USE OF ALKALI ACTIVATED INCINERATION ASH AND COAL BASED FLYASH ALONG WITH PET BOTTLE STRIP REINFORCEMENT IN STABILIZING ROAD SUBGRADE SOIL

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M.Sc. Engineering Thesis

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DECLARATION

I hereby declare that the study reported in this thesis entitled as above is my original work and has not been submitted before anywhere for any degree or other purposes. Further, I certify that the intellectual content of this thesis is the product of my own work and that all the assistance received in preparing this thesis and source has been acknowledged and/or cited in the reference Section.

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ABSTRACT

Use of Alkali Activated Incineration Ash and Coal Based Flyash along with PET Bottle Strip Reinforcement in Stabilizing Road Subgrade Soil

The study presents a laboratory investigation on problematic soil stabilized by various combinations of alkali-activated medical waste based incineration ash (IA) and coal based flyash (FA). The PET bottle strips were added as a reinforcing agent to check further increments of strength and durability of the stabilized soil.

Soil samples were prepared by the modified Proctor method at the optimum moisture content (OMC) and Geo-polymer contents (GPC) of 0, 5, 10, 15, and 20 percent. Unconfined compressive strength (UCS), and split tensile strength tests were conducted to evaluate the development of strength of the stabilized subgrade soil at a curing period of 14 and 28 days and after 24 hours of soaking. Again, soil mixed with incineration ash and fly ash, as above was then mixed with randomly distributed PET strips with 1, 1.5, and 2 percent, and UCS, split tensile strength, California bearing ratio (CBR), flexural strength, scanning electron microscopy (SEM) and energy dispersive spectroscopy (EDS) tests have been performed to determine the characteristics of problematic soil at a curing period of 28 days.

It observed that, with the increase of geo-polymer content and aging, the strength of the soil increases four to five times and UCS was found to be linearly proportional. A maximum of 4032 kPa of UCS value was observed for 15% GPC with 1.5% PET, which is almost six times the untreated sample. The maximum retained strength for 28 days was found to be 82% for 15% GPC with a 1.5% PET strip; 15% GPC shows almost similar results approximately 64 to 82%. A maximum of 781 kPa was obtained for 20% GPC which is 2.76 times of 5% GPC in the split tensile strength test. CBR value shows significant improvement obtaining 145% with 15% GPC and 1.5% PET. Untreated soil depicted a higher axial strain of 7.5% and after treatment with Geo-polymer axial strain reduced i.e., increasing rigidity. During the soaked condition, the strain increases and gives a maximum value of 10% GPC and then gradually decreases. Microstructural analysis by SEM shows significant gel formation for 20% GPC over 5% GPC. EDS analysis also shows significant alkali activating bond with Geopolymer which is higher in 15% GPC over 5% GPC. The present study finds that geopolymer with addition of PET strips has the potential to improve the physical and engineering properties of subgrade soil significantly.

সারসংক্ষেপ

Use of Alkali Activated Incineration Ash and Coal Based Flyash along with PET Bottle Strip Reinforcement in Stabilizing Road Subgrade Soil

গবেষণাটি ক্ষার সক্রিয় (alkali activated) চিকিৎসা বর্জ্য ভিত্তিক দাহ্য ছাই (incineration ash) এবং কয়লা ভিত্তিক ছাই উড়ে (flyash) এর বিভিন্ন সংমিশ্রণ দ্বারা সমস্যাযুক্ত (problematic) মাটির উপর স্থিতিশীলতা (stabilization) এর একটি পরীক্ষাগার তদন্ত (laboratory investigation) উপস্থাপন করে। স্থিতিশীল (stabilized) মাটির শক্তি এবং স্থায়িত্ব আরও বৃদ্ধি পরীক্ষা করার জন্য PET বোতলের স্ট্রিপগুলিকে রিইনফোর্সিং এজেন্ট হিসাবে যুক্ত করা হয়েছিল।

মাটির নমুনা সংশোধিত প্রক্টর (modified proctor) পদ্ধতি অনুসরণ করে সর্বোত্তম আর্দ্রতায় (OMC) ০, ৫, ১০, ১৫, এবং ২০ শতাংশ জিওপলিমার বিষয়বস্তু (content) (GPC) মিশিয়ে প্রস্তুত করা হয়েছিল। ১৪ এবং ২৮ দিনের নিরাময় সময়কাল (curing period) এর এবং ২৪ ঘন্টা ভিজানোর পরে স্থিতিশীল (stabilized) সাবগ্রেডের মাটির শক্তির মূল্যায়ন করার জন্য সীমাহীন কম্প্রেশন শক্তি (Unconfined Compression Strength) (UCS) এবং স্প্লিট টেনসাইল স্ট্রেন্থ (Split Tensile Strength) পরীক্ষা করা হয়েছিল।এরপর আবার, উপরে উল্লেখিত ভাবে Incineration ash এবং Flyash মিশ্রিত মাটির মিশ্রণের সাথে PET স্ট্রিপ ১, ১.৫, এবং ২ অনুপাতে এলোমেলোভাবে মিশিয়ে Unconfined Compression Strength (UCS), Split Tensile Strength, California Bearing Ratio (CBR), Scanning Electron Microscopy (SEM) এবং Energy Dispersive Spectroscopy (EDS) পরীক্ষাগুলি ২৮ দিনের curing period এ problematic মাটির বৈশিষ্ট্য নির্ধারণের জন্য সঞ্চালিত করা হয়েছে।

এটি পরিলক্ষিত হয়েছে যে, জিওপলিমার content ও সময় বৃদ্ধির সাথে, মাটির শক্তি চার থেকে পাঁচ গুণ বৃদ্ধি পায় এবং UCS এর মান রৈখিকভাবে (linearly) আনুপাতিকভাবে পাওয়া গেছে। ১.৫ শতাংশ PET সহ ১৫ শতাংশ GPC এর জন্য UCS এর সর্বাধিক মান ৪০৩২ kPa পরিলক্ষিত হয়েছে, যা treatment না করা নমুনার প্রায় ছয় গুণ। ১.৫ শতাংশ PET স্ট্রিপ সহ ১৫ শতাংশ GPC এর জন্য ২৮ দিনের শক্তি ধরে রেখেছে (retained strength) ৮২ শতাংশ পাওয়া গেছে; ১৫ শতাংশ GPC অনুরূপ ফলাফল দেখায় যা ৬৪ থেকে ৮২ শতাংশ । ২০ শতাংশ GPC এর জন্য সর্বাধিক ৭৮১ kPa split tensile strength পাওয়া গিয়েছিল যা ৫ শতাংশ GPC এর চেয়ে ২.৭৬ গুণ। CBR এর মান উল্লেখযোগ্য ভাবে বৃদ্ধি পেয়ে ১৪৫ শতাংশ পর্যন্ত অর্জিত হয় ১৫ শতাংশ GPC সহ ১.৫ শতাংশ PET এর জন্য। untreated soil এ ৭.৫ শতাংশ অক্ষীয় স্ট্রেন (axial strain) পাওয়া যায় এবং জিওপলিমার treated মাটির axial strain হ্রাস পায় অর্থাৎ, অনমনীয়তা (rigidity) বৃদ্ধি পায়। ভেজানো অবস্থায় strain বৃদ্ধি পায় এবং সর্বোচ্চ মান পাওয়া যায় ১০ শতাংশ GPC র জন্য তারপর ধীরে ধীরে হ্রাস পায়। SEM টেস্ট দ্বারা মাইক্রোস্ট্রাকচারাল বিশ্লেষণে

৫% জিওপলিমারের উপরে ২০% জিওপলিমারের জন্য উল্লেখযোগ্য ভাবে জেল গঠন (formation) দেখায়। EDS বিশ্লেষণে জিওপলিমারের সাথে উল্লেখযোগ্য ভাবে alkali activated বন্ডও দেখায় যা ৫% জিওপলিমারের এর চেয়ে ১৫% জিওপলিমারে অনেক বেশি। বর্তমান গবেষণাটি (study) তে দেখা গেছে যে জিওপলিমার এর সাথে PET স্ট্রিপগুলি যুক্ত করার ফলে সাবগ্রেড মাটির ভৌত (physical) এবং প্রকৌশল (engineering) বৈশিষ্ট্যগুলিকে উল্লেখযোগ্যভাবে উন্নতি (improve) করার সম্ভাবনা রয়েছে।

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LIST OF ABBREVIATIONS

ASTM	American Society for Testing and Materials
CBR	California Bearing ratio
CSH	Calcium Silicate Hydrate
FE-SEM	Field Emission Scanning Electron Microscope
FA	Fly Ash
FSI	Free Swell Index
GGBS	Ground Granulated Blast Furnace Slag
IA	Incinerator Ash
LRF	Ladle Furnace Slag
PI	Plasticity Index
LL	Liquid Limit
PL	Plastic Limit
UCS	Unconfined Compressive Strength
GPC	Geopolymer Content
GP	Geopolymer
USCS	Unified Soil Classification System
OPC	Ordinary Portland Cement
OMC	Optimum Moisture Content
POFA	Palm Oil Fuel Ash
PET	Polyethylene Terephthalate
TA	Total Ash
TS	Total Salt
VA	Volcanic Ash
TXDOT	Texas Department of Transportation
BET	Brunauer-Emmett-Teller
BOF	Basic Oxygen Furnace
EAF	Electric Arc Furnace
BCS	Black Cotton Soil
SPI	Society of Plastic Industry
WPLA	Waste PET Bottles

CHAPTER 1
INTRODUCTION

1.1 General

Structures on problematic soils are always a concern for engineers. Soft inorganic, organic soil clay, collapsible soil, expansive clays, and dispersive soils are the most common types of problematic soil. Among them, expansive soil is one of the most unreliable soils for safe foundation design due to its swell-shrink behavior. This swelling-shrinking pressure is responsible for damage of foundations, roads, embankments etc. (Debanath, 2019). Problematic soil displays high compressibility, low strength, and volume instability, and the bearing limit is exceptionally low. Expansive soils indicate clayey soils that are not just inclined to swell or expand in volume yet, in addition, to shrink or diminish in volume when the overarching moisture condition is permitted to fluctuate (Ene and Okagbue, 2009). These clays are portrayed by having a little molecule size, an enormous explicit surface region and a high Cation Exchange Capacity (CEC) (Fityus and Buzzi, 2009). The reaction of expansive soils through swelling and shrinkage because of changes in water content is often expressed as hurling and settlement of lightly loaded geotechnical designs like pavements, rail routes, and streets, building foundations, embankments and channel or supply linings. This has even driven a few creators to allude to them as "cataclysmic soils" (Chen and Lin, 2009).

The PRISM Bangladesh, a medical waste service provider, operates incinerators in Dhaka South City Corporation Area. In most cases, the cremated fly and bottom ashes are deposited into landfills without consideration for their potential toxicity or the risk of heavy metals being released into the environment, which can be used as a binding material instead of cement. The leachability of heavy metals of the incineration ash is reduced below the allowable limits once stabilized with cement and converted into geo-polymers with alkali activators (Ahmed, *et al*., 2020; Tzanakos *et al.*, 2014).

Stabilization of problematic soil by cementitious materials gives better results (Goodarzi, Akbari and Salimi, 2016; Daraei *et al.*, 2019). However, the utilization of cement and lime is related with ecological worries, because of the intense usage of energy and characteristic assets just as the CO_2 outflow happening during the assembling of these customary fasteners. The cement industry is one of the most significant sources of greenhouse gases (GHG) specifically with carbon dioxide (CO_2) discharges. Cement factories account for almost 5%–7% of worldwide CO_2 emissions, with one ton of cement emitting 900 kg CO_2 (Benhelal *et al.*, 2013).

Fly ash is one of the important supplements of Portland cement as binding material. Fly ash from coal-based power plant, rich in alumina-silicate compounds. Geo-polymers has been used here as binder which are created by mixing materials having high alumina and silica substance, like FA and S, with a fluid alkaline activator (L), wealthy in solvent metals, as sodium (Xu and Van Deventer, 2002; Gao *et al.*, 2013; Pourakbar *et al.*, 2016). On the other hand, waste Polyethylene-terephthalate (PET) bottle ie. plastic is a serious concern for the environment. It has been found that a major percentage of the used plastic is mismanaged in Bangladesh, posing a great threat to the environment and human health (Shafiul Hossain *et al.*, 2021). These waste materials can be an effective alternative to improve the strength characteristics of soil.

Engineers usually prefer to improve the properties of problematic soil by stabilization. Several soil stabilization procedures were used to improve the extent to which soft soil carried loads (Wong, Wong and Phang, 2019). Researchers have been finding efficient and cost-effective remedial strategies to address the risk of structures failing on problematic soil. Several methods were established to date, and the appropriateness of those methods has been demonstrated through practical and in-situ applications. In order to enhance performance, problematic soils are stabilized with stabilizing agents. A geopolymer is a three-dimensional aluminosilicate mineral polymer made up of a mixture of amorphous and semicrystalline phases. These alkali-activated aluminosilicate binders were made by reacting raw materials high in silica and aluminium with an alkali or alkali salt solution, resulting in a combination of gels and crystalline compounds that finally solidify into a new strong matrix. In a high alkaline environment, the polycondensation process reorganizes aluminium and silica into a more stable Si–O–Al type structure, yielding materials with excellent mechanical strength and chemical stability (Cristelo, Glendinning and Pinto, 2011). This polycondensation process continued to generate 3-D net-like structures, resulting an amorphous stiff gel (Zhang *et al.*, 2013). Adding PET strips in this polycondensation process may act as binding materials and aggravate gel processing process.

1.2 Background of the Study

In 2021, during the construction of Padma Multipurpose Rail Link Project (PBRLP) it was observed that many of the places soil treatment is going on to improve the strength of soil characteristics. The length of the embankment of PBRLP is approximately 172 km starting from Kamlapur until Rupdia, Jashore. In many places, ground influent techniques are used namely Removal and Replacement, Cement Mix Pile (CMP), Prefabricated Vertical Drain (PVD) etc. to strengthen the embankment which incurred huge amount of cost and effort.

On the other hand, In Bangladesh, many failures related to natural/problematic soil are reported. Instead of replacing, existing sub-grade is settled using cementitious materials. (Daraei *et al.*, 2019; Goodarzi, Akbari and Salimi, 2016). This is very much alarming while constructing subgrade of Railway track in our country as it is very much conservative in case of settlement. With the global spread of SARS-CoV-2, excessive biomedical waste has emerged as a major concern for human health and the environment. In Dhaka, Bangladesh's capital, the average daily medical waste generation rate is 1.63–1.99 kg per bed (Rahman *et al.*, 2020). Under Bangladesh's Environmental Protection Act of 1995, there is no explicit regulation regarding medical waste disposal, management, or dumping. Incineration ashes are rich in calcium oxide, although they may have a deficiency in alumina-silicate compounds (Tzanakos *et al.*, 2014). When incinerator ash is combined with cement in concrete, promising results in terms of strength development have been observed (Ahmed *et al.*, 2020). it is estimated that 1.3 million cubic feet of fly ash is produced per annum for dumping from thermal power plants alone, and is estimated to reach an alarming crescendo of 9.5 million cubic feet by 2018. The environmental degradation due to dumping of fly ash aggravates the situation. Together, they pose an imminent threat in a densely populated country like Bangladesh, which needs to be addressed urgently. Incineration ashes are rich in calcium oxide although they may have a deficiency in aluminosilicate compounds (Tzanakos *et al*., 2014). Promising results in terms of strength development are found when incineration ash is used in concrete in combination with cement (Ahmed *et al.*, 2020). The leachability of heavy metals of the incineration ash is reduced below the allowable limits once stabilized with cement and converted into geopolymers with alkali activators (Tzanakos *et al*., 2014; Ahmed *et al.*, 2020). Fly ash from coal- based power plant, rich in aluminosilicate compounds, is one of the most important supplements of Portland cement. Moreover, reinforcing the stabilized soil by PET bottle strips may be an alternative to improve the characteristics of subgrade soil as well as reducing the waste materials (Bozyigit *et al*., 2021). Using plastic wastes for soil stabilization can improve the foundation layers of pavement (Khattab et al., 2011).

The unplanned dumping of waste PET bottles makes a large environmental threat. unwanted health hazard and a potential source of re-emerging infection. At the same time waste PET bottle strip is a great concern for the environmental hazards. For developing countries, the rapid growth of hospital waste and industrial waste, is a serious concern. Safe disposal of these has become a challenging issue. For this reason, this study is expected to provide information on strength behavior of alkali activated incineration ash and flyash stabilized subgrade with PET strips reinforcement.

1.3 Problem Statement

In Bangladesh, the average medical waste generation rate is 1·63–1·99 kg/bed/ per day. In April 2020, at least 14, 500 tons of waste from health care was generated across the country, on average, 206 tons per day in Dhaka city alone (Rahman *et al*., 2020). Approximately, 4.0 billion PET bottles and jars are produced each year in Bangladesh of which nearly 3.40 billion of PET bottles are released yearly to the natural environment after one-time use (Hossain *et al*., 2021). These waste materials can be an effective alternative to improve the strength characteristics of soil. Stabilization of problematic soil by cementitious materials gives better results (Ene *et al.,* 2009; Goodarzi *et al.,* 2016; and Daraei *et al.,* 2019). However, use of cement is a growing concern as this industry is a major source of greenhouse gas generation. Approximately 5–7% of global CO_2 emissions are caused by the cement plants (Benhelal *et al*., 2013). As such, utilizing PET bottle strip as a reinforcing agent with a combination of alkali activated incineration ash and coal based flyash could yield an effective solution for improvement of weak road subgrade soil.

1.4 Objectives of the Study

The aim was to evaluate the strength behavior of alkali activated incineration ash and fly ash stabilized subgrade with PET strips reinforcement. The specific objectives were as follows:

(i) To investigate the physical and engineering properties of soil on stabilizing with incineration ash, fly ash and alkali activators

(ii) To investigate the physical and engineering properties of stabilized soil reinforced by PET bottle strips.

1.5 Organization of the Thesis

The thesis report is organized in five (5) Chapters. Chapter 1 starts with the background study and highlights the problem statement after the introduction. Subsequently, research objectives, conceptual framework, and other topics are then covered. A literature review are briefly described in chapter 2. Details of material used, experimental procedures and methodology are presented in Chapter 3. The outcomes of laboratory tests are methodically described in Chapter 4. Besides, this chapter also includes a critical discussion and assessment of each test result. The conclusion and essential recommendations and scope for further research in this field are presented in Chapter 5.

CHAPTER 2
LITERATURE REVIEW

2.1 General

The primary focus of the current study is on the effects of using alkali activated incinerator ash, coal-based fly ash and polyethylene terephthalate (PET) bottle strip reinforcement to enhance the engineering qualities of problematic soil by stabilizing it and lowering its expansiveness. Generally, a treatment method for soil stabilization is one that increases and maintains a soil's stability or enhances the soil's engineering capabilities. This section briefly summarizes the literature and findings of earlier researchers on problematic soil and stabilizing methods.

2.2 Medical Wastes and its Scenario

Medical waste is categorized differently in different nations and institutions, depending on various waste types. Traditionally, garbage produced by healthcare and other related operations that might spread illness or be dangerous has been referred to as "medical waste." According to the Health Regulations Northern Ireland, 2003, "Any other waste arising from medical, nursing, dental, veterinary, pharmaceutical or similar practice, investigation, treatment, care, teaching, or research, or the collection of blood for transfusion, being waste which may cause infection to any person coming into contact with it. Medical waste refers to any waste produced during treatment or diagnostic procedures. Medical waste includes extremely dangerous metals, toxic substances, infectious viruses, and bacteria that can all lead to human disease (Hassan *et al*., 2008). Categories of medical waste described in Figure 2.1:

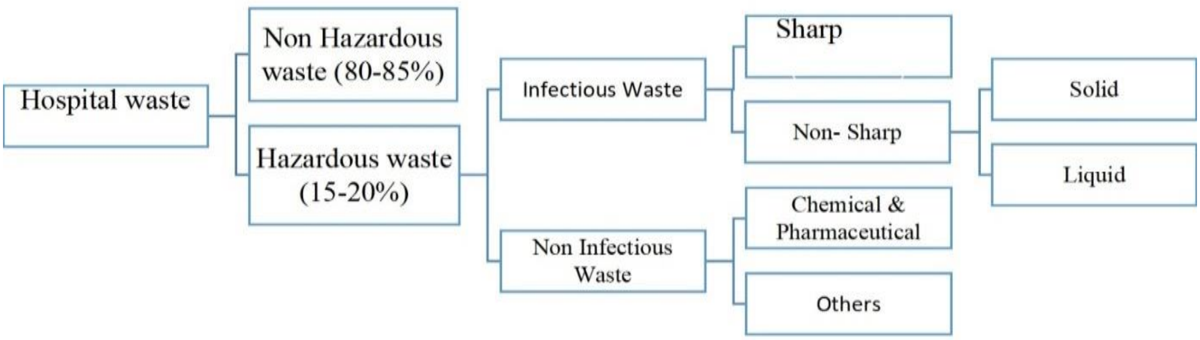


Figure 2.1: Categories of medical waste (WHO, 2001)

Bangladesh is a densely populated developing nation with several challenges related to health, education, and pollution. Rapid growth of population demands increase in hospitals, clinics, diagnostic facilities, and pathology services (Hassan *et al*., 2008). The Covid-19 pandemic heightened management of medical waste led to system failure. Furthermore, a sizable amount of medical waste has been produced as a result of the growing use of plastic items, such as personal protective equipment (PPE). Prior to the COVID-19 epidemic, Bangladesh was already struggling with medical waste management, and the unexpected increase in medical waste volume has made matters worse. For the past three decades, medical waste has been a significant problem, involving both potential health hazards and environmental harm. As a result, it has started to take center stage in many countries' national health policies. In Bangladesh, proper medical waste management is a relatively recent phenomenon. To address this issue, the government is developing a fresh, cutting-edge approach. With financing from the Canadian International Development Agency, the PRISM Bangladesh (Project in Agriculture, Rural Industry, Science, and Medicine), a well-known national NGO in Bangladesh, has constructed a facility for low-cost medical waste treatment and management in Dhaka City.

2.3 Incinerator Ash

In 80% of instances, the makeup of hospital wastes is comparable to that of household solid waste. The remaining 20% consists of radioactive wastes and medications, hazardous wastes such chemotherapy cytotoxic agents, chemical wastes, pathogenic wastes, contaminated sharps, anatomical wastes, and pathological wastes (Idris & Saed, 2002). The disposal of these pollutants, which have a great potential to cause long-lasting health harm, is one of the biggest environmental concerns facing local governments. However, the optimum way for getting rid of hospital waste has often been determined to be incineration. Garbage incineration is the principal technique of dealing with hospital waste in many underdeveloped countries, such as Bangladesh. While this has the advantage of eliminating pathogens in the waste stream as well as reducing garbage volume and reactivity, it has also been revealed that incineration has environmental effect owing to the release of pollutants in ash emissions, which has ecological and public health concerns. Incineration ash contains heavy metals (SiO_2, CaO, Al_2O_3, Sn, Ni, Cu, Ba, and B) and can leach into the soil and groundwater. An important issue with hospital waste incineration is the development of persistent organic pollutants (POPs), which include cancer-causing organics including polychlorinated biphenyls (PCBs), dioxins, and polycyclic aromatic hydrocarbons (PAHs).

2.3.1 Incinerator Ash Production in Bangladesh

PRISM (Project in Agriculture, Rural Industry, Science and Medicine) Bangladesh, a well-known national NGO in Bangladesh, is presently concentrating on clinical waste management in cooperation with the Dhaka South City Corporation (DSCC) and Dhaka North City Corporation (DNCC). For the low-cost treatment and disposal of clinical waste, PRISM Bangladesh has constructed a disposal facility in Dhaka City. PRISM Bangladesh is in charge of handling various forms of clinical was. They collect clinical waste in covered vehicle with segregated bins and qualified workers. They carry them to the Matuail sanitary dump and dispose there. For collection and transportation this institution employs six 3-ton trucks and two 1.5-2-ton special vehicles shown in Figure 2.2 and 2.3 (PRISM Bangladesh, 2017).

Figure 2.2: Clinical waste treatment plant, matuail

(a) (b)

Figure 2.3: Medical Waste Collection System (a) Different types of bins (b) Covered truck

2.4 Various Process to Dispose of Infectious Waste

To dispose of clinical waste a set of procedures are used which are described in following subsections.

2.4.1 Autoclaving

Infectious wastes are autoclaved at 135°-144°F for 45 minutes, as recommended by the World Health Organization, with the assistance of the Canadian International Development Agency shown in Figure 2.4. The cleaned wastes buried immediately in burial pits with 2-3 inches of soil cover above each layer.

Figure 2.4: Autoclaving system

2.4.2 Incineration

Infectious trash (gauge, cotton, test sample, bandage, culture medium, etc.) and expired pharmaceutical materials are incinerated in a two-chamber pyloric incinerator with a moisture content of less than 33%. These incinerators heat up to 1250 degrees Fahrenheit while burning fossil fuels, the residue finally dumped in a concrete pit, shown in Figure 2.5.

Figure 2.5: Incineration system

2.4.3 Chemical Disinfection

In a three-chambered tank, waste (plastics, glassware, metals, etc.) is disinfected using chlorinated water. The first chamber is filled with chlorinated water containing 150-250 ppm, and items are immersed in the solution for 30-45 minutes. It is then moved to the second chamber, which is charged with 20-50 ppm and kept for another 15-20 minutes. After that, the objects are moved from the second to the third chamber for a freshwater rinse, shown in Figure 2.6.

(a) (b)

(c) (d)

Figure 2.6 Recycling and shredding system (a) Recycling system (b) Recycling system (c) Shredding system (d) Shredding system

2.4.4 Deep Burial

Body parts and sharp waste are kept in a well-built concrete tank that is completely closed on all sides with a small door/inlet. Bleaching powder is added as a disinfectant on the wastes for further safety. Other wastes are also handled by this technique. When the tank or pit is filled up then it is permanently sealed, shown in Figure 2.7.

.

(a) (b)

Figure 2.7: Deep burial method (a) Collection (b) Deep burial

2.5 Coal-based Fly Ash

Fly ash is a natural byproduct of coal-based industries that results from the combustion of coal (both bituminous and lignite) (Tamim *et al*., 2013). Fly ash is a fine-grained material composed of glassy, spherical particles. The chemical composition of fly ash varies depending on where it originates from and what it is used for. It is mostly composed of oxides of various elements, such as SiO_2, Al_2O_3, Fe_2O_3, SO_3, and CaO, to mention a few. It is almost insoluble in water. Heavy metals have also been found linked to fly ash in a low percentage (less than 1%). Therefore, fly ash is frequently suspected of being a source of metal leaching due to the presence of these heavy metals (Tamim *et al*., 2013).

2.5.1 Fly Ash Production in Bangladesh

In subsequent paragraph a complete picture of fly ash is being described.

2.5.1.1 Quantitative Analysis

Only one of the six potential coal deposits in Bangladesh the Barapukuria coal field in operation since 2004 with a 390-million-ton of resource. The Barapukuria Coal-fired 250 MW thermal power plant, receives 65 percent of the yearly output of 1 million tonnes, according to the Barapukuria Coal Mining Company Limited. Available data indicates that 10% of the mass of coal burnt ash. Fly ash is around 80% of this ash, while bottom ash is the remaining 20%.

2.5.1.2 Qualitative Analysis

Fly ash comes in two varieties, Class C and Class F. The biggest difference between these two groups is in the calcium content. Compared to Class F fly ash, Class C fly ash contains less than 20% lime (Tamim *et al*., 2013). Table 2.1 shows the classification of coal fly ashes.

Table 2.1: Classification of coal fly ashes (ASTM C 618- 17)

Properties	Fly ash class	
	Class F	Class C
$SiO_2 + Al_2O_3 + Fe_2O_3$ (% min)	70	50
SO_3 (% max)	5	5
Moisture content (% max)	3	3
LOI[a] (% max)	6[b]	6

2.5.2 Uses of Fly Ash

The construction industry has predominantly used CFA as a material substitute. The most widespread use of CFA at the moment is as a raw material or additive in the cement industry. Since clinker, the primary component of ordinary Portland cement, lacks pozzolanic characteristics, most CFAs are routinely used as a partial substitute (OPC). When applied to soil, CFA can enhance soil texture, boost water-holding ability, and reduce swelling capacity. These characteristics may be helpful for projects like building on stable soils that are challenging to build on, such as roads, parking lots, and buildings.

2.5.3 Fly Ash Disposal

To avoid interfering with the primary plant operation, the fly ash generated by the thermal power plant must be disposed of outside the plant. The dry disposal scheme and the wet disposal scheme are used to dispose of the generated fly ash. Dry disposal is removing the generated fly ash from the site using a variety of equipment (truck, conveyor belt, etc.) and placing it in a dry embankment. Fly ash and water are combined for wet disposal, and the resulting slurry is then transported through pipes to an ash pond. In Bangladesh, the dry disposal strategy is in place (Tamim *et al*., 2013).

2.5.4 Recycling of Fly Ash

Instead of being used again, the bulk of FA generated is dumped in landfills. However, environmental concerns have made this method less desirable. Recycling coal fly ash has the potential to be a great alternative both economic and environmental advantages.

2.6 Plastics

Plastics are resins or polymers produced from petroleum or natural gas derivatives. A vast variety of resins are referred to as "plastics," each of which has specific properties and applications. Additionally, additives can modify each resin's properties. It has been able to create a wide variety of products that adhere to a wide range of standards by combining a variety of resins and additives. Massive, inert monomers, or repeating chemical units, are the building blocks of polymers, which are long sequences of molecules. Polymers are pure materials produced through polymerization mixed with additives to generate plastics, yet they cannot be used alone. The term "plastics" refers to a wide range of resins, each of which has distinct characteristics and uses. Additionally, additions can change the qualities of each resin. A diversity of resin and additive combinations have made it possible to produce a wide range of goods that adhere to a wide range of standards. Long chains of molecules called polymers are composed of massive, chemically inert monomers, which are repeating chemical units. Although they cannot be utilized alone, polymers are pure materials created through polymerization combined with additives to create plastics. Plastic manufacture and use growth results from the various benefits polymers provide over more conventional materials. (EPA, 1990) Among the desirable inherent qualities of plastics are:

(i) Plastics can be adapted for a wide range of end purposes allowing for design freedom.
(ii) high corrosion resistance.
(iii) low weight.
(iv) Shatter resistance.

2.6.1 Categories of Plastic

The Plastic Industry Trade Association and the Society of Plastic Industry (SPI, 2000) identifies plastic into seven (7) broad categories and Table 2.2 summarizes their applications.

Table 2.2: Categories of plastic

1.	Polyethylene Terephthalate	• Produce bottles for cleaning supplies, lubricants, oil, vinegar, medicine, peanut butter, and beverages. • Create lidding films for heat sealing and pouch films for sauces, dried soups, and cooked meals. Moreover, combs, ropes, and blisters. • PET plastic waste can be recycled into bidim, geomesh, garments, carpets, fleece coats, luggage, and tote bags.
2.	High-Density Polyethylene	• Produce containers for dairy goods, juice, sauces, lubricants, detergents, bleaches, shampoos, and conditioners. • Create lids and closures for jars, pots, bottles, and cartons. • Create trash and carrying bags. • HDPE waste can be recycled into floor tiles, flower pots, benches, pens, dog homes, picnic tables, plastic lumber, buckets, and recycling containers.
3.	Polyvinyl Chloride	• Create bottles for shampoo, detergent, lubricants, oil, and vinegar. Moreover, tiling and plumbing fixtures • Create lids and closures for jars, pots, cartons, and bottles. • Create trays for meat, poultry, salads, desserts, and candy. • PVC plastic trash can be recycled into traffic cones, floor tiles, electrical boxes, gutters, mats, garden hoses, binders, cassette trays, and mobile homes.
4.	Low-Density Polyethylene	• Create lids and closures for jars, pots, bottles, and cartons. • Make bottles that can be squeezed. • Create sandwich bags, trash bags, and carrier bags. • Create food-safe plastic cling stretch wrap film

5.	Polypropylene	• Make sauce, juice, and syrup bottles. Also, pouch films are used to package cooked meals, dry soups, and sauces. • Create films for sachets, packs, and wrappings. • Create trays for soups, dairy goods, and veggies. • Create yogurt boxes, tubs, plastic diapers, Tupperware, margarine containers, and cups. • Waste polypropylene (PP) can be recycled into items like ice scrapers, containers, oil funnels, battery cables, brooms, brushes, trays, and car battery boxes.
6.	Polystyrene	• Make disposable coffee cups, food boxes, pots, tubs, plastic cutlery, dairy and confectionery trays, packaging foam, and packaging peanuts. • PS trash can be turned into thermometers, thermometer plates, light switch covers, vents, egg cartons, desk trays, license plate frames, and rulers.
7.	Others like: Polyester, Polyamides, Polycarbonate	• Baby bottles, water tanks, compact discs, and medical storage containers are all polycarbonate plastic. • Plastic lumber can be made from scrap polycarbonate plastic.

2.6.2 Plastic Waste Consumption

Today, plastic use has entirely merged into our daily lives. The annual consumption of plastics has been rising significantly. The consumption of plastics is quickly increasing due to several variables, including their low density, ease of manufacturing, longevity, lightweight, and low cost of production (Siddique, Khatib and Kaur, 2008). Packaging, automotive and industrial applications, medical delivery systems, artificial implants, other applications in healthcare, land/soil conservation, water desalination, flood prevention, food preservation and distribution, housing, communication materials, security systems, and other uses are just a few of the many areas in which plastic has been extensively used. The volume of plastic garbage increases as more plastic is used extensively in daily activities.

Plastic consumption has been increasing year after year. According to wasteonline.org.uk the annual usage of plastic materials has surged from roughly 5 million tons in the 1950s to almost 100 million tons in 2001, Table 2.3 shows an statistics of USA.

Table 2.3: Types and quantities of plastics in municipal solid waste in the USA (Subramanian, 2000)

Type of plastic	Quantity (1000 tons)
Polyethylene terephthalate (PET)	1700
High density polyethylene (HDPE)	4120
Low density polyethylene (LDPE)	5010
Polypropylene (PP)	2580
Polystyrene (PS)	1990
Other	3130

2.6.3 Polyethylene Terephthalate (PET)

PET is a significant polymer widely used in producing fibers, films, and molding materials. PET satisfies 40% of the global demand for synthetic fibers (Ravindranath and Mashelkar, 1986). Due to their light weight and ease of handling and storage, PET bottles have replaced glass bottles as beverage storage containers. Widespread use of Polyethylene Terephthalate (PET) in beverage containers and other goods as the drinking of beverages, The quantity of PET bottle garbage in is rising quickly exponentially (Marzouk *et al.*, Dheilly and Queneudec, 2007). The quantity of garbage is merely one issue. Because PET is not biodegradable, inappropriate disposal of post-consumer PET causes environmental concerns. Additionally, the fumes created by burning PET raise issues with air pollution and public health. Recycling PET for industrial applications is thus one of the logical ways to deal with PET waste (Atis, 2010). The process of recycling PET bottles into building materials has been the subject of research on a global scale (Won *et al.*, 2010).

The recycling of used PET bottles in construction projects was one of the topics that interested the researchers. The researchers utilized these wastes in various ways, such as fibers or as a partial replacement for fine or coarse aggregates in concrete mixtures. Few studies have attempted to employ PET plastic bottles' non-degradable and high tensile strength qualities to substitute steel bars in structural elements.

2.6.4 Applications of Plastic in Civil Engineering Field

The primary material are used in many applications. In civil engineering, plastic is used as a component in the development of bridges, buildings, roads, highways, ports, railroads, landscaping, landfills, water retention structures, etc. Today, plastic is used in the fabrication of rail instead of iron steel and in the preparation of modified bitumen to create flexible pavements.

Quality polymer concrete can be made using unsaturated polyester resin based on recycled PET (Siddique, Khatib and Kaur, 2008). Comparing polymer concrete to traditional Portland cement concrete, the former is significantly more resistant to compression and flexion. It can achieve more than 80% of its maximum mechanical strength in a single day. But it does exhibit temperature sensitivity (Sam and Tam, 2002).

Hinislioglu and Agar (2004) researched the potential use of High-density polyethylene (HDPE) wastes from the plastics industry are used as polymer additions in asphalt concrete. The findings showed that waste HDPE-modified bituminous binders, because of their high stability and high Marshal Quotient, offer higher resistance against permanent deformations.

To manufacture fiber-reinforced concrete and strengthen its toughness of concrete, another use suggests using scrap PET bottles as PET fibers (Ochi, Okubo and Fukui, 2007).

The disposal of wastes and the environmental harm caused by the usage of natural mineral aggregate resources will both be improved by the use of PET waste in concrete (Tam, Tam and Wang, 2007).

Utilizing PET bottle waste to create fibers for fiber-reinforced materials Concrete can also prevent cement-based composites from cracking due to plastic shrinkage (Ochi, Okubo and Fukui, 2007). Plastic One of the main reasons for decreased performance in composite materials made of cement (Bentur, Mindess and Vondran, 1989). Expansive surfaces such as paving and parking lot floors or bridge slabs, constraint, which could lead to plastic shrinkage or cracking, the cement-based composite is fully cured (Naaman et al., 1999).

Choi *et al* (2009) mentioned that lightweight aggregate made from PET bottle waste (WPLA) coated with river sand powder was produced using a method carried out at 250^0 C. These aggregates displayed an approximate 0% water absorption, which can mitigate the drawbacks of typical lightweight aggregates with high water absorption. The WPLA flow mortar grew in line with the amount of WPLA in the mixture. When 25% WPLA was added to the mortar mix, the sorptivity coefficients were lower than those of the control mortar. Furthermore, as the mixed proportion of WPLA increased, the compressive strength of mortar decreased.

In the literature, few reports of attempts to reuse WPET plastics as partial or complete replacements for sand or aggregates in conventional concrete.

2.7 Soil Stabilization

To enhance the soil's properties, several components are blended and mixed during the soil stabilization process. Soil stabilization is the process of improving the shear strength characteristics of soil. The soil's ability to support more weight is improved as a consequence. It is essential. Soil stabilization is a technique for preventing soil erosion when the soil that is available for building is inappropriate for sustaining the load on the structure. Shear strength is enhanced by the earth's soil mass structures' compressibility and permeability. Soil stabilization involves adding stabilizing agents (binder materials) to poor soils to improve their geotechnical properties such compressibility, strength, permeability, and durability.

Soil or gravelly material is used as the main body of pavement layers in road building projects. The dirt used to build pavement should meet strict criteria for tensile strength and strain spectrum. Unbound materials can be stabilized utilizing cementitious materials through soil stabilization (cement, fly ash, lime, bitumen, or a combination). The elements in stabilized soil are stronger, have less permeability, and are less compressible than natural soil (Little et al., 1987). The approach is accomplished in two ways: 1) in situ stabilization and 2) ex - situ stabilization.

2.7.1 Types of Stabilization

There are many techniques used to stabilize the soil. Few of those are enumerated below.

2.7.1.1 Mechanical

Mechanical stabilization is the most frequent and typically least expensive way. Compaction is a sort of mechanical stabilization that enhances the shear strength of soil or aggregate by bringing particles close together under load and/or vibration at optimum soil moisture concentrations. The amount of particle interlocking achieved, however, limits the benefits of mechanical stability. In general, increasing the angle of internal friction without reducing cohesiveness increases soil strength (Little *et al.*, 1987).

2.7.1.2 Blending

The second kind of mechanical stabilization is combining aggregates, binders, or mixtures with local materials to increase engineering strength and durability. A fine-grained binder, for example, will fill gaps and boost shear strength. However, using too much binder reduces permeability. This can damage or soften the pavement layer involved owing to a buildup of pore pressures when wet, resulting in fines loss through pumping. As a result, strength is lost and the pavement deteriorates (Little *et al.*, 1987).

2.7.1.3 Additive

This is the modification of soil qualities by the use of chemical additives that can affect the surface molecular properties of soil grains and, in certain circumstances, cement them together. Stabilization with lime, cement, lime-fly ash, asphalt, or any combination of these stabilizers is referred to as additive stabilization. In the case of cement, lime, and lime-fly ash, a chemical interaction between the binder and the soil in the presence of water may occur, resulting in improved shear strength via a cementing action. The percentages of additives used are determined by the soil classification and the degree of improvement required. In general, less additive is needed to change the soil's gradation, plasticity, workability, etc. than it is to increase strength and durability to the point where pavement thickness reduction is possible (Little *et al.*, 1987)

2.7.2 Soil Stabilization Techniques

Soft soils are the most difficult soils to work with because of their meager and weak engineering characteristics, which include their expansive nature, excessive cracking, low compressive and shear strengths, low modulus, large settlement under loading, high volumetric shrinkage, and poor durability against wetting/drying and freezing/thawing cycles (Brand *et al*., 2020). There are several strategies and field application methods for enhancing poor or difficult soil, but soil stabilization is the most popular and straightforward one. The process of stabilizing soil is used to increase or maintain a soil's stability or to enhance its engineering properties. The most widely used soil stabilizing methods include traditional stabilizers, industrial by-products, polymer stabilizers, and other uncommon substances. The efficacy of a stabilizing substance is influenced by a number of variables, including soil characteristics, reaction mechanism and pace, and suitable content.

2.7.2.1 Stabilization Using Lime

When limestone is broken down at high temperatures, lime is created. As a consequence, three products that can be utilized to remediate soils are produced: hydrated lime (calcium hydroxide, $Ca(OH)_2$, quicklime (calcium oxide, CaO), and hydrated lime slurry. To create quicklime, calcium carbonate (limestone, $CaCO_3$) is chemically changed into calcium oxide. In addition, hydrated lime is created when quicklime chemically combines with water. Finally, when clay particles and hydrated lime are mixed, cementitious solid connections are created. According to research, lime increases the soil's optimal water content, shrinkage limit, and strength while decreasing the soil's swelling potential, liquid limit, plasticity index, and maximum dry density. Additionally, it improves the compatibility and workability of subgrade soils (Little et al., 1987).

When quicklime is applied, it hydrates (interacts chemically with water) and nearly immediately releases heat. Soils are dry because the water in the soil takes part in this reaction and the heat that is produced might evaporate more moisture. Hydrated lime is the result of these early interactions; clay particles will then react with it. When hydrated lime is used in place of quicklime, the soil only dries as a result of chemical changes that reduce the soil's ability to retain water and increase stability. Clay particles initially mix and displace water and other ions before calcium ions (Ca_2+) from hydrated lime travel to their surface. The outcome is a more granular and flaky soil that is simpler to handle and compress. At this moment, both the soil's plasticity index and its capacity to expand and contract significantly decrease. It is called "flocculation and agglomeration." Usually, it takes many hours (Firoozi *et al.,* 2017).

When calcium from the lime reacts with silica and alumina that have been released, calcium-silicate-hydrates (CSH) and calcium-aluminate-hydrates (CAH) are created. Similar to how Portland cement is manufactured, CSA and CAH are cementitious chemicals. By creating a matrix, they increase the stability of lime-stabilized soil layers. Consequently, as this matrix develops, the soil changes from a granular, sandy material to a hard, somewhat impermeable layer with significant load-bearing capacity. These reactions maybe summarized in equations 1.1 and 1.2.

Ca^{2+} +OH^- + soluble clay Silica → Calcium Silicate Hydrate (CSH) (1.1)

Ca^{2+} +OH^- + soluble clay Alumina → Calcium Alumina Hydrate (CAH) (1.2)

Bell (1996) used different lime contents to stabilize kaolinite, montmorillonite and quartz reached clay deposits. The plasticity index of montmorillonite clay was found to reduce due to increment of lime content, and kaolinite showed a reverse response. Montmorillonite clays respond much more rapidly to lime stabilization compared kaolinitic clays. As shown in Figure 2.8 rapid gaining of unconfined compressive strength was observed up to 7 days curing period and slow down there after during lime stabilization process.

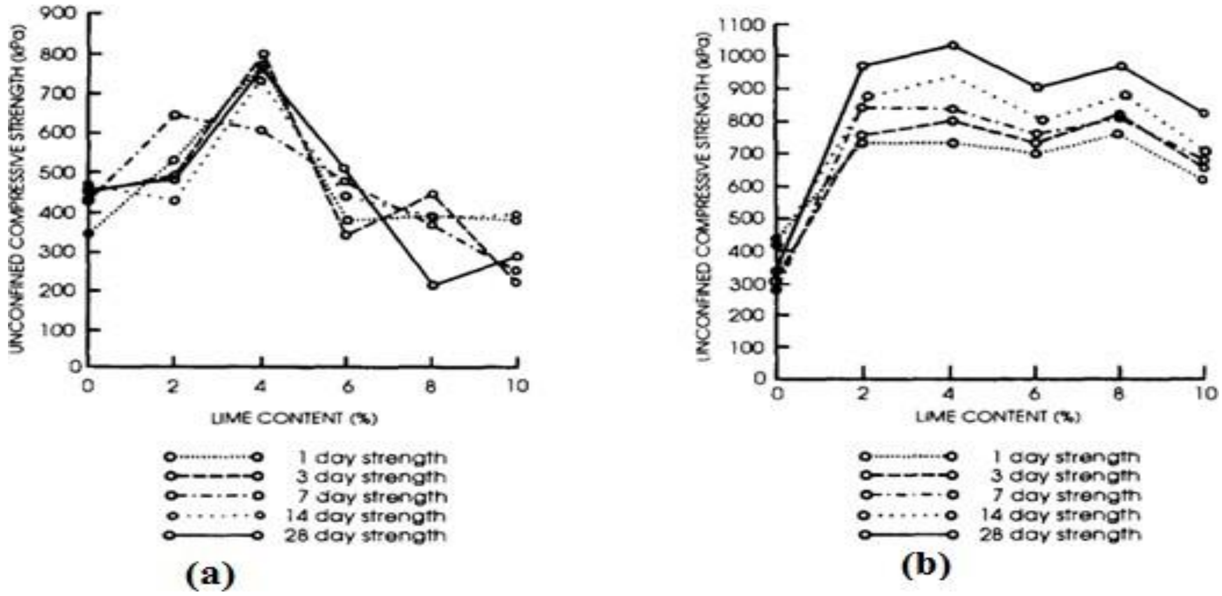


Figure 2.8: Unconfined compressive strength of (a) montmorillonite, (b) kaolinite with various addition of lime (Bell 1996)

2.7.2.2 Stabilization Using Cement

The process of blending cement with soil to create a substance known as soil-cement is one of the most popular ways to chemically stabilize materials. As an enhanced measure, soil-cement has been used as a base material in a number of projects, such as foundation stabilization, slope protection of highway pavement, dams and embankments, building pads, rail and truck terminals, the low-cost base for streets, composting facilities, and parking lots. Construction using soil-cement has been practiced for about a century. It is applied to improve the soil's engineering and mechanical properties. Strength, volume stability, permeability, and durability are the four basic aspects of soil that can be improved by additions. Sand and very flexible clays have somewhat higher maximum dry densities after cement treatment, although silt has lower maximum dry densities (Firoozi et al., 2017). The plasticity index is decreased by cement because it lowers the liquid limit while raising the plastic limit. Other important effects of soil-cement stabilization include decreased potential for shrinkage and swelling, enhanced strength, elastic modulus, resistance to moisture, and resistance to freezing. Cement-treated soils are more fragile than untreated soils. Cement in granular soils has shown to be efficient and effective since smaller amounts are needed. Before mixing in the cement, lime can be added to the soil to improve workability, shown in Figure 2.9 (Ronoh *et al.*, 2014). (Firoozi *et al*., 2014).

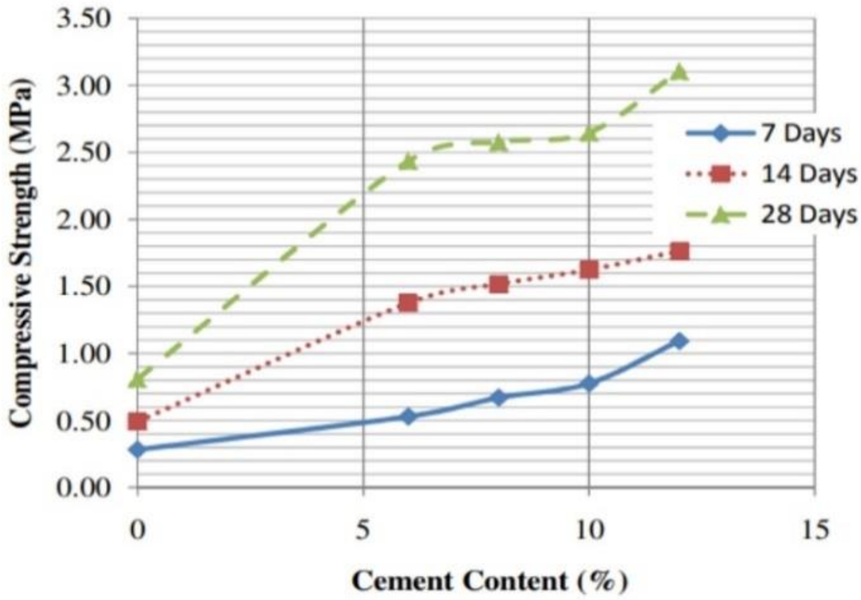


Figure 2.9: Effects of cement content on the compressive strength of interlocking blocks (Ronoh *et al.*, 2014)

2.7.2.3 Stabilization Using Fly Ash

Fly ash and bottom ash, byproducts of coal combustion, can be used to stabilize soil without the need of activators. They are a byproduct of burning non-combustible trash or sub-bituminous coal, both of which have been produced in large quantities in electric plants. Fly ash is the kind of ash that escapes from the chimney or stack, as opposed to clinkers generated from bottom ash, which are located on the furnace wall and gradually sink to the bottom. Fly ash may be separated into two groups based on whether it contains calcium. Class C fly ash, which is produced when sub-bituminous coal is burned, has a calcium content of more than 20%, whereas class F fly ash, which is produced when bituminous coal is burned, has a calcium content of less than 10%. (Cristelo et al., 2013). The researchers found that the fly ash increased the unconfined compressive strength and California bearing ratio (CBR) while decreasing the liquid limit and plasticity index, shown in Figure 2.11. When combined with lime, fly ash may effectively stabilize the majority of course- and medium-grained soils. The USCS classifies soils as SW, SP, SW-SC, SP-SC, SW-SM, GW, GP-GC, GP, GW-GC, GW-GM, GP-GM, GC-GM, and SC-SM. Fly ash can be utilized to stabilize these soils (Firoozi *et al.*, 2017). Variation of CBR (%) of expansive soil treated with fly ash shown in Figure 2.10 (Bose, 2012).

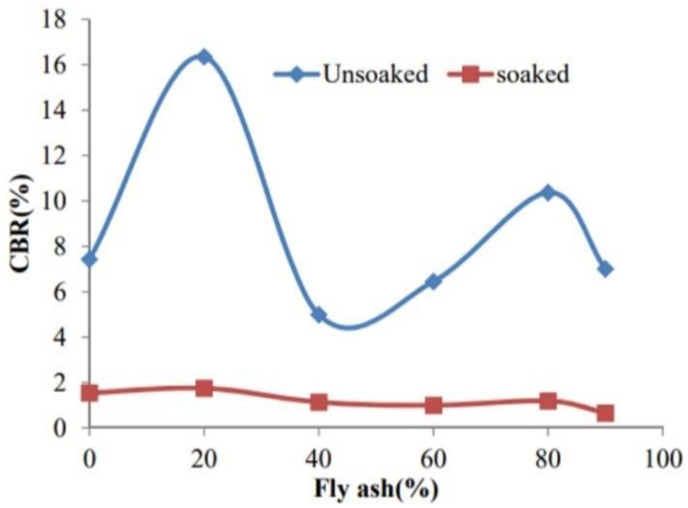


Figure 2.10: Variation of CBR (%) of expansive soil treated with fly ash (Bose, 2012)

2.7.2.4 Stabilization Using Fibers

Hair-sized polypropylene fibers have been employed in many soil stabilization projects due to their low cost compared to other soil stabilization agents. These compounds do not sink into the soil and are resistant to biological and chemical decay Hay fibers were studied by (Sharma *et al.*, 2015) in order to enhance the properties of swelling clay. They observed that the Atterberg limits were not significantly or logically affected by adding hay fiber. Hay was added, and the maximum dry density (MDD) decreased. The optimum moisture content (OMC) decreased as the amount of hay in the mixture increased by up to 1%. The shrinkage limit decreased, then climbed, as hay content increased to 1%. As the hay content to soil ratio rose, the unconfined compression strength decreased. Hay was added, and this greatly improved the direct shear strength. The swelling was reduced and the tensile strength of the air-dried mixture increased with the addition of hay.

2.7.2.5 Stabilization Using PET Strips

The presence of disposable PET bottles increased the burden on the soil. Therefore, it is advised that adding soil to PET bottles to increase their capacity. Plastic is solely used to make waste products, which might be costly to operate in clay and foundation soils. The Proctor Compaction parameters altered as the proportion of plastic grains increased. From 22% to 14%, the maximum moisture level has dropped. Dry metal concentration rises from 1.50 KN/m^3 to 1.57 KN/m^3. As the proportion of plastic granules increased from 6.69% to 9.25%, CBR that was not considerably included raised. The improvement in the water CBR from 1.19% to 1.42% was caused by an increase in the percentage of plastic particles. Using the test findings as a guide, it can be said that soft clay, such as BC (Black Cotton Soil), can be successfully stabilized by adding plastic grades to evaluate its enhanced strength (Iravanian and Haider, 2020).

In this experiment, adding the plastic strips results in an enhanced CBR estimation. Plastic is one of the materials that can be employed as a stabilizing and balancing out operator. Still, the right amount of plastic needs to be present, which aids in extending the CBR requirement for adequate stability. It is generally accepted that the CBR rate keeps rising to 4% plastic content in the dirt before beginning to decline as plastic content increases. So, the optimal concentration of plastic garbage in the soil is 4%. Plastic is increasingly being used in a wide variety of buildings. It is illogical to expect to limit its employment since this negatively influences the environment. In this way, getting rid of plastic waste without creating any natural hazards has turned into a real test of the state of society today. As a result, using plastic to stabilize soil is a prudent and advantageous application, as there is a need for more suitable soil for various developments (Mallikarjuna *et al.*, 2016).

Using these waste materials (PET) for soil stabilization is an alternative method to improve the mechanical properties of soil. This method can meet the requirements of soil improvement and reduce the quantity of waste PET bottle. Using strips obtained from waste pet bottles as reinforcement agents with a combination of a binder on weak soils could be an effective improvement method. (Bozyigit *et al*., Oct. 2021). An effective method to utilise these materials is to be used as a soil stabiliser for road construction. Using plastic wastes for soil stabilisation can improve the foundation layers of pavement (Khattab *et al*., 2011).

Several researches have conducted to investigate the effectiveness of plastic waste materials in the form of discrete fibres on properties of soils. These researchers found that using plastic waste materials for soil stabilization will improve the properties of weak soils such as an increase in UCS, CBR, and Mr and a decrease in the soil plasticity.

2.8 Stabilizing Using Geopolymer

Soil stabilization by using geopolymer is described below in a nutshell.

2.8.1 Chemistry of Geopolymer

Geopolymer is an inorganic polymer formed by alkaline activation of alumina-silica reached materials like fly ash, granulated blast furnace slag, metakaolin or silica flume etc. During polymerization of binder materials tetrahedral silica and alumina linked together by oxygen bond (Si-O-Al-O) and creates monomer. This monomer go- through a polycondensation process to produce 3D polymer ring and chain type structure as shown in Eq. (2.1) (Davidovits, 1999).

$M_n\ [-(SiO_2)-AlO_2]_n.wH_2O$ (2.1)

Where, M is the Cation/alkaline element (K^+/Na^+/Ca^{2+}) and "-" represents a bond; n is 1, 2, 3, ……, 32. Indicates degree of polymerization/polycondensation.

Figure 2.11 represent a simplified technique of geopolymerization. The reaction starts by transforming aluminosilicate materials to synthetic aluminate and silicate. This step occurs in presence of water. In presence of concentrated activators and high pH, gel formation starts immediately by releasing water that consumed during dissolution. This gel undergoes further steps: reorganization, polycondensation to form large network and finally transformed into hardened format as proposed by Duxson et al. (2007).

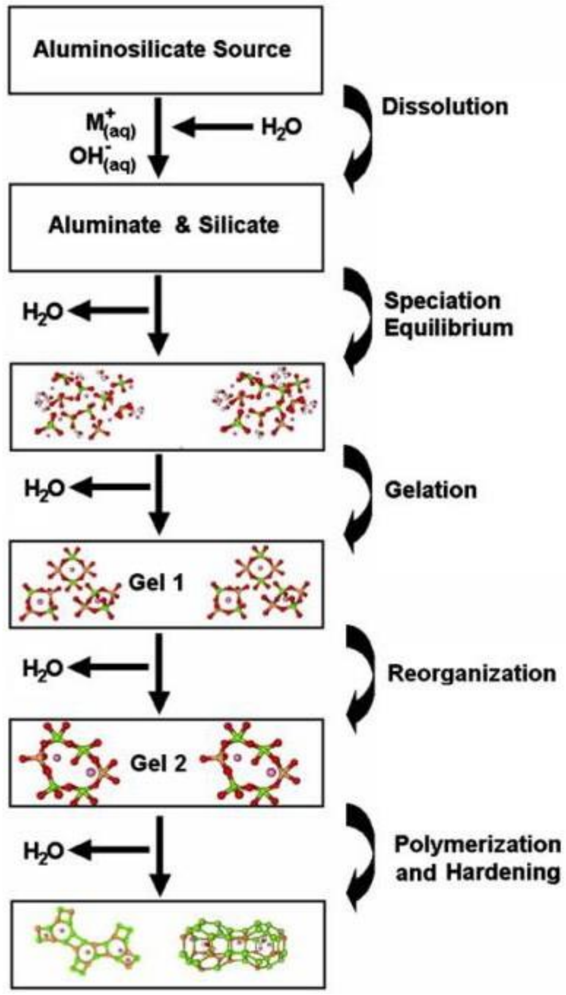


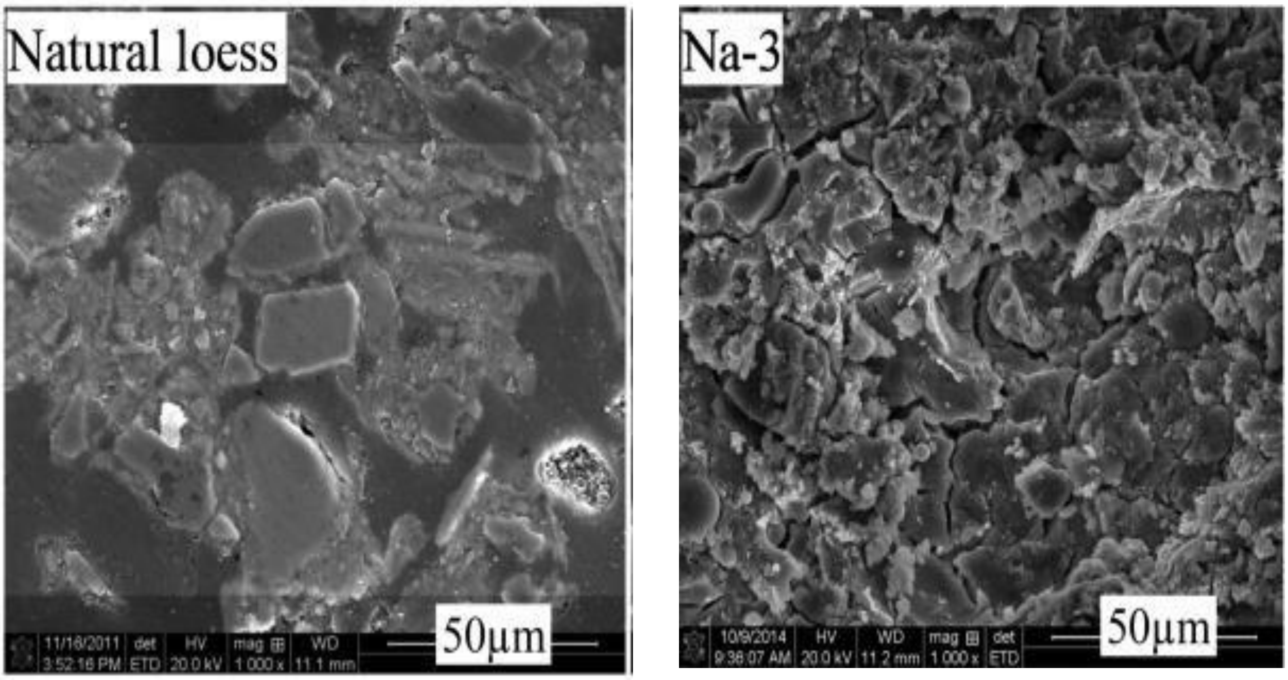
Figure 2.11: Simplified model of polymerization (Duxson et al. 2007)

Geopolymer is an inorganic substance made from a mixture of components high in alumina (Al_2O_3) and silica (SiO_2) (Arulrajah *et al.*,2018). Before the dissolved species is transferred, Al and Si must first be dissolved in the alkaline solution. A network of aluminosilicate formations forms in three dimensions. The geopolymer matrix has ion exchange properties comparable to zeolites because it contains rings of various sizes made of cross-linked tetrahedral silica and alumina units. In the end, the gel becomes amorphous, semiamorphous, or microcrystalline. The primary binding element of Portland cement is widely acknowledged to be calcium silicate hydrate (CSH).

2.8.2 Geopolymer Stabilization

Sargent et al. (2012) found that alkali activated fly ash and GGBS attains around two times higher UCS compared to traditional Portland cement binder after 28 days curing age. In cement treatment process C-H-S gel is formed in reaction whereas ettringite were observed in alkali activated treated soil matrix.

Application of fly ash based geopolymer for stabilizing wind transported loess soil was carried out and the strength development, mineralogical changes in natural loess soil were determined by UCS and SEM analysis respectively. Increment of geopolymer percentage provides strong bonding between soil particles which is reflected in UCS test results and also agrees well with the SEM image analysis conducted by Liu et al. (2016). It was observed that the higher degree of binder used, the more compacted microstructure was rendered in the soil, Figure 2.12.



(a) (b)

Figure 2.12: Microstructure of (a) untreated and (b) geopolymer treated soil matrix (Liu et al. 2016)

A schematic representation of the reaction processes involved in geopolymerization is shown in Figure 2.13 (Van Deventer et al., 2007). Geopolymers have also been improved and now have a wide range of uses, including construction material alternatives to OPC, nuclear waste immobilization, water purification (heavy metal immobilization), and a low-energy processing path to ultra-refractory ceramics powder (Bagci et al., 2016). In general, the majority of geopolymer research and certain environmental assessments of geopolymer support the claim with substantial reductions in CO_2 emissions. However, life cycle analysis encompasses much more than just quantifying greenhouse gas emissions (Salas et al., 2018).

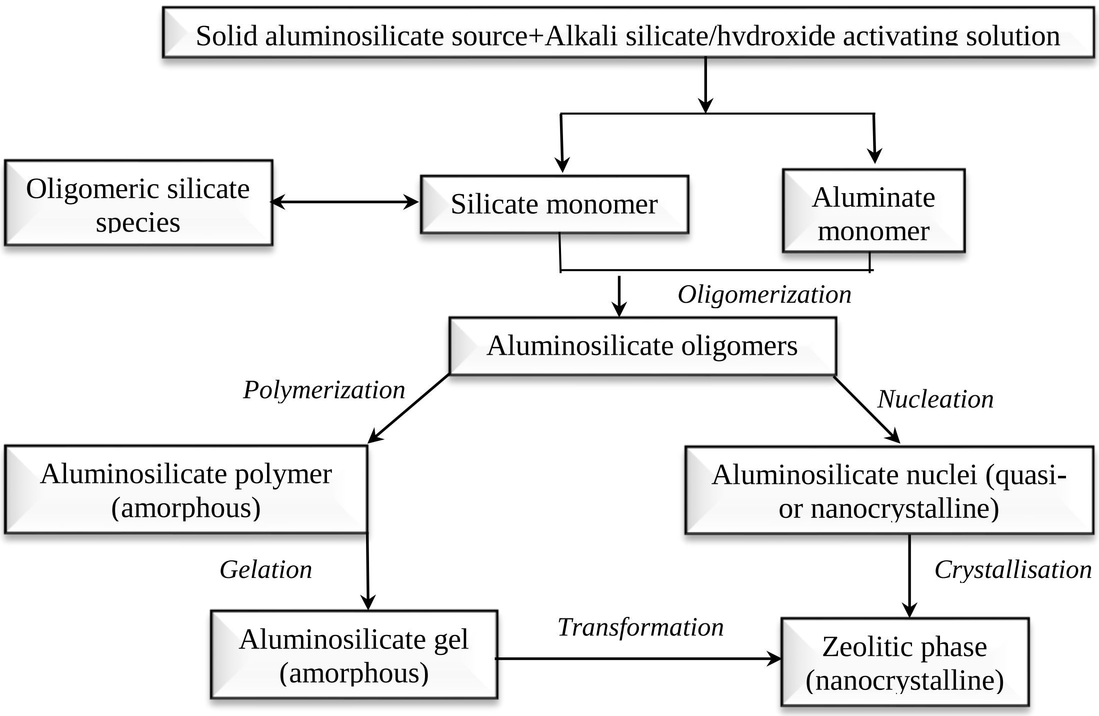


Figure 2.13: Illustration framework of the reaction procedures involved in geopolymerization (van Deventer *et al.*, 2007)

After reactive alumino-silicate minerals are combined with an alkali hydroxide and silicate solution, they dissolve in extremely alkaline solutions, creating common Si and Al species that, after the water is removed during the geopolymerization process, go on to form chains of Al-O-Si and Si-O-Si links.. The polycondensation process produces three-dimensional net-like structures that eventually transform into the rigid amorphous gel known as geopolymer (Zhang et al., 2013).

Experiments using fly ash-based geopolymers to stabilize soft soils have been conducted, albeit it has been discovered that achieving the target strength for fly ash takes a longer curing time than Portland cement (Cristelo *et al.*, 2011).

2.9 Granulated Blast Furnace Slag (GGBS) Stabilization

Slag from steelmaking and blast furnaces has been utilized as engineering fill, subbase, and base in paving projects. The construction of numerous highways, a major road system, and the third runway at Sydney Airport are a few instances of its utilization. Both blast furnace and steelmaking slags have been successfully used in spray sealing and asphalt applications, though steelmaking slag is more frequently used because of its superior strength, abrasion resistance, and impact resistance, making it ideal for use in areas with heavy vehicle loads and high shear stress. Granulated blast furnace slag, also referred to as GGBS or granulated blast furnace slag, is produced when iron or steel is produced. (GBFS). This substance has effective pozzolanic properties to start the first reaction, and it is occasionally used with cement, lime, or a chemical stabilizer to obtain a quick result. As demonstrated in Figure 2.14, the geopolymer created from ground granulated blast furnace slag (GGBS) is a superb binder that cures at room temperature to offer great strength (Singhi, Laskar and Ahmed, 2016).

In a series of studies, Singhi, Laskar, and Ahmed (2016) examined the applicability of GBFS by adding 4, 8, 12, 16, and 20% to a clay soil with poor plasticity. When the index property, strength, and swelling test results of the original soil were compared to those of the treated soil, it was found that the UCS of stabilized soil continuously increases as the slag content increases, with the increase in UCS not being statistically significant below 8% slag content.

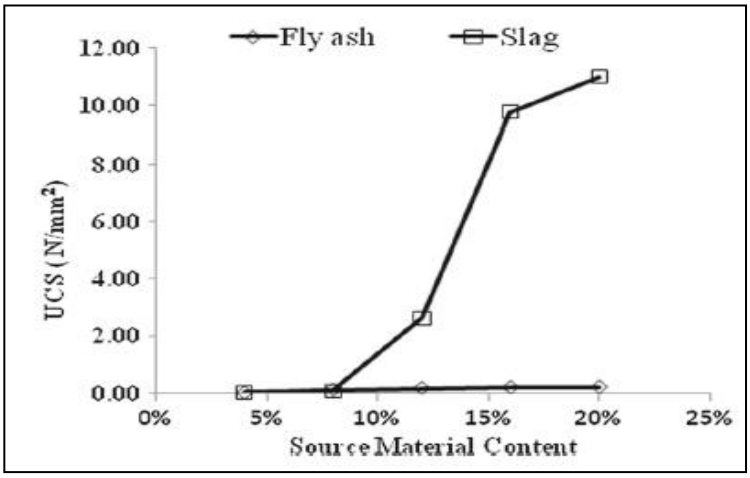


Figure 2.14: UCS of the soil–geopolymer system for different percentages of source material (Singhi, Laskar, and Ahmed, 2016)

2.10 Ladle Furnace (LRF) Slag Stabilization

A useful kind of steel slag for applications is Ladle Furnace (LRF) slag, also referred to as basic slag, reducing slag, white slag, and secondary refining slag. The LRF slag is created as a byproduct following the refinement of molten steel in a basic oxygen furnace (BOF) or an electric arc furnace (EAF). Microscopic analysis revealed that the LRF slag is an uneven material with granules that have sharp edges. LRF slag is a significant by-product of the steel industry; the current production process yields two types of basic slag, one with low and one with high alumina contents.

Diniz *et al* (2017) explored the use of processed Ladle Furnace Slag (LRF) as a chemical binder, either by itself or in combination with conventional binders, in soil stabilization for roads (lime or cement). To achieve this, soil/binder mixtures were developed, and their technical performances were compared. The LRF binder was added directly to soil mixes without the use of two related wastes in order to increase LRF consumption. However, for maximal LRF usage within the performance restrictions, a combination of 20% by weight LRF and 5% by weight cement is proposed, as illustrated in Figure 2.15. The optimal binder concentration was 15% by weight LRF fines combined with 5% by weight cement.

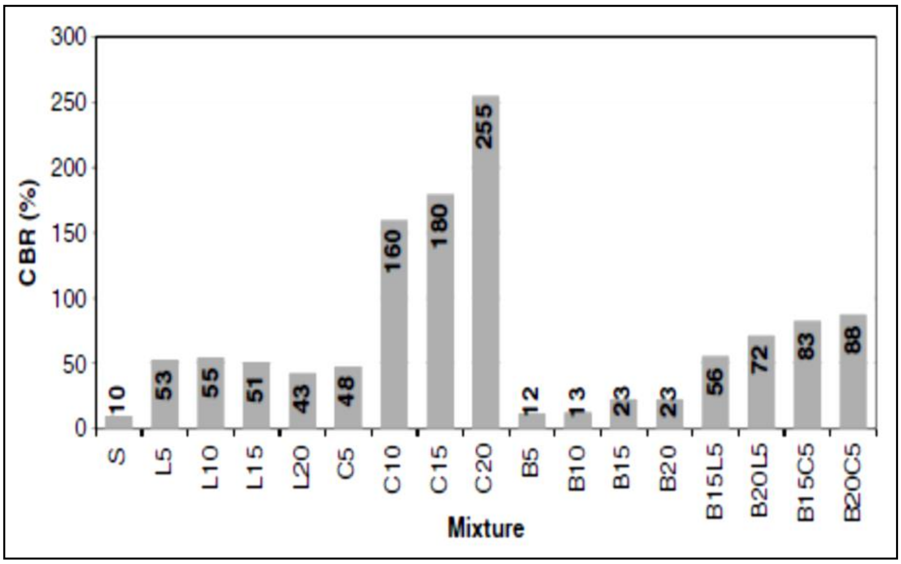


Figure 2.15: CBR at the optimum moisture content for the various mixes (Diniz *et al.*, 2017)

The process of developing strength might be speed up by adding LRF to GGBS-stabilized clay, as seen in Figure 2.16.

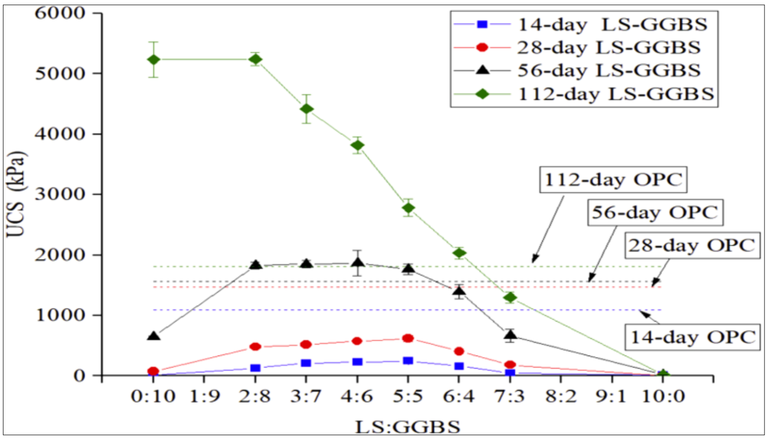


Figure 2.16: Diagram shows the unconfined compressive strength (UCS) of stabilized soil with 20% binder content (Xu and Yi, 2019)

2.11 Alkali-activated Solution

An important by-product of the steel industry, LRF slag is produced using a manufacturing process that results in two different forms of basic slag: one with a low alumina concentration and the other with a high alumina percentage.

Wang, Wang, and Tsai (2016) employed an alkali-activated approach to activate LRF slags. With varying liquid/solid ratios of 0.35, 0.40, and 0.45 as well as various alkali agents of 4%, 6%, and 8%, LRF slags geopolymer was created. The LRF slags geopolymer was cured under various conditions. According to the findings, increasing the liquid/solid ratios and the alkali agent enhances the LRF geopolymer's workability, as illustrated in Figure 2.17.

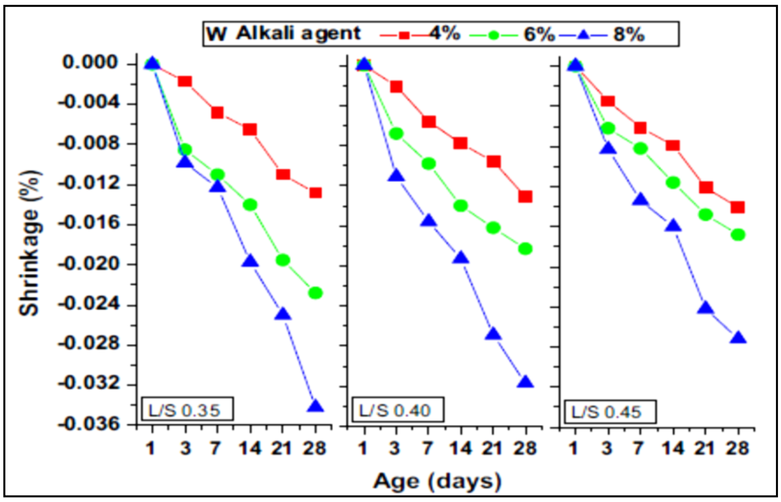


Figure 2.17: LFS geopolymer shrinking after being cured in saturated limewater (Wang, Wang and Tsai, 2016)

Additionally, compressive strength and ultrasonic velocity rose while weight loss decreased as the alkali agent was increased and the liquid-solid ratio dropped. LRF slags can therefore be activated by the efficient application of alkali-activated technology, enhancing their technical properties. Stabilizers significantly enhance the mechanical characteristics of clayey soil, including the UCS and CBR values.

2.12 Stabilization of Expansive Soil

Expansive soil refers to any type of soil whose volume changes are affected by moisture. Expansive soils are thought to be problematic soils because they have an impact on the structural stability of anything put on them. Therefore, in order to be effective, a geotechnical engineer must correctly name and describe these soils. Expansive soil is one of the most difficult soils in geotechnical engineering because of its swell-shrinkage feature. The main components of expansive clay are Na+-based minerals like montmorillonite, which expand in water. If the water table does not change inside the expansive clay deposited, differential swelling-shrinking cannot happen (Langroudi and Yasrobi, 2009). The most worrying element, however, is the impact of seasonal variations in water content. The time-dependent swelling is greater for dry soil as compared to wet soil (Mishra et al., 2008).

2.13 Fly Ash and GBFS Treatment of Expansive Clay

Class C fly ash can effectively improve the plasticity characteristics and prevent the swelling affinity of highly plastic expansive clays (Nalbantoğlu, 2004). During pozzolanic reaction fly ash treatment, new secondary minerals were formed which was cross verified by reducing trend of cation exchange capacity (CEC) of treated soil. A hybrid binder was explored having FA and GGBS ratio of 70:30 to stabilize an artificially synthesized expansive soil (Sharma and Sivapullaiah 2016). Around 40% of this binder is effective for improvement of engineering properties. It was observed that small quantity of lime (1%) induced large aggregation in soil structure as shown in Figure 2.18. Atterberg limits and swelling pressure of sodium riches expansive clay reduced significantly by GBFS treatment. Cokca, Yazici, and Ozaydin (2009) reported that, approximately 80.5% swelling was reduced as a result of 15% GBFS-Cement treatment.

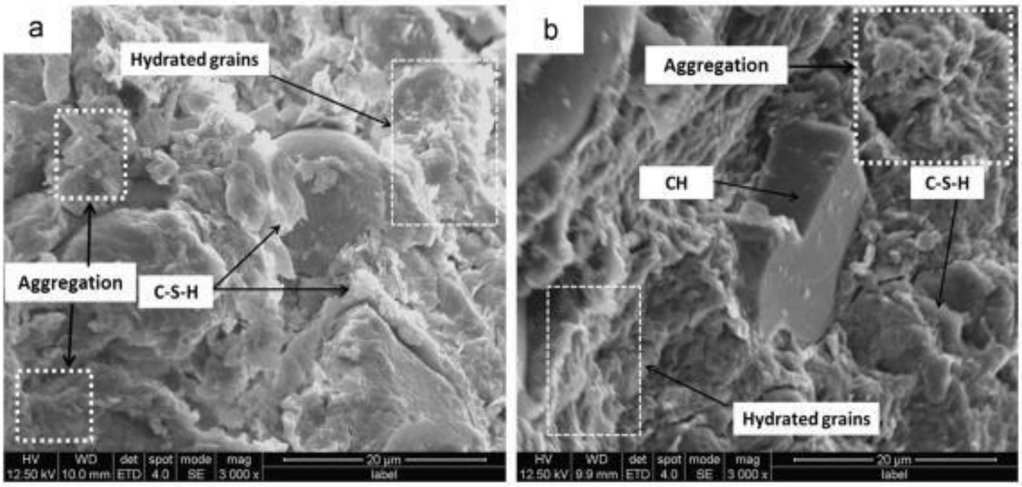


Figure 2.18: SEM image of soil stabilized with 20% binder having (a) No lime (b) 1% lime (Sharma and Sivapullaiah, 2016)

2.14 Economic Benefit of PET Soil Stabilization

Recent research has demonstrated that using Polypropylene (PP) and High Density Polyethylene LDPE plastics to stabilize soil is more affordable than traditional techniques like stabilizing with cement and lime additives. According to research and practical use, plastic substitutes for cement and other chemical components significantly reduce costs. The amounts of cement and lime in the mix can range from 25 to 35 percent of the total volume to stabilize one cubic meter of soil. Cement or lime must therefore make up at least 14 of the volume of the combination to stabilize one cubic meter of soil; this equates to seven bags of cement and 24 bags of lime (Sherwood, 1993). The plastic mixed with bitumen and aggregates is used for the better performance of the roads. The polymer coated on aggregates reduces the voids and moisture absorption. This results in the reduction of ruts and there is no pothole formation. The plastic pavement can withstand heavy traffic and are durable than flexible pavement. The use of plastic mix will reduce the bitumen content by 10% and increases the strength and performance of the road. This new technology is eco-friendly (R. Manju. A, Sathya, S. and Sheema, K, 2017).

2.15 Concluding Remarks

The review of the literature exposed that past studies on PET stabilization of problematic soil are very few. At the same time, in Bangladesh, use of incineration ash and coal based fly ash along with PET strips are not very familiar in soil stabilization. As such, a comprehensive study is required on this aspect, and this research is expected to present a rational outcome of the treatment of problematic soil in the context of subgrade improvement.

CHAPTER 3
MATERIALS AND METHODOLOGY

3.1 General

This chapter described the detailed steps of sample preparation, experimental procedures and methodology to evaluate the strength behavior of alkali activated incineration ash and coal based fly ash stabilized soil with PET strips reinforcement.

3.2 Testing Scheme

Natural soil, industrial waste coal-based fly ash (FA) medical waste incinerator ash (IA), waste PET bottle strips along with alkali activator (NaOH and Na_2SiO_3) were used in this research. Prior to use, the physical properties of the materials were determined. Several laboratory tests have been conducted to determine the soil characteristics of stabilized soil (by FA, IA, and alkali activator) for various combinations to perform the research work. Subsequently, waste PET bottle strips were added to check the strength behavior under different combinations. Mainly strength and durability properties have been evaluated here. Therefore, an unconfined Compressive strength test (OMC condition) and Flexural strength test were carried out. Split tensile test have been performed for the strength of stabilized soil. Whereas for assessing durability, water absorption and unconfined compressive strength test (Wet condition) are carried out. CBR, SEM and EDS tests were carried out to find out the strength characteristics and bonding/ gel formation of the stabilized soil. Subsequent sections describe the procedures in detail.

3.3 Collection of Materials

Materials used in this study were collected from various places and the process involved to prepare the sample are described in subsequent paragraphs.

3.3.1 Collection of Fly Ash

Two types of fly ash are used in this study. Incineration fly ash (IA) was collected from the incinerator of the medical waste treatment facility of Dhaka City Corporation (South) at Matuail Sanitary Landfill. Medical waste from different hospitals in Dhaka city is received in this facility. After the processing of separation, chemical disinfection, shredding, and autoclaving, they are taken into the incinerators, where they are burnt at the temperature of 1100 degrees Celsius.

Coal-based fly ash (FA) was collected from Boropukuria Power Plant, Dinajpur. It is produced in power plants as a by-product of coal burning.

3.3.1.1 Preparation of Fly Ash

In this study, the methodology proposed by Tang *et al.*, was followed to process the sample (Tang *et al.*, 2016). Both Fly ash samples were dried in the oven for 24 hours with the temperature of 105. Then the samples were passed through the series of standard test sieves (#4, #8, #16, #30, #50, #100, #200) using a mechanical sieve shaker. The portion of the sample passing the #200 sieve and received on the pan was used for the study.

3.3.1.2 Properties of Raw Materials

From the chemical composition as shown in Table 3.1, it is being observed that about 62% of incinerator ash contains CaO and 55% of coal based fly ash contains SiO_2. (Ahmed, Chowdhury and Rahman, 2020; Islam *et al.*, 2019). Portland cement mainly gets its strength from CaO and SiO_2. (Arunachalam and Jayakumar, 2015) CaO in OPC consists of 64.64%. SiO_2 consists of 21.28% and Al_2O_3 of 5.6%. To make the perfect balance out of it the ratio of incinerator ash and fly ash has been kept 3:1 by following the research of Tzanakos *et al.*, which matches with the proportion of major components in OPC cement (Tzanakos *et al.*, 2014).

Table 3.1: Chemical composition of fly ashes used in the study

Coal Based Fly Ash		Incinerator Fly Ash	
Name of Oxides	**Composition by Mass (%)**	**Chemical Components (Wt. %)**	**Medical Waste Incinerator Fly Ash (MWIFA)**
SiO_2	54.59	CaO	62.39
Al_2O_3	28.39	SiO_2	8.92
Fe_2O_3	5.27	SO_3	5.92
TiO_2	5.08	Na_2O	5.35
K_2O	1.60	Al_2O_3	3.73
CaO	1.55	TiO_2	3.73
P_2O_5	1.44	MgO	2.65
SO_3	0.83	ZnO	2.13
MgO	0.43	Fe_2O_3	1.75
Na_2O	0.18	P_2O_5	1.38
BaO	0.13	K_2O	1.19
SrO	0.13	NiO	0.50
ZrO_2	0.11	Cr_2O_3	0.21
MnO	0.07	MnO	0.07
Cr_2O_3	0.06	CuO	0.04
ZnO	0.02	Br	0.03
Y_2O_3	0.01	ZrO_2	-

Particle Size Analysis (Sieve Analysis) was done following (ASTM D7928-21e1, 2021). Here, maximum particles retain in the #16 sieve, and only 0.3g ashes from 500g pass through the #200 sieve. Grain size distribution is shown in Figure 3.1.

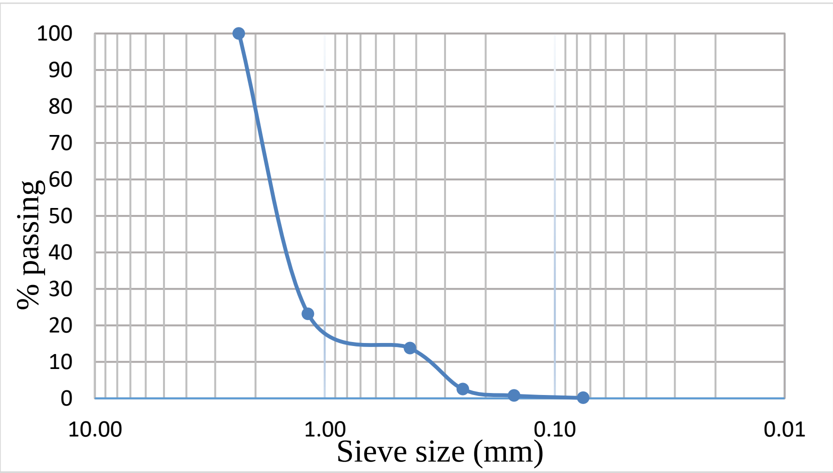
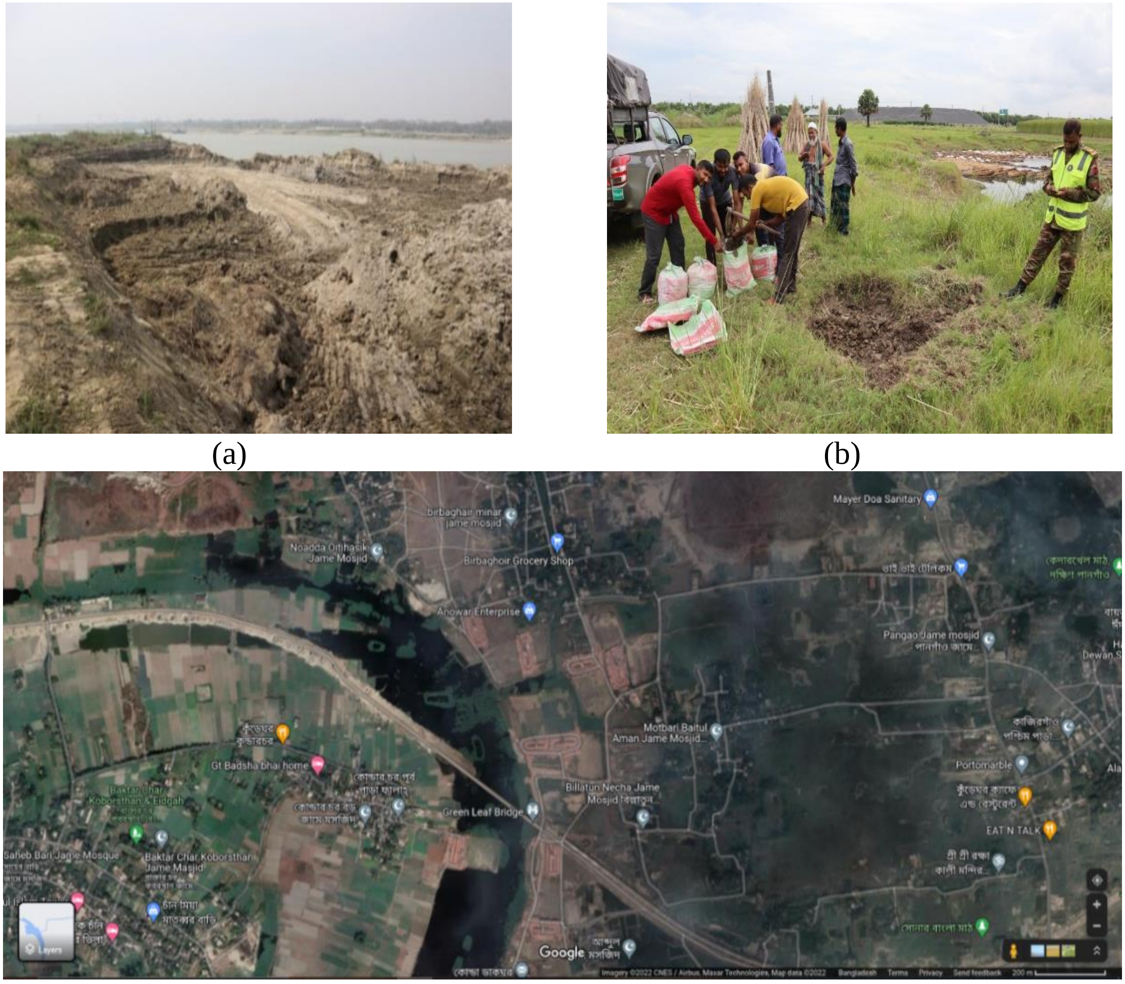


Figure 3.1: Grain size distribution of incinerator ash

3.3.2 Collection of Soil

Soils were collected from Dighol Kandi Brick Field, Zazira, Bangladesh. Soils were collected from an approximate depth of 3-5 feet by excavation. The location and collection process shown in Figure 3.2.



(a) (b)

(c)

Figure 3.2: Sample soil collection point (a) Collection area (b) Collection (c) Google map of collection area

3.3.2.1 Preparation

The methodology proposed by Tang *et al.*, was followed for preparing the sample (Tang *et al.*, 2016). Soil samples were dried in oven for 24 hours. Then the samples were passed through the #40 sieve with the use of mechanical sieve shaker. The portion of the sample passing #40 sieve and received on pan was used for the study. Rubber hammer was used to break the oven dried soil. The preparation procedure is shown below in Figure 3.3.

Figure 3.3: Preparation of sample soil (a) Actual soil from field (b) Manual grinding (c) Preparation for sieving and (d) Soil sample after sieving with #200

3.3.2.2 Properties of Collected Soil Sample

Some specific standard laboratory tests were carried out on the collected soil sample. Particle size analysis was performed according to (ASTM D 6913, 2021 and ASTM D7928, 2021). At the time of wash sieve, we've found that 95 percent of soil has passed through the #200 sieve. Hydrometer analysis has also been done, as shown in Figure 3.4. Figure 3.5 shows the grain size distribution of the collected soil.

Figure 3.4: Hydrometer test of collected soil

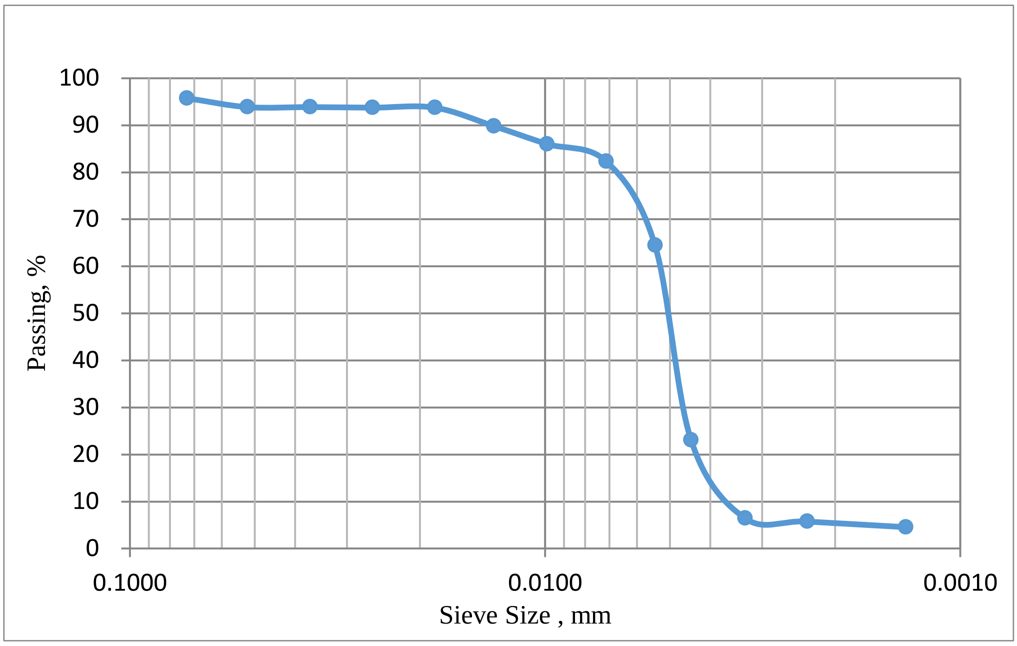


Figure 3.5: Grain size distribution of collected soil

Atterberg Limits test of the collected soil were conducted according to ASTM D 4318. Figure 3.6 shows the sample preparation for Atterberg limits test.

Figure 3.6: Sample preparation for Atterberg limits test

In the test it is found that, Liquid limit (LL=69) of the soil is extremely high. Plastic Limit (PL) was found 25. And thus, PI was found 44. So, it's an moderate expansive soil as LL stays in between the range (50-70) and PI in between (25-45) (AUSTROADS, 2004).

Modified Proctor Test according to (ASTM D1557, 2021) is performed. From the experiment, it was found the Optimum Moisture Content (OMC) of the soil as 17% and the maximum dry density is 1.717 g/cm^3, Figure 3.7. This moisture content was used as a standard for sample preparation in our experiment for various combinations of Fly ash.

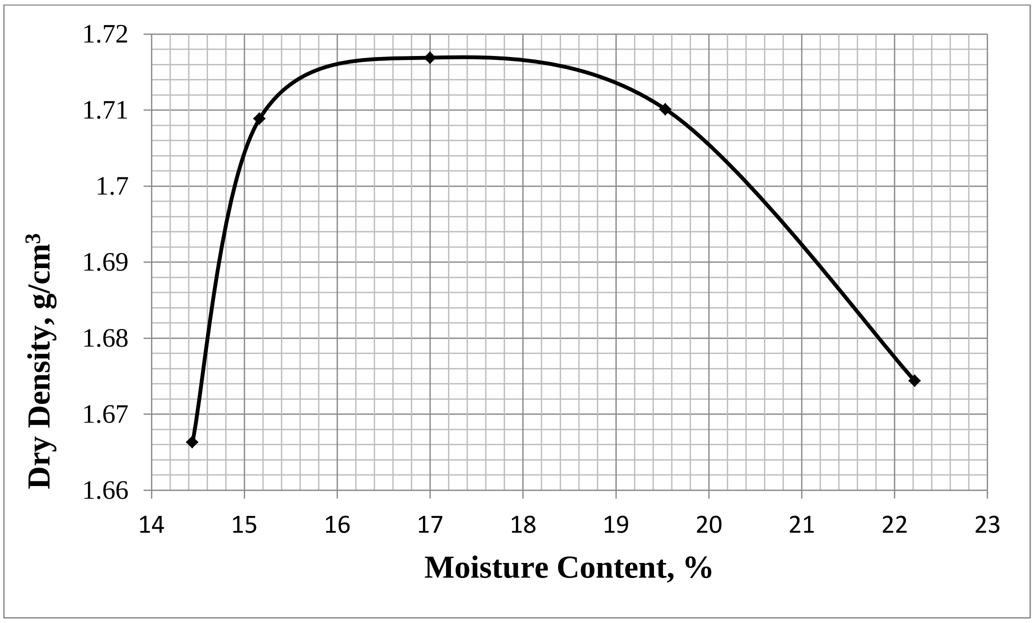


Figure 3.7: Optimum moisture content determination

Figure 3.8 shows the schematic diagram of sample preparation which is described in next page.

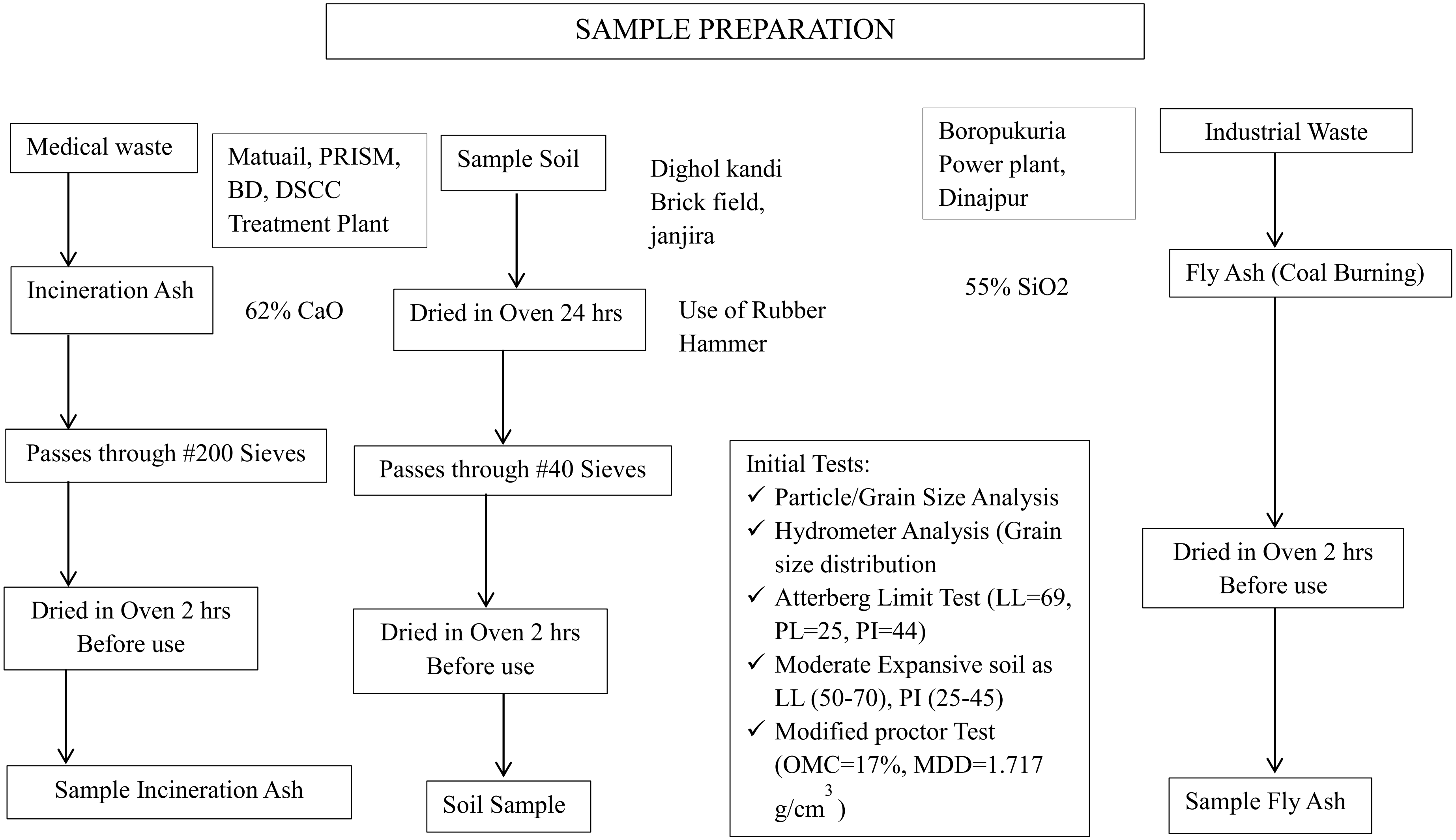


Figure 3.8: Schematic diagram of sample preparation

3.3.3 Collection of Alkali Activators

Alkali activators sodium hydroxide (NaOH) and sodium silicate (Na2SiO3) was collected from the local market.

3.3.3.1 Properties of Alkali Activators

The sodium hydroxide (NaOH) and sodium silicate (Na_2SiO_3) as alkali activators, shown in Figure 3.9, utilized in this study. Na_2SiO_3 is a white-coloured inorganic solid chemical powder with a density of 2.4 g/cm^3. The NaOH is also a white-coloured solid tablet with a bulk density of 2.13 g/cm^3. To prepare a geopolymer, an alkali solution was generated by mixing these two chemicals NaOH and Na_2SiO_3 with a ratio of 3:1, where 10% of the mix were kept constant and were dissolved in water which is also followed by (Algoo, Akhlaghi and Ranjbarnia, 2021).

Figure 3.9: Alkali activators (a) Sodium silicates box (b) Unboxed sodium silicates (c) sodium hydroxides box and (d) Unboxed sodium hydroxides

3.3.4 Collection of PET Bottles

PET bottles were collected from recycle shop. PET bottles were cleaned and cut into specified sizes.

3.3.4.1 Selection of PET Strip Size

PET strips have been cut with the help of scissors from recycled plastic bottle maintaining a size of 5x15 mm i.e., 1:3 ratio. From the paper Saravanan *et al.*, (2020) used various combination of size and the best result obtained for the size 8x24 mm i.e. 1:3 ratio. Following the above finding, 5x15 mm has been selected in this case. The preparation of PET strips shown in Figure 3.10.

Figure 3.10: Collected, cleaned and prepared PET strips

3.4 Sample Preparation

Samples that are prepared for various tests are described below.

3.4.1 UCS Test Sample

The soil is passed through the #40 sieve (0.425 mm) at first. Similarly, incinerator ash and coal-based fly ash is passed through the #200 sieve (0.075 mm). It is then oven dried for 2 hr. At first, the soil and the ash are mixed properly. Alkali activator (NaOH and Na_2SiO_3) is mixed in a beaker then. As NaOH produces too much heat when mixed with water, therefore, Na_2SiO_3 was taken into the jar first and then gradually NaOH is mixed. Total water used during mixing and compaction process is OMC. The pictorial view of the of sample preparation is shown in Figure 3.11, 3.12, and 3.13.

Figure 3.11: Preparation of sample for UCS test

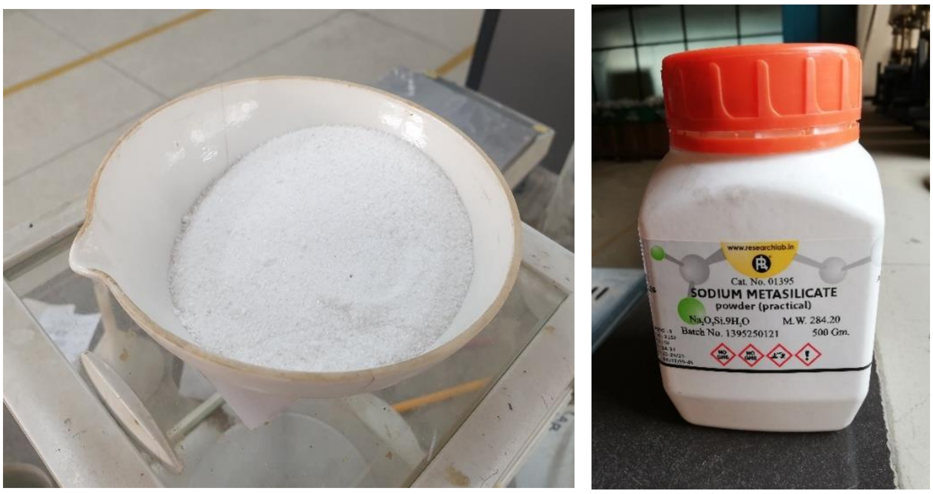


Figure 3.12: Preparation of sample for UCS test

Figure 3.13: Preparation of sample for UCS test

The split mold and the hammer is designed in such a way that it gives the same amount of compaction energy provided in modified proctor. Manual compaction was done as shown in Figure 3.14. The test specimens were then covered by polythene, shown in Figure 3.15 and kept for curing for 14 days and 28 days at the humidity moisture chamber, where specifically 24-degree Celsius temperature is maintained. For the UCS test of the soaked condition, samples were submerged under water for 24hrs and kept 4hrs in ambient conditions before the test.

Figure 3.14: Preparation of sample for UCS test

Figure 3.15: Preparation of sample for UCS test

3.4.2 Flexural Strength Test Sample

Sample preparation for the flexural test is as like as UCS test samples. In this case, the mold has been designed in a way to give 60 blows per layer. Total number of layers for this test is 3. The sample preparation are shown in Figure 3.16 and 3.17.

Figure 3.16: Preparation of sample for flexural strength test

Figure 3.17: Prepared beam for flexural strength test

3.4.3 CBR Mold

Mixing and preparation is same as UCS sample. Compaction has been done in automatic compactor following the ASTM Code for CBR (ASTM D1883-16). Glimpses of mold preparation and the test are shown in Figure 3.18 and 3.19.

Figure 3.18: Mold preparation for CBR

(a) (b)

Figure 3.19: (a) Transferring base plate after 96 hrs and (b) Swelling test in progress

3.4.4 Indirect Split Tensile Mold

Mixing and preparation is same as UCS test. To avoid cohesion with the surface and shear crack, lubricant and polythene was used around the surface of the split mold (Figure 3.20). Compaction was done by using automatic modified proctor machine for preparing the sample (Figure 3.21 and 3.22).

Figure 3.20: Polythene being set with the surface of the mold

(a) (b)

Figure 3.21: Sample preparation (a) Mold setup before compaction; (b) Automatic modified proctor test

(a)

b?

(b)

Figure 3.22: Prepared sample (a) Initial trimming after removing the collar (b) prepared sample after compaction

3.4.5 Experimental Scheme

From the chemical composition shown in Table 3.1, it is observed that incinerator ash contains approximately 62% CaO and whereas coal based fly ash contains only 2 % CaO (Ahmed, Chowdhury and Rahman, 2020; Islam *et al.*, 2019). However, coal based fly ash is rich in silica and alumina. Portland cement mainly gets its strength from CaO and SiO_2 (Arunachalam and Jayakumar, 2015). In OPC, CaO is 64.64%., SiO_2 is 21.28% and Al_2O_3 is 5.6% respectively. To make the perfect balance out of it the ratio of incinerator ash and fly ash has been kept 3:1 by following the research (Tzanakos *et al.*, 2014) which matches with the proportion of major components in OPC cement. Salt and geopolymer ratio was been kept at 1 as it gives the optimum result which was observed in the research of (Arulrajah *et al.*, 2018). From the research of (Cristelo, Glendinning and Pinto, 2011) it has been observed that NaOH can be harmful for workers because of its corrosive nature in higher molarities. It was suggested that 70% Na_2SiO_3 and 30% NaOH should be used which gives adequate strength.

Combination of incineration ash and fly ash activated by alkali compounds was mixed with soil thoroughly in various proportions (shown in Figure 3.23) at optimum moisture content of soil. UCS test at OMC condition and UCS test at a soaked condition with curing periods of 0, 14 and 28 days were carried out. However, the sample was soaked for 24 hours after the curing period and then kept 4 hrs in ambient condition for soaked UCS. Optimum contents of incineration ash and fly ash was determined depending on the maximum UCS value.

Soil mixed with incineration ash and fly ash combination as above, was then mixed with randomly distributed PET strips (5x15 mm) in various proportions which is shown in the schematic diagram below in Figure 3.23. UCS tests for samples both OMC and soaked condition with curing periods of 28 days was conducted. Additionally, CBR, split tensile and flexural, SEM and EDS tests was performed. Samples gave the maximum strength considered as the desirable combination of ash and PET strips.

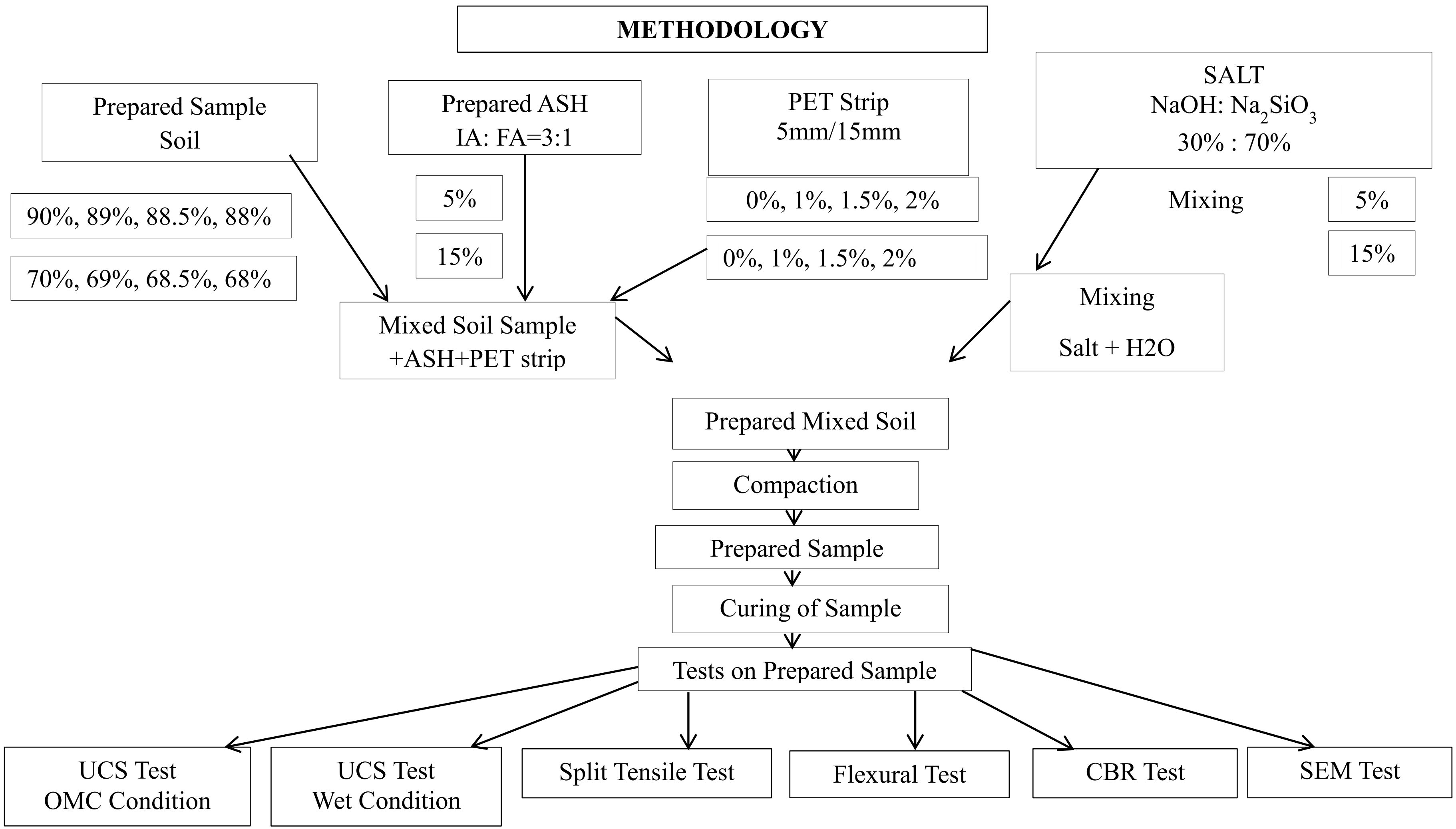


Figure 3.23: Schematic diagram of experimental design

3.5 Various Test Conducted

To ascertain the strength and durability characteristic of the treated soil; unconfined compression strength, split tensile, CBR, flexural, SEM and EDS test have been performed which is discussed in following paragraphs.

3.5.1 Unconfined Compression Strength Test

This is a method to determine the compressive strength capacity of the sample prepared and it was conducted following the code (ASTM D5102, 2009). Prior to the test, bedding surface was cleaned and 2 plate was placed at the top and bottom of the sample for ensuring even contact and loading. UCS Test was performed for both OMC and Wet conditions shown in Figure 3.24. For wet strength test, samples were kept under water for 24 hours and then kept 4hrs in ambient condition for drying out before testing.

(a) (b)

Figure 3.24: Unconfined compression strength test (a) Placing of sample (b) Test in progress

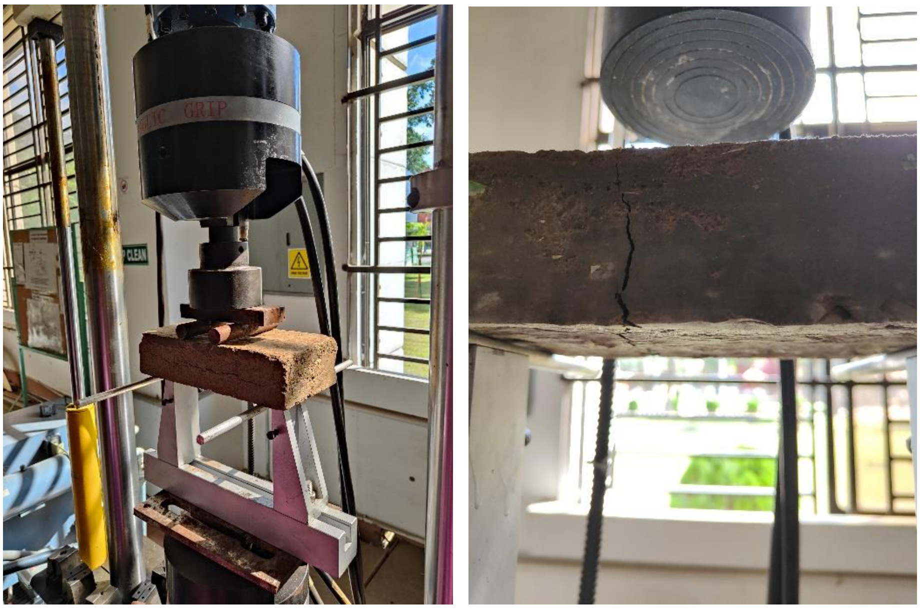
3.5.2 Indirect Tensile Strength Test

Split tensile strength test of the stabilized soil sample was performed following the code (ASTM C496, 1996). For this test, cylinders of diameter 100mm and height of approximately 150 mm were used. Cylinders were placed horizontally within the machine and tested at a rate of 0.20KN/s till failure, shown in Figure 3.25. This test was also performed for both OMC and wet condition. For wet condition, samples were kept under water for 24 hours and then kept 4hrs in ambient condition for drying.

Figure 3.25: Indirect tensile strength test

3.5.3 Flexural Strength Test

Flexural strength test of the stabilized soil sample was performed following the code (ASTM D 1635, 2006). For this test, load has been applied continuously and without shock shown in Figure 3.26, with the moving head operating at approximately 0.02 mm/s.

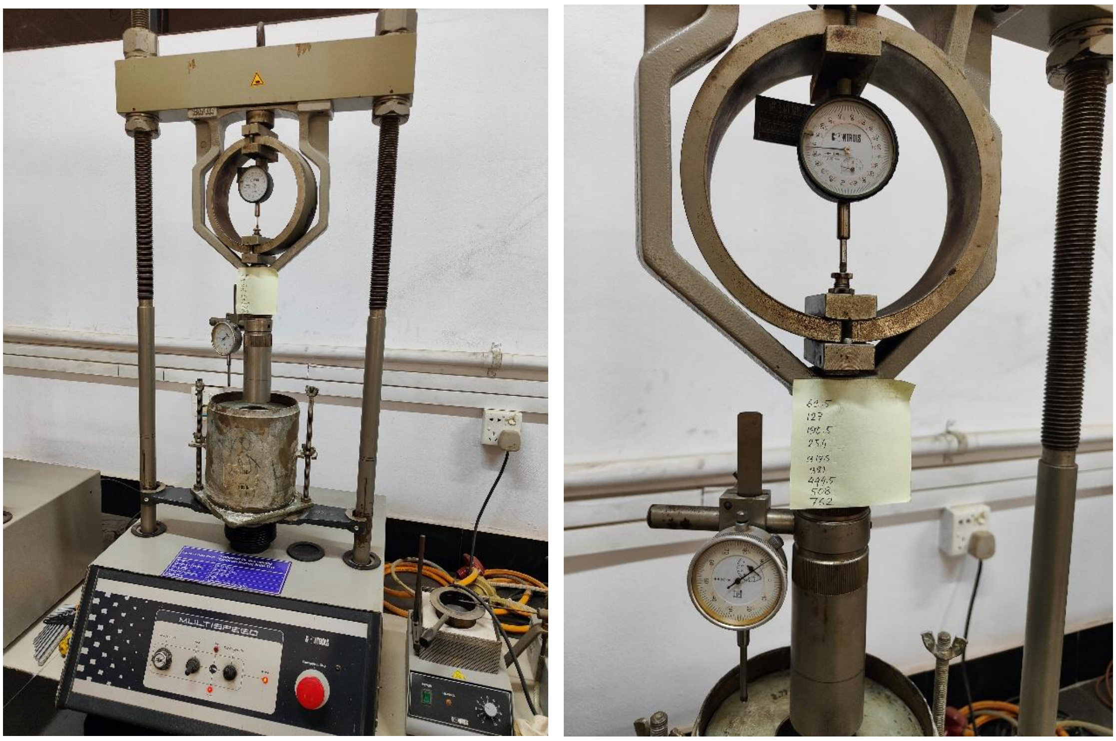


(a) (b)

Figure 3.26: (a) Sample placement before test (b) Failure plane after test

3.5.4 California Bearing Ratio (CBR)Test

For the CBR test, cylindrical specimens were prepared using MDD at OMC in a rigid metallic cylinder mould with an inside diameter of 150 mm and a height of 175 mm. A mechanical loading machine equipped with a movable base that moves at a uniform rate of 1 mm/min and the calibrated proving ring is used to record the load. For this, static compaction is carried out through keeping the mould assembly in the compression machine and compacting the soil by pressing the displacer disc till the level of the disc reaches the top of the mould shown in Figure 3.27. This test was carried out in accordance with ASTM D1883, 2016. In this study, the soaked specimens were made at OMC as determined from the standard compaction test.



(a) (b)

Figure 3.27: California bearing ratio (CBR) test (a) Sample placement before test (b) Test in progress

3.5.5 Scanning Electron Microscopy (SEM) Test

After unconfined compressive strength tests, selected specimens were analyzed by scanning electron microscopy. Before Testing, Sample has been shaped into 10x10x10 mm cube and oven dried at a temperature of 80 degree centigrade for 24 hrs. Gold coating has been done before testing as our sample is a non-conductive material shown in Figure 3.28.

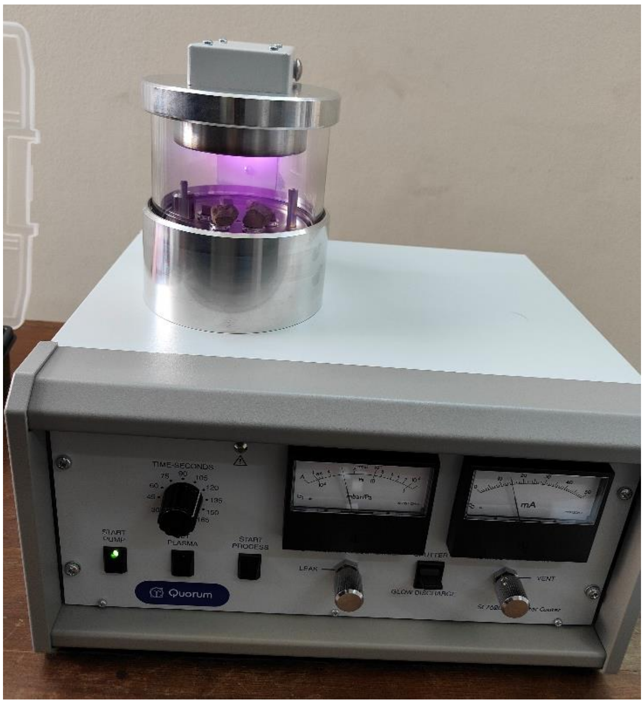


Figure 3.28: Preparation of sample for scanning electron microscopy (SEM) test

CHAPTER FOUR
RESULTS AND DISCUSSIONS

4.1 General

This study was performed to analyze the strength and durability characteristics of treated geo-polymer stabilized soil with the help of PET strip. Results obtained from different laboratory tests of treated sample are presented in this chapter on various aspects. Effects of adding different combinations of GPC along with PET strips on compressive, flexural and tensile strength of stabilized soil are described in this chapter along with relevant discussions. Comparison of experimental results also has been illustrated in this chapter.

4.2 Compressive Strength of the Stabilized Soil

It is observed that, the soil's unconfined compression strength increases when alkali activated fly ash and incinerator ashes are added, Figure 4.1 (a). Maximum of 3725 kPa of UCS value was observed in OMC condition for 20% GPC which is more than 5 times of the untreated soil sample, Figure 4.1 (c). Similar type of result was observed in a study by Ahmed *et al.*, (2020). In soaked condition, untreated soil shows zero strength. Actually, it cannot be put into the Tri-axial machine for UCS Test. However, the scenario changes once the soil treated with geopolymer. It is found that compressive strength of soaked sample is higher than that of OMC with geo-polymer content of 10% and more while testing after 14 days. But in case of test after 28 days, no exceptions have been observed in gaining strength. The strength got reduced due to soaking similar to the previous study (Islam *et al.*, 2020). The maximum retained strength for 28 days is found to be 82% for 15% GPC. But, for 14 days, maximum of 133.79% has been observed that is gain of strength overcoming the soaking effect due to continuation of Cementous process, Figure 4.1 (b).

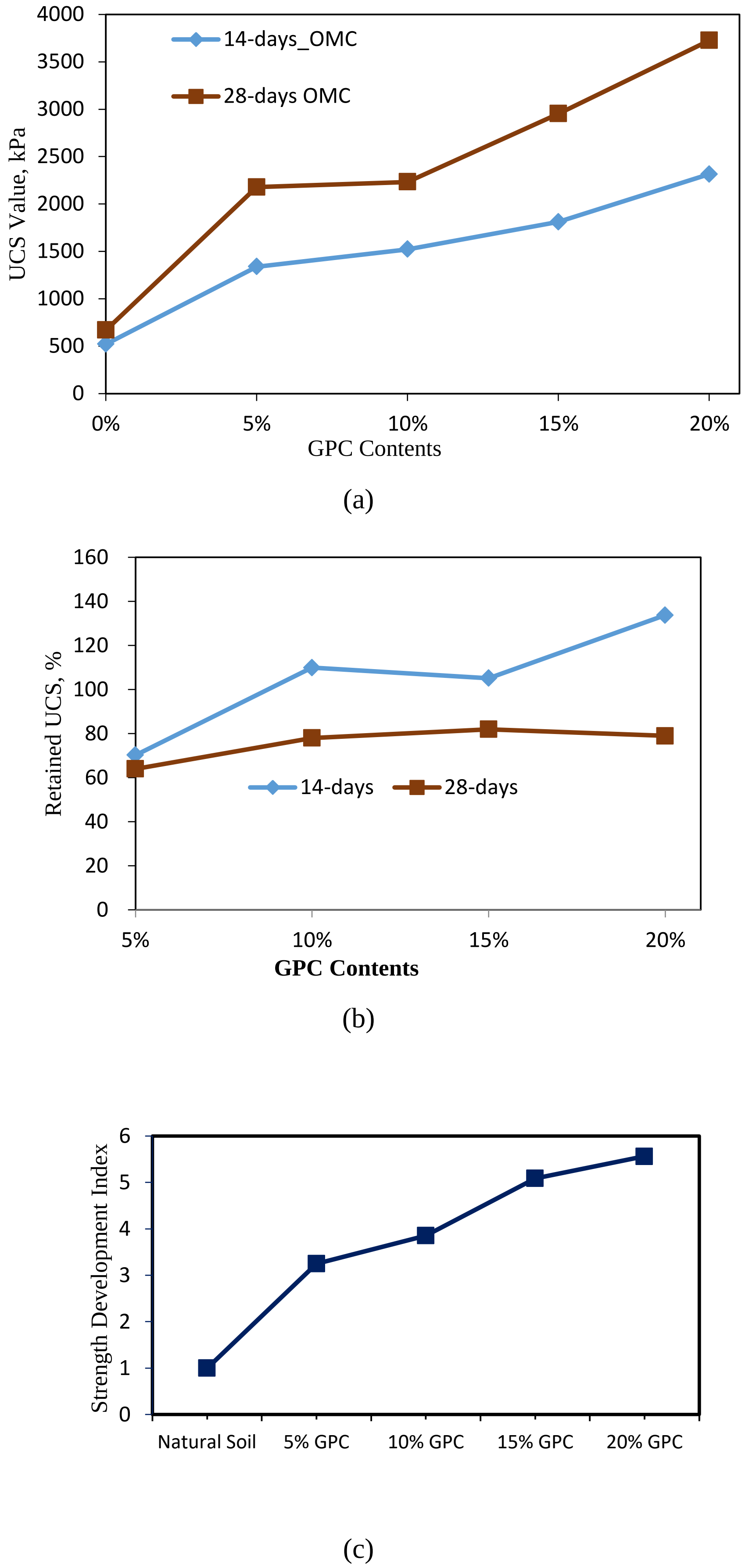
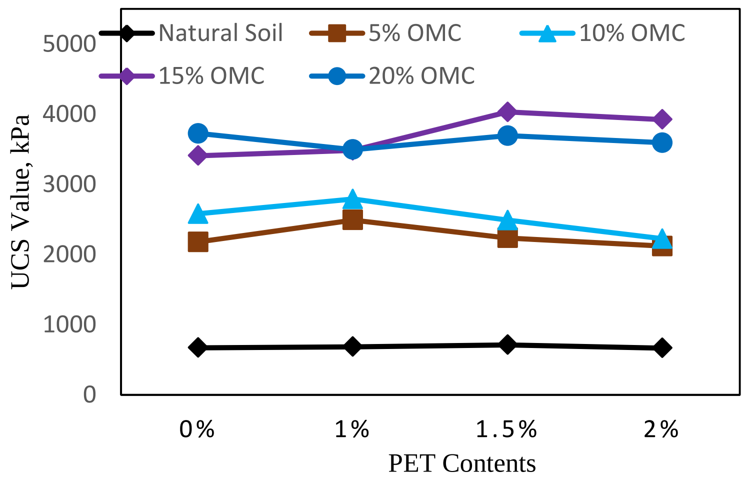
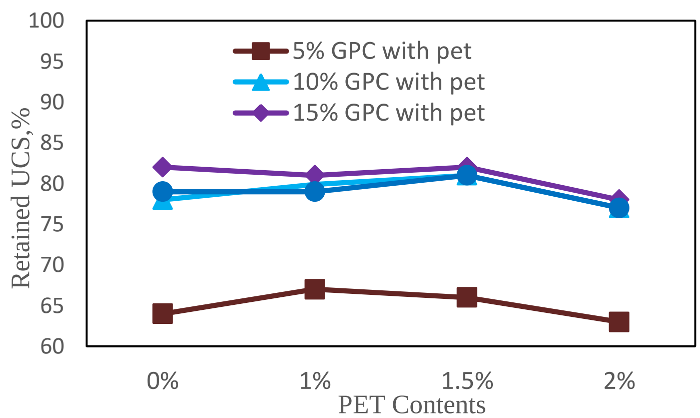


Figure 4.1: Effect of GPC in development of (a) Compressive strength (b) Retained strength after 24-hours soaking (c) Strength development index

The obtained results from the testing scheme corresponding to 28 days curing period are presented in Figure 4.2 which depicts that if no Geo polymer contant and alkali activator was added to the sample beside PET strips, maximum of 713kPa strength is obtained which is 6.42% increase from the untreated soil. It indicates the improvement of strength with the increase of PET strips. Optimum result is found for inclusion of 1% PET with 5% and 10% GPC content. Maximum of 4031.5 kPa of UCS value was observed in OMC condition for 15% GPC and 1.5% PET which is almost 6 times of the untreated soil sample. But, inclusion of PET with 20% GPC shows random behaviour. The trend seemed to decrease with the increase of PET content, Figure 4.2. As per failure plane, it generally shows multiple fracturing and double share failure, Figure 4.3. It was observed that the sample generally fails in a plane where PET strips are large in number. This usually happens during compaction, since Na_2SIO_3 is more slippery therefore, movements takes place and voids formed.



(a)



(b)

Figure 4.2: Effect of PET strip in development of compressive strength (a) At 28-days OMC condition, (b) Retained strength after 24-hours

Figure 4.3: Failure planes while doing UCS test with PET strips

4.3 Flexural Strength of the Treated Soil

The flexural strength of the treated soil shows significant improvement. Maximum of 469.77 kPa strength was obtained for 20% GPC along with 1.5% PET. Almost 3.65 times strength development has been observed in comparison with 5% GPC, Figure 4.4 and 4.5. It was observed that the experimental result gave similar types of result in comparison with the UCS strength. Optimum result was found for inclusion of 1.5% PET. Similar type of result observed when randomly distributed pet bottle strips were mixed with cement stabilized kaolin clay (Bozyigit *et al*., Oct. 2021; Mehdi Koohmishi *et al*., 2022)

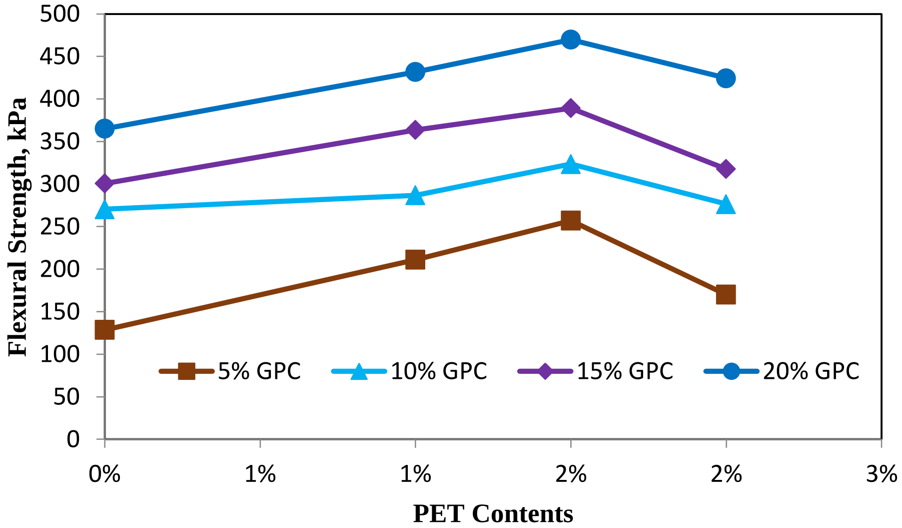


Figure 4.4: Effect of GPC in development of flexural strength after 28 days

Figure 4.5: 3rd Point Loading Flexural Strength Test

4.4 Indirect Tensile Strength of Stabilized Soil

This test was done to identify the tensile strength of the prepared sample of 28 days. It was observed that excess amount of PET strips in a plane generates crack which is shown in Figure 4.6. Maximum of 781kPa strength was observed for 20% GPC without any PET strips. Tensile strength of the prepared sample tends to decrease with the increase of PET strips with GPC. Only 10% and 15% GPC with 1% PET shows some minor increment in comparison with the base, Figure 4.7. Similar types of result was found in (Taallah *et al.*, 2014). The tensile strength of specimens is much lower than the compressive strength.

This is largely because of the ease with which cracks can propagate under tensile loads. (Medjo Eko *et al.*, 2012)

(a)

(b)

(c)

(d)

Figure 4.6: Failure planes while doing split tensile strength test with PET strips

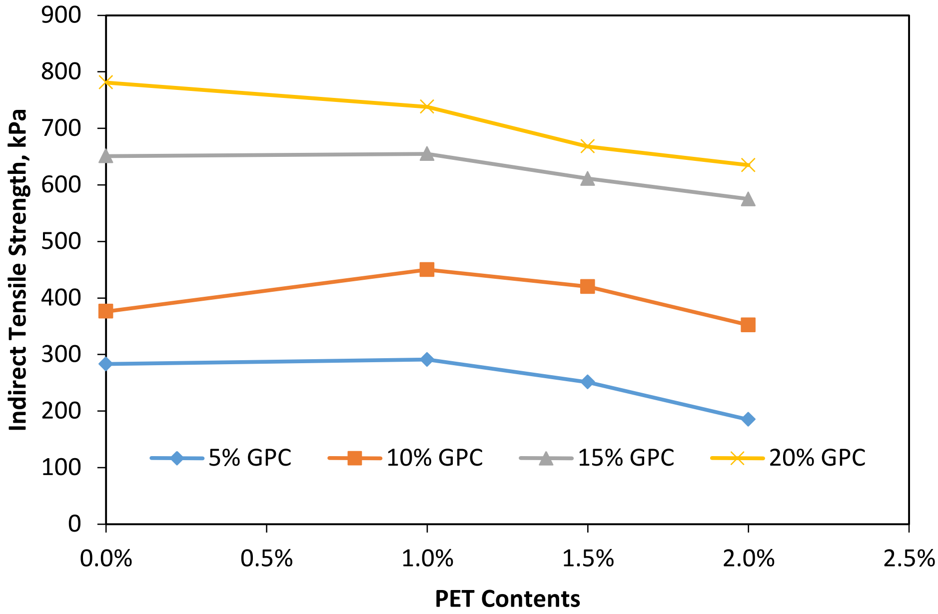


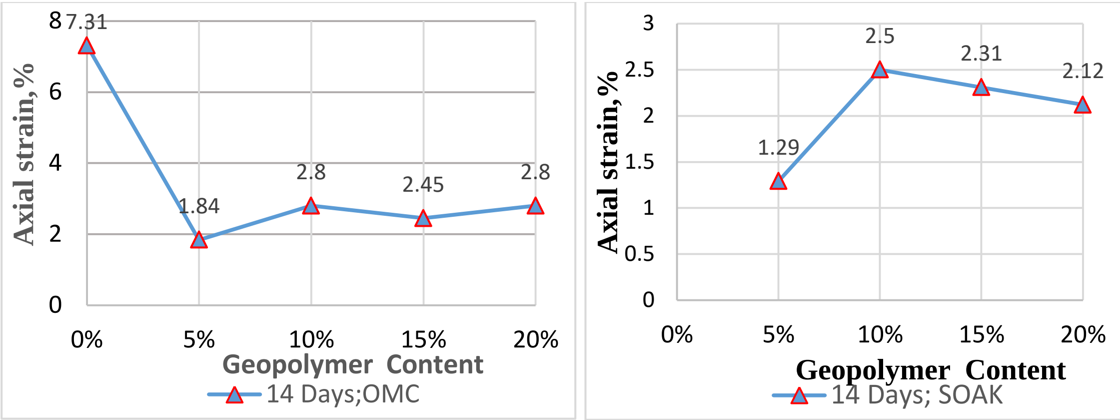
Figure 4.7: Effect of PET strips on indirect tensile strength of stabilized soil

4.5 Effect of GPC on Deflection

Being a moderate expansive soil, the axial strain of untreated soil at OMC is found almost 7.5% before failure as shown in table 4.4 and figure 4.8. This problem was mitigated by adding geopolymer into the soil. After adding geopolymer, the soil shows brittle behavior, gained enough strength and showed very less amount of deformation in comparison. This is very much helpful while constructing subgrade of Railway track in our country as it is very much conservative in case of settlement. The least axial Strain has been found for the 5% combination.

Table 4.1. Axial strain for different combination

Sample	14 days		28 days	
	Axial Strain in OMC Condition	Axial Strain in Soaked Condition	Axial Strain in OMC Condition	Axial Strain in Soaked Condition
M-0	7.31	0	5.05	0
M-5	1.84	1.29	1.97	1.59
M-10	2.8	2.5	2.02	3
M-15	2.45	2.31	2.33	2.14
M-20	2.8	2.12	2.11	1.64



(a) (b)

Figure 4.8: (a) Effect of GPC for axial strain after 14 days (b) Effect of GPC for axial strain after 14 days-soaked condition.

Here, it is found that the moderate expansive soil can be treated with the help of adding GPC and axial strain can be reduced significantly. But, during soaked condition, the strain increases and gives maximum value for 10% GPC and then gradually decreases, Figure 4.9. But it gives optimum result for 5% GPC.

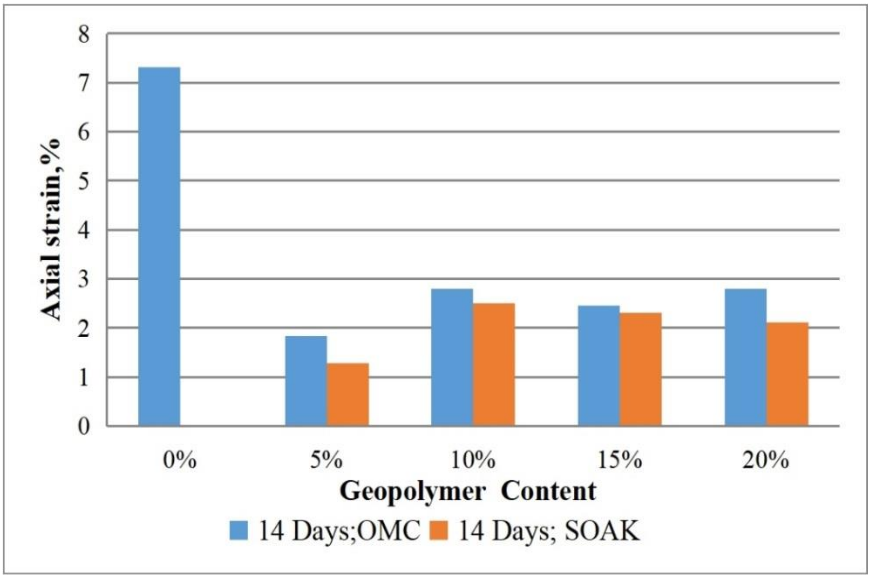
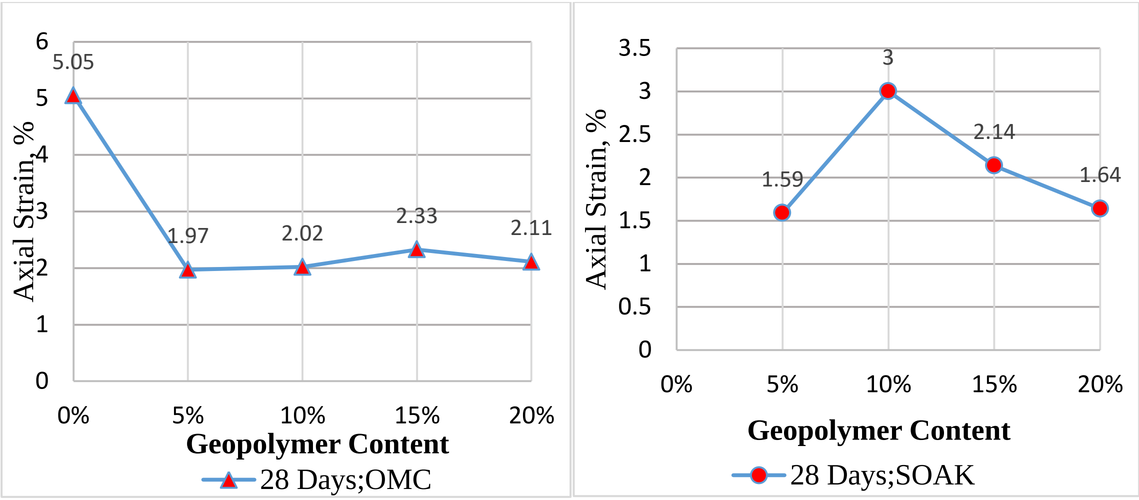


Figure 4.9: Comparison of effect of GPC in axial strain between 14 days and soaked condition

On the other hand, for 28 days, It also gives similar type of results. Though the axial strain decreases comparing to 14 days result, but, still it is facing the problems of soaking which causes increment in axial strain. It also gives optimum result for 5% GPC, Figure 4.10 and 4.11.



(a) (b)

Figure 4.10: (a) Effect of GPC for axial strain after 28 days (b) Effect of GPC for axial strain after 28 days soaked condition

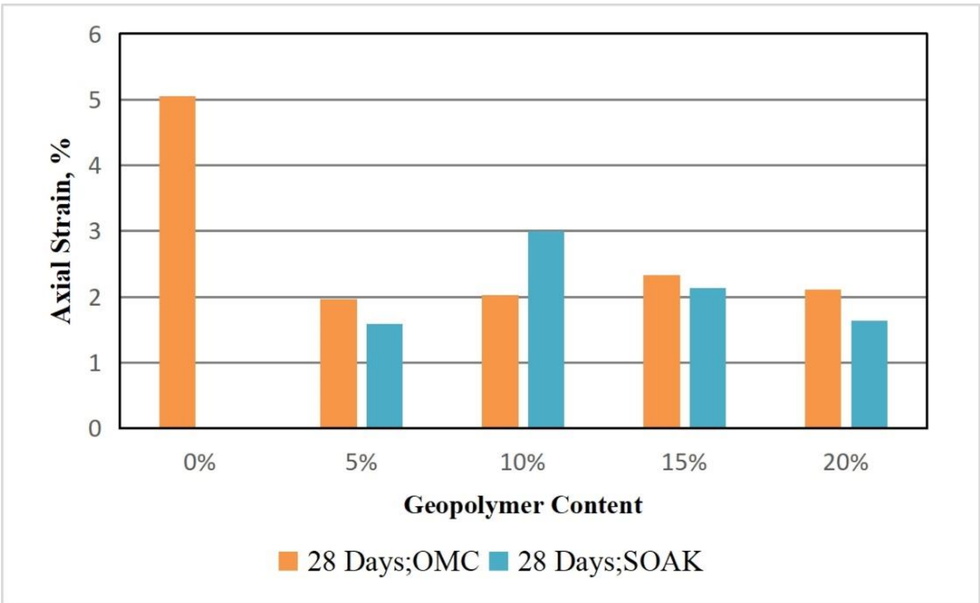
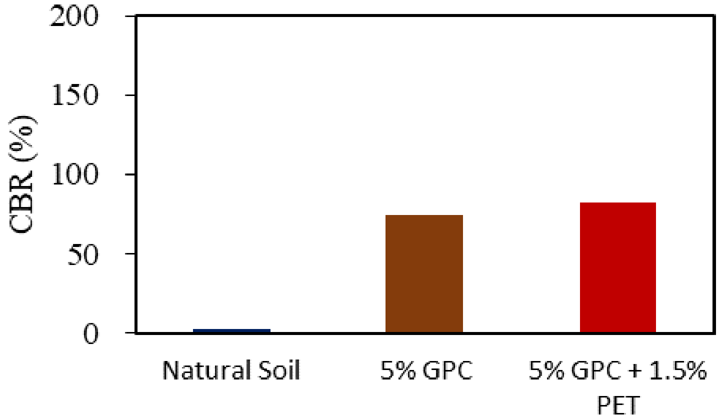


Figure 4.11: Comparison of effect of GPC in axial strain between 28 days and soaked condition

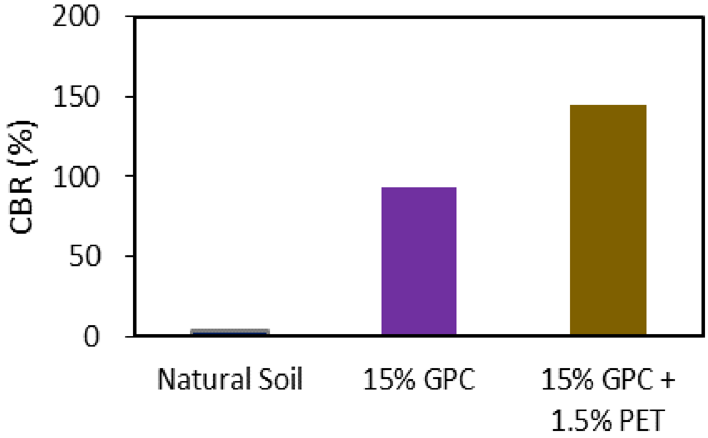
So, adding GPC mitigates the problem of expansion or deflection of soil in a significant manner.

4.6 Effect of GPC on CBR

According to RHD Pavement Design Guide, minimum 5% CBR value is required while constructing roads. Subgrade needs to be improved if the value of In Situ CBR comes less than 5%. From out GPC treated subbase soil, the obtained CBR is much higher than our requirement. Maximum of 119% CBR value was observed from 15% GPC with 1.5% PET inclusion, Figure 4.12. CBR tests demonstrated that the inclusion of plastic fibres in clayey soils improves the strength and deformation behaviour which was also observed in the research on effects of plastic waste materials on geotechnical properties of clayey soil (Hussein *et al.*, Jan 2021). Some minor amount of swelling was observed for 5% GPC and swelling tends to zero in case of higher percentage of GPC.

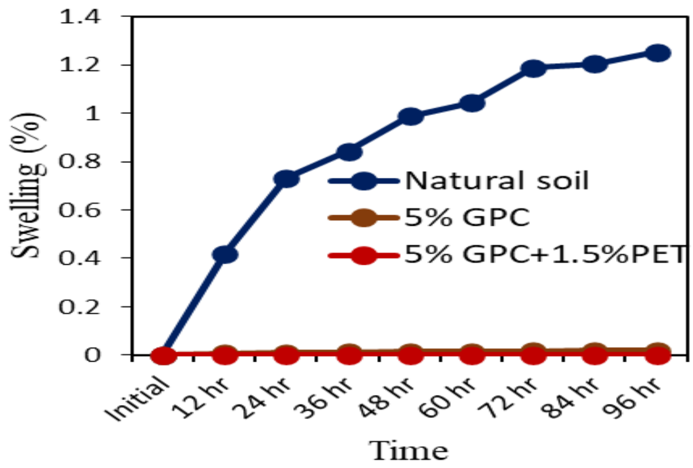


(a)

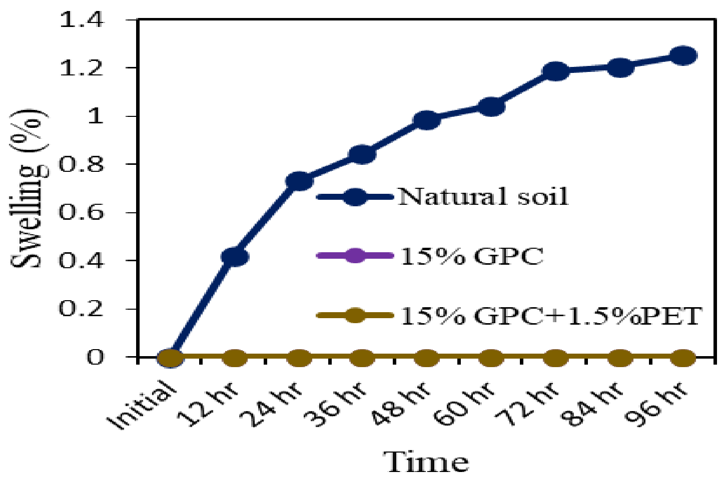


(b)

Figure 4.12: CBR values (a) Natural soil, 5% GPC and 5% GPC with 1.5% PET (b) Natural soil, 15% GPC and 15% GPC with 1.5% PET and swelling values



(a)



(b)

Figure 4.13: Swelling values (a) Natural soil, 5% GPC and 5% GPC with 1.5% PET (b) Natural soil, 15% GPC and 15% GPC with 1.5% PET and swelling values

4.7 Microstructural Analyses

Microstructural analyses also depicts gel formation much higher in 20% GPC than 5% GPC, Figure: 4.14 and 4.15. From the SEM image of Microstructural Analyses it is observed voids between pet strip and soil structure, deformed pet strip and geopolymer bond on PET strip, Figure 4.16 (a), (b), (c) and (d). Since Na_2SIO_3 is slippery and compaction force applied on to it therefore, PET strips moved towards the wall of the mold and bounced back agglomerate to gel and voids formed.

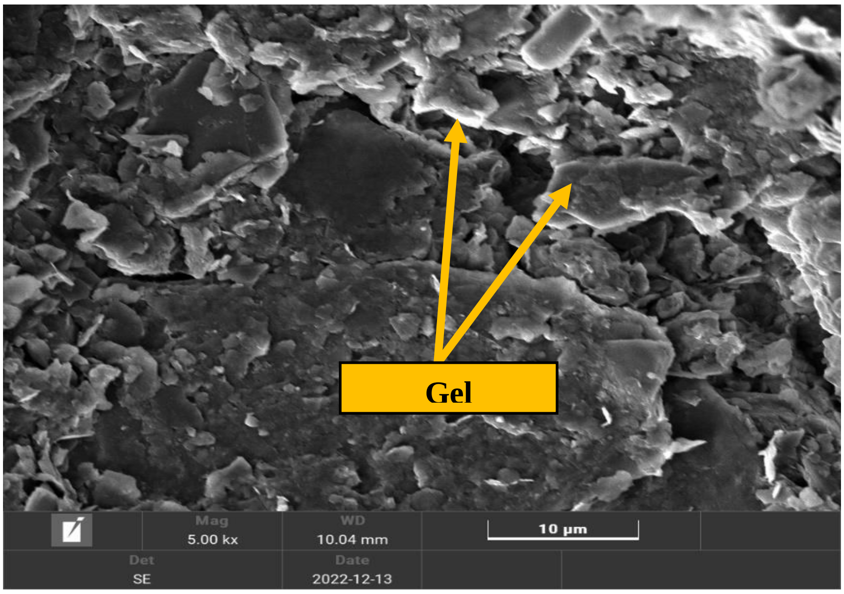


Figure 4.14: SEM image of 5% GPC

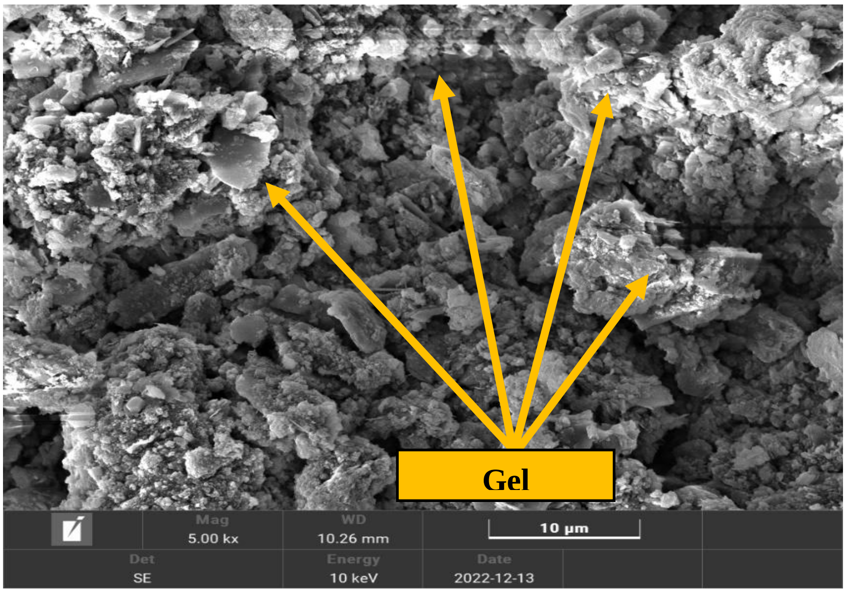
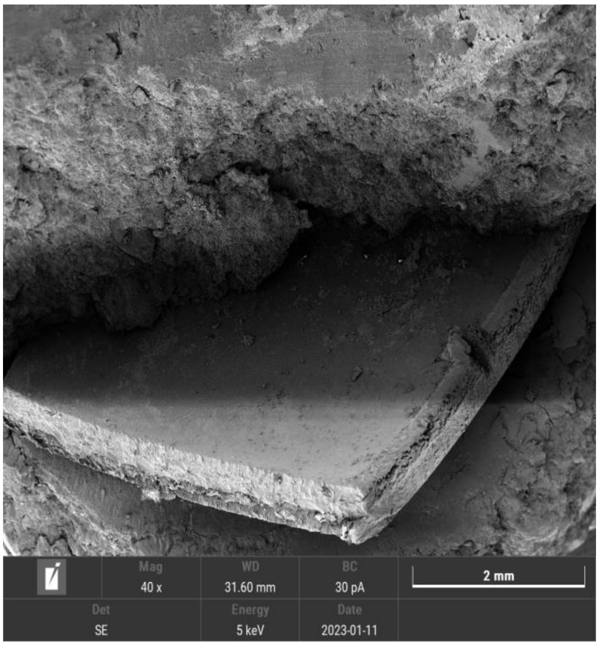
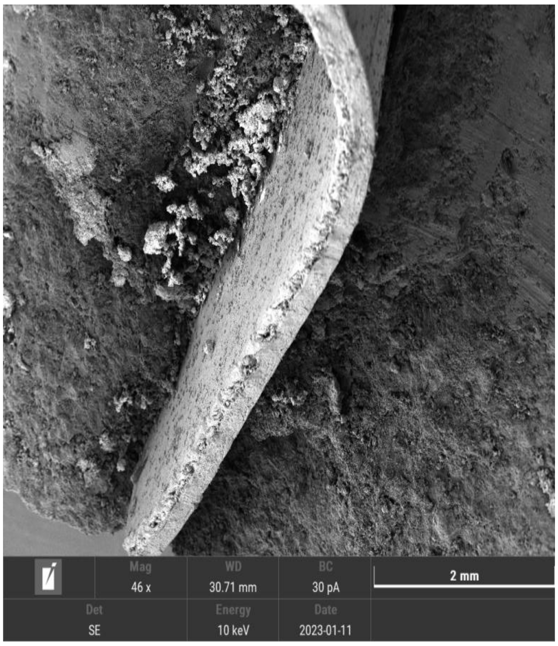
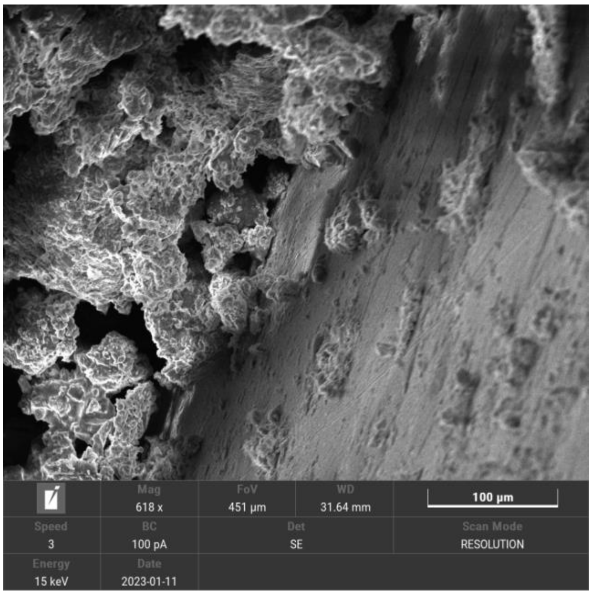


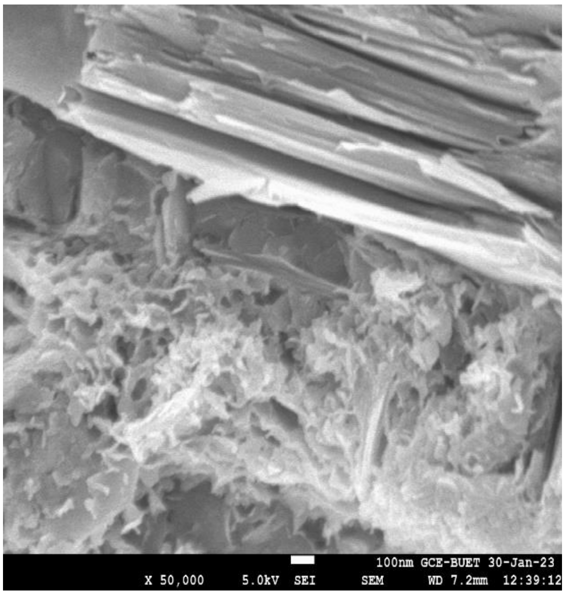
Figure 4.15: SEM images of 20% GPC





(a) (b)





(c) (d)

Figure 4.16: SEM image on PET strip reinforcement in stabilized soil (a) Voids between pet strip and soil structure (b) Deformed PET strip due to compaction force (c) & (d) Geopolymer bond on PET strip.

From the result elemental analysis conducted by energy dispersive spectroscopy (EDS), It is observed that chemical reaction in the sample of 15% GPC is much higher than 5% GPC which indicates that the amount of alkali activating bond with Geopolymer is much higher in the sample of 15% GPC, Figure 4.17 and 4.18.

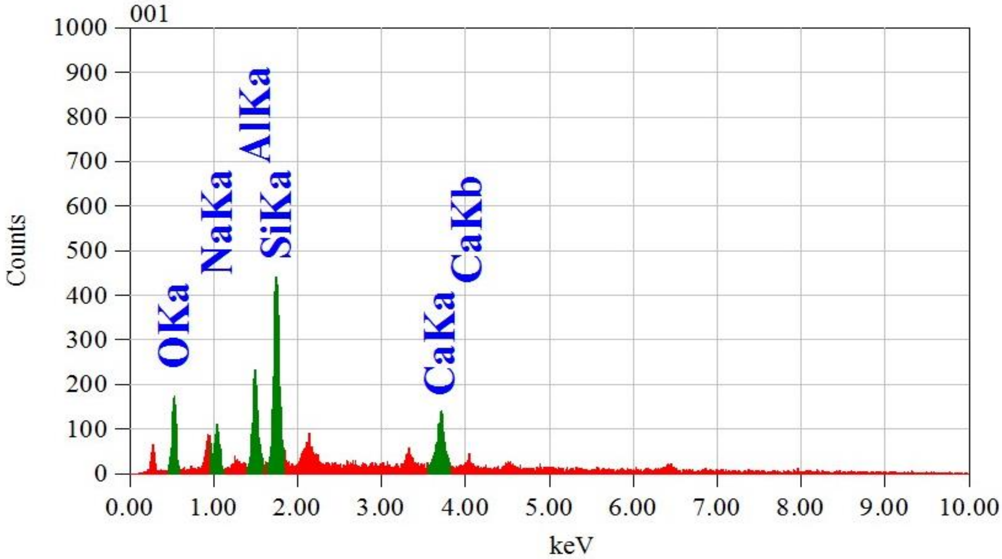


Figure 4.17: EDS of soil stabilized with 5% GPC

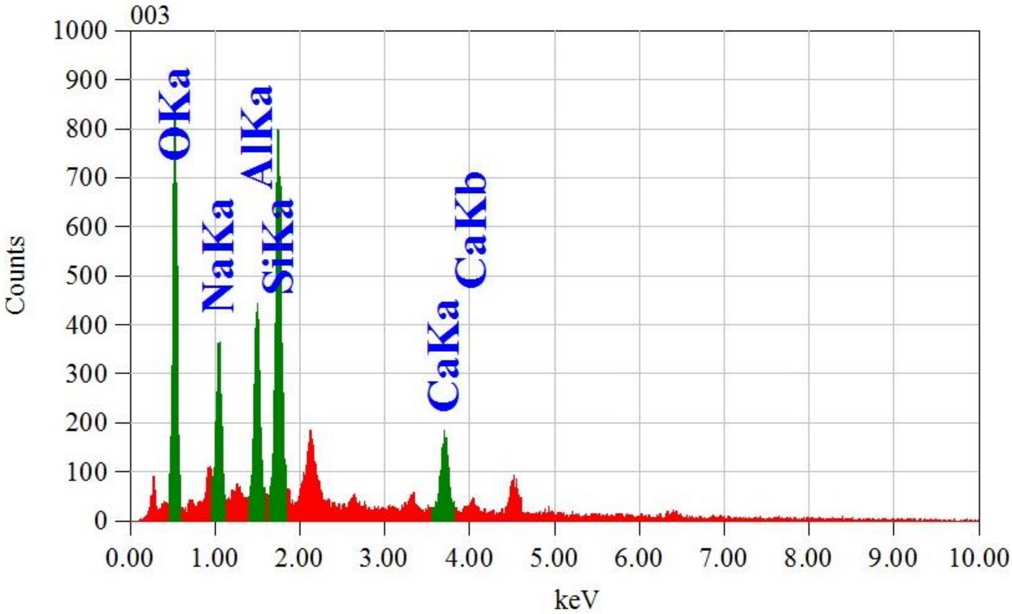


Figure 4.18: EDS of soil stabilized with 15% GPC

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS FOR FUTURE STUDY

5.1 General

This study was aimed to investigate the effectiveness of use of industrial waste fly ash, medical waste incinerator ash, and recycled plastic bottle in terms of strength and durability in stabilizing subgrade soil. Unconfined compression strength, split tensile, CBR, flexural, SEM and EDS test have been performed to determine the strength and durability of the treated soil. This chapter presents the conclusions of the study based on the test result. It also lists the possible research avenues as continuous works of the present study.

5.2 Conclusion

This study concludes with the following findings:

(i) With the increase of geo-polymer content and ageing, the strength of the soil sample increases four to five times. Development of unconfined compression strength test is found to be linearly proportional to geo-polymer content. Maximum UCS value was observed for 15% GPC with 1.5% PET after 28 days, which is almost six times of the untreated soil sample.

(ii) For 28 days result, soaked UCS strength of treated soil is less in comparison to the identical unsoaked sample. The strength got reduced about 20% to 30% due to soaking effect.

(iii) The maximum retained strength for 28 days is found to be 80% for 15% GPC. But, for 14 days, maximum of 134% has been observed. On the other hand, the maximum retained strength for 28 days is found to be 88% for 15% GPC with 1.5% PET strip.

(iv) The flexural strength of the treated soil shows significant development. Maximum strength was obtained for 20% GPC along with 1.5% PET which is almost 3.65 times in comparison with 5% GPC.

(v) In split tensile strength test maximum strength was obtained for 20% GPC which is 2.76 times of 5% GPC.

(vi) Untreated soil sample displayed a higher axial strain of 7.5%. After treating with Geo-polymer axial strain get reduced as proof of increasing rigidity. During soaked condition, the strain increases and gives maximum value for 10% GPC and then gradually decreases. But it gives optimum result for 5% GPC.

(vii) CBR value shows significant improvement obtaining 145% for 15% of GPC with 1.5% PET. Insignificant amount of swelling was observed for 5% GPC. But, no swelling was observed in case of higher GPC percentage.

(viii) Microstructural analysis by SEM shows substantial gel formation for 20% GPC over 5% GPC. Moreover, voids between pet strip and soil structure, deformed PET strip and geopolymer bond on PET strip is also observed. In EDS, chemical reaction in the sample of 15% GPC is much higher than 5% GPC which indicates that the amount of alkali activating bond with geopolymer is much higher in the sample of 15% GPC

5.3 Recommendations for Future Study

There is a vast scope to conduct further research on Stabilized subgrade improvement by incinerator ash and fly ash along with PET strips as reinforcement. Some of the possible field of research has been listed below:

(i) Research can be conducted with different sizes of PET strips with the rough surface following the same procedure.

(ii) Research can be conducted following ambient curing conditions.

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