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The Effect of Human Hair Fibers on the Behavior of Subgrade Clay Soil

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Abstract
Soil reinforcement techniques have been successfully used to improve the shear properties of weak soils in recent years. To improve the utilization of waste resources and promote sustainable development of infrastructure amid rapid urbanization, one potential option for reinforcement materials is human hair fibers (HHF). Because it is a natural fiber, there are risks to human and environmental health associated with the improper disposal of human hair fiber, an occurring waste product that does not decompose completely. This fabric is abundant, has a high reusability rate, and is ideal for use as a reinforcement to address waste management issues and make the most of inefficient or unnecessary manufacturing websites for long-term sustainability. The CBR test was executed on several samples with diverse fiber possibilities to evaluate the engineering properties of the randomly placed HHF in clayey soil samples using fibers whose average length was 50 mm and whose diameter ranged from 60 to 80 microns and compared the outcomes to those of unreinforced soil. The soil sample was treated with different percentages of Human Hair fiber (0%, 0.75%, 1.5%, 1.75% and 2.25%). The results showed that the value of CBR of the soil sample decrease at 0.75% of HHF and then increased up to 2.25% of HHF.

Keywords: Human Hair Fiber, HHF, Liquid Limit, Plastic Limit, CBR test, Soil.

تأثير استخدام ألياف الشعر البشري على تصرف التربة الطينية السطحية

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الخلاصة:
في السنوات الأخيرة، تم تنفيذ تقنيات تقوية التربة بنجاح لتعزيز خصائص القص للتربة الضعيفة. لتحسين استخدام موارد النفايات وتعزيز التنمية المستدامة للبنية التحتية وسط التحضر السريع، أحد الخيارات المحتملة لمواد التعزيز هو ألياف الشعر البشري (HHF). إن HHF، كونه ألياف طبيعية، إن التخلص غير المناسب من ألياف الشعر البشري، وهو منتج نفايات طبيعي لا يتحلل بشكل طبيعي، يشكل مخاطر على صحة الإنسان والبيئة. هذه المواد فعالة من حيث التكلفة، وفيرة، ومناسبة تمامًا للاستخدام كتعزيز لمعالجة مخاوف إدارة النفايات وتعظيم الاستفادة من مواقع البناء غير المناسبة أو دون المستوى المطلوب لأغراض البناء المستدام. تم إجراء اختبار CBR على العديد من العينات بنسب ألياف مختلفة لتقييم الخواص الهندسية لـ HHF الموضوعة عشوائياً في عينات التربة الطينية باستخدام ألياف يبلغ متوسط طولها 50 ملم وقطرها يتراوح من 60 إلى 80 ميكرونًا ومقارنة النتائج مع نتائج التربة غير المسلحة. تم معالجة عينة التربة بنسب مختلفة من ألياف الشعر البشري (0%، 0.75%، 1.5%، 1.75% و2.25%)، وقد أظهرت النتائج أن قيمة الـ CBR لعينة التربة تقل عند 0.75% من ألياف الشعر البشري ثم تزداد حتى 2.25% من ألياف الشعر البشري.

1. Introduction

Incorporating human hair fibers into soil enhances its properties, decreases its maximum dry density, increases its ideal moisture content, and improves its California bearing ratio. Soil compressive strength, failure strain, early Young's modulus, post-failure strength loss, and residual soil strength improved when human hair fibers were mixed with cement slurry. The C.B.R. value of soil is significantly increased when human hair fibers are mixed with fly ash and varying quantities of coconut fiber. When compared to soil that was not treated, unconfined compressive strength (UCS) was 2.85 times higher with the addition of 0.75 percent human hair fibers. Soil C.B.R. is 7.73 times greater in reinforced soil compared to untreated soil. Human hair fibers increased toughness and prevented cracking, bridging the gap between the two and resulting in less brittle failure [1-4].

According to the observation, human hair fiber reinforcement improves the ability of clayey-sand soils. Cement stabilization is well-known and shows more strength than lime remedy. A sustainable alternative to landfills, human hair fiber can improve the shear strength of the clayey soil and prevent cracks. Soil strength increase up to 1.2% of human hair fibers, but it decreases afterward. The studies aimed to analyze more about using human hair fibers to stabilize the soil. Adding human hair fiber and chloride compounds enhances clayey soil's properties. The clayey soil is stabilized by adding chloride compounds and HHF until it reaches a perfect value; the fraction of chloride compounds will increase the soil's dry density [5-8].

The research looked at inexpensive ways to stabilize soil using polypropylene, fiberglass, and fiber plastic, which enhanced soil strength and characteristics. When combined with synthetic materials to enhance qualities, natural fibers were considered an economical and environmentally conscious way to improve soil quality. Reduced prices, lower energy inputs, and equal mechanical properties were highlighted in the study as advantages of adopting natural fibers in soil stabilization and improvement. Improved soil strength and more economically viable pavement designs were the outcomes of reinforcing soil using human hair fibers. Utilizing 20 mm average length fibers and providing a range of test findings and outcomes, the study delves into the necessity and application of human hair fiber in enhancing the strength of soft clayey soil subgrade. The examined ponds had water unfit for human consumption or agricultural use due to a decline in zooplankton diversity. The tensile strength of sand soil increased significantly with the addition of hair fiber. The combination of sandy soil and hair fiber resulted in more significant displacement upon failure. Possible future applications for eco-friendly hair fibers include reinforcing sand and soil with increased tensile strength. The strength of the soil sample was first raised by 1.2% when human hair fiber was added, but it decreased after that. The expanding clay was made more robust by adding human hair fiber. The behavior of dry sand shear is significantly affected by the reinforcement of human hair fibers. Under saturated conditions, shear strength ratings with reinforcement made of human hair fiber are equivalent to unreinforced sand. Reinforcing with unsorted fibers rather than uniformly lengthened sorted fibers is preferable [9–13].

This reveals a growing interest in using human hair fiber for soil stabilization. Researchers have explored the properties of human hair fibers, their effects on various soil parameters, the underlying reinforcement mechanisms, and the practical applications of this technique. While promising results have been reported, further investigations are warranted to optimize the fiber content, explore potential chemical interactions, and evaluate long-term performance in diverse field conditions. Due to the random behavior sometimes of soils with using different ratios of human hair fibers (HHF), different range of ratios were taken in this study than those taken in previous studies for better understand of the nature of soil behavior with the use of human hair fibers and its effect on soil strength. The previous studies showed that the behavior of soil strength mixed with different ratios of Human Hair Fibers (HHF) is basically depends on the adopted ratio of Human Hair Fibers (HHF), so additional different range of ratios were taken in this study than those taken in previous studies for better understand of the nature of soil behavior with the use of human hair fibers and its effect on soil strength [14–20].

2. Methodological Approach

In this part, the components and methods for experimenting are detailed. In brief, these are the main points: Soil: 35 kilograms of clay dirt were collected from a nearby Baghdad construction site at a depth of one meter. After being dried, filtered, and mixed, it was uniform. Materials: Human Hair Fibers sourced from salons and barbershops. The fibers were washed, rinsed, dried, and sorted to eliminate dirt, debris, damage, and short hair. The physical parameters, such as diameter and tensile strength, were assessed using scanning electron microscopy (SEM) and optical analyses. Enhanced Soil with Fiber Reinforcement: To make reinforced samples, dried, sieved soil was combined with several weight percentages of hair fibers (0%, 0.75%, 1.5%, 1.75%, and 2.25%).

They were separated by hand to prevent clumping and ensure the fibers were evenly distributed throughout the soil. A conventional Proctor compaction test established that distilled water attained the ideal moisture content for compaction.

Tests for the Soil: Standard tests were performed to find the soil's index characteristics, including particle size, Atterberg limits, and specific gravity.

Test for compaction and strength was performed. Soil samples that were either unreinforced or reinforced with fibers were subjected to standard Proctor compaction tests (ASTM D698 or a comparable standard) to ascertain the MDD and OMC, respectively.

Soil samples with and without fiber reinforcement were subjected to California Bearing Ratio (CBR) tests, which measure the load-bearing capacity and shear strength as per ASTM D1883 or a comparable standard. When testing the reinforcing impact of hair fibers, the CBR value was evaluated for several fiber content percentages.

No testing of hair fibers was conducted in this trial. Notably absent from the experiment were measures of the tensile strength and elongation of individual hair fibers, as stated in the text. It proposes using a Dia-stron Tensile Module or an In-stron Tensile Tester for these measurements.

The tensile strength of hair fibers is the amount of stress they can withstand before breaking. Hair fiber width is the maximum permissible stretch before breakage, usually represented as a percentage. Understanding hair length is essential for developing hair treatments and head products as hair strength and density increase. The text describes and analyzes in greater detail the steps for developing soil-hair-fiber models to evaluate the effect of hair-fiber reinforcement on soil properties.

3 Analytical Techniques

3.1 Scanning Electron Microscopy

Surface and microstructure of human hair fibers Analysis of fiber-ceramic interfaces by scanning electron microscopy (SEM) revealed the mechanical interaction and bonding of fibers with ceramic particles.

3.2 Limitations and Assumptions

It is important to recognize the limitations and assumptions associated with the methodological choices in this study.

- The study was carried out on a specific soil, and the findings may differ from soils of other minerals or past industrial characteristics
- Fiber parameters, including length and diameter, fell within a certain range, and the study did not examine the effects of sufficiently different fiber sizes
- Experimental settings, including temperature and humidity, were carefully set up. However, differences in environmental variables during field application may affect the performance of fiber-reinforced soils.
- Although there are some limitations, a methodological approach was developed to better evaluate the potential of human hair fibers for soil stability this study contributes to enhance the information currently available and provides a pathway future research and practical applications.

3.3 Sample Size and Replication

To ensure reliability and statistics, the study considered the importance of the results and suitable sample sizes and replications for each experimental method utilized. To account for potential variability, the soil sample underwent twice replication testing for index property tests, such as particle size distribution and Atterberg limits. For compaction testing, the soil samples underwent three replication tests to provide accurate values for the maximum dry density and optimal moisture content. Six specimens were produced and examined for fiber content percentage in the California Bearing Ratio (CBR) tests. The unreinforced soil was used as a reference sample. Determining sample sizes and replications was based on established norms, published literature, and statistical considerations to guarantee sufficient statistical power and confidence in the acquired results.

3.4 Quality Control Measures

3.4.1 Calibration and Equipment Control

Regularly following the manufacturer's guidelines for calibration of testing equipment such as load frames, displacement transducers, and balances ensures accurate measurements and reduces errors.

3.4.2 Sample Preparation

Consistently following established protocols ensures the introduction of uniform samples via proper mixing, moisture manipulate, and compaction strategies. By decreasing variability in the consequences, this addresses variations in sample education.

3.4.3 Data Verification

By thoroughly evaluating and cross-checking the experimental facts, errors or outliers may be diagnosed and addressed prior to similar evaluation. This ensures the accuracy and validity of the information used for evaluation.

3.4.4 Reference Testing

The accuracy of the inspection method can be checked by including references or control samples. Comparing the reference results to known values may reveal any check deviations or systematic errors. These micro-manipulation techniques are important for any clinical application. They help ensure a reliable and accurate method of obtaining results.

3.5 Health and Safety Considerations

The stringent safety protocols were adopted during the tests, demonstrating a dedication to a secure and responsible study environment. Here is a breakdown of the precise measures taken:

- Personal Protective Equipment (PPE): This minimizes the threat of publicity to risky materials like pollution or irritants in soil samples or human hair fibers. Wearing gloves, protection glasses, and breathing protection, even as critical, protects researchers from potential fitness risks.
- Ergonomic measures ensure proper posture and work practices to save you from accidents and decrease the physical pressure of pattern instruction, trying out, and cloth managing sooner or later. By following ergonomic tips, researchers can avoid musculoskeletal issues that could arise in any other case.
- Waste Disposal: Following proper tactics for disposing of volatile and non-hazardous waste protects human health and the environment. This guarantees responsible management of waste generated during the test.
- Laboratory Safety Protocols: These set-up protocols cover emergency strategies and operating tool tips. By following the recommendations, researchers are organized to deal with sudden situations and perform machines competently, minimizing the hazard of injuries or injuries.

Overall, these health and protection measures demonstrate a well-designed and well-completed study that prioritizes the well-being of researchers and contributors.

4 Experimental Results

4.1 The Human Hair Experiments

The physical properties of the human hair fibers were characterized using scanning electron microscopy (SEM). The average fiber diameter ranged from [60-80] microns.

4.1.1 The SEM Test

Electron microscopy is a mighty approach that employs a focused move of electrons to generate distinct pictures of a sample's surface. Scanning electron microscopy (SEM) pictures provide insights into the surface's topography, composition, and crystal shape. The device examines microstructures, characterizes surfaces, researches nanoparticles conducts forensic investigations, and conducts organic studies. The method includes the coaching of samples, the positioning of a vacuum chamber, the production of pics, and subsequent evaluation. The blessings of SEM include a high stage of magnification, a greater critical capacity to consciousness on objects at exclusive depths and the capacity to research the factors present. Supplementary sensors can verify the elemental composition of a given pattern. Figure 1 displays a scanning electron microscope (SEM) picture that offers statistics on the diameter of the hair.

Figure 2, then again, gives a well-known SEM photograph that shows facts about the move-phase of the hair. Furthermore, Figure 3 presents the scanning electron microscope (SEM) photographs that offer insights into the characteristics of the hair's outer surface. Table 1 shows the summary of Human Hair Fiber Properties.

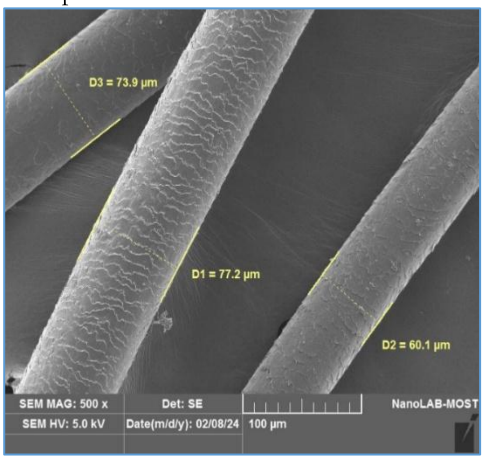


Figure (1): SEM image reveal information about hair dimeter.

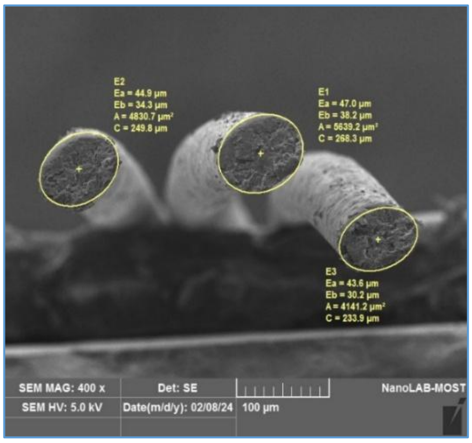


Figure (2): SEM image reveal information about hair cross section.

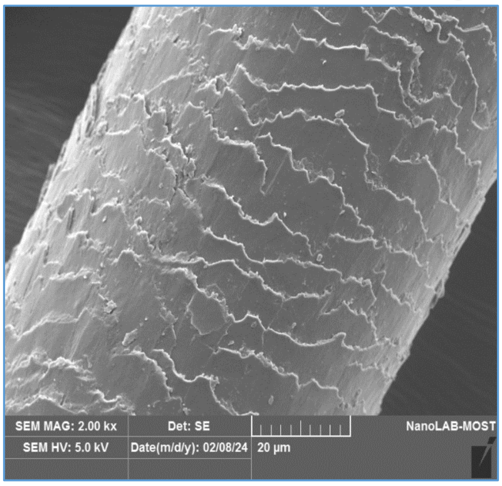
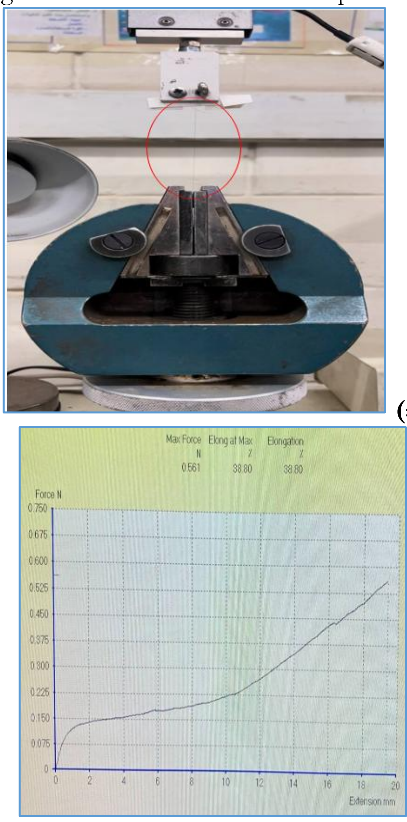


Figure (3): SEM images reveal information about the hair outer surface.

4.1.2 Instron Tensile Tester

An Instron Tensile Tester is a machine designed to evaluate the mechanical properties of materials under tension. It comprises a load frame, crosshead, load cell, grips, extensometer, control system, and data analysis software. Tests performed include tensile strength, yield strength, elongation, and modulus of elasticity. Applications include materials research, quality control, product design, and failure analysis. Advantages of Instron Tensile Testers include high accuracy, versatility, customization, and reliability. Advantages include precision, repeatability, versatility, and customization. This test was performed at the Ministry of Science and Technology labs. Figure 4-a shows Instron tensile tester gripping the hair sample and Figure 4-b shows Tensile Test Graph.



(a)

(b)

Figure (4): (a): Instron tensile tester gripping the hair sample (**b)**: Tensile Test Graph.

Table (1): The summary of Human Hair Fiber Properties.

Properties of Human Hair Fiber	Remark
Cross-Section	Circular
Length	400-600 mm
Avg. Diameter	70 µm
Avg. Elongation	38.80%
Avg. Tensile strength	1.4x10-9 N/m2

4.2 The Soil Sample Experiments

4.2.1 Soil Natural Moisture Content

To determine soil natural moisture content, one can use the oven drying method, which involves collecting a soil sample, weighing the wet sample, drying it in an oven at 105-110°C for 24 hours, and reweighing the dry sample. The formula for calculating soil natural moisture content is provided. Soil's Natural Moisture Content is 21.43%.

4.2.2 Liquid Limit Test and Plastic Limit

The Liquid Limit (LL) is the moisture degree at which soil changes from a plastic circumstance to a liquid one. The determination is made by depositing a soil paste in a steel cup, growing a groove, and then raising and dropping the cup. The number of droplets that had to seal the indentation is documented. The Plastic Limit (PL) is the moisture content at which soil changes from a plastic situation to a semi-strong one. The ellipsoid is shaped and turned around until it becomes a thread with a diameter of 3mm. The plastic restriction (PL) refers to the moisture content material at which the soil thread disintegrates when compressed to a 3mm diameter. The water content has a mean value of 24.9%. Figure 5 shows the Casagrande device, Figure 6 shows the Liquid Limit chart for 25 blows and Figure 7 shows the plastic limit samples.

Figure (5): Casagrande Device.

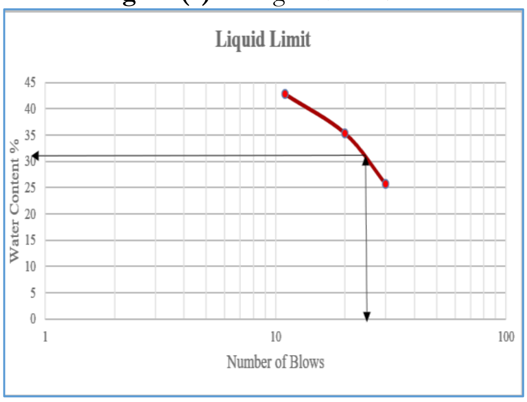


Figure (6): The Liquid Limit chart for 25 blows.

Figure (7): The plastic limit samples.

4.2.3 Compaction

The Standard Proctor Compaction Test is used to determine the connection between soil moisture content material and dry density under a standardized compaction effort. It pursues to establish the top-rated moisture content (OMC) in which the soil achieves its maximum dry density (MDD). This fact is crucial in production and geotechnical engineering to ensure the steadiness of earthworks like embankments, road bases, and foundations. The check includes preparing a representative soil pattern, blending it with varying quantities of water, compacting it into three layers, and calculating the dry density. The dry density is plotted towards the corresponding moisture content material to supply a compaction curve, with the peak indicating the finest moisture content and MDD. The test presents a controlled laboratory method that simulates compaction attempts within the field using a lighter compaction device—six trials, adding 4% water percent of the total soil weight for every trial. Figure 8 shows Proctor curve of OMC and MDD and Figure 9 shows the compaction soil sample can for different WC percentage.

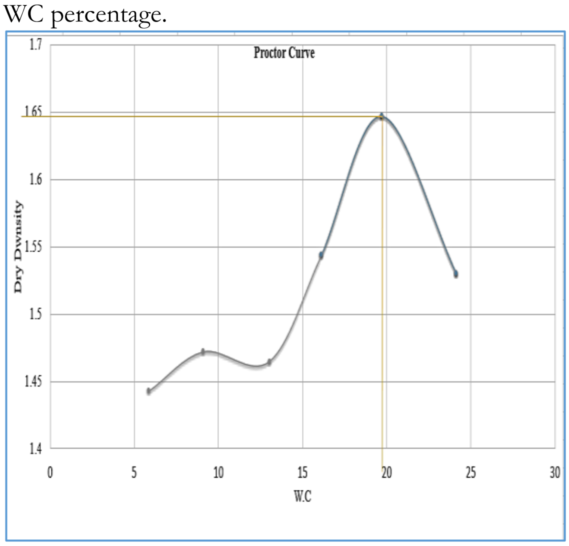


Figure (8): Proctor curve of OMC and MDD.

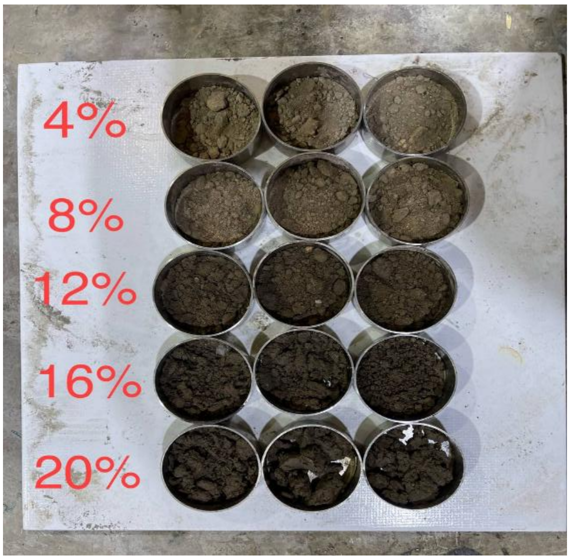


Figure (9): Compaction soil sample can for different WC percentage.

4.2.5 California Bearing Ratio (CBR)

Samples are prepared before starting the CBR test, initially the human hair fibers are well separated by hand to obtain a homogeneous process of mixing human hair with soil as shown in Figures 10 to 13. The California Bearing Ratio (CBR) test determines the strength of subgrade soils, subbase, and base course materials in constructing roads, pavements, and airfields. It quantifies the ability of soil to withstand the penetration of a standardized plunger at a consistent pace of 1.25 mm per minute. The CBR test comprises sample preparation, immersion, penetration, load measurements, and computation. CBR values are shown as a percentage of the force needed to accomplish a specific penetration level in the soil sample relative to the force needed to achieve the same penetration level in a typical crushed rock material. CBR values offer a broad indicator of soil strength,


Figure (10): Prepare the human hair by separating the strands to enhance mixing with the soil.


Figure (11): Soil sample before mixing with HHF


Figure (12): Soil sample after mixing with HHF.


Figure (13): Close up photo of the mixed soil sample with HHF.

With a range of values between 3 and 50. They are vital in pavement design, subgrade evaluation, and construction quality control. Nevertheless, CBR is an experimental examination that does not directly yield a theoretical quantification of attributes such as stiffness modulus or shear strength. In addition, CBR values obtained in the laboratory typically require correlation with field conditions due to potential variations in moisture content and compaction between the laboratory and the actual field. Figure 14 shows CBR standard mold, Figure 15 shows CBR tester machine, Figure 16 shows CBR soil sample after the test complete, Figure 17 shows soil sample mixed with HHF after CBR test preformed and extracted from the mold and Figure 18 shows soil sample mixed with HHF cut in half after CBR test preformed.

Figure (14): CBR standard mold.

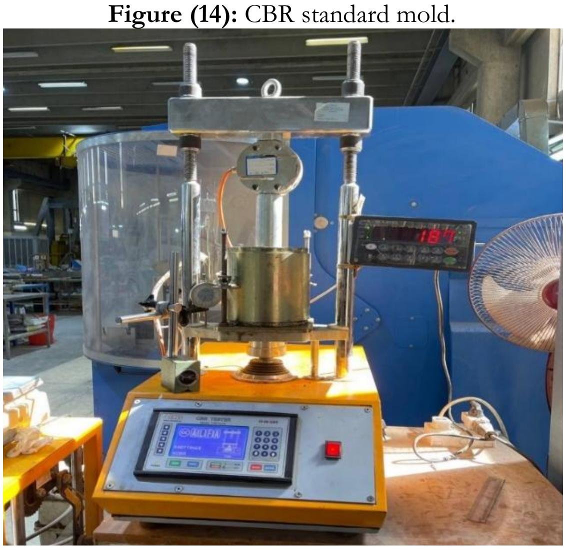


Figure (15): CBR tester machine.

Figure (16): CBR soil sample after the test complete.

Figure (17): Soil sample mixed with HHF after CBR test preformed and extracted from the mold.

Figure (18): Soil sample mixed with HHF cut in half after CBR test preformed.

The soil sample exhibits a natural moisture content of 21.4% and a specific gravity of 2.46. Its Atterberg limits indicate a liquid limit of 31 and a plastic limit of 25, resulting in a plasticity index of 6. The soil's maximum dry density is 1.664, achieved at an optimum moisture content of 19.72%. Finally, the California Bearing Ratio (CBR) at the optimum moisture content (OMC) is 2.28%. Further tests were conducted based on MDD and OMC. Table 2 shows the summary of soil sample properties and Table 3 shows the CBR value for different HHF percentage

Table (2): The summary of soil sample properties.

Property	Value
Natural moisture content	21.4%
Specific gravity	2.46
Liquid Limit	31
Plastic Limit	25
Plasticity Index	6
Maximum Dry Density	1.664
Optimum moisture content	19.72%
CBR at OMC	2.28%

Table (3): The CBR value for different HHF percentage

HHF %	0%	0.75%	1.50%	1.75%	2.25%
CBR1 @2.5mm	2.10	1.35	5.10	5.39	9.29
CBR2 @5mm	2.46	1.81	6.72	7.02	10.38

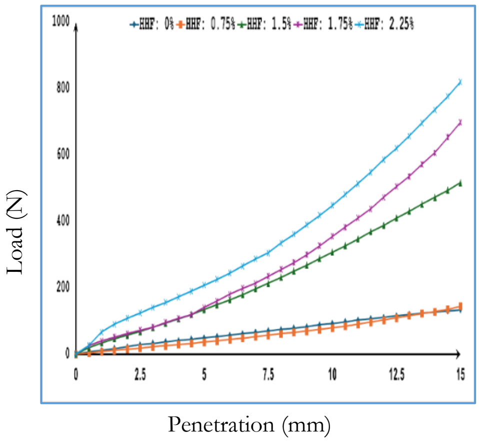


Figure (19): Schematic diagram of dynamic model from CBR test

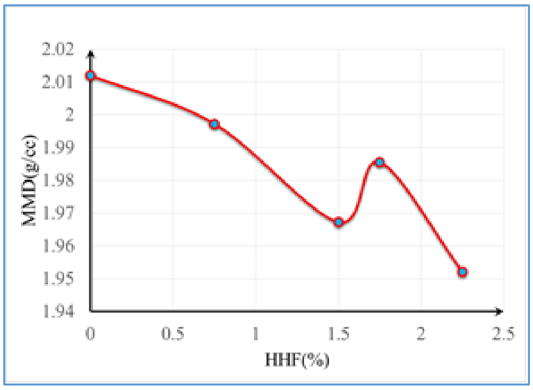


Figure (20): The Results of MDD test.

Table (4): California bearing Ratio (CBR) test results

Percentage of HHF	CBR Value	Increase in CBR value in% with comparison with unreinforced soil.
0	2.5	NA
0.75	1.8	-26.5
1.5	6.7	173.5
1.75	7.0	185.7
2.25	10.4	322.4

5 Results and Discussion

Based on test results, human hair can be used as a natural reinforcing medium to stabilize marginal soft clayey soils. HHF exhibits many advantages, such as good strength properties, low cost, and high toughness for biodegradability. However, increasing the HHF content marginally affects composite specimens' dry density-moisture content relationships. MDD initially reduces lightly due to the addition of lightweight hair fiber, but it remains the same. Hence, using HHF as a reinforcing agent has a two-fold advantage. First, to avoid the tremendous environmental problems caused by dumping human hair waste in open fields, and second, to help develop the various infrastructures on marginal soils reinforced with HHF. This reinforcement may also be used in the field for embankments, especially for approach roads that connect the bridges to the road. It is also beneficial for the stability of slopes. The subgrade thickness will decrease if this reinforcement is used in the flexible pavements.

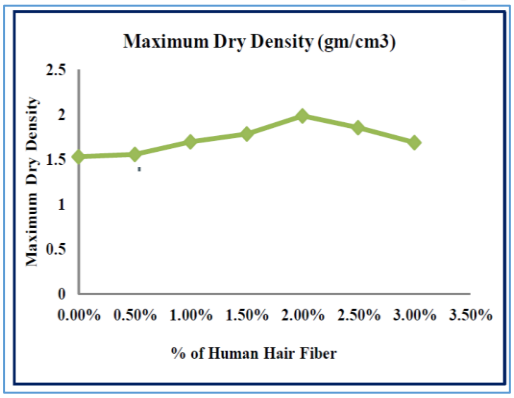


Figure 21: The Results of MDD from another Similar Research.

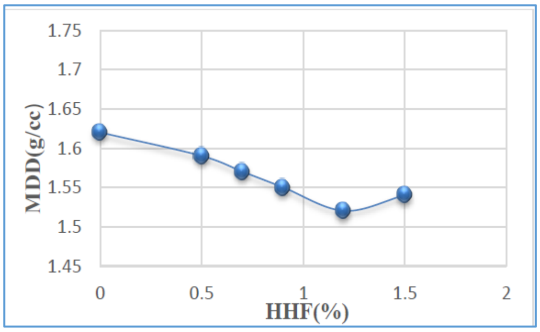


Figure 22: MDD test results of soil sample with varying percentage of HHF

From the test results, it can determine that the (CBR%) will increase by increasing (HHF%) This increase happens because some of that load is taken on by the HHF fibers in the soil matrix, which helps distribute the stresses more evenly and prevents localized failure. The CBR value of the soil specimen decreased at 0.75% of human hair fiber content compared with 0%. The CBR value is maximum at 2.25% of HHF content in soil specimens as shown in Figure 19 and Table 4. Also, it can be determined that the (MDD) value will decrease by increasing (HHF%) as shown in Figure 20. This reduction occurs because HHF is a lightweight material compared to the soil particles. When we add HHF, it occupies some volume within the soil matrix, displacing heavier soil particles. Consequently, the overall density decreases slightly. Tests of Maximum Dry Density MDD of soil sample with varying percentage of HHF from similar studies and researches were shown in Figure 21 and 22.

The incorporation of human hair fibers into the soil mixture results in an improvement in the engineering qualities of the mixture. These characteristics contribute to the soil's enhanced adaptability and strength. Using human hair fiber to strengthen clayey soil would result in greater strength and will prevent cracking; this has the potential to become a building material beneficial to the environment. Test findings were obtained from soil samples subjected to varying concentrations of human hair fibers (the strength of the hair fibers) to determine the soil samples' effectiveness.

6 Conclusion:

At the end of this work, the following points can be stated as a conclusion;

1. The CBR value of the soil specimen decreased at 0.75% of human hair fiber content compared with 0% of HHF.
2. The CBR value increased with increasing the content of HHF and has maximum value at 2.25% of HHF.
3. Dry density decreases with increase in fiber percent up to 2.25% of HHF.

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