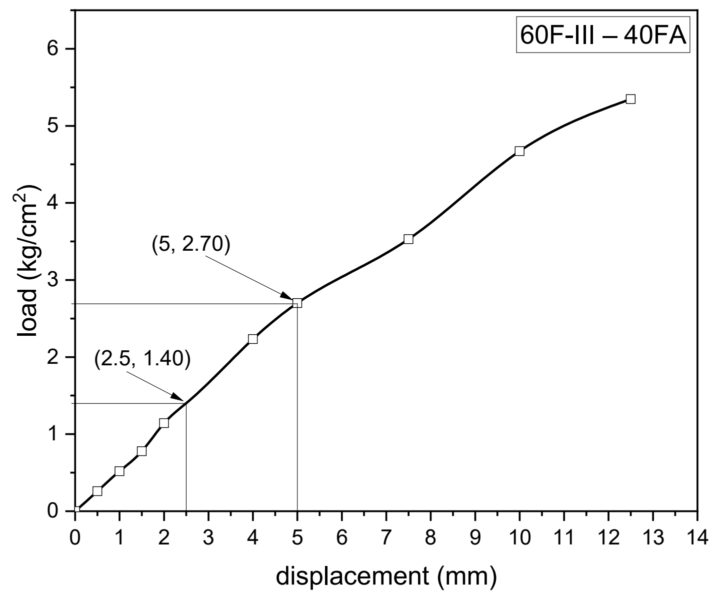

Figure 4. 41 Load vs Penetration curve of Soaked 60F-III – 40FA

CBR at 2.5 mm penetration = $\frac{load\ (kg/cm^2)}{70} \times 100$

$= \frac{1.40}{70} \times 100$

= 2.00 %

CBR at 5 mm penetration = $\frac{load\ (kg/cm^2)}{105} \times 100$

$= \frac{2.70}{105} \times 100$

= 2.57 %

Grater CBR is considered so CBR of 60F-III – 40FA comes out to be 2.57 %

4.3 Brine sludge as an alternative precursor in geopolymer bricks

Brine sludge can be used as a precursor replacement or partial replacement of fly ash in fly ash geopolymer bricks. In this chapter work has been done on optimisation of strength and density of fly ash partially replaced with brine sludge geopolymer bricks.

4.3.1 Optimisation of ratio of materials

Table 4. 31 Density and Compressive Strength of Bricks

Brick Code	Average Density	Standard Deviation (Density)	Average Compressive Strength (Mpa)	Standard Deviation (Strength)
S1	1.938	0.137	5.286	0.196
S2	1.834	0.041	2.022	0.185
S3	2.097	0.01	7.913	0.043
S4	2.046	0.017	11.943	0.376
S5	2.014	0.029	15.304	0.113
S6	2.073	0.014	19.891	0.152
S7	2.097	0.011	18.222	0.169
S9	1.847	0.003	4.613	0.179
S10	2.089	0.012	19.487	0.325
S11	2.083	0.017	17.117	0.34
S12	2.06	0.018	14.848	0.117

Firstly the ratio of precursors (Brine Sludge : Fly Ash) was optimised for density and strength.

Figure 4. 42 Weighing of Brick

The brick was waved and its dimensions were measured for the purpose of density calculation.

Three different ratios of precursors were tested i.e., 1:1, 3:7, and 7:3. The results of those different ratios are shown in Fig. 3.47 below.

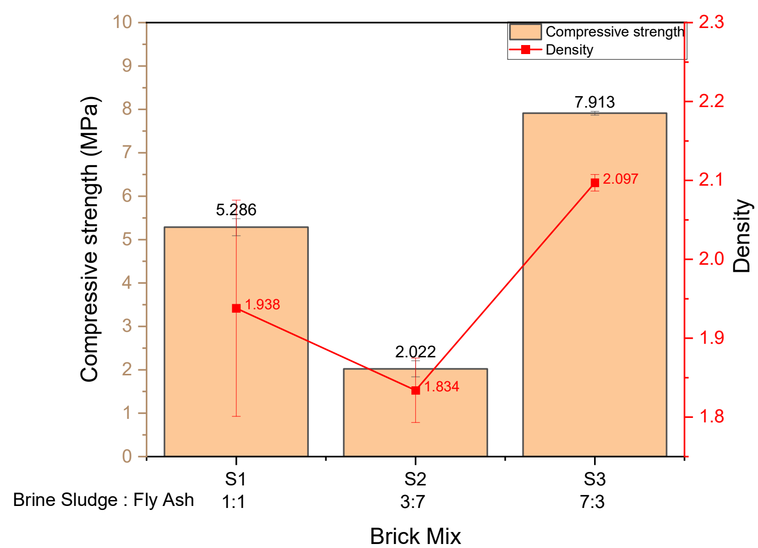

Figure 4. 43 Effect of variation of Precursor internal ratio (Brine Sludge : Fly Ash)

According to the tests performed most optimised ratio of Brine Sludge : Fly Ash comes out to be 7:3. So all the later tests which we performed had this ratio fixed.

After the optimisation of precursor ratio, comparison of precursor to total liquid was done. In the comparison, precursor to total liquid was varied as 1 : 0.6 and 1 : 0.68, the comparison is shown in graph 3.48 below.

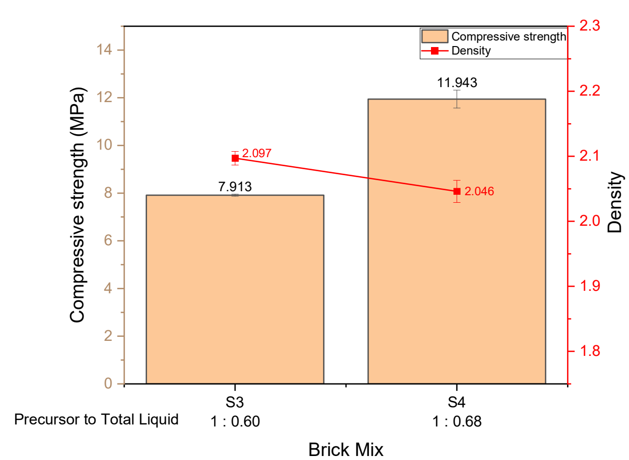

Figure 4. 44 Effect of variation of ratio of Precursor to Total Liquid

On comparison of different ratios of precursor to total liquid it was found that density almost remained same and compressive strength of brick increased to almost 3 MPa when the ratio was changed from 1 : 0.60 to 1 : 0.68.

Now we have fixed the ratio of precursor i.e. Brine Sludge : Fly Ash (7 : 3) and the ratio of precursor to total liquid(1 : 0.68).

Now the ratio of chemicals was varied i.e., Sodium Silicate and Sodium Hydroxide.

Sodium Hydroxide to Sodium Silicate was varied as 1 : 1, 1 : 0.67, 1 : 0.5 and 1 : 0.4 while keeping the precursor to total chemical ratio at 1 : 0.68 (no dilution with water).

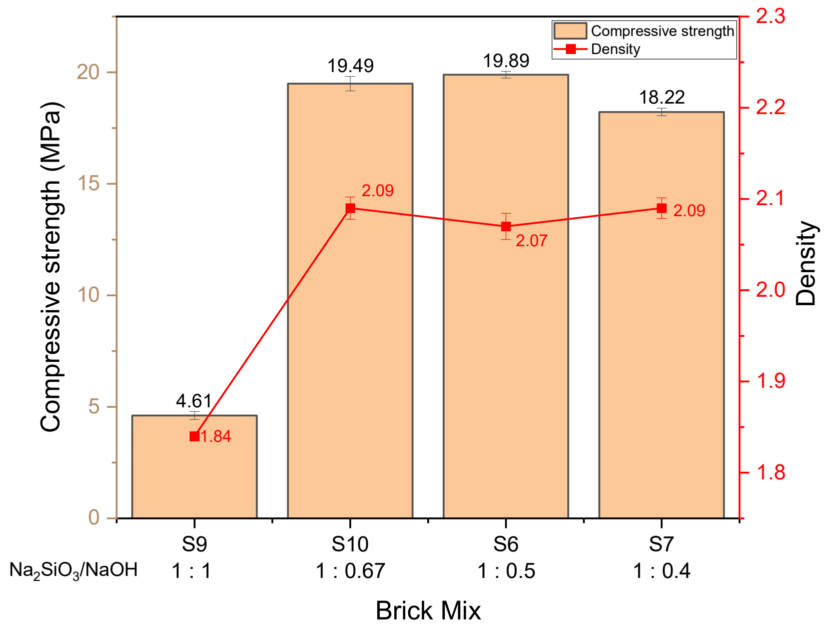

Figure 4. 45 Effect of variation of ratio of Sodium Silicate to Sodium Hydroxide (Na_2SiO_3 to NaOH)

Above results indicate that on decreasing the quantity of Sodium Silicate up to half, the compressive strength increases and then decreases, while the density is lowest for 1 : 1 and increases for 1 : 0.67 and then almost remained constant for 1 : 0.5 and 1 : 0.4. It shows the ratio of Sodium Silicate to Sodium Hydroxide best suitable is 1 : 0.67 and 1 : 0.5.

Later we tried to optimise the dilution of chemicals with water by keeping the total precursor to total liquid ratio at 1 : 0.68 and reducing precursor to total chemical ratio to 1 : 0.58, Thus making chemical to water ratio as 1 : 0.167.

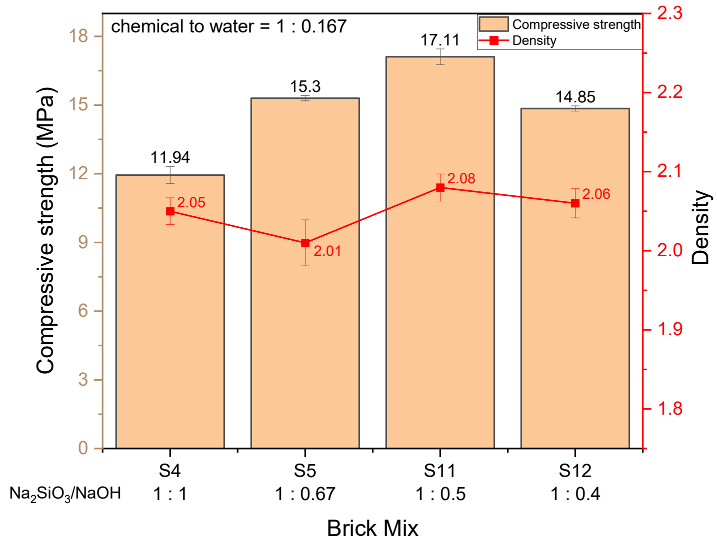

Figure 4. 46 Effect of variation of ratio of Sodium Silicate to Sodium Hydroxide with constant dilution with water (chemical to water ratio as 1 : 0.167).

From the Fig. 3.50 it can be concluded that maximum density and compressive strength is achieved at Sodium Silicate to Sodium Hydroxide ratio at 1 : 0.5, here the chemical to water ratio was 1 : 0.167.

A comparison can be made between dilution and no dilution with water keeping all the other parameters constant and chemical to water ratio as 1 : 0.167. Below is the Fig. 3.51 showing comparison between diluted and non-diluted bricks while the ratio between Sodium Silicate : Sodium Hydroxide

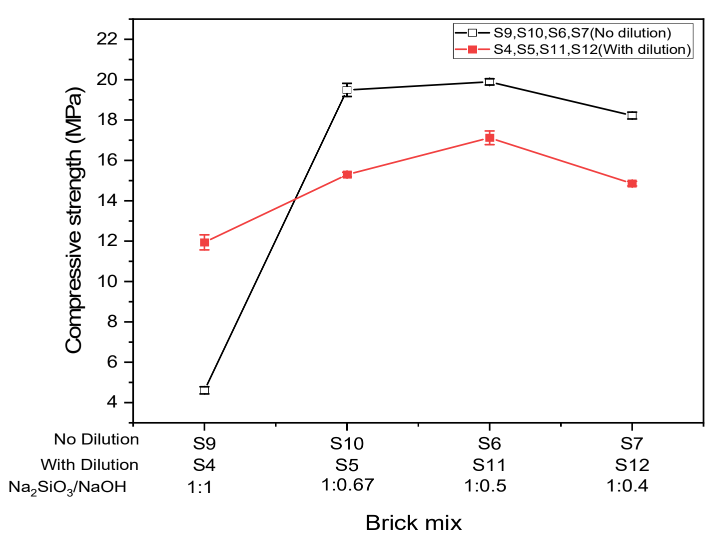

Figure 4. 47 Comparison of compressive strength with and without dilution

Below is the Fig. 3.52 between S6 and S11 in which the only difference is of dilution with water S6 have no dilution with water while S11 have total chemical to water ratio as 1 : 0.167.

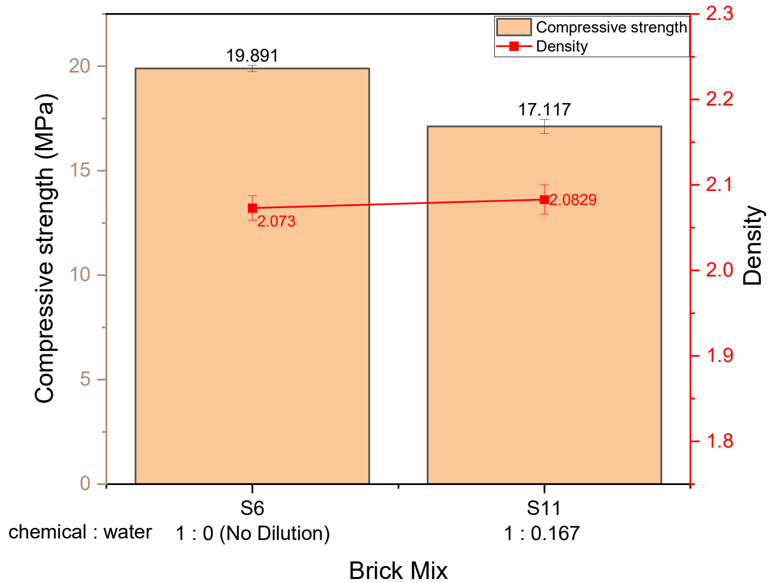

Figure 4. 48 Effect of dilution with water (chemical : water).

From the above Fig. 3.52 it can be concluded that on dilution of chemical with water density almost remained same while the compressive strength decreases.

Thus from all the tests conducted on bricks best optimised for strength brick is S6 which have following ratio:

Brine Sludge : Fly Ash = 7 : 3

Precursor : Stone Dust = 1 : 2

Precursor : Total Liquid = 1 : 0.68

Precursor : Total Chemical = 1 : 0.68 (no dilution with water)

Sodium Silicate : Sodium Hydroxide = 1 : 0.5

Figure 4. 49 Sample of brick with highest strength

4.3.2 Economic comparison of geopolymer brick mixes

Cost per brick and cost per unit compressive strength is estimated and most economical brick will have future scope of further optimisation to make it more economical.

4.3.2.1 Cost of raw materials

The cost discussed below are my estimates according to my research which I got by calling and visiting websites on internet these costs might vary person to person.

Table 4. 32 Cost of material

Material	Cost (₹/kg)
Brine Sludge	0
Fly Ash	1
Stone Dust	0.5
NaOH	35.5
Na_2SiO_3	20
Other cost	0.65

4.3.2.2 Calculation of per brick cost

A comparison can be made between compressive strength of bricks and cost per brick which will allow us to see the economic feasibility of the bricks and what more changes up to what amount can be done to further reduce the cost of bricks.

From the Table 4.33 below it can be seen that S6 have maximum compressive strength i.e., 19.891 MPa and cost per brick i.e., ₹19.61 which is on high side of the samples tested.

The strength required for a brick is 10 MPa so there is scope to reduce the cost with reduction in compressive strength.

Table 4. 33 Compressive strength of bricks and Cost/Brick

Brick Code	Sludge (g)	Fly Ash (g)	Stone dust (g)	NaOH (g)	Na_2SiO_3 (g)	Water (g)	Compressive Strength (MPa)	Cost/ Brick (₹)
S1	517	517	2067	300	300	0	5.286	18.85
S2	310	723	2067	310	310	0	2.022	19.61
S3	723	310	2067	310	310	0	7.913	19.20
S4	723	310	2067	300	300	100	11.943	18.64
S5	723	310	2067	240	360	100	15.304	17.71
S6	723	310	2067	233	467	0	19.891	19.61
S7	723	310	2067	200	500	0	18.222	19.09
S9	723	310	2067	350	350	0	4.613	21.42
S10	723	310	2067	280	420	0	19.487	20.33
S11	723	310	2067	200	400	100	17.117	17.09
S12	723	310	2067	171	428	100	14.848	16.62

Brick sample S12 which have least cost have the compressive strength is 14.848 MPa also the cost per brick is ₹16.62 which is the least in all of the samples tested. S12 also have a margin to reduce strength thus the cost of the brick.

4.3.2.3 Calculation of cost of brick per unit compressive strength

An analysis can be done on cost of brick per unit compressive strength which will show as which mix gave us the maximum amount of compressive strength in least cost of material and labour all the costs of materials and labour in other cost section have been discussed above in table 4.32. A table 4.34 below has been made showing the cost of brick per unit compressive strength.

Table 4. 34 Cost of brick per unit compressive strength

Brick Code	Brine sludge : Fly Ash	Precursor : Total Liquid	Precursor : Total Chemical	Na_2SiO_3 : NaOH	Chemical : Water	Compressive Strength (MPa)	Cost per unit compressive strength (₹/MPa)
S1	1 : 1	1 : 0.58	1 : 0.58	1 : 1	0	5.286	3.57
S2	3 : 7	1 : 0.6	1 : 0.6	1 : 1	0	2.022	9.70
S3	7 : 3	1 : 0.6	1 : 0.6	1 : 1	0	7.913	2.43
S4	7 : 3	1 : 0.68	1 : 0.58	1 : 1	0 : 0.17	11.943	1.56
S5	7 : 3	1 : 0.68	1 : 0.58	1 : 0.67	1 : 0.17	15.304	1.16
S6	**7:3**	**1 : 0.68**	**1 : 0.68**	**1 : 0.5**	**0**	**19.891**	**0.99**
S7	7:3	1 : 0.68	1 : 0.68	1 : 0.4	0	18.222	1.05
S9	7:3	1 : 0.68	1 : 0.68	1 : 1	0	4.613	4.64
S10	7:3	1 : 0.68	1 : 0.68	1 : 0.67	0	19.487	1.04
S11	7:3	1 : 0.68	1 : 0.58	1 : 0.5	0 : 0.17	17.117	1.00
S12	7:3	1 : 0.68	1 : 0.58	1 : 0.4	1 : 0.17	14.848	1.12

From the table it is clear that least cost of brick per unit compressive strength is ₹ 0.99 of S6 specimen which have maximum compressive strength also. S11 is similar to S6 with difference that it is diluted with water. So, specimen S11 have almost same cost per unit compressive strength with less total compressive strength.

Chapter 5

Conclusion and Future Scope

5.1 Conclusion

5.1.1 Use of Brine Sludge in Subgrade

The soaked and unsoaked CBR of weathered sludge is obtained maximum as 3.81 and 6.032 respectively for sample F-I. At 20% fly ash, there is an improvement in soaked and unsoaked CBR of fly ash blended sludge, whereas at 40% fly ash, soaked CBR of fly ash blended sludge is found less than that of sample F-I (100% sludge).

The soaked CBR of un-weathered sludge is obtained maximum for sample F-IV as 1.137, whereas, maximum unsoaked CBR is obtained for sample F-III as 6.21. At 20% fly ash, the improvement is more in soaked CBR as compared to 40% fly ash blended sludge. Whereas, unsoaked CBR increases with the increase in fly ash blending in sludge up to 40%.

5.1.2 Brine sludge as partial replacement of cement in concrete

The value of 7 days compressive strength increases with the increase in percent replacement of cement with brine sludge up to 5% replacement later on increasing the replacement the value started decreasing and at about 10% replacement the value again becomes slightly less than control sample with a variation of 3%, while for 28 days compressive strength the value increases up to 5 % replacement and later decreases but even after decreasing at 10 % replacement the value of compressive strength is much higher than that of control sample with 34 percent variation.

At 5% replacement there is maximum increase in strength with the percent variation of 21.68 and 53.7 at 7 days and 28 days respectively.

The value of 7 days flexural strength increases with the increase in percent replacement of cement with brine sludge up to 10%, with the percent variation of 14.03, while for 28 days the value of flexural strength for 2.5% replacement first decreases with a percent variation of 14.23 and then increased more than that of control sample and remained more up to 10 % replacement with a percent variation of 7.39.

These results conclude that brine sludge can be used as a partial replacement of cement and to increase the strength 5% replacement is the best option as it has maximum compressive and flexural strength at 28 days.

5.1.3 Brine sludge as an alternative precursor, blended with fly ash in geopolymer bricks

The work on optimisation of geopolymer bricks was done and it was found that the internal precursor ratio (Brine Sludge : Fly Ash) was best optimised at 7 : 3.

Later Precursor to total liquid was optimised and it was found that 1 : 0.68 is the best optimised ratio.

Keeping the precursor to total liquid fixed further chemical ratio was varied and it was found that at ratio 1 : 0.67 the strength is maximum.

Same samples were diluted to the chemical to water ratio as 1 : 0.167 and again the same sample had maximum strength.

It can be concluded that for maximum strength S6 is the best optimised brick.

The estimation of cost was also done and it was found that the best optimised brick according to cost per unit compressive strength is brick S6 which have cost per unit compressive strength as 0.99 ₹/MPa and have maximum strength also with a per brick cost of ₹ 19.61 and compressive strength of 19.891 MPa. The required amount of compressive strength is 10 MPa for the bricks, so the brick S11 is considered best optimised according to cost and strength as its per brick cost is ₹ 17.09 with the compressive strength of 17.117 MPa and cost per unit compressive strength as 1 ₹/MPa.

5.2 Future Scope

5.2.1 Use of Brine Sludge in Subgrade

Further studies can be done on blending lime with brine sludge at different ratios.

5.2.2 Brine sludge as partial replacement of cement in concrete

In future work can be done on checking these mixes with other test like durability test, splitting tensile strength, modulus of elasticity, sorptivity. Further replacement of cement can also be tested.

5.2.3 Brine sludge as an alternative precursor, blended with fly ash in geopolymer bricks

In future work can be done on optimisation of cost per brick and reducing the cost per unit compressive strength to 0.5 ₹/MPa this could be achieved by further optimising S6 and S11 bricks. More work is needed to be done around the dilution of geopolymer which could reduce the cost per brick.

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