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Laboratory Investigations on Mechanical Properties of Subgrade Soil Stabilized with Polypropylene in Powder Form

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Abstract- *The f*oundation is important for any structure built on ground, that is subgrade in case of roads and it must be strong to support the entire loading coming from above layers. For the subgrade to be strong, the properties and behavior of soil is important. While laying foundation (Sub-grade) for roads Engineers often come across soils with low bearing capacity, shear strength and other mechanical properties like CBR (California Bearing Ratio), UCS (Unconfined Compressive Strength) but the construction of road is important, in such situations the process of soil stabilization helps to achieve the required properties of soil for road construction. From the beginning of construction work, the necessity of enhancing soil properties has come to existence. The service of any road depends upon the strength of subgrade. In India, the modern era of soil stabilization began in early 1970's, with the shortage of petroleum and aggregates, it became necessary for the engineers to look at means to improve soil other than replacing the poor soil at the construction site. In this project an attempt is made to improve the mechanical properties of soil by adding Polypropylene a plastic industry by-product in powder form to increase the strength and interlocking characteristics. Polypropylene (PP) is the second most used fiber in plastic manufacturing industry after polyethylene.

***Key Words*: Polypropylene (PP), California Bearing Ratio, Stabilization, subgrade, UCS (Unconfined Compressive Strength)**

1. INTRODUCTION

Often in the construction of roads, Engineers come across different types of problems; one such major problem is with the foundation of road that is subgrade. Subgrade for any type of road made up of soil, it plays a very important role in transfer of load to the soil below it and gives the stability, strength to the sub-base, base and surface courses.

In practice engineers come across different type of soils for subgrade, some of those may be suitable for the construction of subgrade and some may not be, in such cases the engineer has two choices

1) transportation of suitable soil from other places. 2) Increasing the mechanical properties of same (virgin) soil. Transportation of soil may not be feasible as it requires a large quantity of soil to be transported. So, in such typical situations soil is preferable.

Soil stabilization is the process of enhancing the mechanical properties of virgin soil by adding different stabilizers. The most used stabilizers are cement, lime and Fly ash etc. In the consideration of Economical and environmental point of view these stabilizers are not recommendable. So, many researchers started focusing on materials which fulfil this requirement. The purpose of soil stabilization is not only limited to enhance the load bearing of the soil but also improve the shear strength, drainage, permeability, enhance soil resistance to the weathering process and traffic usage to meet specific engineering projects requirement.

1.1 Methods of soil stabilization

Soil stabilization is a procedure wherein the engineering properties of the soil are altered and enhanced to increase its suitability for construction purposes. In civil engineering, soil stabilization is a technique to refine and improve the engineering properties of soils such compressive strength, permeability, compressibility, durability and plasticity. This is very important in road construction which involves in increasing load bearing capacity of layers of road.

There are different types of stabilization methods and techniques available. They are broadly categorized into two different types.

1. Mechanical Stabilization
2. Chemical Stabilization
3. Polymer stabilization

1.2 Motivation of the research

The construction of road involves considerations of many factors like Economy, availability of materials, availability of labor, water near the construction site etc. The major problems that affect the project are availability of good subgrade material. Subgrade layer is the most prominent layer in roads because it is the foundation of the roads. The life, quality of the road depends upon the subgrade soil strength.

Having good subgrade strength, it results in overall decrease on the cost of project. As the subgrade strength increases the pavement layer thickness will be reduced accordingly. In general Road construction engineers always encounter different types of weak soils available for subgrade foundation. In such cases there are two primary possibilities one we can replace the soil from other place which is Uneconomical in terms of Transportation and placing. The other possibility is increasing the strength of weaker soil as per requirement. This process of increasing the mechanical properties of weaker soil to meet its requirement is known as Soil stabilization.

Hence in this study an attempt is made to evaluate the mechanical properties of the subgrade soil stabilized with polypropylene in powder form. Polypropylene is widely used in manufacturing of plastic industry. The soil is stabilized with varying percentages of polypropylene powder and the engineering properties like Maximum Dry Density, California Bearing Ratio, Un-confined compressive strength etc., are evaluated and compared.

The plastic manufacturing industries produce a large amount of polypropylene waste, some of the sample from the industry is collected and grounded into powder form and mixed with virgin soil in various percentages to evaluate its performance on various factors like CBR, MDD, UCS etc.

2. Methodology

In the present investigation, The Laterite soil was collected within NITK campus behind civil engineering department. The soil was collected was undisturbed sample collected using shovels and bought in sacks to the Transportation Engineering laboratory. Some amount of the sample was collected in polythene bag for determining its natural moisture content. The soil was then oven dried and sieved from 4.75 mm Indian as required for laboratory tests.

The materials used in the study are

1. Laterite soil
2. Polypropylene (PP) in powder form.

2.1 Laterite soil

The virgin soil used in the research is Laterite soil, these soils are developed in areas with high temperature and rainfall. These are formed as the result of intense leaching due to tropical rains. With rain, lime and silica are leached away, and soils are mostly found rich in iron oxide and aluminum compound are left behind. Generally, the soils found in the coastal areas are problematic for construction The laterite soils are commonly found in Karnataka, Kerala, Tamil Nadu, Madhya Pradesh and the hilly areas of Orissa and Assam. The soil for this present study is collected within NITK campus.

Figure-1: Polypropylene in powder and Laterite soil

2.2 Polypropylene

Polypropylene fiber is commonly used in wide range of varieties, it is mostly used in the furniture manufacturing industry, In India the demand for polypropylene is increasing at very high rate. The polypropylene demand is 5.08Million metric tons out of 16Million metric tons of plastic demand. As the usage of Polypropylene is increasing the recycling of the material is very important because it is polymer. So, in the aspect of recycling polypropylene sample (Pulverized) was collected from a plastic chairs manufacturing industry in Hyderabad and investigations are conducted in Transportation Engineering Laboratory of Civil Engineering Department at NIT Karnataka.

Important Characteristics of polypropylene

1. Polypropylene is a very lightweight fiber.
2. It does not absorb water. It has good resistance towards water absorption.
3. Polypropylene has good chemical resistance.
4. PP fibers are very resistant to acids and alkalis.
5. The thermal conductivity of this fiber is lower than that of many other fibers.

The index and engineering properties of the natural laterite soil and polypropylene are listed below.

Table-1: Physical characteristics of polypropylene

Physical characteristics	Range of values
Density of polypropylene	536 Kg/m^3
Specific gravity of polypropylene	0.536
Coefficient of conformity Cc	2.73
Coefficient of uniformity Cu	1.28
Chemical Formula	$(C_3H_6)_n$

Table-2: Index and Engineering properties of natural laterite soil

S.NO	Property of soil		Value
1.	Specific gravity of soil (IS 2720 Part 3 1980)		2.22
2.	Grain size analysis of soil (IS 2720 Part4 1985) %		
	Sand Gravel Silt Clay		56.4 15.8 22.8 05.0
3.	Consistency Limits IS 2720 Part5 1985 in (%)		
4.	IS classification of soil		SM
	Type of compactions	Standard Proctor IS 2720 (Part 7)-1980	Modified Proctor IS 2720 (Part 8)-1983
5.	MDD, gm/cm^3	1.857	1.985
6.	OMC, %	13.11	11
7.	California Bearing Ratio CBR in % (IS 2720 (part 16)-1987)		
	Un soaked		3.85
	Soaked		3.71
8.	Unconfined compressive strength in kpa (IS 2720 (part 10)-1973)		96.39

2.3 Tests conducted on soil

The soil was collected within NITK campus and the basic index properties like specific gravity, grain size distribution, Atterberg limits and soil classification as per IS classification is done. The engineering properties like Maximum dry density, Optimum moisture content using both standard and modified tests are found along with CBR for both soaked, un soaked condition and Unconfined compressive strength are Evaluated.

The following tests are conducted on the soil sample

1. Specific gravity determination (IS 2720 Part 3 1980)
2. Grain size distribution & Hydrometer analysis (IS 2720 Part4 1985)
3. Atterberg limits (IS 2720 Part5 1985)

(a) Liquid limit test

(b) Plastic limit test

4. Compaction test (Standard & Modified proctor test) (IS 2720 (part 16)-1987)
5. California Bearing Ratio (Soaked & Un soaked condition) (IS 2720 (part 16)-1987)
6. Unconfined Compressive strength (IS 2720 Part 7-1987)

2.3.1 Specific gravity of soil IS 2720 Part 3 1980

$$Sp.Gravity(Gs) = \frac{(W_2 - W_1)}{((W_2 - W_1) - (W_3 - W_4))}$$

Table -3: Specific gravity of Natural soil

Empty weight of Pycnometer (gm) W1	560.5
Pycnometer + Soil (gm) W2	1026
Pycnometer +Soil + Water (gm) W3	1716
Pycnometer + full of Water (gm) W4	1460
Specific gravity of Soil, G	2.22

Table -4: Specific gravity of polypropylene powder

Empty weight of Pycnometer(W1)	33.29
Pycnometer + Soil (W2)	43.99
Pycnometer + Soil l+ Water (W3)	71.93
Pycnometer + full of Water (W4)	81.17
Specific gravity of Soil, G	0.53

2.3.2 Grain size distribution of natural soil and polypropylene powder

The results from sieve analysis of the soil when plotted on a semi-log graph with particle diameter or the sieve size as the abscissa with logarithmic axis and the percentage of finer as the ordinate axis gives a clear idea about the particle size distribution. With the help of this curve, D10 and D60 are determined. This D10 is the diameter of the soil below which 10% of the soil particles lie. The ratio of, D60 and D10 gives the uniformity coefficient (Cu) and Cc co efficient of curvature which is used as a measure of the particle size range.

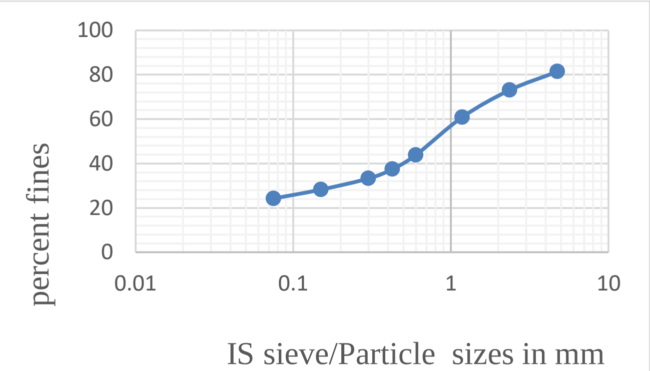

Chart-1: Grain size distribution of natural soil

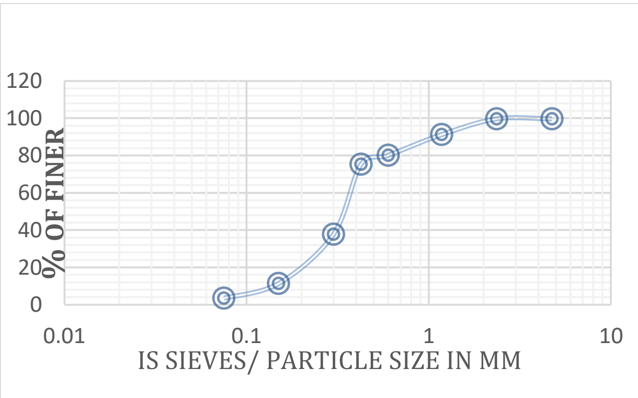

Chart-2: Grain size Distribution Curve of polypropylene powder

2.3.3 Atterberg Limits

A) Liquid limit test: The results from Casagrande apparatus are shown below

Table-5: determination of liquid limit of soil

Cup No	8	25	10	42	174
Empty cup weight (gm)	19.03	12.43	12.96	22.51	11.4
Weight of cup + wet soil (gm)	29.48	21.35	22.6	33.45	20.19
Weight of Cup + dry soil (gm)	26.58	18.84	19.84	30.23	17.55
Weight of water (gm)	2.9	2.51	2.76	3.22	2.64
Weight of Dry soil (gm)	7.55	6.41	6.88	7.72	6.15
Water content (gm)	38.41	39.15	40.11	41.70	42.92
No of blows	31	27	24	22	14

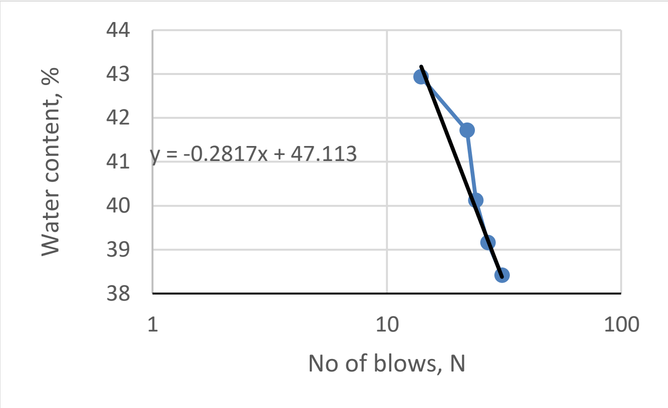

Chart-3: Relation between water content and no. of blows for determination of liquid limit

The liquid limit of natural soil corresponding to 25 blows is **39.93%**

b) Plastic limit

Table-5: Plastic limit test of natural soil

Sample Number	1	2
Cup Number	201	101
Empty cup weight (gm)	9.03	11.04
Weight of cup +wet soil (gm)	9.92	12.15
Weight of cup + dry soil (gm)	9.74	11.93
Weight of Water (gm)	0.16	0.22
Weight of Dry soil (gm)	0.71	0.89
Water content, %	22.53	24.71

The Plastic limit is determined by rolling out soil till its diameter reaches approximately 3 mm and measuring water content for the soil which crumbles on reaching this diameter.

The plastic limit of natural soil is **23.621%**

2.3.4 Compaction

Both standard and Modified Proctor tests were conducted to determine the Maximum Dry Density (MDD), and Optimum Moisture Content (OMC) of soil with different dosages of Polypropylene (3,5,7.5 and 10 %) using standard test equipment and procedure suggested in IS 2720 (part 8)- 1983. The compaction test gives parameters MDD and OMC of stabilized soil. The modified proctor test results are used in further tests like CBR and UCS as it gives the more precise values of compaction considering maximum compaction energy corresponding to field compaction.

3.3.5 California Bearing Ratio (CBR) test

CBR test was conducted using standard test equipment and procedure available in IS: 2720 (part 16)-1979. Stabilized soil samples were tested for un soaked and soaked (4 days after specified curing period) condition at modified Proctor's compaction densities. The rate of penetration of the plunger was maintained at 1.2 mm/minute. The height of the CBR specimen was measured before and after soaking by using a dial gauge fitted to a tripod to measure the swelling.

Figure-2: CBR test apparatus

Figure-3: sample after soaked CBR test

2.3.6 Unconfined compressive strength (UCS) test

The UCS tests were performed as per IS 2720 (part 10)-1973 on the stabilized specimens of 38mm diameter and 76 mm height. UCS test specimens were prepared by using modified Proctor densities. Before testing the specimen, the diameter and heights were measured. The load was applied in the axial direction. The load applied produces an axial strain rate of 1.2 mm/minute. Three identical soil specimens were tested for each combination, and the average UCS is reported.

The UCS test is generally used to report the shear strength of the soil, as we cannot measure the pore water pressure this method of shear strength is not significantly used.

Figure-4: UCS testing apparatus

3. Results and Discussion

The effect on stabilizing soil with polypropylene in varying percentages on different Index and Engineering properties are discussed below:

1. Liquid limit
2. Plastic limit
3. Compaction (Modified compaction) & Optimum moisture content
4. Unconfined Compressive strength (UCS)
5. California Bearing Ratio (CBR)

3.1 Effect on addition of varying percentages of polypropylene with soil on Liquid limit

Liquid limit is determined using Casagrande's apparatus on natural soil was found to be 39.93%. The variation of liquid limit with different varying percentage of polypropylene is tabulated below.

With the addition of varying percentage of polypropylene powder with soil the liquid limit has decreased. The liquid limit of natural soil is 39.93% and the decreasing liquid limit of soil with varying percentage of polypropylene as 3%, 5%, 7.5% and 10% are 36.395%, 35.421%, 33.582% and 32.203% respectively.

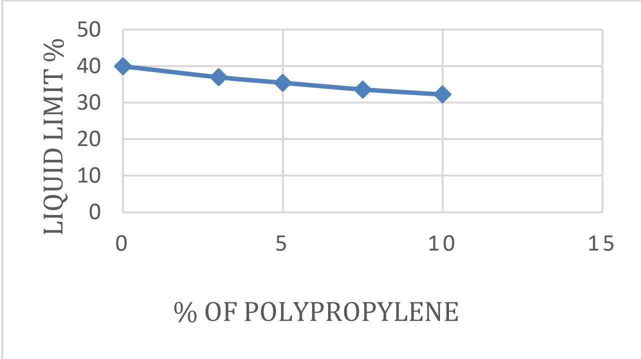

Chart-4: Overall Variation of Liquid limit of soil with different percentage of polypropylene powder

3.2 Effect on addition of varying percentages of polypropylene with soil on Plastic limit

Variation of plastic limit of soil with different percentage of polypropylene powder

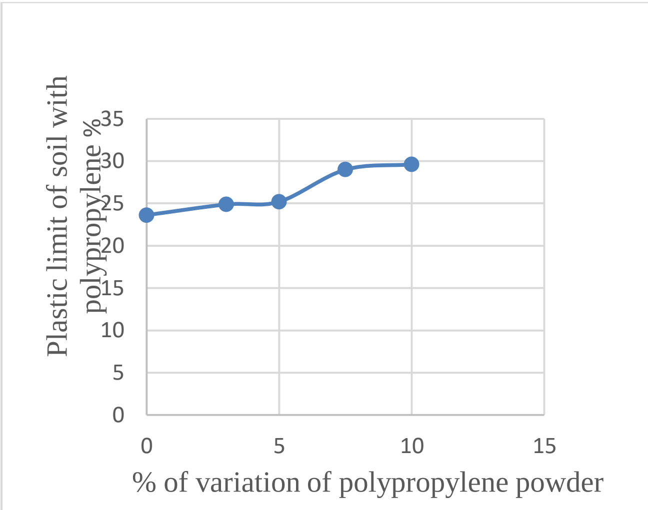

Chart-5: Variation of Plastic limit of soil with different percentage of polypropylene powder

The plastic limit of natural soil is found to be 23.61% and the plastic limit of soil with varying percentage of polypropylene powder as 3%, 5%, 7.5% and 10% are found to be 24.88%, 25.2%, 28.98% and 29.61% respectively.

3.3 Effect on addition of varying percentages of polypropylene with soil on Maximum Dry Density

The MDD & OMC of soil with 10% of polypropylene mix are 1.76 gm/cc & 13.40%.

With the addition of polypropylene, the MDD of soil have decreased slightly, the major criteria to define the strength of subgrade is its CBR values. Hence further investigation on CBR & UCS are performed to evaluate the effect of polypropylene powder.

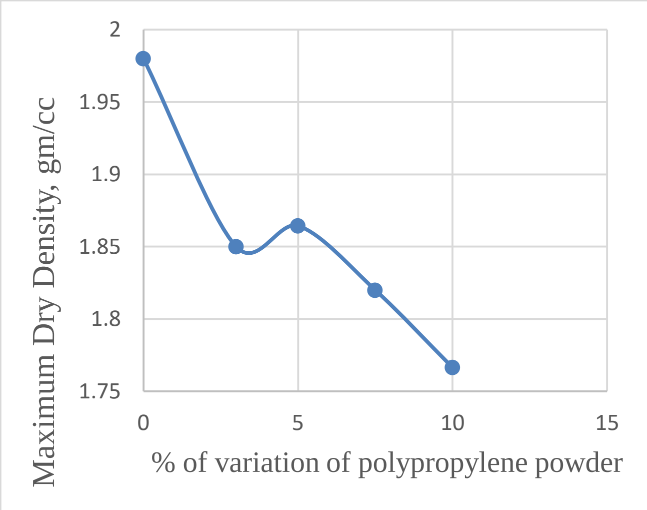

Chart-6: Variation of Maximum Dry density of soil with different percentages of polypropylene with soil

3.4 Variation of Optimum Moisture Content of soil with different percentages of polypropylene with soil

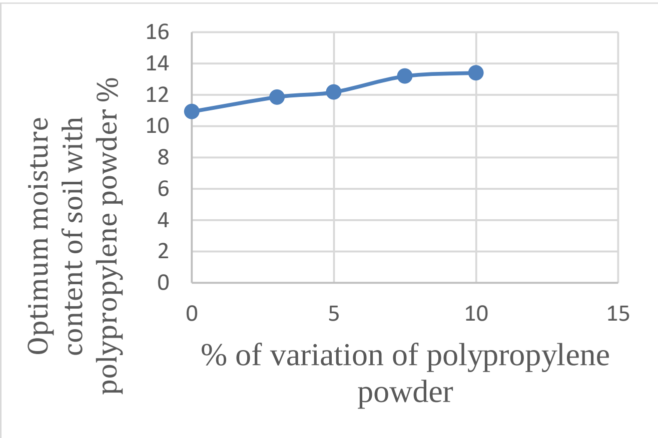

Chart-7: Variation of OMC on soil with different percentages of polypropylene with soil

With the increase in addition of percentage of polypropylene the OMC of soil is increasing due to which the dry density of soil mix is decreasing.

3.5 Effect on addition of varying percentages of polypropylene with soil on California Bearing Ratio CBR

CBR of subgrade is the most important criteria to evaluate the strength of the sub grade soil, the CBR of soil with varying percentage of polypropylene powder is performed for both Soaked and Un-soaked condition. The minimum CBR of subgrade is 2%, If it is less than 2% it can be increased by means of stabilizing or the design should be based on a CBR of 2% and a capping layer of 150 mm thickness of material with a minimum CBR of 10% shall be provided in addition to the subbase.

With the increase in variation of polypropylene powder the CBR values for both Soaked and unsoaked condition have increased drastically. This is because of the intermolecular bond between soil and polypropylene particles.

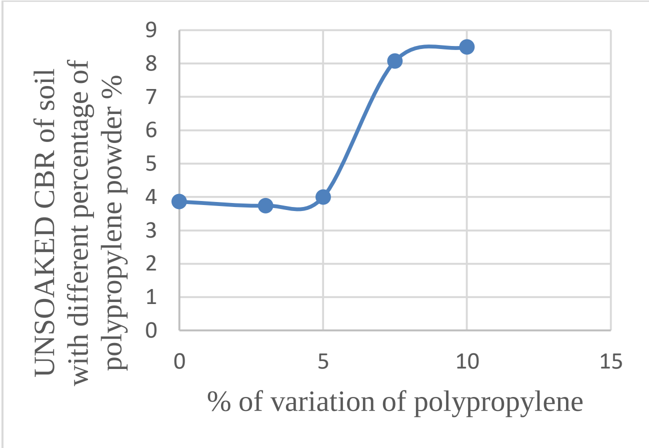

Chart-8: Variation on Un soaked CBR of soil with varying percentage of polypropylene powder

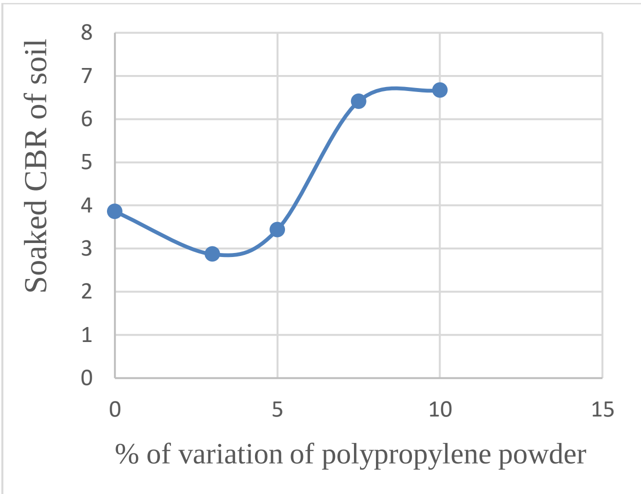

Chart-9: Variation on soaked CBR of soil with varying percentage of polypropylene powder

3.6 Effect on addition of varying percentages of polypropylene with soil on Unconfined compressive strength UCS

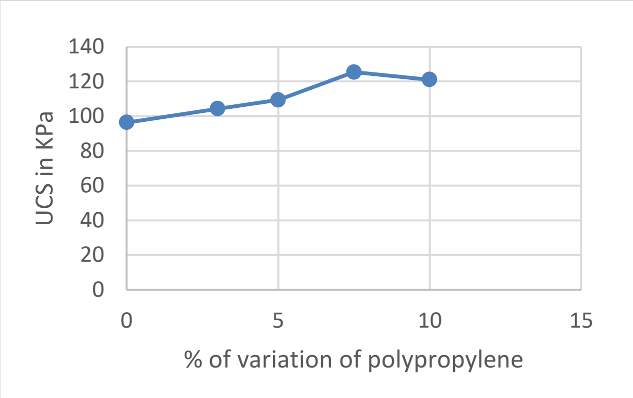

Chart-10: UCS of soil with varying percentage of polypropylene powder

The UCS of natural soil was found to be 96.3KN/m², and when the soil is tested for UCS which is treated with varying percentage of polypropylene the UCS values are found to be increased up to 7.5% of polypropylene powder with soil and then reduce slightly.

4. CONCLUSIONS

Based on present experimental study, the following conclusions are drawn:

1) The addition of polypropylene in powder form have resulted in decreasing of liquid limit with increase in percentage of polypropylene powder with soil and resulted in increasing the plastic limit.

2. The addition of polypropylene has resulted in increasing of Optimum moisture content and decreasing of Maximum dry density for same degree of compaction.

3. There is a significant improvement in CBR with varying percentage of polypropylene powder. The CBR of natural soil for unsoaked condition was found to be 3.86% and 3.74% for soaked condition. After addition of polypropylene with varying percentage as 3%, 5%, 7.5%, and 10% the Unsoaked CBR Values are 3.76%, 4%, 8.07%, and 8.49% and Soaked CBR values are 2.87%, 3.44%, 6.41%, and 6.67% respectively.

4. Initially at addition of 3% of polypropylene the CBR values in both soaked and unsoaked conditions are reduced and then started to increase up to 10% of polypropylene started to increase up to 10% of polypropylene

5. The UCS of natural soil was found to be 96.3 KN/m², and when the soil is tested for UCS which is treated with varying percentage of polypropylene as 3%, 5%, 7.5% and 10% the UCS values are found to be increased as 104.30 KN/m², 109.16 KN/m², 125.30 KN/m² and reduced for 10% of polypropylene.

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