INVESTIGATION ON GEOTECHNICAL AND PHYSICOCHEMICAL PROPERTIES OF SOIL-LIKE MATERIAL AND FEASIBILITY OF IT'S USE AS INFILL MATERIAL

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DECLARATION

I hereby declare that the work presented in this report entitled "**INVESTIGATION ON GEOTECHNICAL AND PHYSICOCHEMICAL PROPERTIES OF SOIL-LIKE MATERIAL AND FEASIBILITY OF IT'S USE AS INFILL MATERIAL**" in the partial fulfilment of the requirement for the award of the degree of Master of Technology in Civil Engineering with specialization in Geotechnical Engineering submitted in the Department of Civil Engineering, Assam Engineering College, Jalukbari, Guwahati-13 under Assam Science and Technology University, is an authentic work carried out in the said college under the supervision of Dr. Abinash Mahanta, Assistant Professor, Department of Civil Engineering, Assam Engineering College, Jalukbari, Guwahati-13, Assam. Whatever I have presented in this report has not been submitted by me for the award of any other degree or diploma.

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ABSTRACT

Open dumping involves unregulated waste disposal in open areas due to inadequate infrastructure, awareness, urbanization, and weak regulations. It harms the environment and health, necessitating better practices. Responsibly managing persistent waste is vital for developing nations and urban authorities, with soil-like material (SLM) being a major part of reclaimed content from old MSW dumps, often over half of the excavated material. To assess the feasibility of utilizing the finer portion of soil-like material derived from 10-15 years age municipal solid waste, for the purpose of earth-fill applications investigation have been done on the geotechnical and physicochemical properties of SLM (<4.75mm). From Laboratory test results revealed that the SLM is a light, non-plastic, fine-grained material. Although SLM's maximum dry density was lower compared to native soil, the strength parameter assessed through unconfined compressive strength reflects its consistency in stiff category.

To verify its appropriateness for the project, environmental pollution, and safety concerns physicochemical parameters of the SLM is evaluated. The analysis considered factors like heavy metals, organic content, total dissolved solids and the release of dark-colored leachate. These findings were compared with values from existing literature, as well as national and international regulatory standards. The elevated presence of organic matter, heavy metals, and soluble salts suggests that the SLM needs treatment before being used off-site or requires precise design considerations when being utilized as earth-fill in embankments, low-lying zones, and deep excavations.

When examining the impact of polypropylene (PP) flakes and high-density polyethylene (HDPE) granules on the geotechnical properties of both the SLM and native soil, it was discovered that these additives exhibit varying effects on the tested parameters. For soil sample 4 and SLM, they enhanced strength up to a certain additive percentage known as the optimal percentage. However, in other samples, no positive impact of additives on strength was observed compared to their strength in their original state.

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CHAPTER 1

INTRODUCTION

In many developing nations, open dumping stands as the primary method for disposing of municipal solid waste (MSW) generated within their boundaries. These MSW dumpsites introduce surface water pollution through the discharge of leachate from the dumping location. Open dumping causes a range of environmental in the form of uncontrolled fire, pollution of nearby water bodies, contamination of soil, leachate migration into subsoil, emission of toxic gases, flies and rodents, health, and social issues, largely due to the uncontrolled disposal of waste materials without proper management or containment. The environmental problems associated with open dumps currently demands immediate rehabilitation. Among the potential approaches, open dumps could also be viewed as reservoirs for materials, enabling the recovery of secondary soils, refuse-derived fuels, and more **(Somani et al. (2019)).**

According to annual Report on **Solid Waste Management (2020-21), CPCB, Delhi,** solid waste is generated a total of 160038.9 tons per day (TPD). Out of this, 152749.5 TPD is collected with an efficiency of 95.4%. Within the collected waste, 79956.3 TPD (50%) is treated, and 29427.2 TPD (18.4%) is directed to landfills. Notably, a segment of the waste, specifically 50655.4 TPD representing 31.7% of the total waste generated, lacks a designated disposal or treatment method. Assam produces a total of 1199 tons per day (TPD) of waste. Among this, 1091 TPD is gathered, 41.4 TPD undergoes treatment, and none of it is disposed of in landfills.

In the present-day global scenario, there's a lot of competition for resources, materials are getting more expensive, diminishing reserves of valuable resources, and a growing focus on environmental issues. These factors have driven the search for alternative means of resource extraction. One noteworthy approach that has come to the forefront is bio-mining. This method is strategically positioned to primarily extract valuable materials and energy from natural sources **(Banerjee et al. (2022)).**

Biomining concept was first implemented at Hiriya Landfill in 1953 by the Dan Region Authority, next to Tel Aviv, Israel. Bio-mining, also known as bioremediation or bioleaching is a waste management technique that involves the use of biological organisms to recover valuable metals such as copper, gold, nickel, and uranium, from ores or waste material, while minimizing the ecological footprint and environmental damage associated with traditional mining methods). According to **Reno Sam (2009),** some of the advantageous reason for choosing Bio-mining are extension of the lifespan of landfills, increase of storage capabilities along with landfill preservation, reduction of pollution and mitigation of point source contamination, stabilizes waste using biological processes, recovers energy and materials, and cuts waste management costs. Additionally, this technique is employed to extract valuable metals from electronic waste (e-waste) or waste containing abundant metals.

According to the **Central Pollution Control Board (CPCB)** guidelines, "Biomining is the scientific process of excavation, treatment, segregation and gainful utilisation of aged municipal solid waste lying in dumpsites typically referred to as legacy waste." Subsequently, the waste is treated for stabilization through bioremediation, achieved by exposing the waste to air and utilizing composting bio-cultures. The stabilized waste is then subjected to a screening process to reclaim valuable resources such as organic fines, bricks, stones, plastics, metals, textiles, soil and soil-like material etc. This recovered material is then managed sustainably through methods like recycling, co-processing, and utilization in road construction (**Solid waste Management Rules, 2016**).

The prominent byproduct obtained from landfill mining is the soil-like material (SLM), which arises from the accumulation of silts, street sweepings, as well as construction and demolition waste at the landfill site. The feasibility of repurposing this material for diverse on-site applications relies on its compatibility. As a result, this utilization highlights the economic feasibility of mining projects. While the wide-scale utilization of SLM as earth-fill in external contexts lacks extensive documentation, its substantial implementation remains relatively infrequent. The array of potential reuse opportunities hinges on factors like the material's composition, quality, and market demand. Since SLM originates from dumpsites, it undergoes evaluations of its strength characteristics, potential risks, and the extent of contamination **(Najamuddin et al. (2021)).**

The nation is putting in a significant effort to enhance its infrastructure, which involves constructing larger structures like roads and bridges. This is driven by increased production in factories and greater consumer purchases. They are in the process of building many kilometers of roads as part of special programs like the National Highway Development Program and the Pradhan Mantri Gram Sadak Yojana. However, creating these roads demands a substantial number of materials, both for their construction and ongoing maintenance. It's crucial to reduce the use of local soil and rocks for making these roads, as using them can harm the environment. Moreover, in certain areas, especially cities, there's a shortage of good quality soil and rocks, necessitating their transportation from distant places, which significantly raises project costs.

One potential solution is to utilize municipal solid waste (MSW), which is present throughout the country, as a viable source of road construction material, especially for constructing embankments. By segregating and processing the MSW, it can be used effectively in embankment construction. Despite its potential, there's a lack of global literature regarding the utilization of such segregated MSW in embankment construction.

In the present study, fine fraction reclaimed from waste' pertains to the portion of aged municipal solid waste (MSW) that measures less than 4.75mm in size. The material below 4.75mm comprises clay, silt and sand following geotechnical standards (as specified in IS 2720-4 (1985)).

In the present study, aged municipal solid waste (MSW) was gathered from the Boragaon dumpsite. Aged waste refers to the MSW that was discarded in an unlined dumpsite (with minimal or no soil covering) over a decade ago. The primary goal of this study is to evaluate the viability of utilizing the finer fraction of excavated material for earth-fill purposes. This study concentrates on the fraction smaller than 4.75mm. An on-site analysis of the composition of matured MSW was conducted by employing a series of sieves to determine the grain size distribution (GSD)."

The objectives of the present study are:

(a) Investigation of the geotechnical and physicochemical properties of soil-like material (SLM) and feasibility for utilization as road construction filling material.

(b) Comparison of geotechnical properties of SLM with those of the native soil.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

The geotechnical characteristics of SLM have been investigated by Song et al. (2003), Oettle et al. (2010), and Hyun et al. (2011). With the exception of Song et al. (2003), who noted a decline in strength as organic content increased, all researchers found the strength properties to be satisfactory. Long-term settlement concerns due to elevated organic content have been raised by Oettle et al. (2010). For off-site applications such as roads and embankments, Oettle et al. (2010) and Wanka et al. (2017) proposed the utilization of washed and blended SLM, respectively.

Prior research has predominantly focused on heavy metals as contaminants within soil-like material obtained from mining dumpsites. Leaching of total soluble solids can heighten subsoil salinity (Somani et al. 2019). Additionally, leaching of colored liquids can lead to the discoloration of surrounding water bodies, influencing how consumers perceive drinking water quality (Somani et al. 2019). Although organic content is not inherently a contaminant, excessive levels could lead to prolonged settlements when the material is employed in earthworks.

2.2 REVIEW OF LITERATURE

Savage (1993) reported that the initial efforts for landfill mining was attempted in Tel Aviv, Israel as long back as 1953 for obtaining fertilizers for orchards.

Kurian et al. (2003) explored and analyzed the results derived from studies conducted on the retrieval of decomposed materials from dumpsites situated near Chennai, specifically Kodungaiyur and Perungudi. These findings will be compared with similar investigations carried out in Deonar, located in the vicinity of Mumbai, India, and also across Europe and the USA.

This investigation uncovers that approximately 65% of the samples procured from the dumpsites, aged around 10 years, were composed of fine particles. The depth of the fill within these dumpsites was shallow, measuring approximately 3 meters, and no noticeable alterations in waste characteristics were observed with the deepening of the fill. The fine fraction of these samples exhibits the potential for usage as compost for non-edible crops or as a covering material for forthcoming landfills, contingent upon a geotechnical suitability evaluation.

Song et al. (2003) explored the geotechnical characteristics of soils derived from solid waste, with the intention of determining their viability as sub-base materials in road development. Both field and laboratory assessments were conducted to analyze the physical and mechanical traits of solid waste soils obtained from a landfill site located near a riverside. This landfill site had undergone reclamation efforts over the past two decades. The findings revealed a noticeable correlation between geotechnical properties and the concentration of organic matter within the soil. Elevated organic matter levels led to a decrease in the maximum dry unit weight, shear strength, and ground bearing capacity, alongside an increase in void ratio and compressibility. When the organic matter content exceeded approximately 8% in solid waste soils, their suitability for application as sub-base materials in road construction diminished due to a substantial reduction in shear strength and bearing capacity.

Naeini et al. (2008) conducted a test where waste polymer materials were selected as the reinforcement material and were randomly incorporated into clayey soils with varying plasticity indexes at five different percentages of fiber content (0%, 1%, 2%, 3%, 4%) by weight of raw soil. The main aim of the investigation was to examine the strength behavior of unsaturated clayey soils reinforced with randomly included waste polymer fiber, which were then subjected to direct shear tests. The results demonstrated a clear and significant enhancement in the shear strength parameters (C and Φ) of the treated soils, with the degree of reinforcement increasing with higher fiber content.

Oettle et al. (2010) focused on a landfill site in Southern California, USA, where 60-year-old MSW from a partially closed area near a freeway access ramp was excavated, treated, mixed with soil, and utilized as engineered fill to accommodate the proposed post-closure development. The paper provides comprehensive insights into the characterization, processing, and laboratory testing of representative bulk waste samples, which can serve as a foundation for similar future undertakings. Additionally, the paper details the procedures of processing, placement, and compaction of the excavated waste.

Degraded waste samples predominantly consisted of materials falling within the classification of "soil and soil-like material." Employing ASTM D 1557 (the modified Proctor compaction test) allowed achieving a maximum dry density of at least 15.2 kg/m³ when compacting the waste material. The corresponding optimal moisture content ranged between 11% and 19%. Increasing organic content led to a decrease in maximum dry density and an increase in optimal moisture content. Similarly, plasticity index and liquid limit tended to rise with higher organic content. Waste with comparable gradation exhibited distinct compaction characteristics due to varying organic content, despite their Atterberg limits aligning along the same A-line. The difference in waste moisture content determined at 55°C and 105°C was practically negligible (0.8%).

Ashraf et al. (2011) involves the detailed study on the possible use of waste plastic bottles for soil stabilisation. The analysis was done by conducting plate load tests on soil reinforced with layers of plastic bottles filled with sand and bottles cut to halves placed at middle and one third positions of tank. The comparison of test results showed that cut bottles placed at middle position were the most efficient in increasing strength of soil. The optimum percentage of plastic strips in soil was found out by California Bearing Ratio Test and using this percentage of plastic, plate load test was also performed. The size and content of strips of waste plastic bottles have significant effect on the enhancement of strength of the soil.

Hyun II, P. et al (2011) conducted a geotechnical investigation to evaluate the engineering properties of old municipal solid waste sampled in Whamyung MSW landfill site, Bussan, Korea. The conducted tests included water content, specific gravity, Atterberg limits, grain-size distribution, compaction, small scale and large-scale consolidation, triaxial compression (CU), and direct shear tests. Ninety percent of the total weight of the samples was comprised of soil materials.

Muntohar et al. (2013) explores the potential of using plastic waste as reinforcing materials, despite its abundant presence in the environment. However, a promising pozzolanic material, a blend of rice husk ash and lime, is found to possess superior properties in soil stabilization. The study focuses on investigating the engineering behavior of clayey/silty soil stabilized with randomly distributed discrete plastic waste fibers. The results demonstrate that this approach effectively enhances the engineering properties of the soil, including its compressive, tensile, and shear strength, which in turn improves the soil's stability and durability. The optimal amount of fiber mixed in the soil/lime/rice husk ash mixture is found to be between 0.4% to 0.8% of the dry mass, based on the compressive strength, California bearing ratio (CBR), shear strength, and failure characteristics of the soil.

Olgun (2013) evaluated the influence of polypropylene fiber inclusions on the geotechnical properties of a clayey soil that was chemically stabilized using cement and fly ash, an experimental investigation was conducted. In all stabilized soils, cement and fly ash were incorporated at a rate of 8% and 30%, respectively. Reinforced stabilized soil samples were prepared with four different fiber content percentages (0.25%, 0.50%, 0.75%, 1.0%) and three different fiber lengths (6 mm, 12 mm, 20 mm). Unconfined compressive and split tensile strength tests were performed after 7- and 28-day curing periods. The volume change characteristics of the reinforced stabilized soil were determined by assessing shrinkage limits and crack reduction values. The interactions between the fiber surface and the stabilized soil were investigated using scanning electron microscopy. The results indicated that the addition of fiber to the stabilized soil led to a significant increase in both compressive and especially, tensile strength values. The highest strength values were achieved with 0.5-0.75% fiber content for 12 mm-long fibers. As fiber content and length increased, shrinkage limit and crack reduction values also increased, while volume changes decreased.

Havangi et al. (2017) conducted a comprehensive investigation to explore the feasibility of utilizing Municipal Solid Waste (MSW) collected from Ghazipur, East Delhi as material for embankment construction. This application was intended for the widening of NH-24 from a 4-lane to a 16-lane configuration. Approximately 200 tons of MSW were gathered from Ghazipur and segregated into various size categories at the existing compost plant. Based on the proportions of the different segregated fractions, along with laboratory segregation studies, composition analysis, and initial geotechnical assessments, a segregation methodology for preparing embankment material at the plant was proposed. The segregated MSW was then subjected to characterization of its geotechnical properties. Design cross-sections for 3-meter and 5-meter high MSW embankments were developed through detailed stability analyses. Settlement analyses were also conducted to ascertain the suitability of the MSW for embankment construction. Key conclusions drawn from the study are summarized below:

- Approximately 65-75% of the segregated Municipal Solid Waste can be employed for embankment construction.
- Apart from soil, plastics and textiles were identified as the predominant components in different segregated MSW categories. The content of metals, wood, paper, rubber, and glass was observed to be less than 1% in various segregated MSW samples. Soil content and other constituents showed no significant variation with the age of the MSW.
- Leachate studies indicated that the MSW is non-hazardous, with heavy metal concentrations within permissible limits.
- The fraction passing through a 16 mm sieve displayed minimal plastic content. Due to its higher percentage in the MSW (44-48%) and its compliance with MORTH specifications for Maximum Dry Density (MDD), this fraction can be directly utilized for embankment construction.

(Kaczala et al. 2017) aimed at the physicochemical assessment of leachate originating from the fine fraction (<10 mm) of waste extracted from a full-scale landfill mining project. Samples were collected from the Kudjape Landfill on Saarema Island, Estonia, using four distinct test pits (TP1, TP2, TP3, TP4) divided into four layers (L1, L2, L3, L4). Analysis was conducted on various parameters, including total organic carbon (TOC), dissolved organic carbon (DOC), and metal concentrations (Zn, Cu, Pb, and Cd).

The findings revealed TOC release exhibited a range of 3,530 to 2,326 mg/kg dry matter across different test pits. DOC concentrations varied between 365-874 mg/kg and 317-940 mg/kg for distinct test pits and sampling layers, respectively. The leaching rates of metals were observed to be quite low, ranging between 0.2% and 1.5%. This phenomenon could be attributed to the limited solubility of these metals at alkaline pH levels. Notably, Pb demonstrated a significantly higher average leaching rate (1.0%) compared to Zn (0.70%) and Cu (0.35%).

Somani et al. (2018) presents the feasibility of landfill mining operation specifically to recover soil-like material at old dumpsites of India for re-use in geotechnical applications. Aged municipal solid waste was collected from three dumpsites of India and initial tests were conducted on the soil-like material of the municipal solid waste. Initial tests results of grain size distribution, compositional analysis, organic content, total dissolved solids, elemental analysis, heavy metal analysis and colour of the leached water from finer fraction of aged municipal solid waste are presented. From the preliminary investigation, it was found that organic content in 15–20-year-old dumpsites varies between 5%–12%. The total dissolved solids range between 1.2%–1.5%. The dark-coloured water leaching out from aged waste, with reference to local soil, is one of the objectionable parameters and depends on the organic content. The concentration of heavy metals of the finer fraction was compared with the standards. It was found that copper, chromium and cadmium are present at elevated levels in all the three dumpsites. The study concluded that the bulk of the soil-like material from aged municipal solid waste landfills can be used as cover material for landfills at the same site. However, some treatment in terms of washing, thermal treatment, blending with local soil, biological treatment, etc., is required before it can be re-used in other geotechnical applications.

Somani et al. (2019) focused on investigating the leaching behavior of the finer fraction (smaller than 4.75 mm) of aged municipal solid waste extracted from three historical dumpsites in India. The objective was to evaluate the potential of utilizing this soil-like fraction as an earth fill material.

The leaching characteristics of the aforementioned soil-like fraction were thoroughly examined, particularly in comparison to water extracts from local soil. Parameters such as total dissolved solids (TDS), chemical oxygen demand (COD), color release, and ammoniacal nitrogen in the leachate were analyzed. The outcomes revealed significantly higher values for these parameters in the leachate originating from the soil-like material compared to water extracts from the indigenous soil. Furthermore, an elevated concentration of certain metals (including arsenic, chromium, copper, cobalt, and nickel) was detected in the leachate of the soil-like material when contrasted with the water extracts of local soils.

Consequently, the study underscores the importance of subjecting soil-like fractions obtained through landfill mining to thorough screening for their physicochemical attributes and potential pollution effects before considering their application as earth-fill material.

Somani et al. (2019) conducted an examination to evaluate the properties of leachate originating from six major landfills situated in India, specifically in Delhi, Hyderabad, and Kadapa. The analysis encompassed the assessment of both physicochemical parameters and heavy metal concentrations in the leachate. The leachate collected from all six landfills displayed varying levels of total dissolved solids, hardness, alkalinity, sulfates, and chlorides, ranging from 15,000 to 50,000 mg/L, 10,000 to 30,000 mg/L, 10,000 to 20,000 mg/L, 300 to 1500 mg/L, and 5000 to 10,000 mg/L, respectively. Furthermore, the impact of aging on leachate characteristics was investigated by comparing samples from two locations within the same landfill (located in Hyderabad and Okhla, Delhi). One sample was taken from a recently generated leachate outflow, while the other was collected from a pond where leachate had accumulated over time. The findings revealed that freshly generated waste leachate posed a greater hazard compared to the leachate that had accumulated in the pond. In fact, the majority of physicochemical parameters exceeded regulatory thresholds across all landfill sites.

M. Datta et al. (2020) explores the practicality of utilizing soil-like material (SLM) recovered from the excavation of old waste sites in India, with a particle size less than 4.75 mm, for various applications such as embankments, low-lying areas, deep pits, and horticultural and agricultural compost. This SLM constitutes a significant portion, approximately 60-70%, of the total excavated waste.

The potential for reusing the SLM as earth-fill material was evaluated by assessing its contamination levels in terms of heavy metals, organic content, soluble salts, and the release of dark-colored leachate. Additionally, the viability of using SLM as compost was appraised based on nutrient levels (total organic carbon, nitrogen, phosphorous, and potassium), heavy metal content, and physicochemical attributes. The results obtained were benchmarked against data from existing literature, both national and international regulatory standards, and background soil conditions.

Elevated concentrations of organic matter, heavy metals, and soluble salts in the SLM indicate that either treatment is necessary before off-site reuse or specific design measures must be implemented when employing it as earth-fill for embankments, low-lying areas, and deep pits. Furthermore, the study highlights that repurposing mined SLM as compost should be limited to non-agricultural contexts due to excessive heavy metal content even after supplementing the total organic carbon.

Najamuddin et al. (2021) aimed at understanding the engineering properties of soil-like-material (SLM) obtained from landfill mining and its feasibility to be reused in multiple potential directions. The engineering properties of the material are taken from the researchers. This study undertakes a comprehensive comparison between the attributes of soil-like material (SLM) and those exhibited by the indigenous soil. The analysis extends to the assessment of heavy metal leaching from the soil-like material, aimed at discerning the levels of contamination. Properties like organic content, release of dark colour leachate and number of soluble salts are analyzed in comparison to local soils.

The geotechnical examination of the SLM yields significant findings, establishing its non-plastic nature and its possession of a low specific gravity due to the presence of organic constituents. The strength properties are found to be satisfactory and permeability is similar to that of local soil. From the laboratory test results, it is found that the SLM is not hazardous. It is not similar to local soil. It is not inert and hence the unrestricted re-use of SLM is avoided. Treatment techniques and design measures can be adopted and SLM can be used in various applications.

Banerjee et al. (2022) investigated that due to intense competition for resources, rising raw material costs, depleting natural reserves of valuable resources, and growing environmental concerns, seeking alternative sources for resource extraction has become a practical solution. One such method is Bio-mining.

The city of Kolkata generates approximately 4500 metric tons of waste daily, most of which has accumulated at the major landfill site Dhapa since 1987, turning it into legacy waste. Based on composition analysis, it is estimated that about 85-90% of this legacy waste can be recovered. Material balance indicates various components of bio-mining: combustible (5.23%) and non-combustible materials (29.97%), compostable (56.04%), recyclables (0.476%), and residuals (8.642%).

Sample analysis of a 100 kg material from the dumpsite reveals different component fractions: 25-30% non-combustible or construction and demolition (C&D) materials, 10-15% combustible or refuse-derived fuel (RDF) materials, 1-2% recyclables, 15-20% bio-earth, 20-30% coarser organic fraction, 5-10% process rejects, and 15-25% evaporated moisture. A comparative analysis has been conducted using probabilistic data alongside specific on-site data

CHAPTER 3

EXPERMENTAL PROCEDURE AND RESULTS

3.1 INTRODUCTION

To fulfill the project objective, relevant experiments were performed in the laboratory as per Indian standard procedures following the respective IS codes. The test program of the different tests performed in the laboratory and their corresponding results have been portrayed in this chapter.

3.2 TEST PROGRAM

With an objective of exploring the geotechnical and physicochemical attributes of Soil-Like Material (SLM) derived from aged Municipal Solid Waste (MSW), and assessing its viability for use as filling material in road embankments, a comparative analysis is conducted. This comparison involves evaluating the geotechnical characteristics of SLM against those of the native soil. The physicochemical properties of the SLM are examined to understand its behavior, and strength tests are performed on both SLM and soil samples. Furthermore, preliminary tests are conducted on soil specimens. Two types of plastic waste, namely polypropylene and high-density polyethylene, are incorporated as additives, and their influence on strength and bearing capacity is evaluated.

The entire test program is divided into the following phases:

i) Collection and preparation of SLM, native soil sample and waste plastic.

ii) Determination of physicochemical properties of SLM.

iii) Determination of physical properties of SLM and native soil.

iv) Determination of compaction of properties of SLM and native soil by standard Proctor compaction test.

v) Determination of CBR value of SLM and native soil with different percentage of waste plastic.

vi) Determination of UCS value of SLM and native soil with different percentage of waste plastic.

3.2.1 Collection of SLM, native soil and plastic waste:

Soil-like material (SLM) from aged municipality solid waste (MSW) of 10-15 years old was collected from Boragaon dump site. The SLM used in this research were a byproduct of the Bio-mining project under Guwahati Municipal Corporation (GMC). Once collected, the SLM was left to air-dry for a week. Subsequently, sieving was performed using a 4.75mm IS sieve, and the portion of the sample that passed through the sieve was used for subsequent characterization

Fig.3.1: Location- Boragaon dump site

Fig.3.2 : SLM - Boragaon dump site

The native soil specimens tested in this study are disturbed soil samples with different geological origin and engineering properties. To perform the necessary tests, four samples were collected; two samples are collected from Udalguri district, one sample is collected from Boko and the rest is collected from Deepor Bheel. For collecting the fine-grained soil samples from the sites, the top (30-60) cm of the soil is removed so that there is no trace of organic matter amalgamated with the soil specimen. About (50-60) kg of soil sample is collected from each site. The co-ordinate of the sites from where the soil samples are collected is shown below.

Prior to the performance of the experiment native soil samples are also allowed to dry in room temperature. The samples are pulverized manually to attain desired size of the soil particles and sieving is done as prescribed by the Indian standard code.

Fig.3.3: Location-Bengbari, Udalguri

Fig.3.4: Location-Ambagaon, Udalguri

Fig.3.5: Location-DeeporBheel, Kamrup(M)

Two type of waste plastics are used in this study- polypropylene (PP) and high-density polyethylene (HDPE) which are generated from plastic-product manufacturing industries. The stabilizers used are shredded plastic of size less than 5 mm. The PP waste was flaky whereas the HDPE were granular in shape. The sample of each PP and HDPE are shown below –

Fig.3.6: Shredded PP plastic

Fig.3.7: Shredded HDPE plastic

3.2.2 Determination of physiochemical characteristics of SLM:

1. Determination of pH was performed according to IS 2720 (Part 26)– 1987.
2. Determination of the color of the leached water was performed according to IS 3025 (Part 4) – 1983
3. Determination of the Organic Matter was performed according to IS 2720 (Part 22)– 1972
4. Determination of Total Dissolved Solids was performed according to IS 3025 (Part 16) – 1984
5. Determination of Heavy Metal Analysis was performed by X-ray fluorescence spectrometry.

3.2.3 Determination of physical properties of soil samples and SLM:

1) Determination of liquid limit was performed by cone penetration method according to IS:2720(Part 5)-1985
2) Determination of plastic limit was performed according to IS:2720(Part 5)-1985
3) Determination of specific gravity was performed according to IS:2720(Part 3)-1980
4) Determination of gradation of soil samples by wet sieve analysis was performed according to IS 2720 (Part 4) 1985.

3.2.4 Determination of the compaction properties of soil samples and SLM:

Using the light compaction technique standard proctor test is done to get the compaction characteristics of both the soil samples and SLM and thus the optimum moisture content (OMC) and maximum dry unit weight (MDUW) of the soil samples are determined as per IS 2720 (part -7) 1980.

3.2.5 Determination of CBR value of soil and SLM with different percentage of waste plastic:

In this study, unsoaked CBR value is calculated as per IS 2720 (part-16) 1980. The soil samples and SLM are prepared at their respective OMC and the experiment is performed by adding 0%, 1%, 2% and 3% of waste plastics (PP and HDPE) by weight of the dry soil.

3.2.5.1 Preparation of the test specimen:

A representative soil sample of weight 4.5 kg, passing through 19 mm IS sieve is mixed thoroughly with predetermined quantity of water to get the soil at OMC and the mixed soil is kept in a desiccator for a period of 24 hours for maturation. Corresponding to different percentage of waste plastic (%by weight of dry soil), the amount of soil, water to be added and waste plastic is calculated. The amount of plastic is mixed uniformly to the soil just before the experiment is performed.

The mould and the collar are clamped to the base plate and the spacer disc is inserted into the compaction assembly. Placing the filter paper on top of the spacer disc, the soil is compacted in the mould in accordance with IS 2720(part 7)-1980. So, the soil is compacted in 3 layers giving 56 numbers of blows on each layer, using 2.6 kg rammer with a free fall of 31 cm.

Fig.3.8: Different component of compaction assembly -base plate, mould, collar. Spacer disc, rammer, surcharge plate (from right hand side)

After completion of the compaction, the collar is removed and the top surface is trimmed carefully. Then the mould is turned upside down and spacer disc is removed. The mass of the compacted soil is recorded so that the maximum dry unit can be maintained.

3.2.5.2 Penetration test:

The mould containing the soil specimen with top face exposed, base plate in position was placed on the lower plate of the loading assembly. Two surcharge plates each weighing 2.5 kg is placed on top the soil specimen prior to the application of the load. Setting the load and deformation readings to zero, load is applied to the soil at the rate of 1.25mm/min. The load-penetration readings are taken corresponding to specified penetration of (0.5, 1.0, 1.5, 2.0, 2.5, 4.0, 7.5, 10 and 12.5) mm as shown by the monitor. Then corresponding to penetration value 2.5mm and 5 mm, the percentage CBR values of the soil specimens are recorded.

Fig. 3.9: CBR testing machine (digital)

3.2.5.2.1 Load- penetration curve:

Taking load as the ordinate and penetration as abscissa, load-penetration curve is plotted for each soil sample. This curve is usually convex upwards although the initial portion of the curve may be convex downwards due to surface irregularities and in such cases required correction is applied as specified by Indian standard code.

3.2.5.2.2 California bearing ratio (CBR):

The CBR value is calculated at penetration 2.5 mm and 5 mm penetration. Usually, the CBR value at 2.5 mm penetration is higher than that at 5 mm penetration. Whenever the CBR for 5 mm is more than 2.5mm, the experiments need to be repeat and the higher value of the second trial is reported as the final CBR value of the soil.

California bearing ratio = $\frac{P_T}{P_S}$x100

Where,

P_T = corrected unit test load corresponding to the choosen penetration from the load penetration curve

P_S = standard load corresponding to the specified penetration

Table 3.1: Standard load used in CBR test:

Penetration depth	Unit standard load (kg/cm^2)	Total standard load (kgf)
2.50 mm	70	1370
5.00 mm	105	2025

3.2.6 Determination of UCS value of soil samples and SLM with different percentage of waste plastic:

The unconfined compression test is done as per IS 2720 (part 10)-1991, with length to diameter ratio 2 where the diameter of the sample is taken as 38 mm. The UCS sample is obtained from standard Proctor mould, compacted at their respective OMC. Stress-stain graph is plotted for each soil sample mixed with different percentage of plastic waste and the unconfined compressive strength of the soil is determined.

Fig. 3.10: UCS testing machine

3.3 Test results:

The experimental results involved performing a series of laboratory tests are shown below in the following tables and graphs.

3.3.1 Test results of the physicochemical characteristics of SLM:

Physicochemical tests provide insights into the suitability of soil for specific uses. In geotechnical engineering, these tests help determine whether soil can be used as foundation material, road embankment, or backfill material based on its strength, compaction, and permeability characteristics.

Table 3.2 Physicochemical properties of SLM

Sample	pH	Color (TCU)	Organic content (%)	Total dissolved solids (mg/L)
SLM	6.98	10	8.52	576

Table 3.3: Heavy metals concentration of SLM in solid phase:

Metal	Solid phase (mg/kg)
As	3
Cd	7
Cr	87
Cu	646
Ni	33
Pb	94
Zn	619

3.3.2 Test results of the soil physical properties and SLM:

The physical properties of four fine-grained soil samples are shown in **table 3.4**. The soil classification based on Atterberg limits and plasticity index is also included in the table.

Table 3.4: Physical Properties of the soil samples

Sample No.	Site location	Depth from G.L (m)	Colour	Specific Gravity (G_s)	Liquid Limit (%)	Plastic Limit (%)	Plasticity Index (%)	% silt +clay	Soil Type
1	Boko, Kamrup	0.6	Grey	2.65	36.77	19.05	17.7	72.32	CI
2	Bengbari, Udalguri	0.5	Yellowish grey	2.7	33.42	16.99	16.42	75.38	CL
3	Ambagaon, Udalguri	0.3	Grey	2.7	30.70	18.07	12.62	85.29	CL
4	Deeporbheel	0.6	Yellowish grey	2.65	33.1	16.59	16.51	92.42	CL

SLM obtained from Boragaon dumpsite was dark brown in colour with relatively low specific gravity of 2.41. The GSD curve shows fraction of 57.52% passing for particles of size below 0.075mm. From consistency limit test, it is observed no 3mm size thread was formed. This indicates a lack of plasticity in the clay size range, leading to the classification of the material as non-plastic within the clay-size range, (Manoj Datta, IIT Delhi).

Wet sieve analysis is done to find the grain size distribution of the particles and the superimposed gradation curve are shown in **figure 3.12**

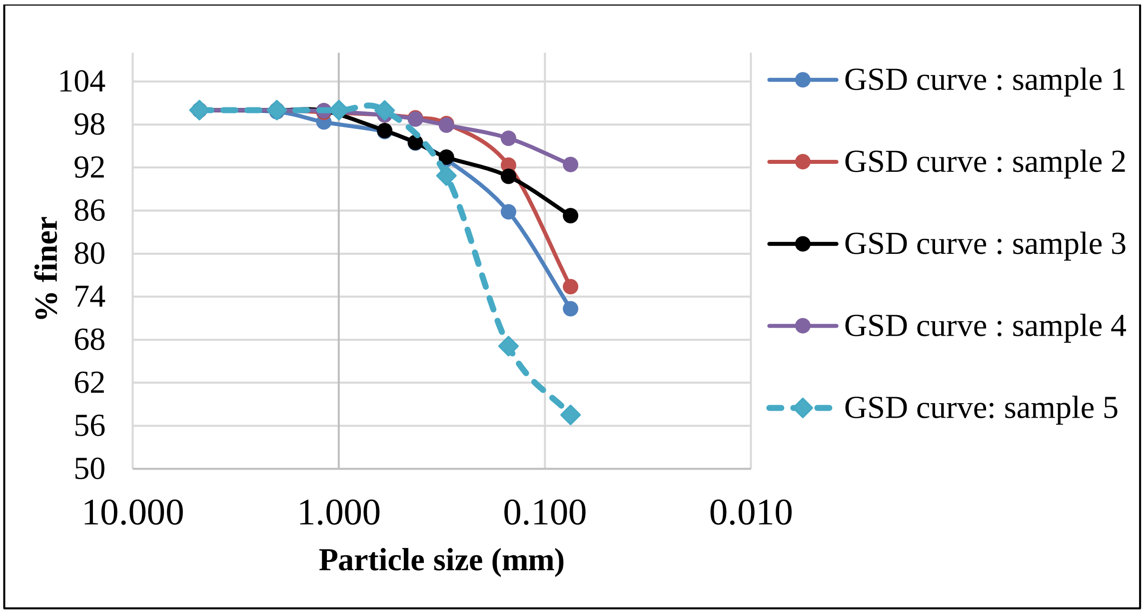

Figure 3.11 Superimposed curve of stress vs. strain of both the soil samples and SLM

3.3.3 Test results for Standard Proctor Compaction Test:

Standard Proctor test is done to get the OMC and MDUW of soil so that the soil can be tested at OMC to attain the maximum possible strength. The compaction parameters of the four soil samples and the SLM are presented in the **table 3.5**.

Table 3.5: Maximum Dry Unit Weight (kN/m³) and Optimum Moisture Content (%) of the four soil samples and SLM

Sample No.	Site Location	Maximum Dry Unit Weight (kN/m³)	Optimum Moisture Content (%)
1	Boko, Kamrup	16.40	17.50
2	Bengbari, Udalguri	16.70	17.50
3	Ambagaon, Udalguri	17.00	16.00
4	DeeporBheel, Kamrup	17.64	17.00
5	Boragaon	13.53	26.50

3.3.4 Test results for Unconfined Compression Strength (UCS) Test:

The Unconfined compression tests are performed on compacted soil specimens as per IS Code to determine the unconfined compressive strength of the four soil samples and SLM at their respective OMC, mixing 0%, 1%, 2% and 3% plastic of each type (PP and HDPE) on each soil. The UCS results obtained from all the five samples mixed with both PP and HDPE plastic waste at various percentages are shown in the following table:

Table 3.6: Unconfined compression strength Value of compacted soil specimens

Sample No.	% waste plastic	UCS Value for PP Plastic	UCS Value for HDPE Plastic
		kPa	kPa
1	0	424.029	424.029
	1	284.885	267.672
	2	303.66	281.471
	3	263.556	243.82
2	0	499.747	499.747
	1	364.611	454.796
	2	467.97	381.631
	3	370.10	277.52
3	0	389.618	389.618
	1	280.274	381.380
	2	298.907	368.337
	3	228.789	359.511
4	0	381.58	381.58
	1	410.66	546.256
	2	531.65	500.07
	3	402.03	471.70
5	0	167.713	167.713
	1	160.549	226.036
	2	229.491	263.194
	3	159.613	174.915

3.3.5 Test results for California Bearing Ratio (CBR) Test:

Adopting light compaction method, the unsoaked CBR test, with different percentage of plastic waste is done at OMC of each soil sample as per IS 2720 (part 16)-1987. Similar procedure is adopted for SLM as well. The unsoaked CBR values of all the soil samples and SLM for both PP and HDPE at different percentage are tabulated in the following **Table 3.7**

Table 3.7: Unsoaked CBR value at (0 to 3) % plastic waste:

Sample No.	% Waste Plastic	CBR Value (%)	
		PP	HDPE
1	0	22.67	22.67
	1	18.82	18.66
	2	27.71	26.49
	3	14.71	21.5
2	0	12.26	12.26
	1	22.69	16.14
	2	29.14	21.14
	3	27.77	14.77
3	0	19.93	19.93
	1	10.56	30.36
	2	29.54	31.13
	3	12.26	20.26
4	0	15.89	15.89
	1	10.74	13.87
	2	19.98	16.31
	3	8.94	11.53
5	0	8.83	8.83
	1	5.05	4.59
	2	9.85	9.05
	3	6.82	6.06

CHAPTER 4

ANALYSIS OF TEST RESULTS

4.1 INTRODUCTION

The rapid increase in population, industrialisation, and urbanisation in recent decades has led to the accumulation of significant quantities of Municipal Solid Wastes (MSW) in various cities. These waste accumulations consist of a wide range of materials, including groceries, food remnants, vegetable scraps, packaging items, paper, residues from burned coal, ash, wood, metals, plastics, ceramics, textiles, glass, and even debris resulting from construction and demolition activities (C&D). In India, an annual MSW generation of approximately 60 million tonnes takes place, with these wastes being deposited in designated landfills across different urban areas. Regrettably, these landfills are causing adverse effects on the general health, sanitation, hygiene, and visual attractiveness of their surroundings. Without proper waste disposal measures, there is a potential for significant environmental and hazardous threats to arise.

Municipal solid wastes (MSW) exhibit a wide range of physical, chemical, and biological attributes due to their inherent heterogeneity in terms of geo-environmental and geotechnical parameters. This heterogeneity arises from diverse sources, consumption behaviors, as well as cultural, climatic, and social distinctions that impact their characteristics based on their point of origin.

The fundamental concept of sustainable solid waste management is to optimize the utilization of materials to the highest degree feasible, while relegating disposal to the least favored course of action (Directive, 2008; Wagner and Raymond, 2015).

As part of a sustainable approach to road construction, the CSIR-Central Road Research Institute in New Delhi undertook an investigation into the feasibility of utilizing Municipal Solid Wastes (MSW) collected from Ghazipur in East Delhi as a material for embankment filling. The different constituents of the waste were closely examined to determine their suitability for inclusion in embankment construction. The refined MSW underwent a thorough geotechnical analysis to understand its characteristics. Extensive evaluations of stability and settlement were conducted to assess its appropriateness for embankment establishment. The findings revealed that around 65-75% of the segregated MSW could be effectively employed in the process of constructing embankments.

In the present study, fine fraction reclaimed from waste has been defined as the fraction of aged MSW finer than 4.75mm in size. Material finer than 4.75mm comprises of clay, silt and sand as per geotechnical application (**IS 2720-4 (1985**)). In this study we are trying to investigate the geotechnical and physicochemical characteristics of SLM obtained from aged MSW and its feasibility for utilization as road embankment filling material. Alongside, an attempt has been made to compare the geotechnical properties of SLM with those of the native soil.

4.2 GEOTECHNICAL CHARACTERISATION OF SLM

The characterization of excavated landfill waste has been accomplished through the segregation of the waste into distinct particle size categories, followed by analysis of these segregated fractions (Hogland, 2002; Hull et al., 2005; Kurian et al., 2003; Prechthai et al., 2008; Quaghebeur et al., 2013).

The soil sample collected from the designated borrow site with the intention of constructing a highway embankment undergoes essential laboratory tests. These tests encompass the evaluation of parameters such as liquid limit, plasticity index, free-swell index, soluble sulfate content, organic matter, and compacted density. Once it is confirmed that the soil meets the prescribed criteria, its suitability for construction purposes is confirmed. As a result, a range of laboratory characterization assessments were performed on the soil-like material (SLM). These assessments included analyses of grain size distribution, plasticity characteristics, specific gravity, free swell index, compaction properties, shear strength, and California bearing ratio. These analyses were conducted to determine the feasibility of employing the SLM as a construction material.

4.2.1 Grain size distribution of SLM

When performing the Grain Size Distribution (GSD) analysis following IS 2720 part 4, it was observed that the SLM had a percentage finer value of 57.52%, indicating its classification as fine-grained soil-like material. In comparison to the original soil samples, the SLM exhibited a notably coarser texture. This discrepancy can be attributed to the notable proportion of Construction and Demolition (C&D) waste falling within the sand size range.

Different definitions of 'finer fractions' can be found in the literature, depending on the specific sieve size used. Generally, fine fractions (commonly referred to as sizes ranging from <10mm to <60mm) have been established to make up 40%–80% of the extracted materials in prior research studies (Hogland, 2002; Hull et al., 2005; Kaartinen et al., 2013; Kurian et al., 2003; Monkare et al., 2016).

The laboratory analysis of grain size in SLM samples (4.75 mm and below) was conducted following air drying. Both dry and wet sieve analyses were performed on the SLM sample. The wet sieve analysis yielded a higher proportion of fine fraction in comparison to the dry sieve analysis. The increased fine fraction in the wet sieve analysis is attributed to a more effective breakdown of waste particle clumps, as noted al. (2016), by Somani et al. (2018). Consequently, the wet sieving method was adopted for this study, and the corresponding Grain Size Distribution (GSD) curve is depicted in Figure 3.12.

Somani et al. (2018) found that the proportion of soil-like material in the Hyderabad landfill decreased when the Grain Size Distribution (GSD) analysis was conducted without prior air drying. The GSD results indicate that a substantial portion of soil-like material was detected within the aged MSW samples from all landfills, thereby suggesting its potential geotechnical suitability.

As per IRC 36-2010 the size of the coarse material in the mixture of earth shall be less than 75 mm when placed in the embankment and 50 mm when placed in subgrade. However, the maximum particle size in no cases can be more than two-third of the compacted layer thickness. In the SLM, as the particles have passed through 4.75 mm IS sieve, it could be used in both embankment and subgrade provided the sample fulfils all the requisite criteria to consider the same as suitable for the construction.

4.2.2 Atterberg limit test

The plasticity properties of various samples were determined according to IS: 2720 (Part 5) – 1985. While the native soil displayed plasticity characteristics, the SLM was found to lack plasticity. Additionally, the SLM exhibited a liquid limit of 45.8%. Nonetheless, Havangi et al. (2017) reported that the liquid limit of SLM from different locations ranged between 32-34%, indicating a moderate level of plasticity. This discrepancy might arise from the water absorption by the organic humus content present in the MSW. In a similar context, Oettle et al. (2010) concluded that waste with comparable gradation exhibited varied compaction characteristics, even though the Atterberg limits for the different samples all aligned along the A-line. This variation was attributed to differences in the organic content.

4.3.3 Free Swell Index Test

The Free Swell Index (FSI) test was conducted following the guidelines outlined in IS: 2720- Part 40. The results indicated that the SLM from the Boragaon dumpsite exhibited a free swell index of zero, signifying its non-swelling properties. In contrast, Havangi et al. (2017) found that the free swell index of SLM from various locations ranged from 12% to 24%, indicating a limited propensity for swelling.

In accordance with IRC specifications, the free swell index should remain below 50% for the SLM to be used as fill material. Consequently, the SLM meets the swelling requirement necessary for its application in embankment construction. Furthermore, referring to IS: 1498-1970, the SLM's degree of expansion and severity was classified as low and non-critical, respectively, given its FSI value of $<50\%$.

4.4.4 Specific gravity

The average specific gravity of the SLM was found to be 2.41 which is relatively low compared to the native soil specimens. M. Datta et al. (2020) found that the specific gravity ranges from 2.10-2.62 for aged MSW. These lower values could be attributed to the higher percentage of organic material in the SLM. Specific gravity of the SLM in the range 2.20-2.30 was obtained by Najamuddin et al. (2021).

4.4.5 Compaction characteristics

Standard Proctor compaction tests, as per IS: 2720 (Part 7) - 1980, were conducted to investigate the compaction properties of all samples. The relationship between Maximum Dry Density (MDD) and moisture content is depicted in Figure 4.1. Notably, the compaction curves for the SLM exhibit a plateau-like nature, indicating minimal fluctuations in dry density with changing moisture content. Havangi et al. (2017) reported that the MDD and Optimum Moisture Content (OMC) of SLM ranged from 16 kN/m^3 to 16.7 kN/m^3 and 14% to 17%, respectively. They suggested that the

SLM material could be suitable for constructing embankments exceeding a height of 3 meters according to MORTH specifications. However, it's essential to perform stability analysis considering the prevailing site conditions before initiating construction.

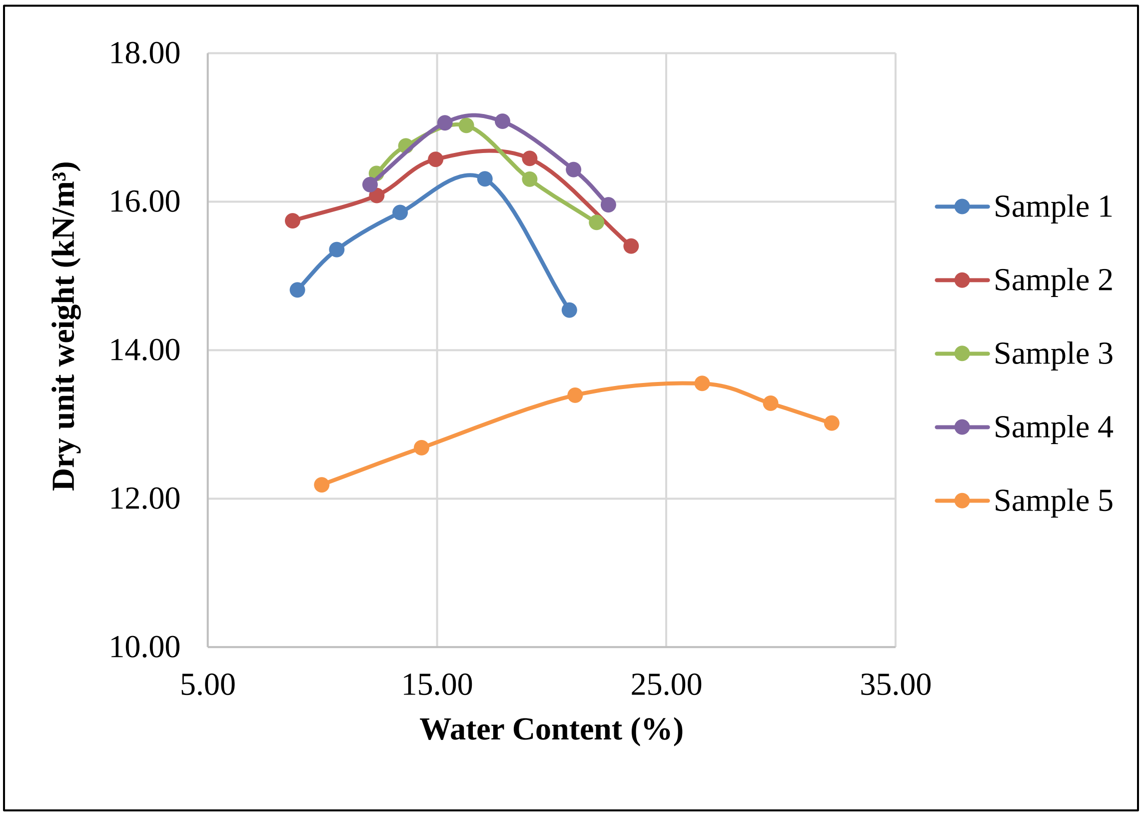

Figure 4.1 Compaction curve for SLM and native soil

The compaction curves indicate that the native soil samples demonstrate a higher maximum dry unit weight (MDUW) and a lower optimum moisture content (OMC) in contrast to the SLM. This observation aligns with findings from M. Datta et al. (2020), who noted that SLM exhibited a decreasing MDUW and an increasing OMC as organic content increased. Thus, it can be inferred that the native soil samples displaying higher MDUW and lower OMC likely contain a lower amount of organic content in comparison to the SLM.

The MDUW and OMC of the SLM were found to be 1.38 g/cc and 26.56 % respectively. As per IRC:36-2010 value of subgrade when not subjected to frost action found to be poor since the MDD is less than 1.44 g/cc. The soaked CBR value is estimated around 3% and the comparable soil groups in Indian Standard Soil

Classification System for SLM is found to be OI, MH or OH. But the liquid limit of the SLM was less than 50%. So, the classification of SLM on the basis of IS soil classification is not possible.

Along with the standard Proctor compaction test, modified Proctor compaction test was done the SLM and the MDUW and OMC corresponding to modified Proctor compactive effort was found to be 1.45 g/cc and 20.45% respectively. As per IRC:36-2010 following requirements need to be followed:

Table 4.1 Density requirement of embankment and subgrade materials

<table>
<tr><th>Type of road</th><th>Type of work</th><th>Embankment</th><th>Subgrade</th></tr>
<tr><td rowspan="2">For national highways/ state highways/ major district roads (As per IS:2720-part-8)</td><td>Embankment upto 3m height not subjected to extensive flooding</td><td>Not less than 15.2 kN/m³</td><td rowspan="2">Not less than 17.5 kN/m³</td></tr>
<tr><td>Embankment upto 3m height not subjected to extensive flooding</td><td>Not less than 16 kN/m³</td></tr>
<tr><td rowspan="2">Rural Roads (As per IS:2720-part 7)</td><td>Embankment not subjected to flooding</td><td>Not less than 14.4 kN/m³</td><td rowspan="2">Not less than 16.5 kN/m³</td></tr>
<tr><td>Embankment subjected to flooding</td><td>Not less than 15.2 kN/m³</td></tr>
</table>

The MDUW were found to be 14.25 kN/m³ and 13.54 kN/m³ when the SLM is subjected to heavy compaction and light compaction respectively. It is observed that the densities are slightly less than the required density for both embankment and subgrade. So, the SLM cannot be used directly either in embankment construction or as subgrade materials. By adopting suitable soil improvement technique, the density can be increased to the desired level. Blending the SLM with native soil could be an effective as well as economic way to resolve the density gap which needs to be investigating further.

As all the four native soil show densities greater than 16 kN/m³. Therefore, they can be used in all type of embankment works. The potential use of the native soil as subgrade materials depends on whether a particular soil fulfills the minimum density requirement or not.

4.4.6 Analysis of test results of unconfined compression test (UCT)

Strength characteristic of MSW were studied as per IS:2720 (Part 10)- 1991. The test was carried out on compacted sample with length to diameter ratio 2 where the sample was compacted at OMC so that the MDD is maintained in the sample. Typical stress-strain curves for the SLM and native soil are shown in Figure 4.2.

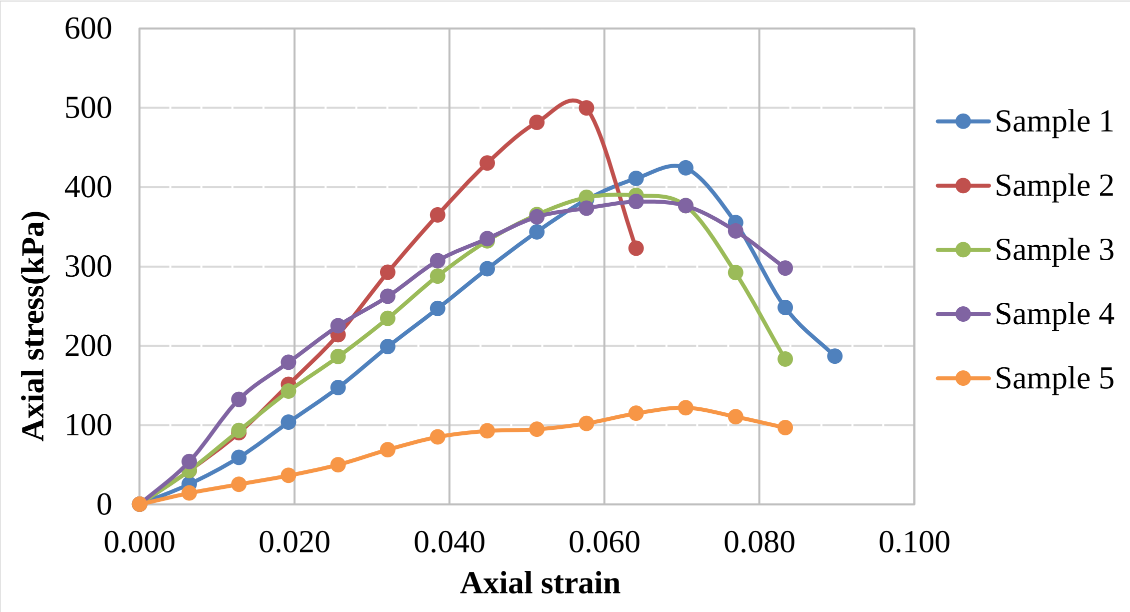

Figure 4.2 Stress- strain relationship between SLM and native soil

From the graph it is evident that the UCS of the SLM is much lower than the native soil. This may be due to the heterogeneity of the SLM and higher organic content of the soil compared to native soil. Moreover, non-swelling behaviour (i.e. FSI=0) of the SLM suggests minimal clay content which helps to build cohesion in the sample. Microstructure study of the compacted specimen can reveal the cause in the variation of UCS which can be investigate further using scan electron microscope (SEM), mercury intrusion porosimetry (MIP) etc.

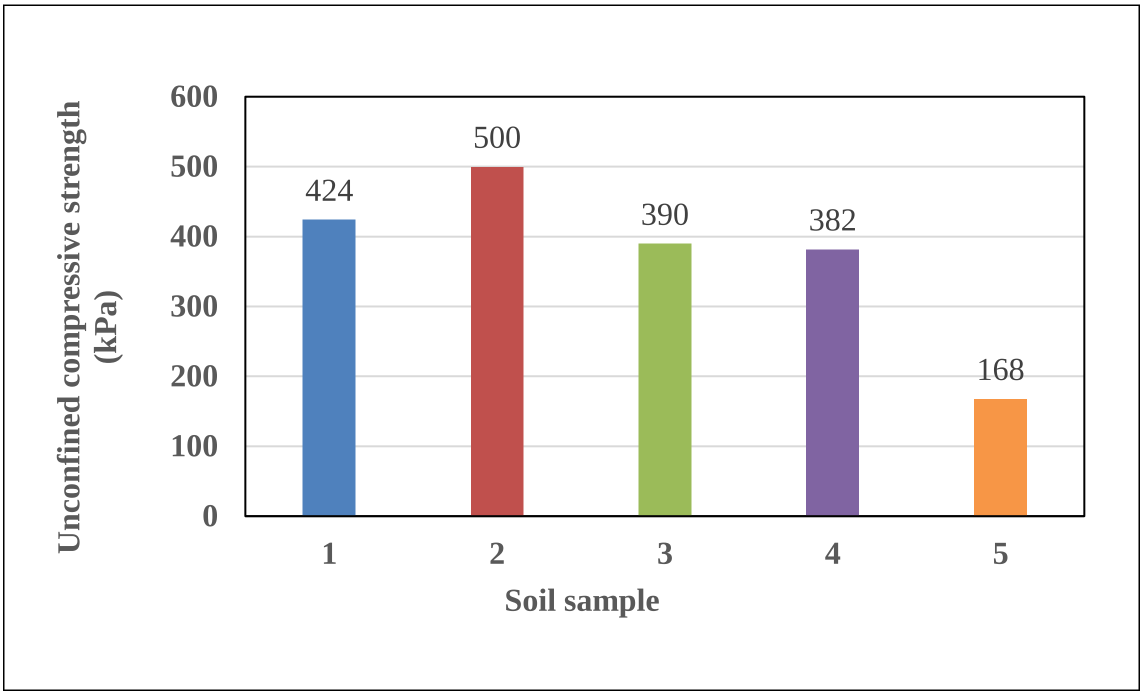

Figure 4.3 Histogram for SLM and native soil

After the investigation on geotechnical properties of contaminated soils at dumping sites in Chickballapur city of Karnataka, Nanda et al. (2011) reported that the unconfined compressive strength decreased considerably for soil samples obtained at 0.0 m, 0.5 m and 1.0 m depths below waste dump. At depths greater than 1.5m compaction characteristics and UCS closely matches with the uncontaminated soil. They have further stated that leachate contamination leads to alter the compaction, density and strength properties of soil and this is attributed due to chemical reactions with the leachate and soil particles.

To investigate the influence of PP flakes and HDPE granules on the compressive strength of SLM and native soil samples, the additives are mixed in different percentage (namely 1%, 2% and 3% of dry sample) to the samples and the corresponding unconfined compressive strength parameters are assessed. The superimposed stress-strain curve for sample 1 and sample 5 for soil mixed with both PP and HDPE are shown below and the rest of the stress-strain curves are attached in appendix I

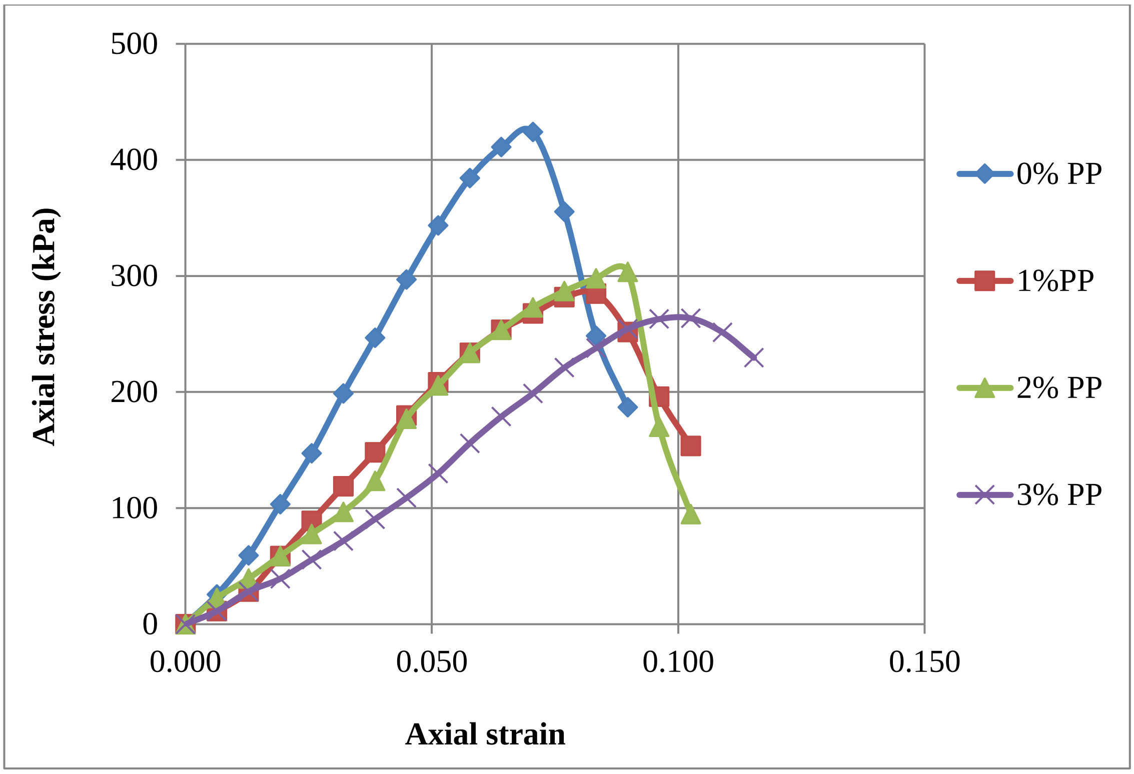

Figure 4.4 super-imposed stress-strain curve of sample 1 at different percentage of PP

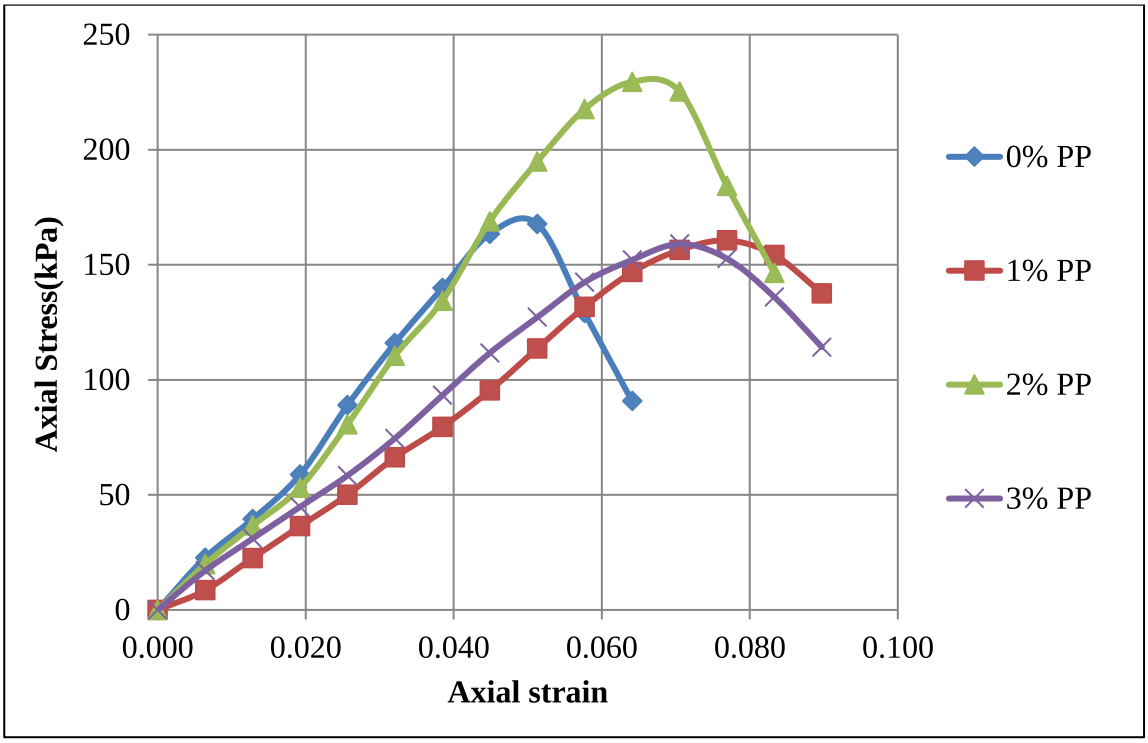

Figure 4.5 super-imposed stress-strain curve of sample 5 at different percentage of PP

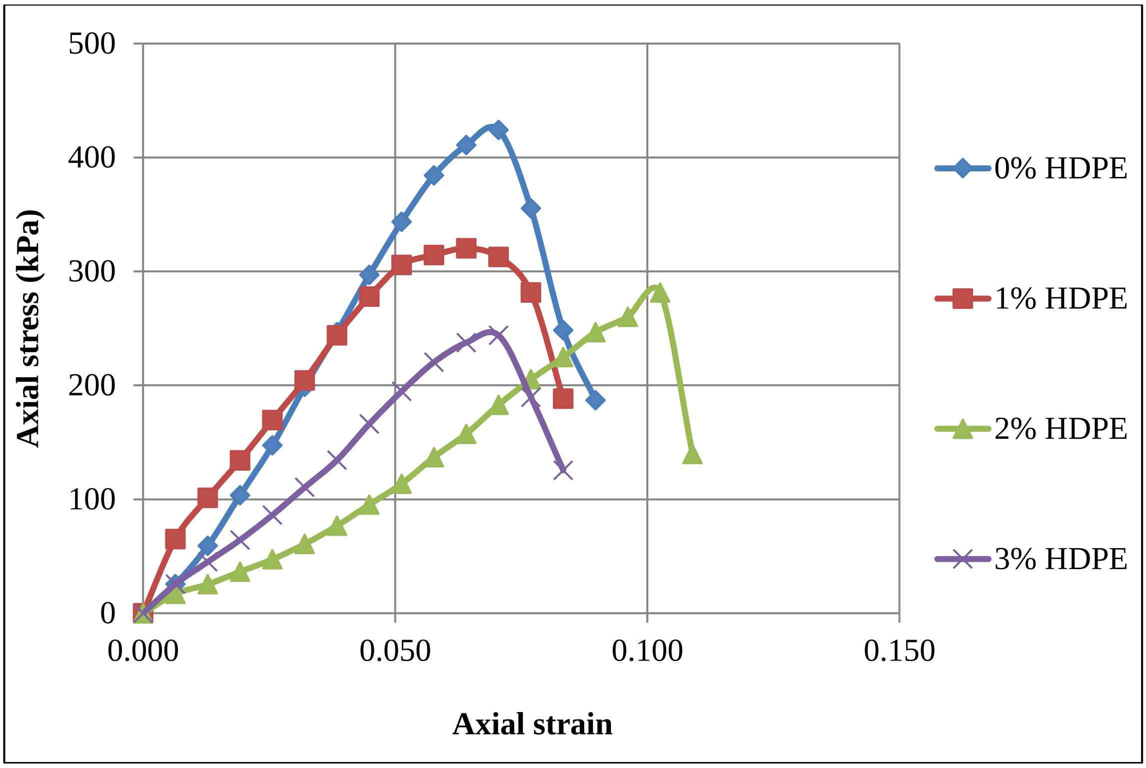

Figure 4.9 super-imposed stress-strain curve of sample 1 at different percentage of HDPE

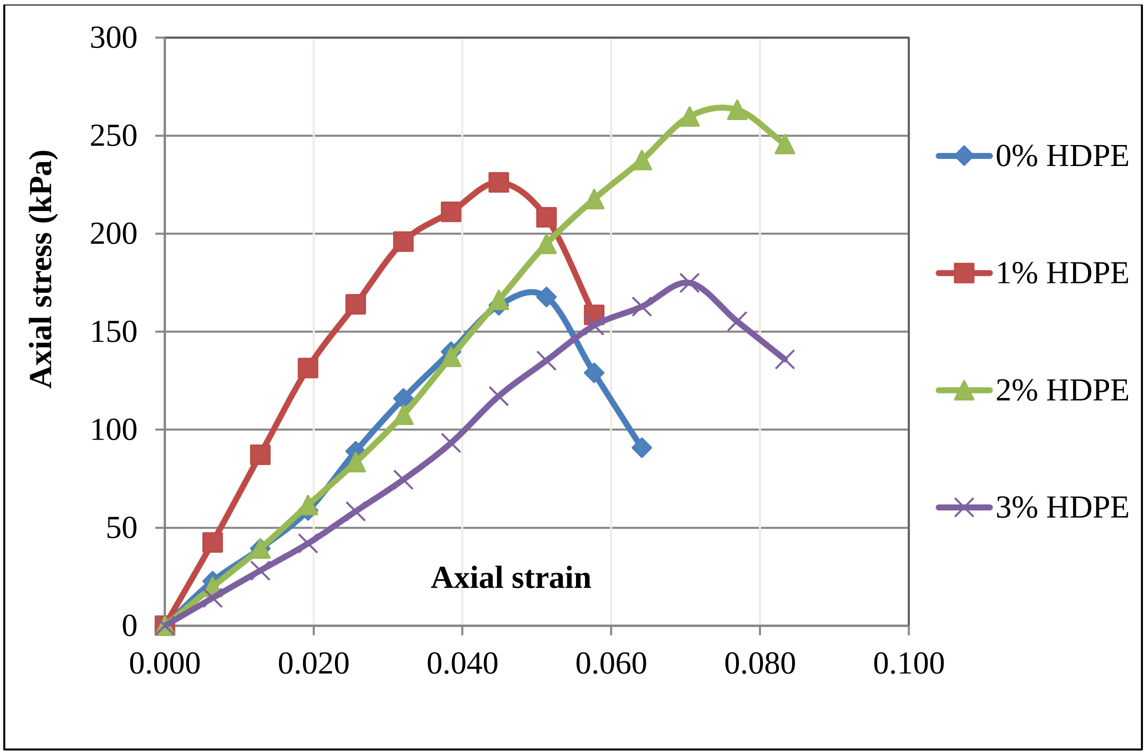

Figure 4.10 super-imposed stress-strain curve of sample 5 at different percentage of HDPE

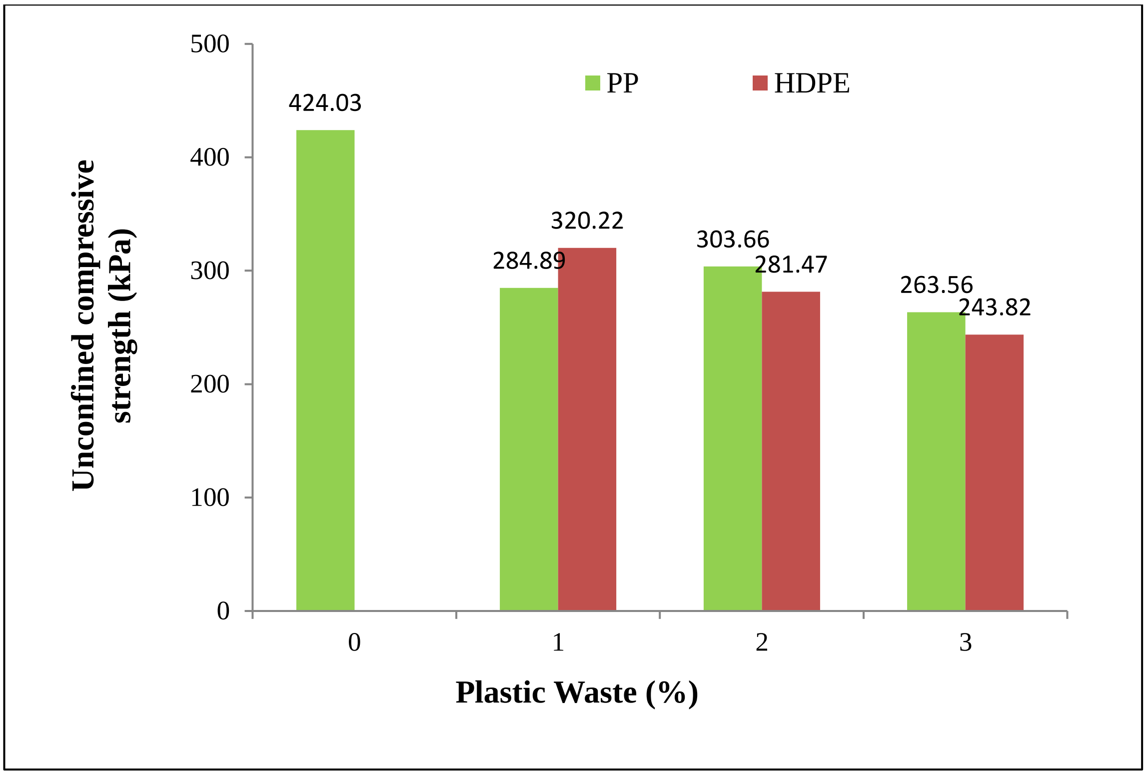

Figure 4.14 Plastic waste (PP & HDPE) vs UCS of sample 1

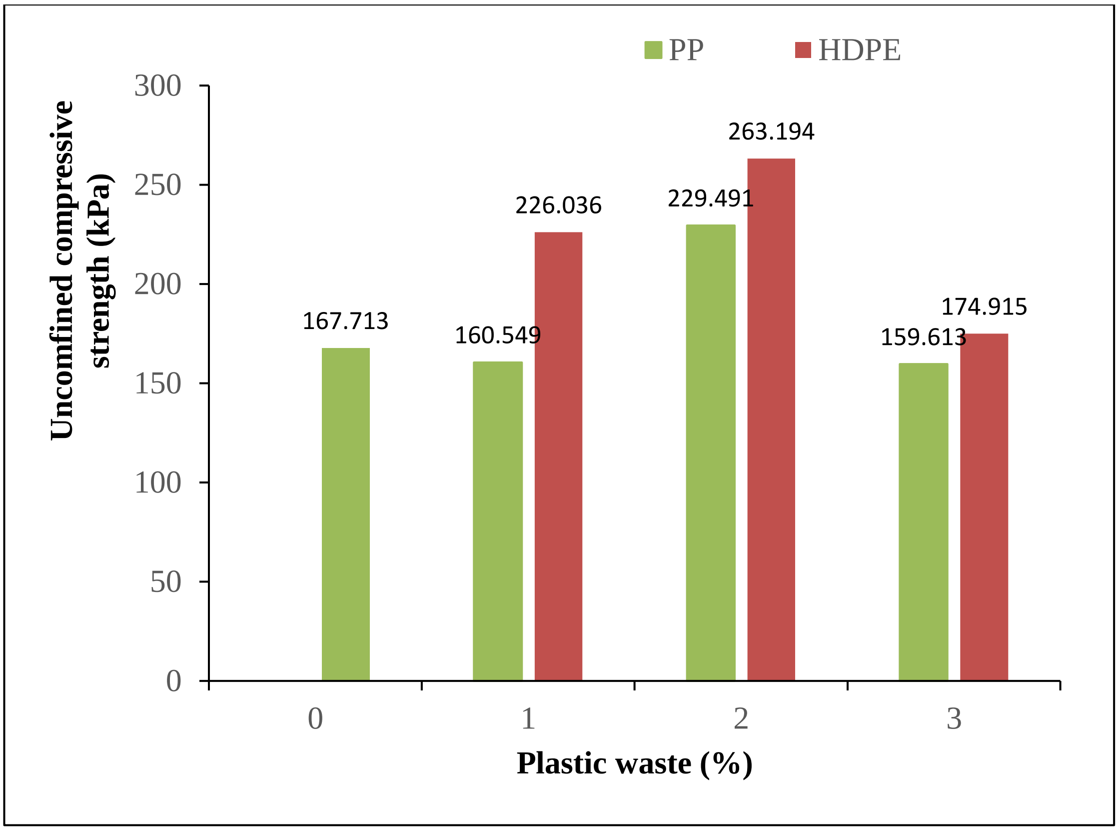

Figure 4.15 Plastic waste (PP & HDPE) vs UCS of sample 5

The histogram clearly illustrates that the optimum plastic content is 2% for PP flakes and 1% for HDPE granules. However, the native soil, with 0% plastic content, exhibits higher UCS values for soil samples 1, 2, and 3. In the case of soil sample 4, there is a gradual rise in UCS from 0% plastic content, followed by a decrease after 2% for PP and 1% for HDPE. This UCS trend remains consistent for other soil samples (1, 2, & 3) at 2% PP and 1% HDPE, displaying the highest UCS value at 0% plastic content for the native soil.

In the SLM, the addition of both PP and HDPE elevates UCS, with the optimal plastic content identified as 2%. Subsequent additive increases result in reduced strength, notably evident at 3%. Thus, it can be deduced that additives function as reinforcing agents in the SLM, up to a waste percentage of 2% of the dry SLM weight.

The incorporation of 1% plastic into soil samples 1, 2, and 3 leads to diminished UCS values, likely due to plastic addition disrupting the soil structure, which is more compact in its original state. Furthermore, the constant optimum moisture content contributes to this UCS reduction. In contrast, samples 4 and 5 (SLM) show a similar UCS trend upon additive inclusion, with the peak UCS value observed at 2%.

The test outcomes highlight that the impact of adding PP flakes and HDPE granules to soil does not consistently enhance UCS; it hinges on the soil type. Soil initially exhibiting satisfactory strength might weaken with plastic additive incorporation, with strength variation depending on plastic content. Soils with low initial UCS values exhibit augmented strength up to the optimal plastic content. The relative UCS increases for all soil samples are summarized in Table 4.2.

Naeini and Sadjadi (2008) noted that unconfined compressive strength (UCS) of soil increases with fiber content up to a certain threshold, after which it decreases. They postulated that surpassing the threshold prompts fiber panels to slide over each other, causing soil particle separation and subsequent strength decline.

Muntohar (2009) observed that the presence of fibers in soil stabilization causes the applied load to be transferred to the frictional interface between soil particles and fibers. The number of interfaces between soil and fibers increases as the fiber content increases, leading to a rise in friction between soil particles and fibers (Olgun, 2013). Consequently, soil particles surrounding the fibers find it challenging to change position, resulting in an improvement in the soil cohesion between soil particles (Muntohar et al. 2013). Moreover, the fiber's high tensile strength significantly contributes to increasing the soil's ability to withstand more loads and its unconfined compressive strength (UCS) (Tang et al., 2007a, b).

Table 4.2 Relative increase in UCS

Sample	**UCS (kPa)**				
	Virgin soil	**At optimum percentage of PP**	**At optimum percentage of HDPE**	**% increase for PP**	**% increase for HDPE**
1	424.03	303.66	320.22	-28.39*	-24.48*
2	499.75	467.97	454.79	-6.36*	-9.00*
3	389.72	298.91	381.38	-23.30*	-2.14*
4	381.58	531.65	546.26	39.33	43.16
5	167.71	229.49	263.19	36.84	56.93

*(-) sign indicates % decrease in value

Unconfined Compressive Strength (UCS) represents the maximum axial compressive stress a soil sample can endure without lateral support. The incorporation of plastic flakes into fine-grained soil can potentially impact its UCS value, contingent upon plastic flake quantity and properties.

Initially, the addition of plastic flakes can bolster the UCS of fine-grained soil. This enhancement stems from the plastic flakes reinforcing soil structure and occupying voids, culminating in an overall strength improvement. However, heightened plastic flake volume may introduce micro cracks and defects, subsequently diminishing UCS.

Furthermore, the lasting repercussions of plastic flakes on the UCS of fine-grained soil are influenced by multiple factors: plastic type, flake size and shape, and environmental conditions. In scenarios where non-biodegradable plastic is used, eventual degradation of plastic flakes could lead to prolonged strength deterioration within the soil.

It's essential to recognize that the impact of plastic flakes on soil strength and stability is intricate, contingent upon several factors. This complexity underscores the need for thorough testing and analysis to comprehensively assess both the potential advantages and disadvantages associated with the introduction of plastic flakes into fine-grained soil.

The fundamental aspect that governs the frictional interplay between reinforcing materials like PP and HDPE and the surrounding soil particles is the surface area. A larger surface area of the reinforcing material facilitates interaction with a higher count of soil particles, augmenting overall frictional resistance and thereby enhancing the soil's UCS.

Additionally, the reinforcement material's surface area also holds sway over soil permeability. An increase in the reinforcement material's surface area can lead to a reduction in void spaces within the soil, resulting in decreased soil permeability. This reduction in permeability elevates effective stress within the soil, further contributing to heightened UCS values. It is important to note that the effects of plastic flakes on soil strength and stability are intricate and reliant on multiple factors, necessitating comprehensive testing and analysis to evaluate the possible benefits and drawbacks of introducing plastic flakes to fine-grained soil.

4.4.7 Analysis of the test results of CBR test:

The CBR test was employed to indirectly determine the soil's bearing capacity. The unsoaked CBR is only tested in this study because it is more time-efficient and cost-effective compared to soaked CBR test. The primary focus of the study was to investigate the optimum plastic content which is expected to provide best results in terms of strength. Comparative study of the CBR value (unsoaked) of all the soil samples mixed with different percentage of plastic (PP and HDPE) is trying to discuss here. The variation of CBR value of the plastic mixed soil compared to native soil is presented in table 4.3

Table 4.3 Variation of CBR value at different plastic content:

Sample	CBR (%)				
	Virgin soil	At optimum percentage of PP	At optimum percentage of HDPE	% increase for PP	% increase for HDPE
1	22.67	27.71	26.49	22.20	16.85
2	12.26	29.14	21.14	137.68	72.43
3	19.93	29.54	31.13	48.22	56.20
4	15.89	19.98	16.31	25.74	2.64
5	8.83	9.85	9.05	11.55	2.49

The superimposed curves of load vs penetration for sample 1 and sample 5 (i.e. SLM) at different plastic content are presented below along with their respective histogram. The rest of the graphs and corresponding histograms are shown in appendix II

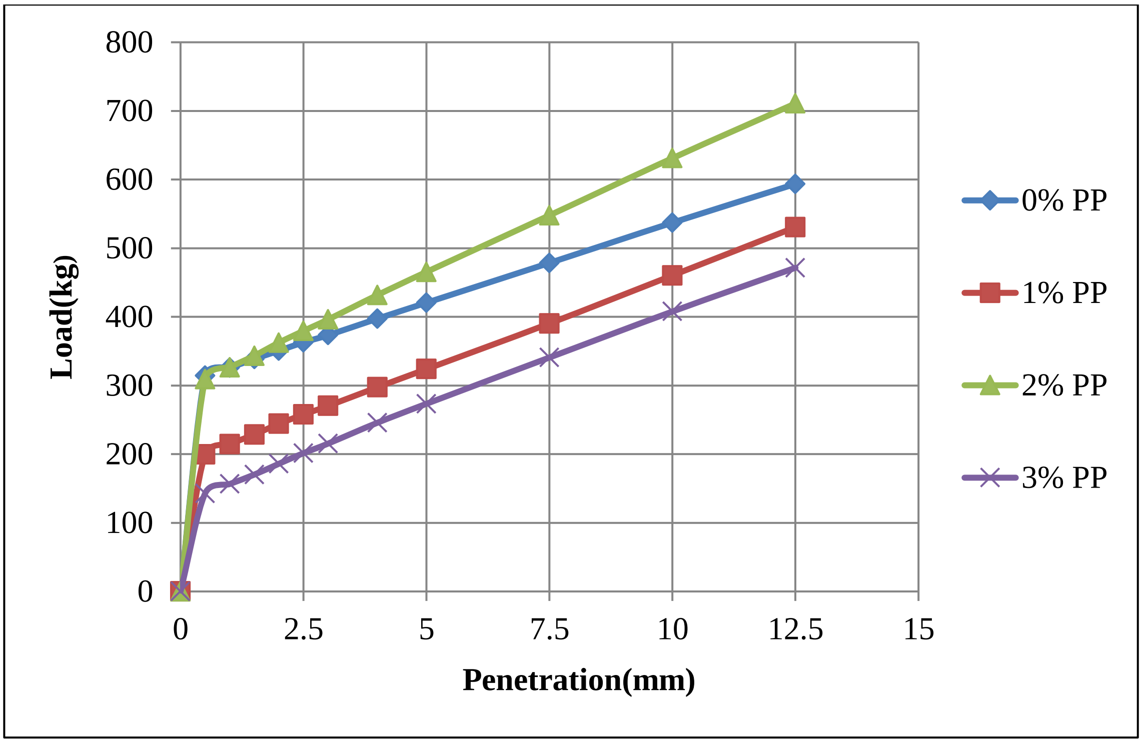

Figure 4.19: Superimposed curves of load vs penetration for Sample 1 with PP

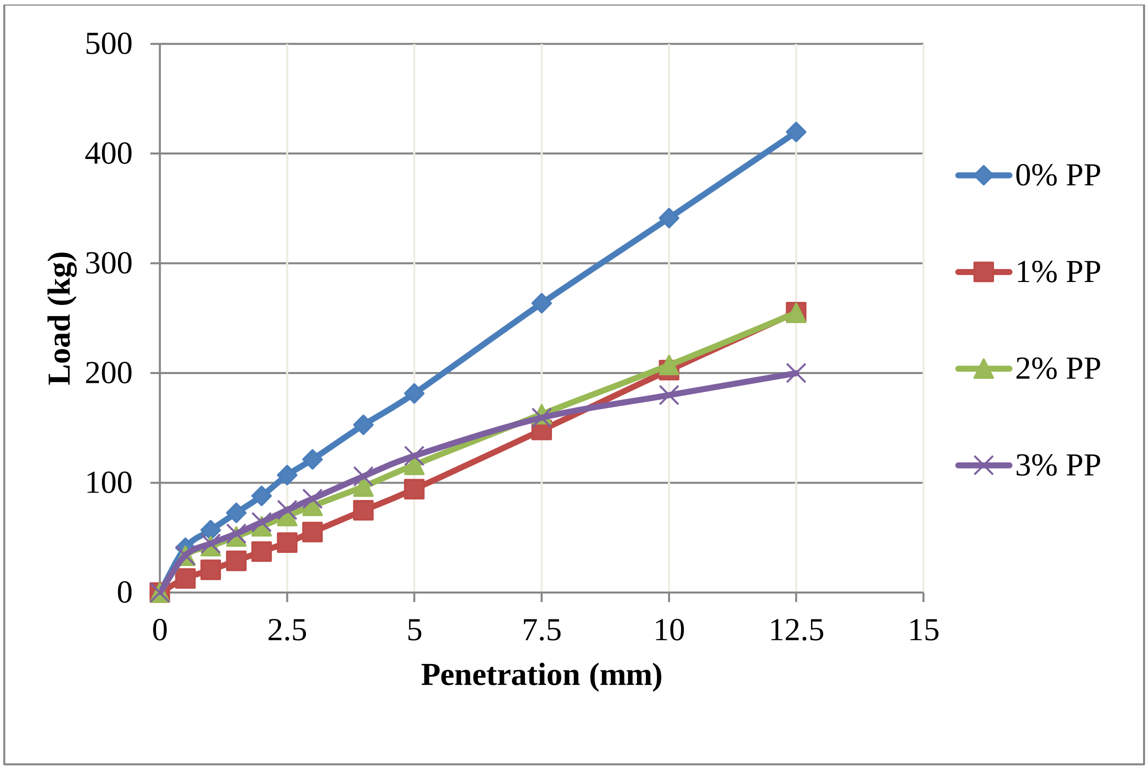

Figure 4.20: Superimposed curves of load vs penetration for Sample 5 with PP

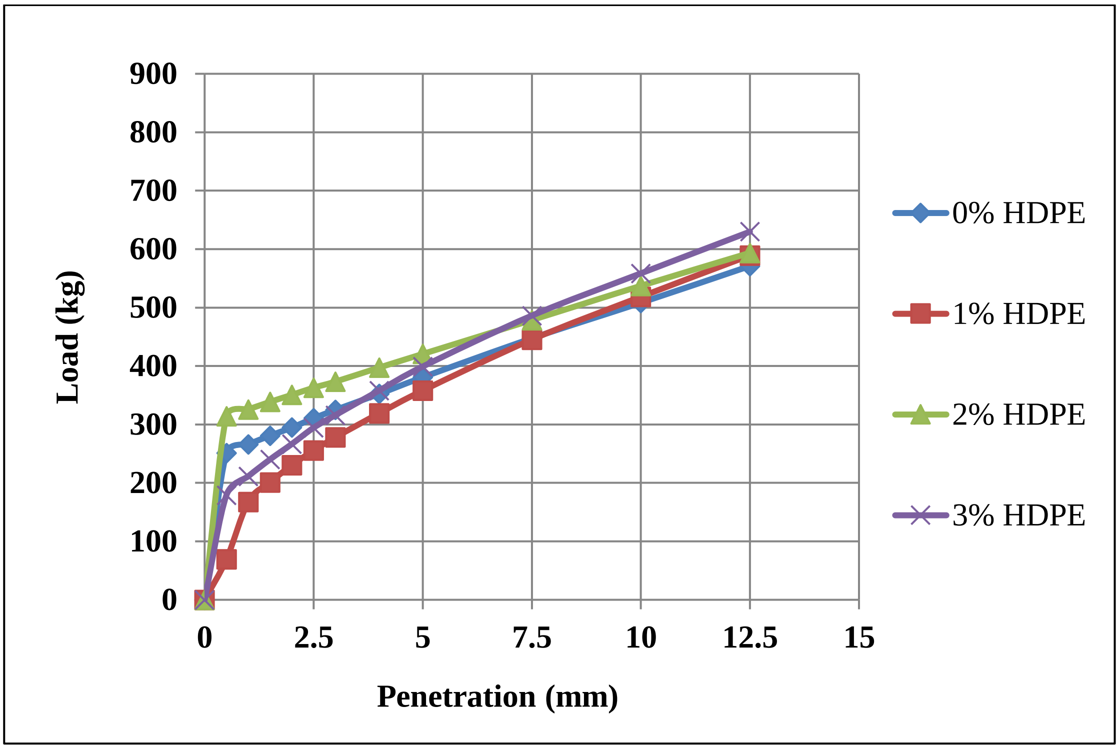

Figure 4.24: Superimposed curves of load vs penetration for Sample 1 with HDPE

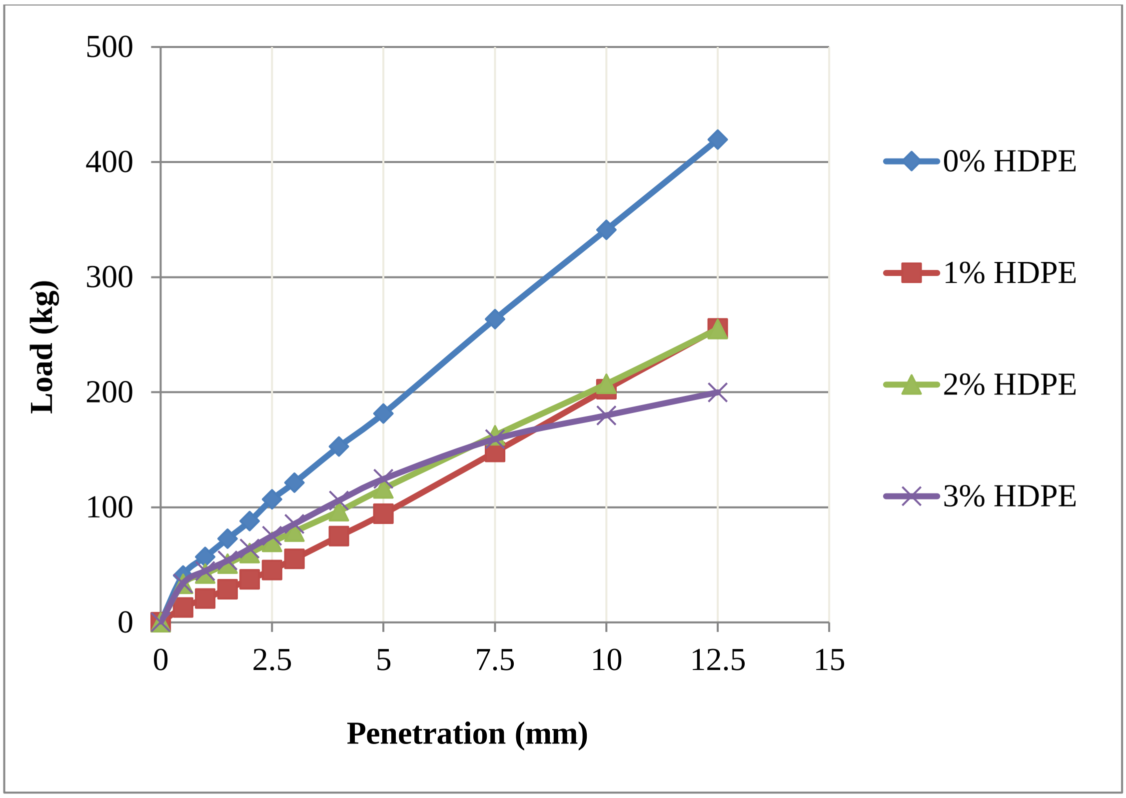

Figure 4.25: Superimposed curves of load vs penetration for Sample 5 with HDPE

The variation of CBR value on addition of different percentage of PP and HDPE to the fine-grained soil is presented below.

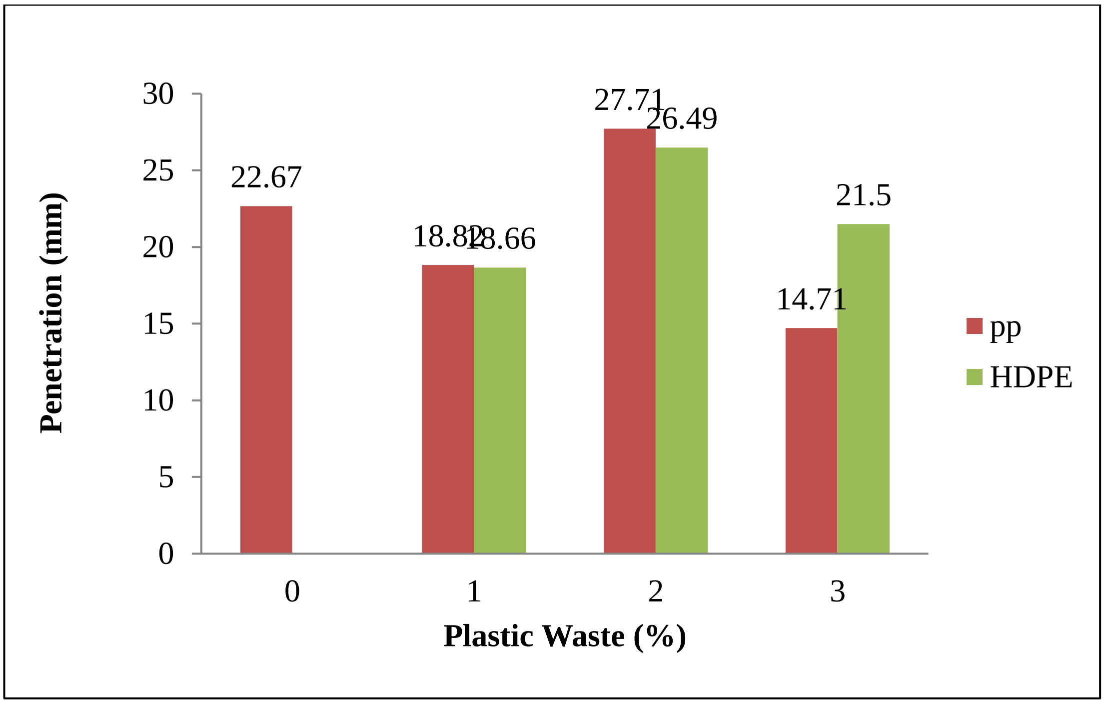

Figure 4.29: Plastic waste vs CBR of Sample 1 for both PP and HDPE

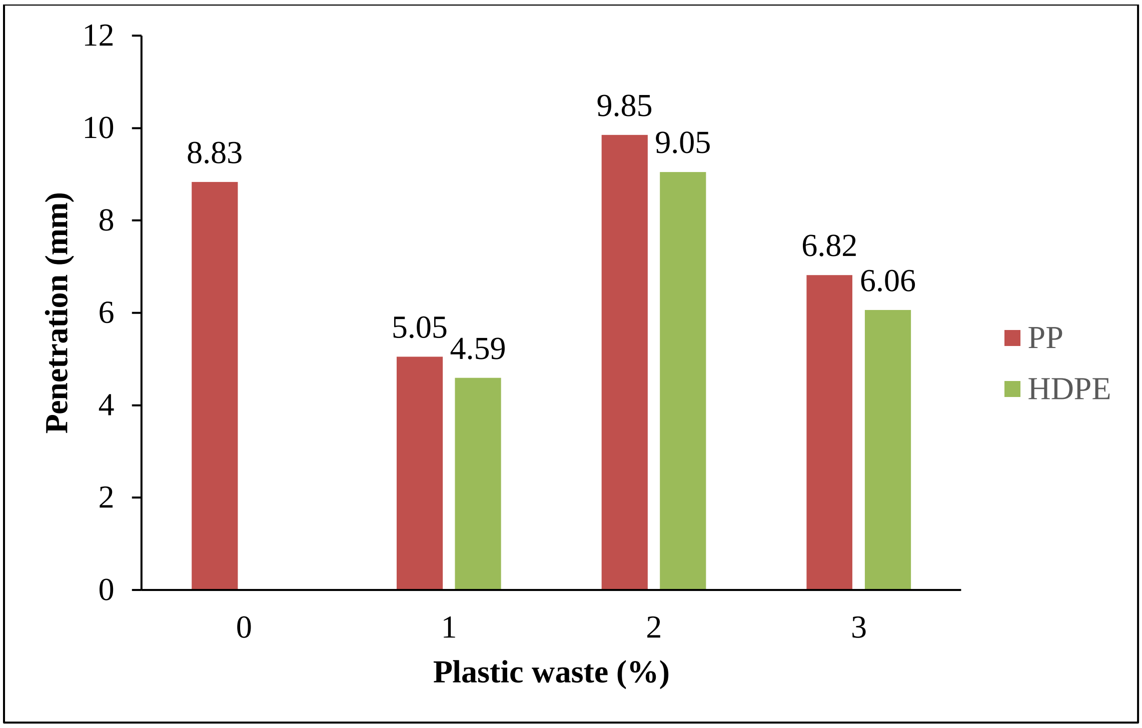

Figure 4.30: Plastic waste vs CBR of Sample 5 for both PP and HDPE

Referring to Table 4.2 where the results of the CBR test is presented, it can be seen that the CBR value of the clayey soil is a function of both plastic content and type of plastic added to the soil. The variation of the CBR value with different plastic content follows a non-linear pattern with maximum CBR value corresponding to 2% plastic content. This optimum plastic content i.e 2%, is found to be same for both PP and HDPE.

Comparing the CBR results corresponding to optimum plastic content, PP mixed soil is showing higher CBR values than HDPE mixed soil. In the soil stabilised with PP, the addition of 2% plastic content produces a percentage increase in CBR as 22.23%,137.68%,48.22%, 25.74% and 11.55% for soil sample 1,2,3,4 and 5 respectively. For the soil stabilised with HDPE, addition of 2% plastic content increases the CBR values by 16.85%, 72.43%, 56.20%, 2.64% and 2.49 for soil sample 1,2,3,4 and 5 respectively. From this result it is clear that plastic content plays a significant role in CBR values.

Again, from the test results is clear that there was a reduction in the CBR value from 0% to 1% plastic content for soil sample 1, 3, 4 and 5. This is because the addition of small amount of plastic into soil lead to a dispersed and disturbed structure to soil than that it was in its compact form (Ashraf et al. (2011)). But in soil sample 2, there is a gradual increase in CBR value from 0% to 2% plastic content and then the value dropped at 3% plastic content.

The incorporation of plastic fibers typically results in an augmentation of the CBR value. This enhancement can be attributed to the interactions taking place between the soil and the fibers. Such interactions create resistance against the penetration plunger, leading to an elevation in the CBR value. This phenomenon has been substantiated by several studies, including Neopaney et al. (2012) and Yetimoglu and Salbas (2003). Choudhary et al. (2010) noted a threefold improvement in CBR values with soil stabilization using polyethylene fibers, as compared to non-stabilized soils. Similarly, Fletcher and Humphries (1991) found a marked enhancement in CBR for soil samples stabilized with polypropylene fibers, particularly with longer fibers. Madavi and Patel (2017) suggested that the optimal plastic content for attaining the highest CBR value is 4%, a slightly higher value than what was observed in the present study.

It is reasonably anticipated that, much like plastic fibers, the interaction between the soil and PP flakes and HDPE granules is expected to follow a comparable pattern as observed with plastic fibers. The increase in CBR values within subgrade soils can wield a significant impact on the required foundation thickness, particularly concerning pavement design methodologies reliant on the subgrade's CBR and modulus of elasticity. An enhancement in the subgrade's CBR and modulus of elasticity can substantially reduce the essential sub-base thickness, thereby leading to a reduction in the expenses associated with road pavement construction. This cost-saving effect can be attributed to the decreased demand for materials and labor that would otherwise be imperative for constructing a thicker sub-base layer.

4.3 PHYSICOCHEMICAL CHARACTERISATION OF SLM

Analyzing the physicochemical characteristics of SLM holds paramount importance in optimizing waste management strategies, resource recovery, environmental safeguarding, and the establishment of sustainable protocols. This examination facilitates well-informed decision-making across various stages of the waste management lifecycle, fostering a more effective and responsible waste handling approach.

The primary focus of this thesis is to explore the viability of utilizing soil-like material (SLM), smaller than 4.75 mm in size, extracted from an old MSW excavation at an open dump yard. The objective is to repurpose this material as embankment fill. The study entails an assessment of the contamination levels within the SLM to gauge its suitability for embankment reuse. Key parameters such as heavy metal content, organic matter presence, total dissolved solids, pH levels, and the release of dark-colored leachate are considered in the evaluation. The findings are subsequently compared to data available in existing literature, as well as national and international guidelines, as elaborated below.

4.3.1 pH

Leachate pH provides insights into the conditions under which waste-derived leachate is generated. The established pH range for leachate at MSW landfills, as documented in literature, typically falls between 5.5 and 8.5 (Kjeldsen et al. 2002; Kulikowska and Klimiuk 2008; Naveen 2015). According to IS 2720 (Part 26) 1987, the pH of the water extract measures 6.98, aligning within the acceptable range of 6.5 to 8.5 for drinking water. Havanagi et al. (2017) noted pH values ranging from 7.4 to 7.6 for different aged samples, indicating a slightly acidic nature of the MSW sample. In the research by Somani et al. (2019), leachate from diverse dump sites exhibited pH values spanning between 7.10 and 8.00. Limited investigations focusing on the leaching behavior of fine fractions have documented pH ranges from 7.1 to 8.3 (Kaczala et al. 2017).

The critical reaction in MSW is the degradation of organic materials to produce carbon dioxide and a small amount of ammonia that further results in the formation of ammonium ions and carbonic acid. The carbonic acid readily undergoes breakdown, generating hydrogen cations and bicarbonate anions, which collectively impact the pH level within the system. Additionally, the pH of leachate can experience alterations due to the partial pressure exerted by the generated carbon dioxide gas, which interacts with the leachate. Dissolved materials and gases shift the pH of natural water either to acidic or alkaline side. pH lower than 7 are usually softer waters and the acidity is due to carbonic, humic, fulvic and other organic acids (Mahapatra et al., 2011 a,c)

4.3.2 Organic content

Elevated levels of moisture and organic matter are typically anticipated within the fine fractions. The intricate connection between these parameters holds substantial significance, as the processing methods and potential applications for these fractions hinge on their quantities (Parrodi et al., 2017).

In accordance with Indian standard specifications, the organic content of the SLM sourced from the Boragaon dump site measured 8.52%. This signifies that utilizing the SLM as earth-fill could lead to extended settling over time due to its gradual degradation (Datta et al., 2020).Somani et. al (2018) reported that the organic content in mined SLM varies between 5% -15%, whereas the organic content in local soil (Delhi silt) was found to vary between 0.6% and 0.9%.

Vilar and Carvalho (2004) conducted an examination of the compressibility and shear strength of 15-year-old MSW sourced from the Bandeirantes Sanitary Landfill (São Paulo, Brazil). Their study revealed that the SLM extracted from the MSW comprised approximately 12% organic matter.

Song et al. (2003) observed a discernible influence of organic matter content on the geotechnical properties. The rise in organic matter content corresponds to a reduction in the maximum dry unit weight, shear strength, and ground bearing capacity. If the organic matter content surpasses around 8% in solid waste soils, it renders the material unsuitable for utilization as a sub-base material in road construction due to the significant decrease in shear strength and bearing capacity.

The organic content, assessed through loss in ignition, ranged from 5.6% to 12.4%, as reported by Oettle et al. (2010). Examination of the testing data reveals a direct correlation between higher organic content and lower maximum dry densities, as well as higher optimum water contents.

Different regulatory bodies establish tolerance limits for the organic content of soil utilized in earthfill or subgrade applications. In India, the permissible organic content in soil for subgrade or earthfill usage is set at 3% according to MoRTH (2002), while the corresponding values are 2% for the UK and 1% for Australia, as stipulated by their respective transportation authorities.

The measured organic content of the SLM is 8.85%, surpassing the maximum allowable limit according to MORTH specifications. Havangi et al. (2018) observed that even with an organic content ranging between 10-12% (determined through loss of ignition testing), the settlement remained within the permissible limits specified by IRC: 75-2014 for embankment construction. This implies that the settlement analysis has already incorporated the impact of degradability, demonstrating that the total settlement adheres to the IRC: 75-2014 stipulations.

Consequently, a higher organic content than what is permitted does not definitively indicate the soil's ineligibility for embankment construction. The decision of whether the soil can be employed as construction material depends on the settlement analysis results, along with other parameters that require evaluation to meet the requisite criteria.

4.3.3 Colour

The potential for soil employed in road subgrades to release colored water raises concerns of contaminating surrounding water bodies and giving rise to aesthetic issues. A color test was executed in the current study in accordance with IS 3025 (Part 4) – 1983, revealing a water extract result of 10 TCU. This measurement exceeds the permissible limit as established by IS 10500 (BIS 2012), marking it twice as high. The elevated result might be attributed to the presence of a significant quantity of volatile dissolved solids within the leachate (Somani et al. 2019), necessitating further investigation.

Prior to the re-use of SLM, the presence of yellowish leachate emerges as a significant consideration. It has been observed that such leachate can lead to coloration of subsurface water, potentially influencing consumers' perceptions of water consumption (M. Datta et al. 2020). This underscores the importance of addressing this aspect before the reuse of SLM.

To check the change in colour in leachate extracted from SLM with time, it was observed in 24 hours intervals for 3 consecutive days and found that there was no variation in colour for all the three trials in the leachate obtained from the SLM.

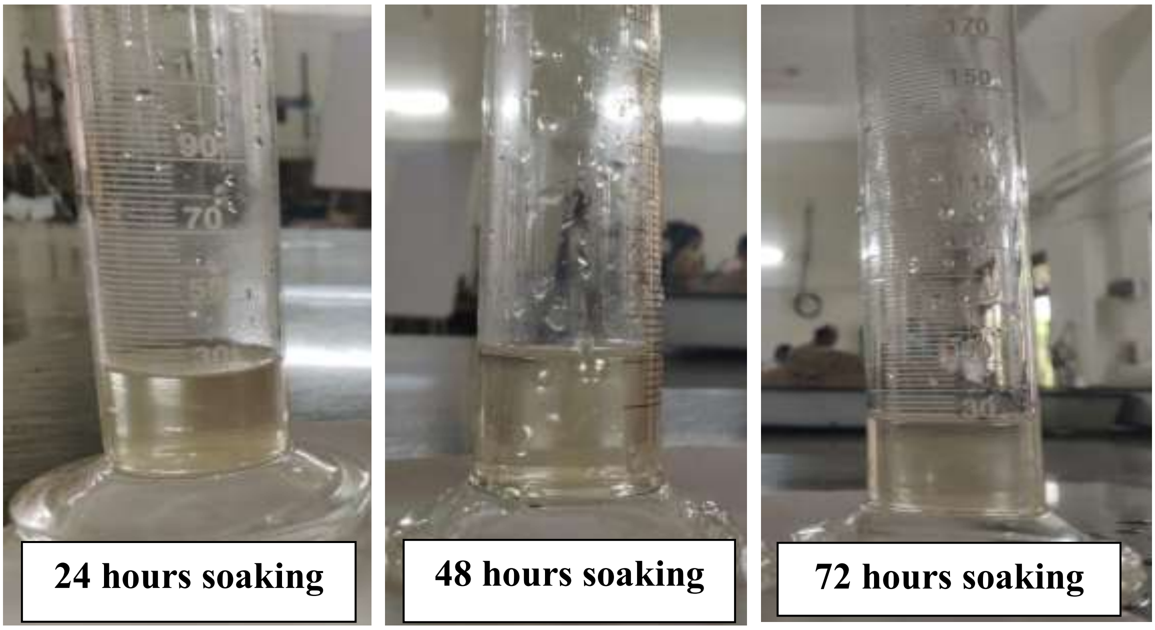

Figure 4.31: Colour of the leachate extracted from SLM

4.3.4 Total dissolved solid

Total Dissolved Solids (TDS) serves as an indicator of the presence of both inorganic salts and certain levels of dissolved organic matter within water. Predominantly, these inorganic salts comprise calcium, magnesium, potassium, sodium, bicarbonates, chlorides, and sulfates. High TDS levels in water can impede the growth of aquatic organisms and potentially result in their mortality.

In the current investigation, the TDS content within the leachate derived from SLM was determined in accordance with IS 3025 (part 16), resulting in a measured value of 576 mg/l. This reading slightly surpasses the maximum allowable threshold of 500 mg/l established by IS 10500 (BIS) for drinking water standards.

Elevated levels of Total Dissolved Solids (TDS) concentration in leachate (ranging from 10,000 to 30,000 mg/l) have been extensively documented in the literature concerning accumulations near dumpsites (Kjeldsen et al. 2002; Moody and Townsend 2017; Somani et al. 2019).

In a study conducted by Somani et al. (2019), the TDS content within leachate from SLM was observed to fall within the range of 600 to 1,800 mg/l, while the water extract from local soils exhibited a considerably lower TDS concentration of 100–200 mg/l. The advanced age of the waste materials is also a contributing factor to the diminished values across all parameters.

4.3.5 Heavy metal analysis

The prospect of repurposing soil-like material (SLM) as filler or construction material post-organic content removal is a common suggestion. However, the feasibility of using SLM for external applications may not always be assured, primarily due to the heightened presence of metal concentrations in comparison to background soils, a finding echoed by Jain et al. (2005) and Quaghebeur et al. (2013).

Six heavy metals including arsenic (As), chromium (Cr), copper (Cu), zinc (Zn), nickel (Ni), and lead (Pb) were considered as a potentially toxic heavy metal for human health by US Environmental Protection Agency (USEPA). In this study using X-ray Fluorescence (XRF) these potentially toxic heavy metals are studied. The results are compared with the MSW Management and Handling Rules (2000), USEPA standards and global standards (Canadian, Dutch and Continental crust) and presented in Table 4.4. On comparing the concentration of heavy metal in the present study with the various standards it was found that copper, chromium and cadmium were found to be high in almost all the landfills. A comparison between the heavy metal concentrations in this study and various standards reveals elevated levels of copper, chromium, and cadmium.

Table 4.4 Heavy metals in SLM at Boragaon dumpsite

Landfill sites	Heavy metals concentration (mg/kg dry weight)						
	Ni	Cr	Pb	Zn	Cu	As	Cd
Boragaon	33	87	94	619	646	3	7
MSW Management and Handling Rules, 2000	50	50	100	1000	300	10	5
USEPA (for compost standard)	420	1200	300	2800	1500	41	39
Canadian standards	50	64	70	200	63	-	1.4
Dutch standards	100	-	530	720	190	-	13

From results of similar studies reported in literature, it was found that copper concentration appears to be considerably higher than those reported from the other contaminated waste dump sites.

To assess the potential environmental ramifications of heavy metal presence, Kurian et al. (2003) conducted a comparison between leachates collected from the Perungudi dumping ground in Chennai and water extracts (in a 1:10 ratio) obtained through 24 hours of agitation. The outcomes demonstrated that heavy metal concentrations within water extracts are lower than those found in the leachate. This implies a diminished solubility and a slower leachability of heavy metals in water. The divergence in heavy metal contents between leachate and water extract is particularly pronounced for Cu, Cr, Ni, Pb, and Zn. Conversely, there is minimal disparity between leachates and water extracts for other heavy metals (As, Cd, and Hg), possibly attributed to their extremely low concentrations.

In an attempt to assess the leachability characteristic of the heavy metal from the SLM, leachate was artificially prepared by mixing with deionized water in the ratio 1:10 and the traces of heavy metal was found to be below detection level. This signifies the poor leachability characteristics of the SLM.

The concentration of heavy metal in SLM, it’s leachate and water extract from local soil was examined by Somani et al. (2018) and Somani et al. (2019) the results of heavy metal of our interest are shown in Table 4.5

Table 4.5 Concentration of heavy metal in different condition of SLM

Tested parameters	**Heavy metal**					
	Cr	**Ni**	**Cu**	**Zn**	**Cd**	**Pb**
SLM[a]	68.5-135	20.5-66	150-270	60-130	2-8	80-90
Leachate from SLM[b]	1-11	15-45	100-270	70-280	0.18-0.72	2.5-4.6
Leachate of local soil[c]	0.7-1.8	1.5-3	8.5-40	25-50	0.01-0.03	1-3

a-mg/kg; b,c- µg/l

From the test results they have found that leaching ratio ranges between 0.06% to 2.5% which was considered to be very low. Low leaching of metals (0.2% to 1.5%) is also reported by Kaczala et al. (2017)

In a study conducted by M. Datta et al. (2020), a comprehensive analysis comparing the total heavy metal content in SLM with that of background soils and reported values in existing literature was carried out. The comparative examination unveiled significantly elevated levels of all metals within SLM from all dumpsites in contrast to the background soils. A further assessment of SLM's heavy metal content against Flemish standards indicated that most metals exceeded the limits for unrestricted SLM utilization. However, with the exception of copper, all other metals fell below the limits prescribed for using SLM as a construction material. When comparing the concentration of heavy metals in SLM as reported in previous studies for potential earthfill or construction material applications, the majority of results aligned with values documented in the literature. Notably, zinc concentrations were relatively lower than most of the reported values.

SLM has the potential to function as on-site cover material for landfills, and its satisfactory strength attributes suggest it could also perform effectively on inclined surfaces. However, employing SLM beyond the site as fill material seems viable only in thinner layers, accompanied by ample soil covering to avert subsurface pollution. This approach could be suitable for scenarios like parks, golf courses, and adaptable parking zones, where extended ground settling holds lesser significance.

For off-site fill applications involving substantial thicknesses, appropriate pre-treatment methods such as incineration, washing, and blending as indicated in Wanka et al. (2017) and Oettle et al. (2010), or the incorporation of sealing layers at the base, sides, and top of the fill, would need to be devised. Notably, careful consideration is essential in regions where the underlying soil is granular and the water table lies near the surface. These findings align with existing literature, where the predominant use of SLM has been as on-site cover material, with minimal instances of untreated off-site reclamation.

When considering the utilization of SLM in embankments, the matter of prolonged gradual settling caused by the elevated organic content within the SLM becomes a noteworthy consideration. It becomes imperative to assess the capacity of the road or rail track to endure such settling. One potential approach to mitigate this issue is by incorporating SLM into the indigenous soil, which has the potential to notably diminish the organic content.

CHAPTER 5

CONCLUSIONS AND SCOPE FOR FUTURE STUDY

5.1 INTRODUCTION

Based on the analysis of geotechnical properties and physicochemical characteristics of SLM and assessing the effect of different percentage on plastic on both soil sample and SLM following conclusions can be drawn. Furthermore, this chapter includes several recommendations for potential areas of future research in this filed.

5.2 CONCLUSIONS

Following conclusions can me made the based on the analysis and interpretation of the results-

1. The particle size distribution of the SLM (<4.75mm) reveals that it is a fine-grained soil, but it shows lack of plasticity. So, the material can be termed as non-plastic within the clay-size range.
2. The free swell index of the SLM is found to be zero which is within the permissible limit for use the same as embankment material though other parameters need to be checked for final consideration.
3. The organic content of the SLM is found to be higher when compared to MoRTH specification. Higher organic content may cause the lower maximum dry unit weight and higher OMC of the SLM which makes it unsuitable to use in embankment or subgrade but it may be used a filling material.
4. The colour and average pH of the leachate extracted from the mixture of SLM and water (1:10 ratio) after 24 hours, 48 hours and 72 hours of soaking was found to be 6.98 which is within the acceptable limit and 10 TCU respectively. On the contrary the value of the TDS was found to be little higher than the permissible limit which reflects presence of inorganic salts and some amounts of organic matter in the leachate.
5. On comparing the concentration of heavy metal in the present study with the various standards it was found that copper, chromium and cadmium were

found to be high in the SLM and does not satisfy prescribed limits to use it as compost.

6. Assessment of the leachability characteristic of the heavy metal from the SLM revealed that traces of heavy metal was below detection level. This signifies the poor leachability characteristics of the SLM. Thus, leachate study indicated that MSW is a non-hazardous material as concentration of heavy metals is within the permissible limit. So, it is essential to dealt with leaching characteristics to use the SLM as an earthfill material.
7. Allowing SLM to be freely and extensively used as fill material for external applications doesn't seem like a viable choice due to its considerable organic content, increased levels of heavy metals, and release of yellowish-brown colour liquid. In scenarios where earth-fill applications involve layers of several meters in thickness, it is essential to monitor these critical parameters and suitable treatment measures should be adopted.
8. Compaction characteristics of SLM reflected low maximum dry density compared to the native soil which may be due to higher organic content in the SLM. As the SLM did not satisfy minimum density requirement for using it in embankment or subgrade it should not be allowed to use for the purpose directly.
9. Though the unconfined compressive strength of the SLM showed satisfactory strength, presence of high organic content, elevated heavy metals and significant release of yellowish- brown colour liquid restrict the direct use of SLM as earth-fill material.
10. The unsoaked CBR value of the SLM is found to be less compared to native soil.
11. Addition of PP flake and HDPE granules have reinforced the SLM and the highest compressive strength was observed at optimum plastic content of 2%.
12. Non-linear variation of UCS and CBR was observed at different percentage of PP and HDPE when mixed with the soil sample. In native soil samples the additives are not acting as a reinforcing agent and decrease in strength parameters was noticed compared to its virgin state.

5.3 SCOPE FOR FUTURE STUDY

To get a proper insight on the feasibility of SLM as construction material further assessment is required on this material. Taking following points into consideration the study can be continued.

1. Determination of shear parameters of the compacted SLM
2. Slope stability and settlement analysis of MSW embankment.
3. Development of typical cross sections for use application in a Highway.
4. Permeability and compressibility characteristics of the SLM can be investigated.
5. Electrical conductivity of the leachate can be examined to know the effect of dissolved organics and inorganics present in the leachate.
6. Quantity of soluble salts (sulphates and chlorides) in the leachate can be checked whether it is within the permissible limit to use the same in embankment construction.
7. The variation in geotechnical and physicochemical properties of SLM when it is blended with different percentage of native soil can be studied.
8. The properties of SLM of different age can be examined and correlation can be established with different parameters of interest.

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APPENDIX I

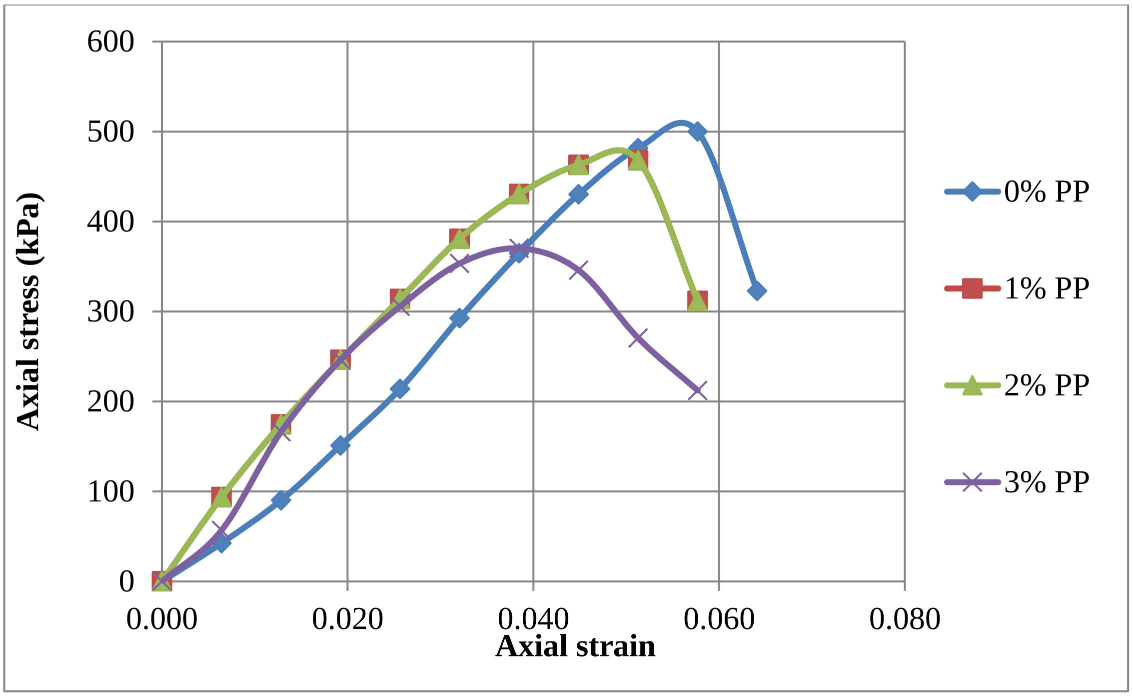

Figure 4.6 Super-imposed stress-strain curve of sample 2 at different percentage of PP

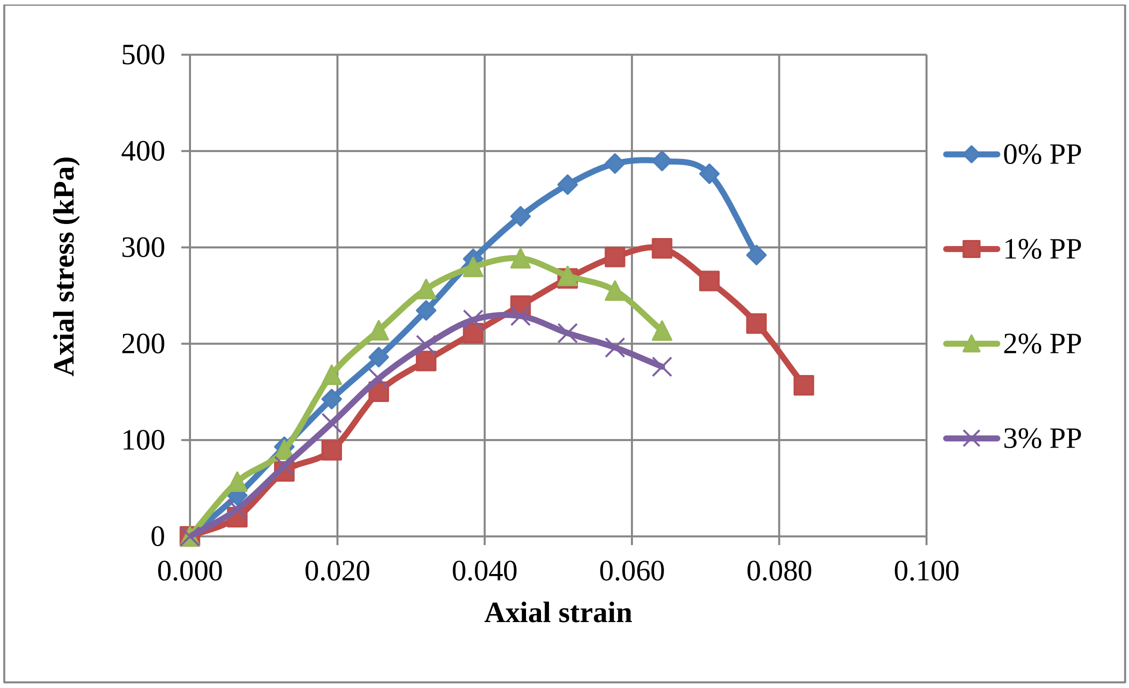

Figure 4.7 Super-imposed stress-strain curve of sample 3 at different percentage of PP

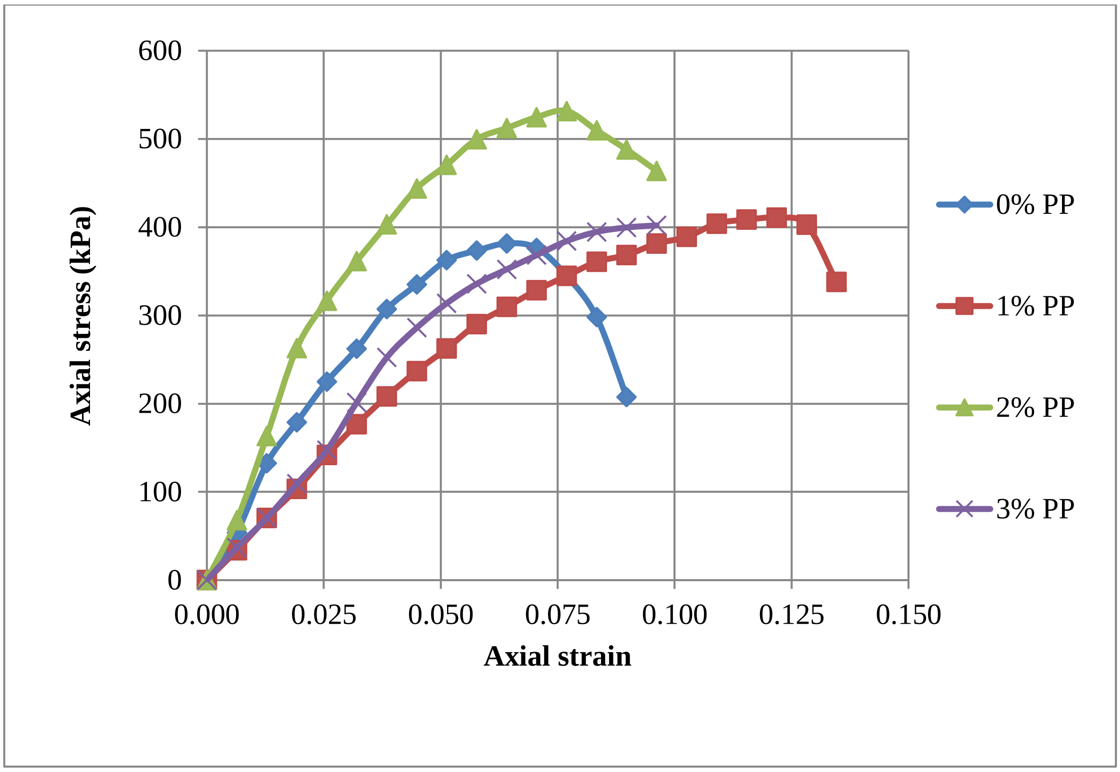

Figure 4.8 Super-imposed stress-strain curve of sample 4 at different percentage of PP

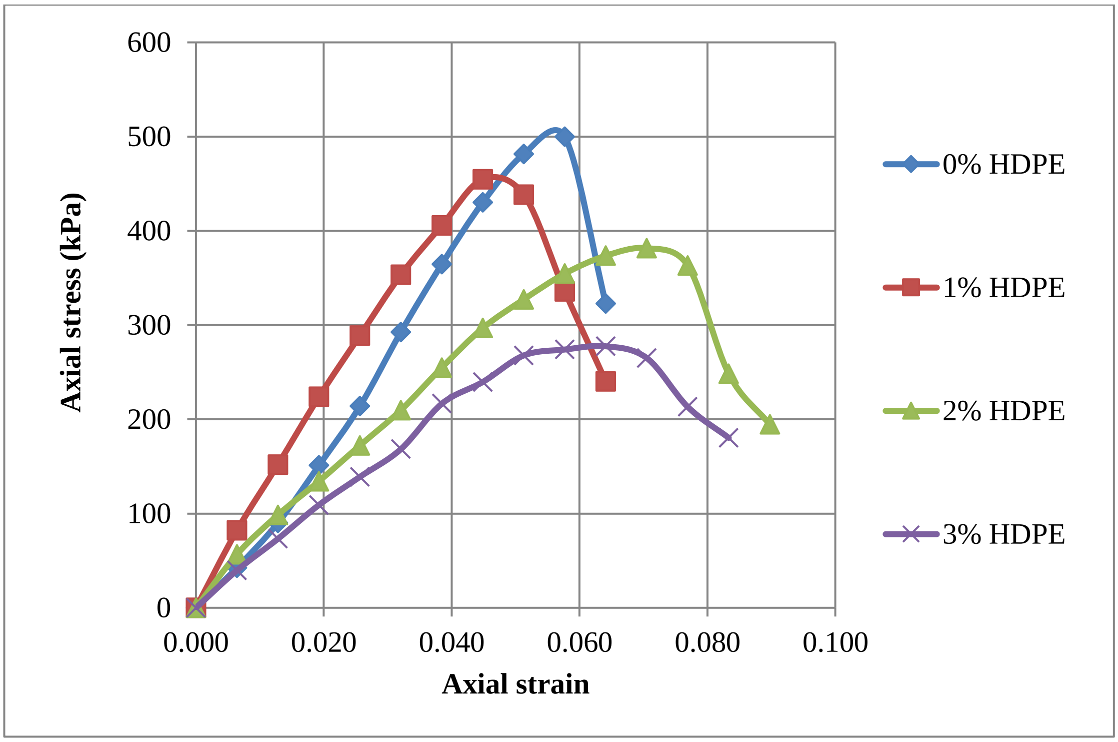

Figure 4.11 Super-imposed stress-strain curve of sample 2 at different percentage of HDPE

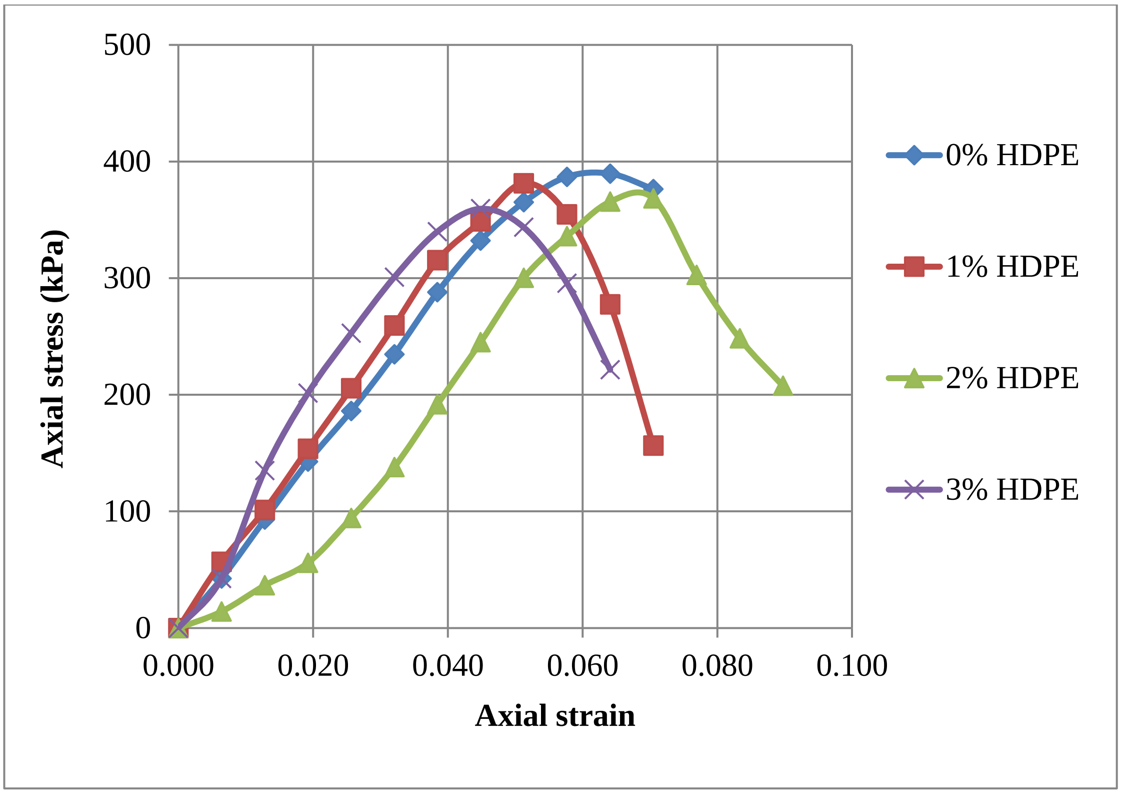

Figure 4.12 Super-imposed stress-strain curve of sample 3 at different percentage of HDPE

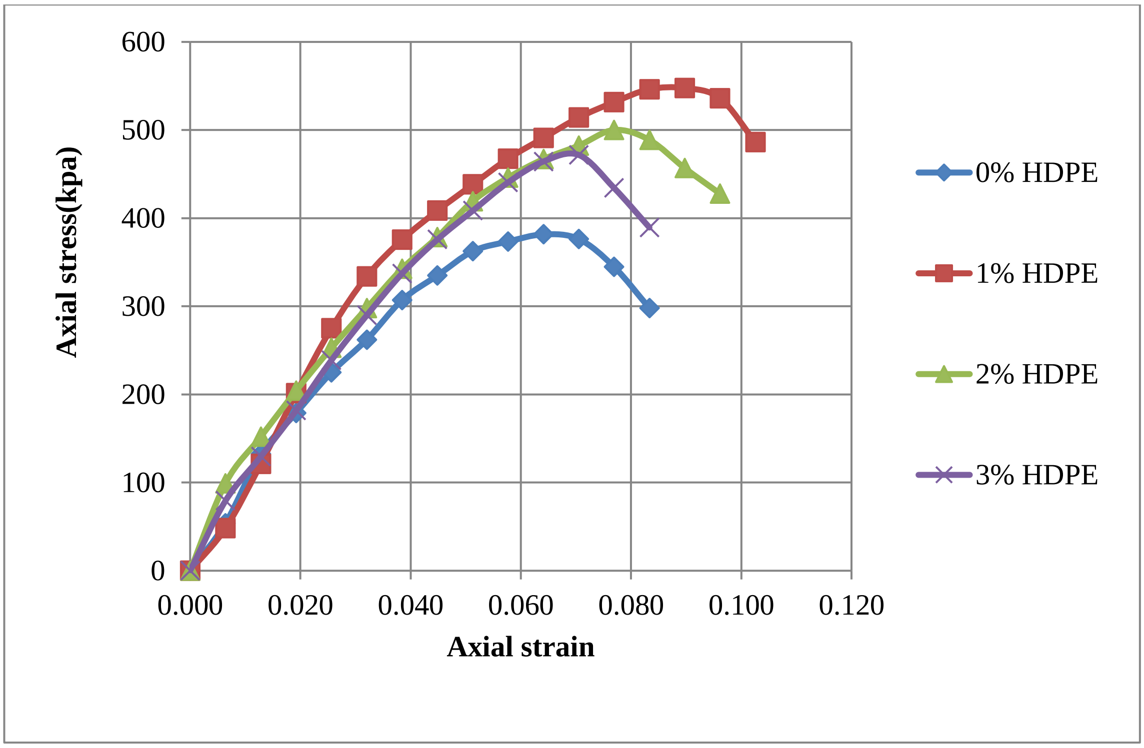

Figure 4.13 Super-imposed stress-strain curve of sample 4 at different percentage of HDPE

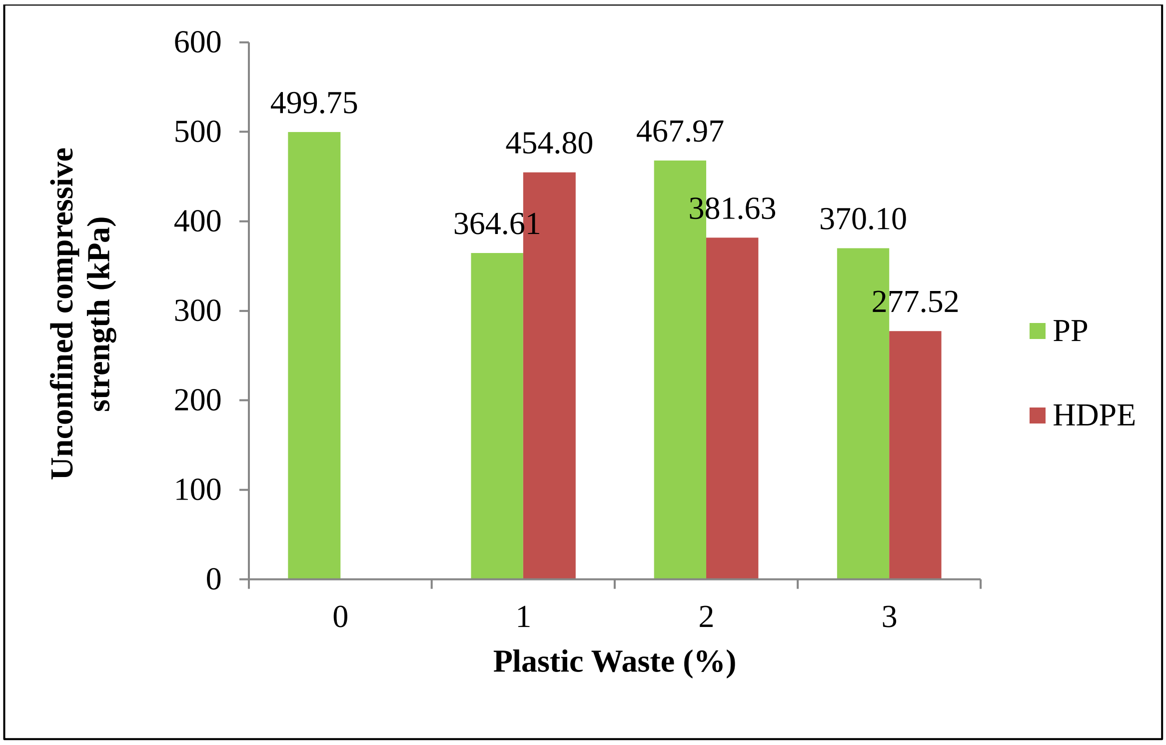

Figure 4.16: Plastic waste vs UCS of Sample 2 for both PP and HDPE

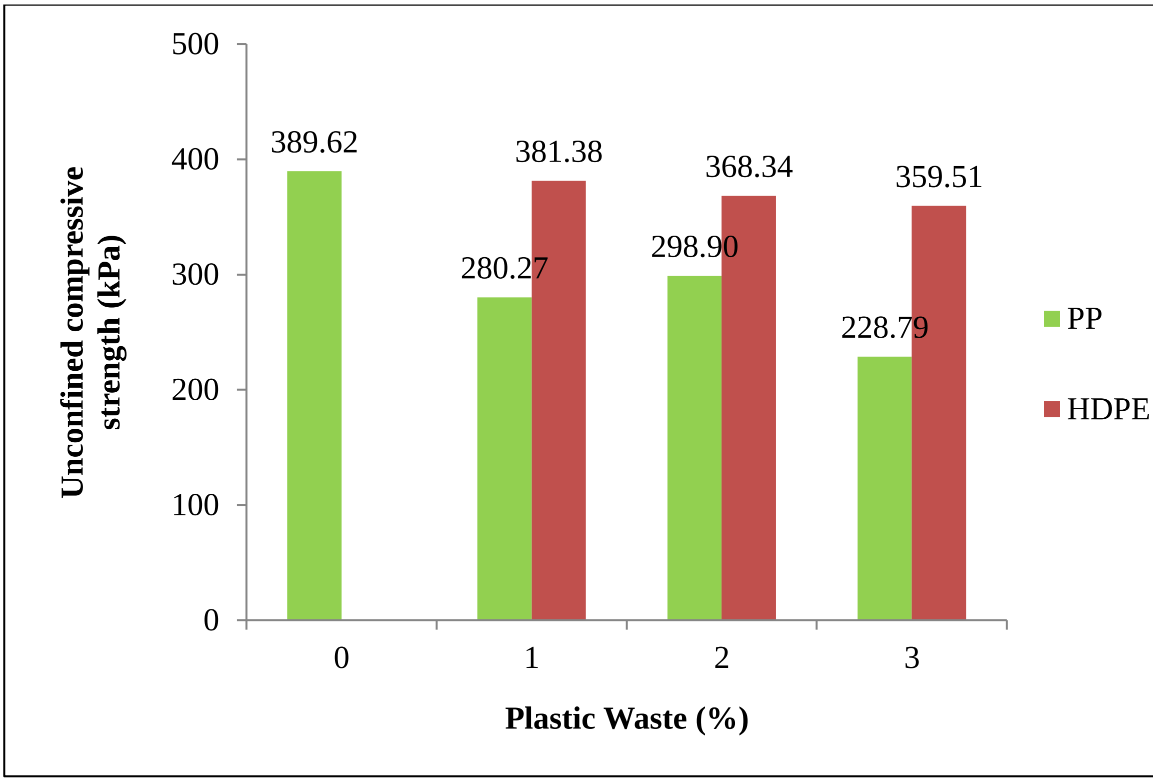

Figure 4.17: Plastic waste vs UCS of Sample 3 for both PP and HDPE

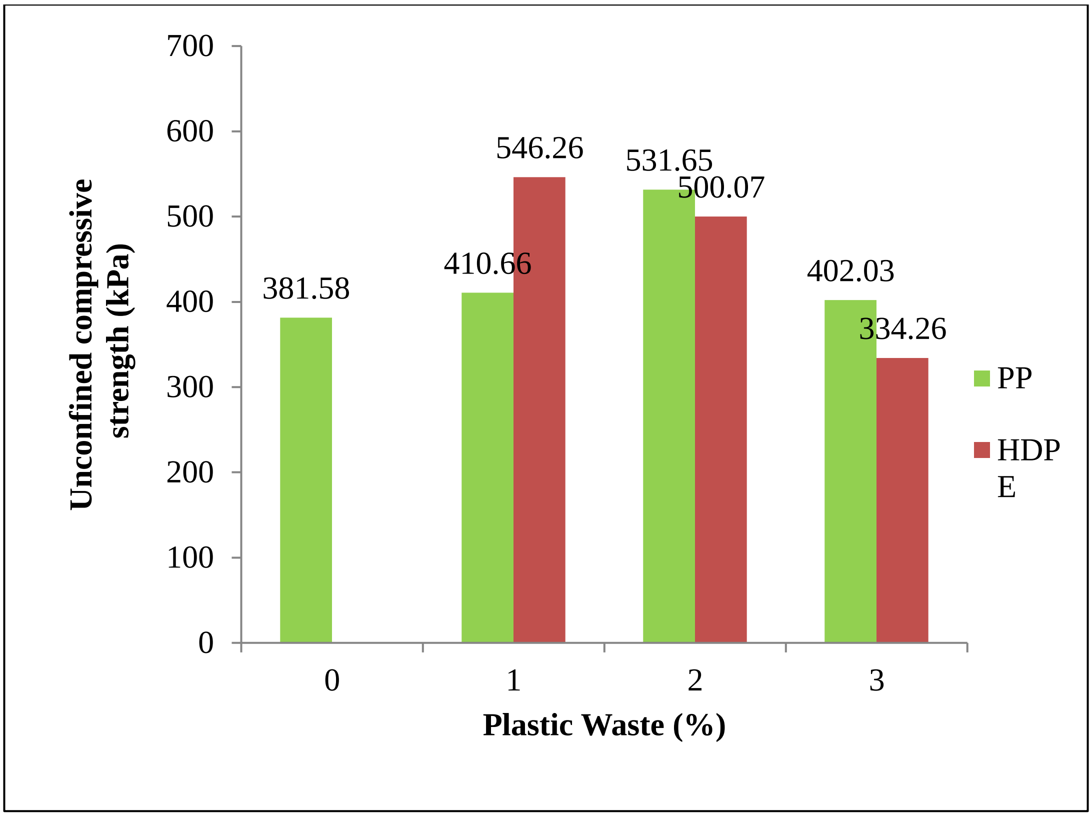

Figure 4.18: Plastic waste vs UCS of Sample 4 for both PP and HDPE

APPENDIX II

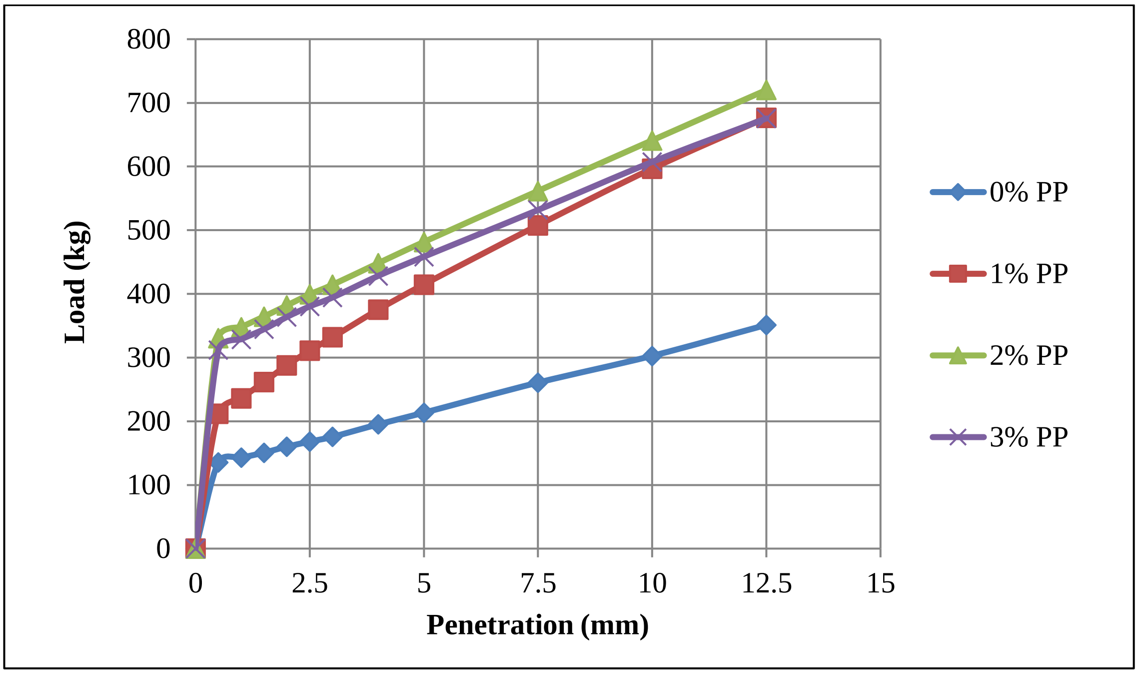

Figure 4.21: Superimposed curves of load vs penetration for Sample 2 with PP

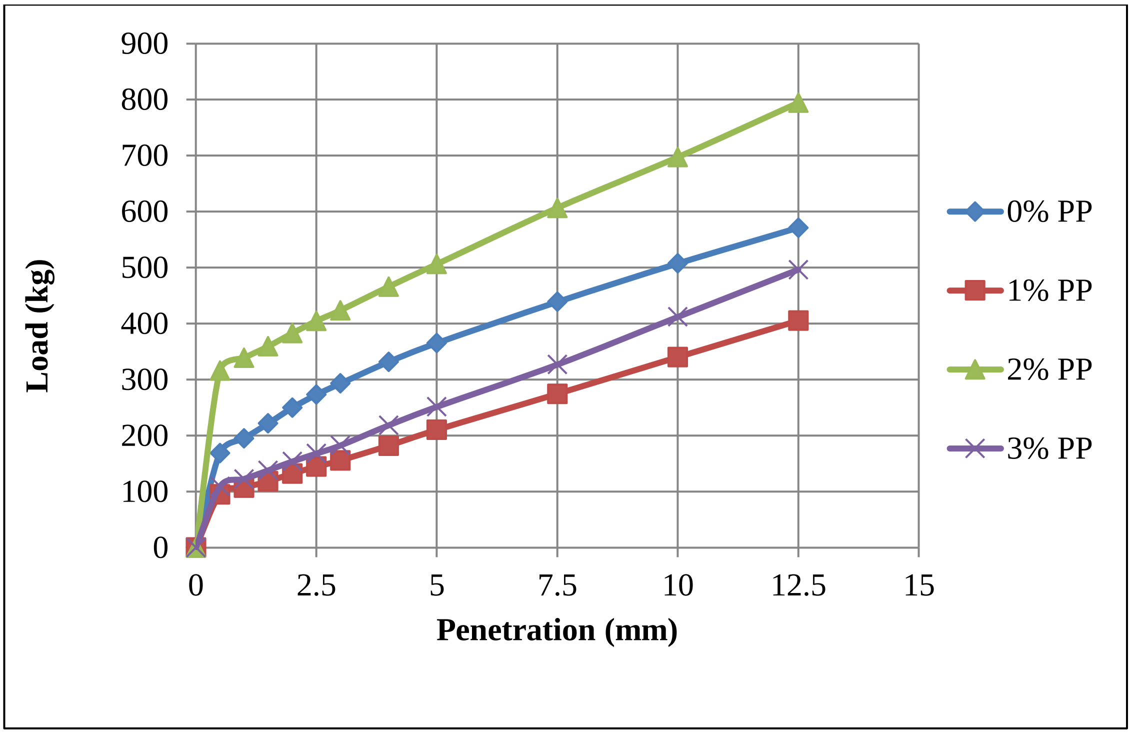

Figure 4.22: superimposed curves of load vs penetration for Sample 3 with PP

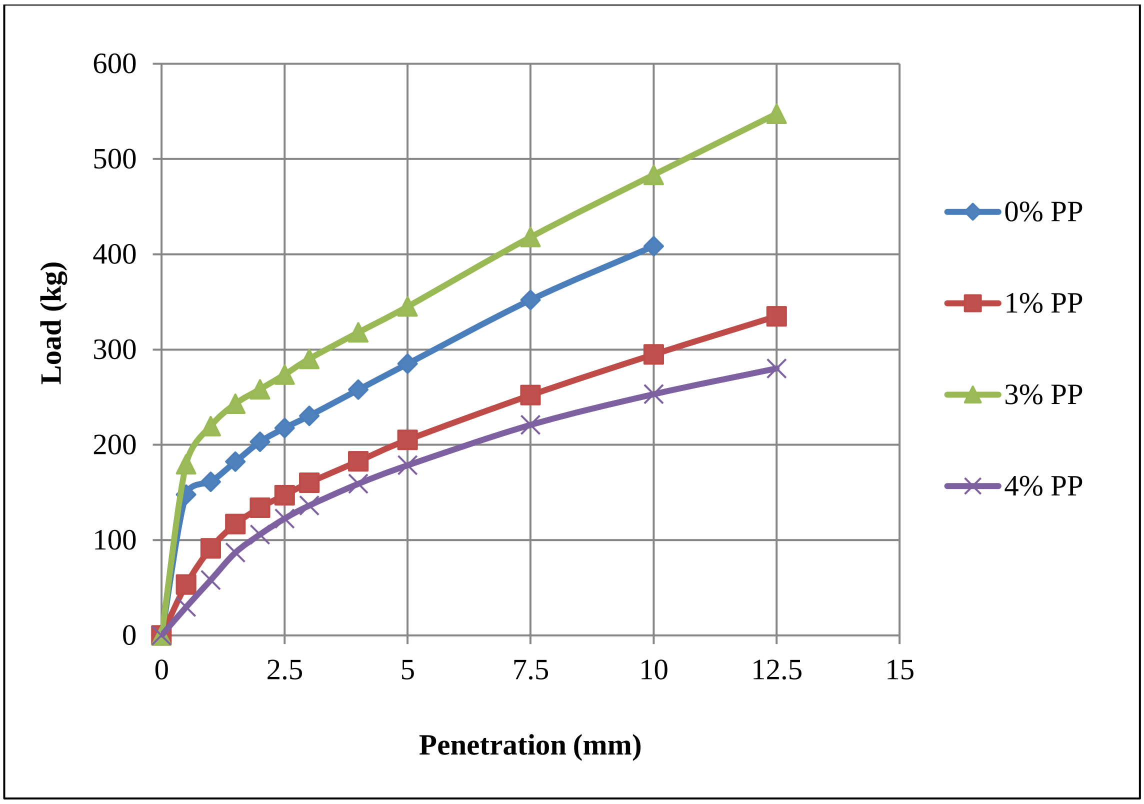

Figure 4.23: Superimposed curves of load vs penetration for Sample 4 with PP

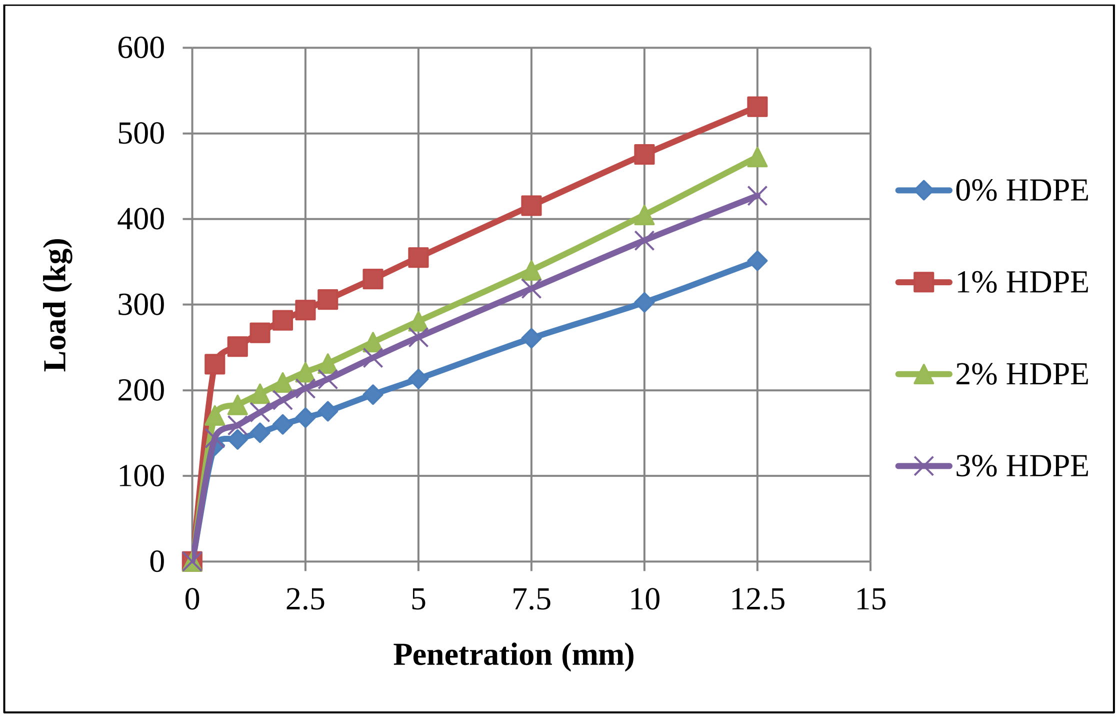

Figure 4.26: Superimposed curves of load vs penetration for Sample 2 with HDPE

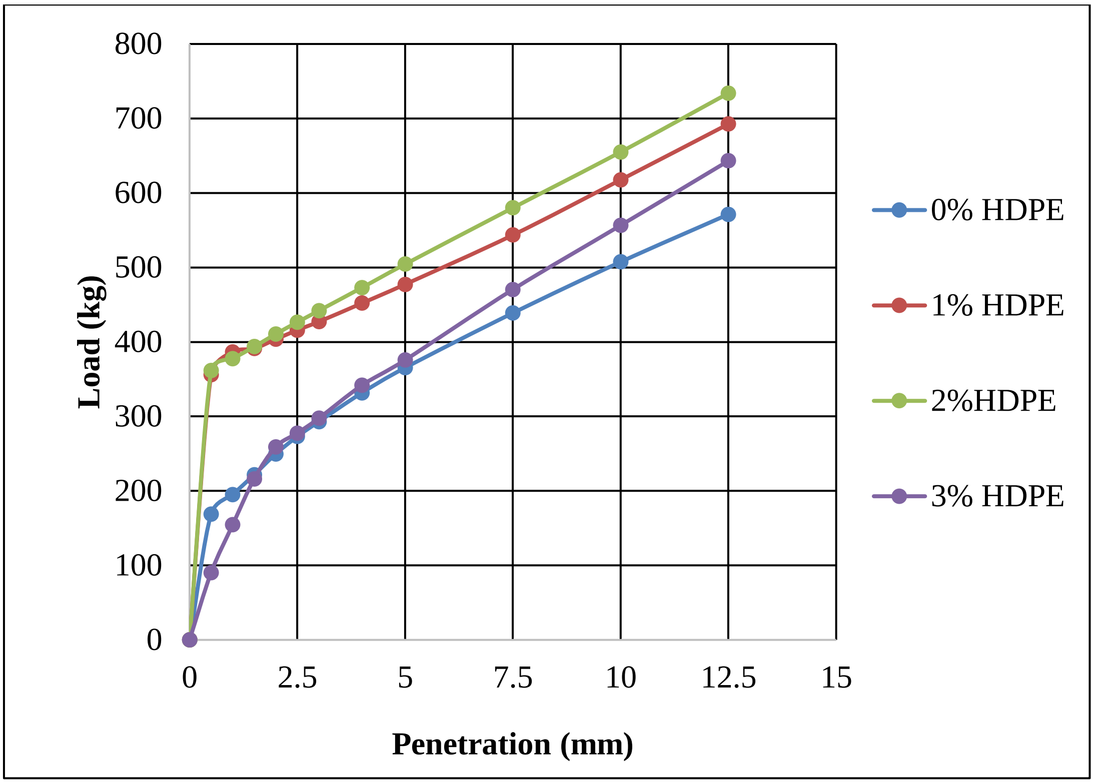

Figure 4.27: Superimposed curves of load vs penetration for Sample 3 with HDPE

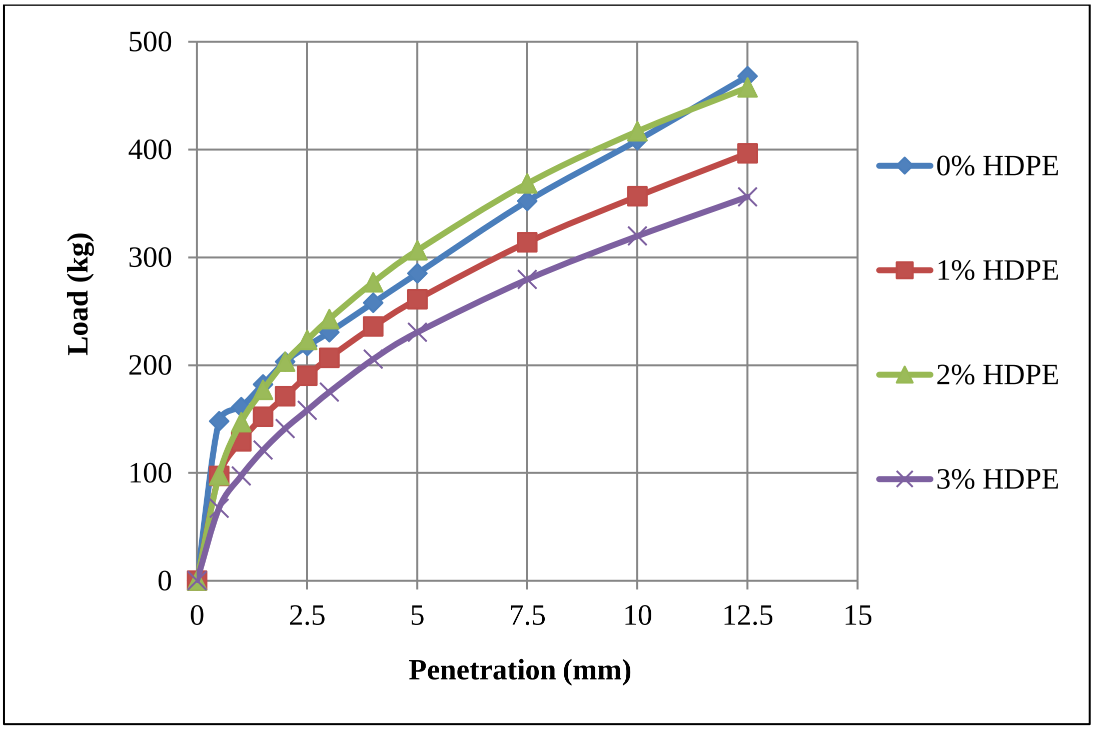

Figure 4.28: Superimposed curves of load vs penetration for Sample 4 with HDPE

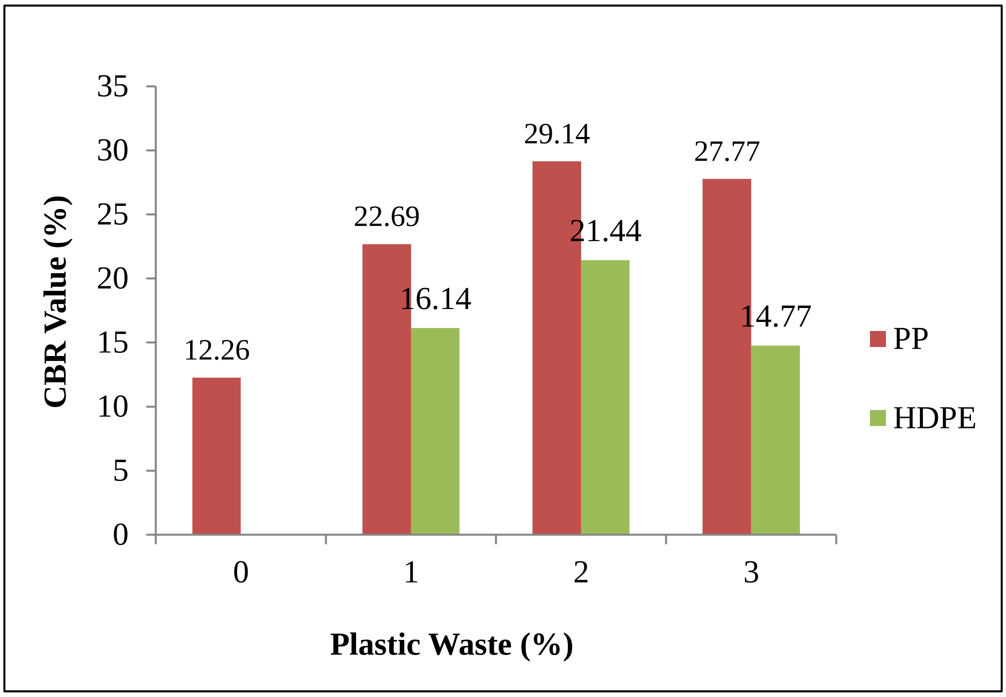

Figure 4.31: Plastic waste vs CBR of Sample 2 for both PP and HDPE

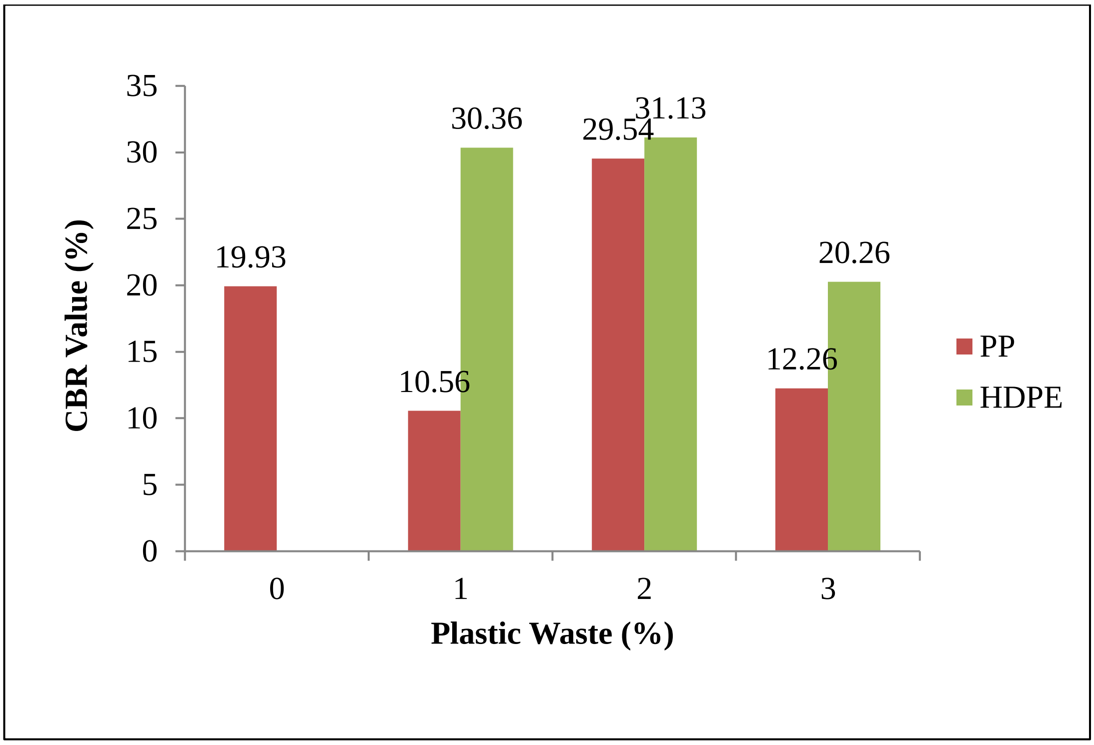

Figure 4.32: Plastic waste vs CBR of Sample 3 for both PP and HDPE

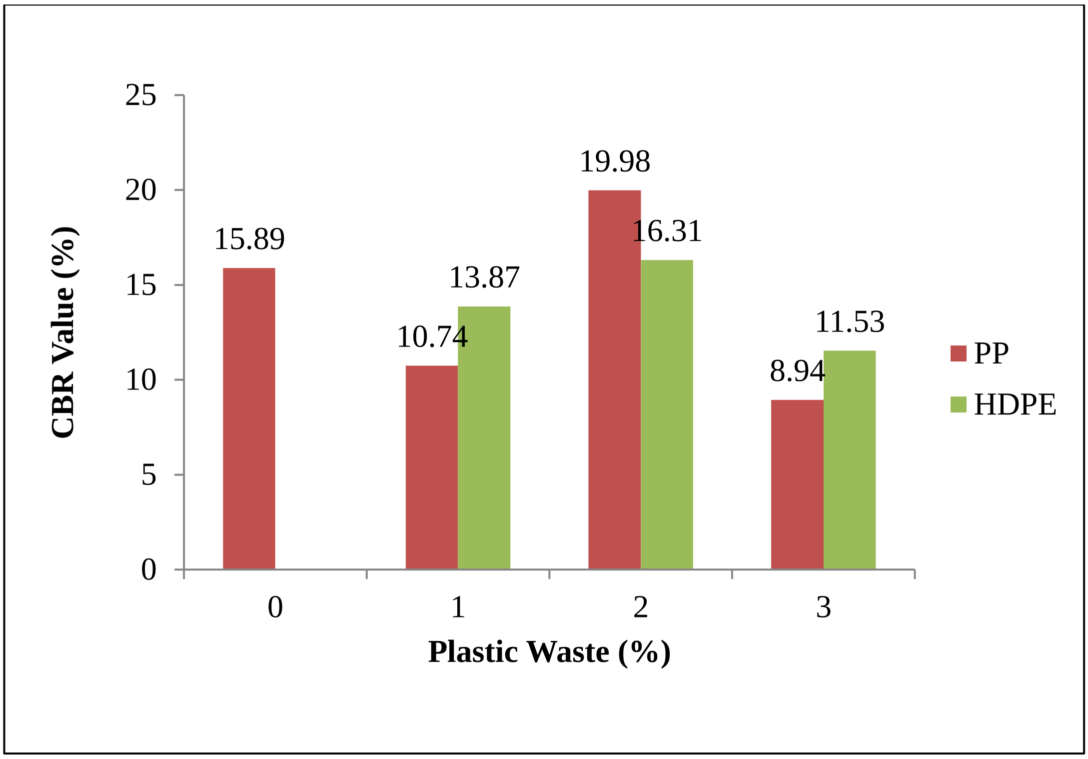

Figure 4.33: Plastic waste vs CBR of Sample 4 for both PP and HDPE