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# Study on the effect of soil properties in the presence of plastic waste

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**Abstract**

This study investigates the impact of plastic waste on the properties of soil, focusing on its effects on physical and chemical characteristics. With the increasing accumulation of plastic waste in landfills, its interaction with soil has become a significant concern for environmental and engineering practices. The research aims to conduct a comparative analysis of soil samples with varying concentrations of plastic waste, evaluating changes in parameters such as permeability, compaction, strength, water retention, levels. Laboratory tests, including Atterberg limits, Proctor compaction, Permeability tests, specific gravity test, moisture content, particle size distribution, ph., EC, Organic matter and unconfined compressive strength test were performed on soil mixed with different types and quantities of plastic materials (e.g., polyethylene, polypropylene). The findings reveal that the incorporation of plastic waste leads to altered soil behavior, which may either improve or degrade soil properties depending on the type of plastic and its concentration. This study provides essential insights into how plastic waste impacts soil's physical stability, offering potential implications for soil stabilization techniques, soil remediation methods, and sustainable engineering practices.

*Keywords*: Soil properties, Plastic waste, Permeability test, Moisture content test, Atterberg limits test, UCC test, particle size distribution, specific gravity, soil comparative analysis, Soil remediation, pH, organic matter, EC, sustainable engineering.

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## 1. Introduction

Plastic pollution in soil is a growing environmental issue with far-reaching consequences for ecosystems, agriculture, and human health. As global plastic production and consumption continue to rise, an increasing amount of plastic waste finds its way into terrestrial environments, including agricultural lands, forests, and urban soils. Unlike in oceans, where plastic waste is highly visible and receives substantial attention, soil pollution by plastics is often overlooked. However, recent studies have shown that soil can harbor significant quantities of plastic debris, especially microplastics, which are often smaller than 5 mm in size. These small fragments accumulate in soil over time, causing adverse physical and chemical changes that can degrade soil quality and disrupt its essential functions.

In recent years, the environmental impact of plastic has expanded beyond aquatic ecosystems and landfills, infiltrating terrestrial environments where its effects on soil are still not fully understood. Engineering studies have begun to address this gap by examining how plastic waste changes soil properties, with particular attention to soil mechanics, water retention, and soil structure. plastic particles, when present in soil, change the way soil particles aggregate, leading to variations in soil texture, porosity, and permeability. For instance, high levels of plastic particles can increase soil porosity by filling the voids between soil particles, while also impacting soil stability. This change in soil structure can influence the soil's load-bearing capacity, making it a significant consideration in engineering projects involving soil, such as foundation design and soil stabilization efforts.

The persistence of plastics in soil presents unique challenges due to their slow degradation rates. Once in the soil, plastics break down into smaller particles through weathering processes like sunlight exposure, wind abrasion, and microbial activity, but they do not fully decompose. This gradual fragmentation process can lead to the formation of microplastics and even smaller nano plastics, which can be absorbed by plants, interfere with soil structure, and alter water retention. These changes can negatively impact crop growth and yield, affecting food security in the long term.

One of the most profound impacts of plastic in soil is on its physical properties, such as texture and compaction. plastic particles, when present in soil, change the way soil particles aggregate, leading to variations in soil texture, porosity, and permeability. For instance, high levels of plastic particles can increase soil porosity by filling the voids between soil particles, while also impacting soil stability. This change in soil structure can influence the soil's load-bearing capacity, making it a significant consideration in engineering projects involving soil, such as foundation design and soil stabilization efforts. Plastic fragments can interfere with soil particle bonding, often reducing soil density and altering its capacity to retain water. Additionally, plastics may affect the thermal conductivity of soil, as they differ in heat retention compared to natural soil materials.

For instance, plastics may prevent the soil from warming up or cooling down effectively, which can disrupt natural processes like nutrient cycling and microbial activity. This disruption could have cascading effects on crop growth and soil biome, highlighting a need for engineers and environmental scientists to address plastic waste in soil through innovative waste management systems and soil remediation technologies. plastic waste can lead to chemical changes in the soil that may have long-term consequences for soil health and productivity. Additives used in plastics, such as phthalates and bisphenols, are known to leach out, introducing potentially toxic compounds into the soil. These chemicals can alter the pH of the soil, impact its microbial life, and even accumulate in plants, eventually entering the food chain.

Addressing the physical effects, this study will utilize laboratory experiments and analyze to assess the impact of type and sizes of plastic waste on taken soil type. The findings will contribute to a better understanding of plastic's long-term effects on soil and help inform strategies for mitigating plastic pollution in terrestrial environments. This study aims to identify not only the direct effects of plastic waste on soil properties but also to develop solutions, such as chemical techniques and to restore and protect soil health effectively.

**1.1. Objectives of the Study**

- To determine the Physical and chemical Impact of Plastic Waste on Soil Structure.
- To evaluate the Effects of Plastic Contamination on Soil.
- To analyze the physical and chemical properties between Plastic-Contaminated and un-Contaminated Soil.

- To the potential negative impacts of soil quality.
- To determine a solution to the plastic contamination in soil.

### 1.2. Scope of the Study

Plastic waste has significant effects on soil texture, structure, and fertility, impacting its ability to support plant growth and agricultural productivity. The addition of plastic materials alters the soil's composition by affecting sand, silt, and clay ratios, leading to changes in compaction, porosity, and permeability, which in turn influences water retention, drainage, and root penetration. Plastic contamination also impacts soil bulk density, pH levels, and nutrient availability, disrupting essential elements like nitrogen, phosphorus, and potassium, which are crucial for plant health. Furthermore, plastic waste can leach toxic substances into the soil, harming microbial communities, such as bacteria, fungi, and earthworms, that play key roles in nutrient cycling and organic matter decomposition. The formation of microplastics in the soil poses additional threats by potentially entering food chains and causing harm to terrestrial and aquatic organisms. Plastic contamination also affects the soil's mechanical properties, influencing its capacity to support infrastructure projects and compromising landfill containment systems. To mitigate these effects, strategies such as improving soil structure with organic matter and using remediation techniques, including chemical treatments and physical removal, may help reduce plastic pollution and its adverse impact on agricultural and environmental health.

## 2. Materials and Methods

### 2.1 Materials Used

The various materials used in the experimental program are described below.

**Laterite soil**

It is the locally available laterite soil, which is available nearby IES College Of Engineering, Chittilappilly and is collected from the site. Laterite soil is a type of soil that forms in tropical and subtropical regions under conditions of high rainfall and temperature. It is known for its distinctive reddish color, which is primarily due to the high iron oxide content. Its strength, compaction characteristics, and workability can make it an excellent material for road construction, foundations, and building blocks, provided proper stabilization and compaction techniques are used. However, its sensitivity to moisture changes, potential for erosion, and variable quality mean it requires careful consideration and management for optimal use in civil engineering projects. Laterite soil can support certain vegetation with adaptations to its unique characteristics. In agriculture, it often requires significant fertilization and soil management techniques to enhance its fertility for cultivation.


Figure 1: location of soil Figure 2: soil sample

**Plastic**

The plastic that we are used in the project is LDPE (Low-Density Polyethylene) is a type of plastic known for its flexi- bility, low density, and ease of processing. It is commonly used for making plastic bags, plastic wraps, bottles, and other packaging materials. LDPE has a relatively low melting point, making it ideal for applications that require flexibility and durability. It is considered one of the more recyclable plastics, although it is not as commonly recycled as other types like PET (Polyethylene Terephthalate). LDPE is characterized by its simple molecular structure, which gives it a more branched, less crystalline form, contributing to its soft and flexible properties. The plastic is collected from the local shop.

Figure 3: plastic covers

**Titanium dioxide**

Titanium dioxide (TiO2) often recognized as titanium (IV) oxide, belongs to the transition metals oxides family and has been used in numerous applications such as cosmetic products, sunscreens, photovoltaic cell, environmental remediation, nano paint, and antibacterial agent. Several other environmentally friendly materials such as nickel nanowires, nickel nanopillars , and bismuth have been used for environmental applications but these materials have not been tested for plastics decomposition. TiO2 is considered a vital photocatalyst that mainly works under the UV region. It has been used in different applications for decades and is documented as a safe and inert photocatalytic material. It plays an effective role in pollutant oxidation during photocatalytic degradation reactions. It is a low-cost commonly used semiconducting material that can be easily prepared at lab scale. Notably, this white pigment material is used since ancient times, which proved it a safe material for humans and the environment. Generally, two kinds of photochemical reactions occur on TiO2 upon light irradiation. One incorporates the light-induced redox reactions of adsorbed materials, while other involves the light-induced hydrophilic conversion of TiO2. These combinations open new avenues for the novel application of TiO2, especially in the building materials discipline. TiO2 has been used for different kinds of pollutants decomposition such as persistent pollutant, azo dyes, and emerging contaminants. Simultaneously, scientists also used TiO2 for the decomposition of macro and micron size plastics.

Figure 4: Titanium Dioxide

**2.2 Methodology**

The primary aim of the study was to investigate the "Effect of Soil Properties in the Presence of Plastic Waste" aims to evaluate how the introduction of plastic waste affects the engineering characteristics of soil. Specifically, the research will focus on soil mechanics, geotechnical properties, and hydrological behavior, with an emphasis on how plastic waste alters the soil's physical properties, which are critical for construction, agriculture, and land stability.

**Determination of Soil Properties**

Different properties of soil sample were determined in the laboratory by conducting several tests. The properties of soil sample determined are;

- Natural Moisture Content (IS: 2720 (Part 2) – 1973)
- Specific gravity (IS: 2720 (Part 3) – 1980)
- Particle size distribution (IS 2720 (part 4) – 1985)
- Atterberg (IS: 2720 (PART 5) – 1985)
- Unconfined Compressive Strength (IS 2720 (Part 10) 1991)
- Compaction characteristics like optimum moisture content and maximum dry density (IS: 2720 (Part 8)
- Permiability test (IS 2720 (Part 17))

**Determination of Properties of plastic contaminated soil**

The soil was mixed with different percentage of plastic content. Several tests are conducted in the plastic contaminated soil to get the properties of soil. The following tests are conducted;

- Atterberg (IS: 2720 (PART 5) – 1985)
- Unconfined Compressive Strength (IS 2720 (Part 10) 1991)
- Compaction characteristics like optimum moisture content and maximum dry density (IS: 2720 (Part 8) – 1983)
- Permiability test (IS 2720 (Part 17))

**Determination of Properties of plastic contaminated soil with titanium dioxide**

The plastic-contaminated soil sample which as high negatively affect but plastics are subjected to a remediation process involving photocatalysis. Titanium dioxide ($TiO_2$) is applied to the soil at a required percentage of the total weight of soil, and the degradation of plastic waste is facilitated under the presence of sunlight and the following tests are conducted;

- Atterberg (IS: 2720 (PART 5) – 1985)
- Unconfined Compressive Strength (IS 2720 (Part 10) 1991)
- Compaction characteristics like optimum moisture content and maximum dry density (IS: 2720 (Part 8) – 1983)
- Permiability test (IS 2720 (Part 17))

**Test procedure**

The samples are collected and is carried into the laboratory for the further investigation. The basic properties of the materials are gained by conducting various test like moisture cont., specific gravity, permeability, consistency limit, dry sieve analysis, light compaction, unconfined compressive test. Plastic waste is then introduced into the soil in varying concentrations, typically in the range of 2%, 4%, and 6% of the soil's weight. The plastic is shredded into small pieces to simulate contamination in real-world scenarios. After incorporating the plastic waste, the soil undergoes a series of tests to evaluate changes in its physical and chemical properties. These tests may include compaction tests to assess changes in bulk density and porosity, permeability tests to measure the soil's ability to retain and drain water, and moisture retention tests to understand how plastic affects the soil's water-holding capacity. Additionally, soil pH and nutrient availability are examined to determine if the presence of plastic waste affects soil chemistry. To assess microbial impacts, soil samples may also be analyzed for microbial activity and diversity. The results from these tests will help identify how the presence of plastic waste influences soil quality and its suitability for plant growth and agricultural productivity. After testing the plastic waste into the soil samples at varying concentrations (2%, 4%, and 6% of soil weight), titanium dioxide ($TiO_2$) is added as the photocatalyst. The soil sample which has high variation is then exposed to sunlight or UV light in a controlled environment. The $TiO_2$ particles, when activated by the light, generate reactive oxygen species (ROS) such as hydroxyl radicals ($OH\cdot$) and superoxide ions ($O_2\cdot$), which begin to break down the plastic polymers into smaller, less harmful substances like carbon dioxide ($CO_2$) and water ($H_2O$). During the process, soil samples are periodically collected and analyzed to assess changes in physical and chemical properties, such as soil texture, pH, moisture content, permeability, and microbial activity. The photocatalytic degradation of plastics is measured by examining the weight loss of soil over time, and the impact on soil health is monitored by com- paring pre- and post-treatment soil samples. This procedure will help determine the effectiveness of the photocatalytic process in remediating plastic contamination and its influence on soil properties, ultimately offering insight into its viability as a sustainable solution for plastic waste management in soils.

Figure 5: cutting plastic into tiny shredded plastic pieces.

Figure 6: adding plastic in soil

Figure 7: plastic contaminated soil

## 3. Results and Discussion

### 3.1 Determination of basic properties of soil

The basic properties of laterite soil, were determined using standard laboratory method

| Properties | Value |
|---|---|
| Moisture content | 4.49 |
| Specific gravity | 2.5 |
| Uniformity coefficient, $C_u$ | 11.9 |
| Coefficient of curvature, $C_c$ | 0.685 |
| Liquid limit(%) | 34.5 |
| Plastic Limit(%) | 21.59 |
| Plasticity Index(%) | 12.91 |
| Maximum Dry Density | 2.111g/c |
| OMC | 8.97% |

Table 1 Basic Properties of Soil

The moisture content test was conducted as per IS 2720 Part 2: 1973 by the oven-drying method. The moisture content of the soil sample was found to be 4.49%. The moisture content of soil typically ranges between 5% to 30% for most soil types, though it may be higher in organic-rich soils or in regions with high precipitation. Soils with low moisture content, such as sandy soils, may have values lower than 5%, while clayey soils or poorly- drained soils may have values exceeding 30%.

The test for specific gravity was conducted as per IS 2720 Part 3: 1980 by density bottle method. The specific gravity of soil was obtained as 2.5. The specific gravity of laterite soil is a measure of the density of soil particles relative to the density of water. It typically ranges from 2.5 to 2.75, depending on the mineral composition and iron content.

According to soil classification standards, a **Cu** value greater than 6 and a **Cc** value between 1 and 3 typically indicate well-graded soil, meaning the soil contains a good distribution of particle sizes. A **Cu** value less than 4 suggests poorly graded soil. In this case, with a **Cu** of 11.9 and **Cc** of 0.685, the soil sample appears to be well-graded with a good range of particle sizes, indicating that it has a relatively uniform distribution of grain sizes.

The water content at which the soil changes from one state to other are known as Atterberg's limits. It includes liquid limit, plastic limit, and shrinkage limit and these are considered as the most important index properties of fine-grained soils. Consistency limits (LL, PL and SL) were carried out and the soil was classified as per standards of IS code specifications. The liquid limit of the soil is found to be 34.5% While plastic limit is found to be 21.59% and Plasticity Index is 12.91% . Therefore, the soil sample lies in CH of Plasticity chart.

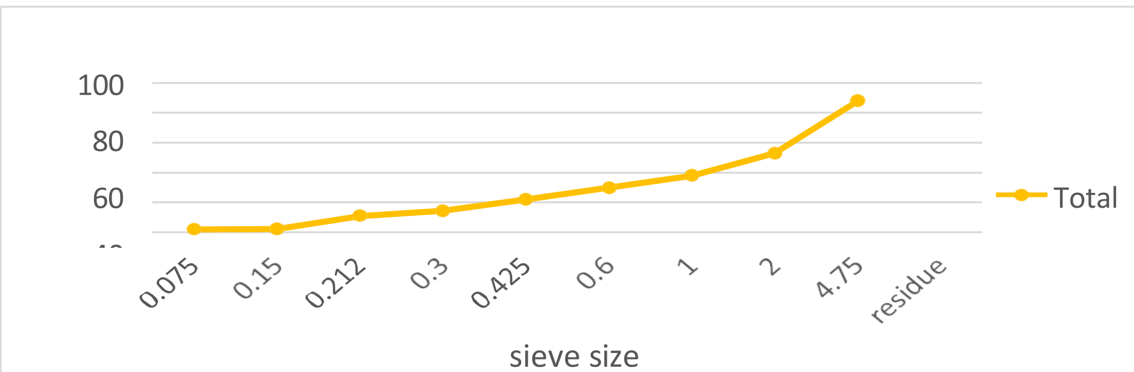


Figure 8: Sieve size vs Percentage Finer

### 3.2 Determination of properties of plastic contaminated soil

The tests for index properties and engineering properties of plastic contaminated soil was determined by conducting series of laboratory experiments. Results obtained from tests are drawn into graphs and comparison is done between soil sample mixed with different proportions of plastic.

#### 3.2.1 Consistency limits

| | **Liquid limit** | **Plastic limit** | **Plasticity index** |
|---|---|---|---|
| 2% plastic | 32.5% | 23.2 % | 9.3% |
| 4% plastic | 38.5 % | 20.45 % | 18.05% |
| 6% plastic | 36 % | 25.72% | 10.28% |

Table 2: Consistency Limit Values with varying percentage of plastic

The li**quid limit (LL)** was determined using the casagrades method. The results indicate a significant different variation in the liquid limit of plastic-contaminated soil compared to the non-contaminated soil. The non-contaminated soil had an average liquid limit of 34.5%, whereas the liquid limit of soil was found to decrease (32.5%) at 2% plastic contamination, but interestingly, a increase in liquid limit was observed at 4% contamination -38.5%, followed by an decrease again at 6%- 36%. These results suggest that plastic waste may have a complex interaction with the soil at different concentrations.

The results show a non-linear trend in the **plastic limit** as the percentage of plastic contamination increases. Specifically, the plastic limit increased at 2% plastic contamination, decreased at 4%, and increased again at 6%. The plastic limit of the control soil was 21.59%. The plastic limit increased to 23.2%, showing a 1.29% increase from the control. The plastic limit decreased to 20.45%, representing a 1.46% decrease from the control. This reduction may be due to plastic particles aggregating or altering the soil structure in ways that affect water retention and plasticity. The plastic limit increased to 25.72%, reflecting a 3.81% increase from the control. At this higher concentration, plastic waste appears to disrupt the soil's structure and increase its plasticity.

The results of the **Plasticity Index (PI)** for soil samples with different plastic contamination percentages (2%, 4%, and 6%). The plasticity index for the control soil is 12.91%. The plasticity index decreased to 9.3%, representing a 3.61% decrease compared to the non – contaminated soil. The plasticity index increased significantly to 18.05%, showing a 5.14% increase compared to the non – contaminated soil. The plasticity index decreased again to 10.28%, reflecting a 7.77% decrease compared to the 4% contamination.

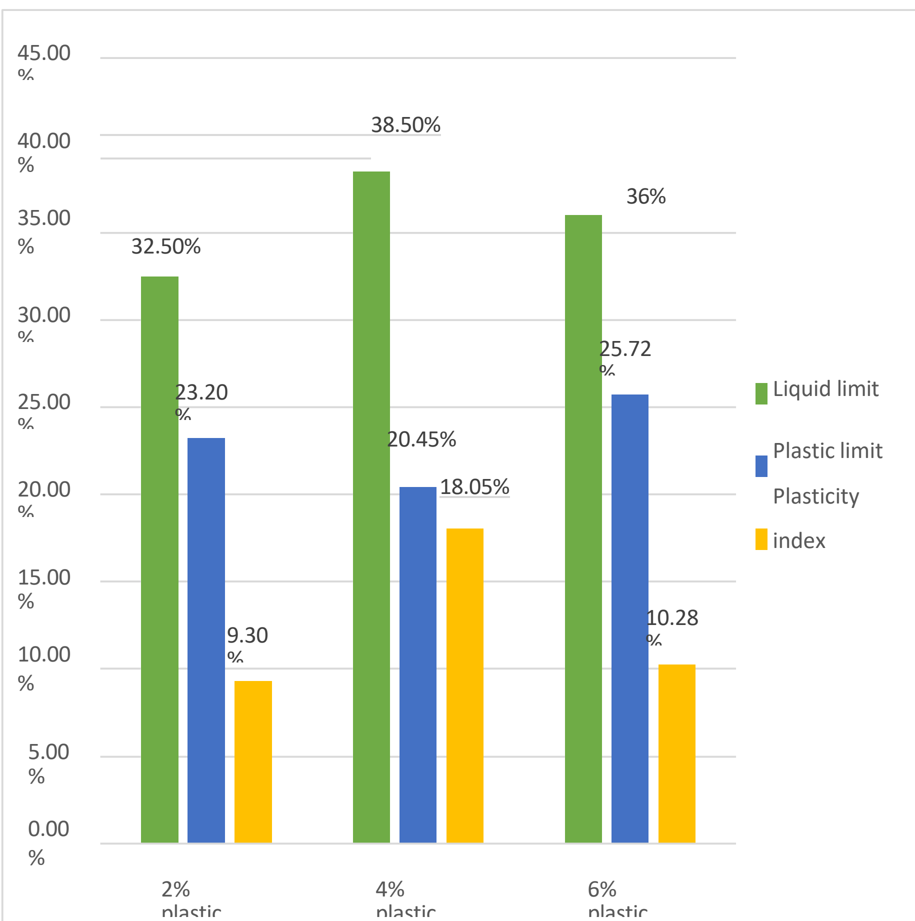


Figure 9: Plasticity Index (PI)

### 3.2.2 Light compaction

| | MAXIMUM DRY DENSITY | OMC |
|---|---|---|
| 2% PLASTIC | 1.888 g/cc | 7.43 % |
| 4% PLASTIC | 1.707g/cc | 10.1% |
| 6% PLASTIC | 1.559 g/cc | 8.9% |

Table 3: MDD and OMC values with varying percentage of plastic

The compaction results, expressed as dry density (g/cc), for the soil with different percentages of plastic contamination are presented above. As the plastic content in the soil increased, the compaction density decreased, which is consistent with the known behavior of plastic contamination in soils. The presence of plastic particles, being non-cohesive and non-compacting, reduces the soil's overall density. This trend indicates that even small amounts of plastic contamination can significantly affect the compaction characteristics of soil, with higher plastic contamination resulting in increasingly lower compaction densities. These results emphasize the potential challenges of using plastic-contaminated soils in con- struction or engineering projects, as the reduced compaction density could lead to lower stability and strength of the soil under load.

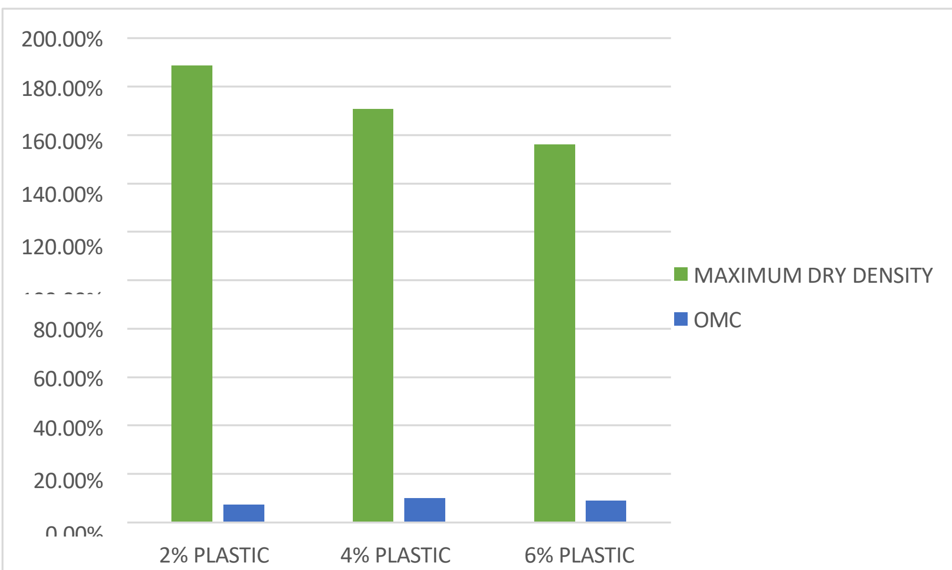


Figure 10: percentage of contamination

## 4. Conclusion

The results of this study highlight the significant impact of plastic contamination on the engineering properties of soil. In terms of consistency limits, the liquid limit (LL), plastic limit (PL), and plasticity index (PI) exhibited complex and non-linear trends with increasing plastic contamination. At 2% plastic contamination, the liquid limit decreased, while at 4%, it increased, and then decreased again at 6%. This suggests that plastic waste interacts with the soil in a variable manner depending on its concentration. Similarly, the plastic limit and plasticity index showed fluctuations, with the plastic limit initially increasing at 2%, decreasing at 4%, and increasing again at 6%. These variations point to the disruptive effect of plastic particles on the soil structure, influencing its water retention and plasticity.

The light compaction results confirmed the general trend that increasing plastic contamination decreases the maximum dry density (MDD) of the soil. This is due to the non-cohesive nature of plastic, which hinders the soil's ability to com- pact efficiently. At higher contamination levels (4% and 6%), the compaction density declined significantly, suggesting that plastic contamination severely affects the soil's stability and strength.

Overall, the presence of plastic waste in soil compromises its mechanical properties, which could pose challenges in construction and engineering applications.

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