EFFECT OF POLYMER STABILIZER ON THE GEOTECHNICAL PROPERTIES OF BLACK COTTON SOIL

Vijay Rajoria1,Suneet Kaur2

ABSTRACT

In the present scenario soil stabilization has become a vital term in the field of geotechnical engineering due to the construction of heavy structures such as high rise buildings, large dams, underground structures etc. These structures impose immense pressure on soil. Most of the time engineers are not lucky enough to get the soil strata having sufficient strength to sustain this pressure, especially in case of highly cohesive soil which undergo huge variation in strength in dry and wet conditions. Thus it becomes essential to choose an alternative solution to enhance the geotechnical properties of poor soil. In this paper, an attempt has been made to find a solution to these problems by conducting a detailed laboratory investigation on the soil sample stabilized with polymer stabilizer. The geotechnical properties of the stabilized soil are determined and attempt has also been made to understand the stabilization mechanism of the polymer stabilizer. The locally available black cotton soil due to its high shrinkage and swelling characteristics is selected in the present study. Most of the area in the central region covered with the black cotton soil. This soil is highly cohesive and contains enormous amount of montmorillonite, which makes it erratic for any construction project. The polymer stabilizer is used in conjunction with cement to improve its efficiency with the soil particle. The soil sample was treated with different doses of polymer stabilizer and cement. The results obtained from the geotechnical tests conducted on black cotton soil treated with polymer stabilizer were analyzed. The various tests such as Liquid Limit, Plastic Limit, Differential Free Swell, Unconfined Compressive Strength, and California Bearing Ratio were performed on each sample. Scanning Electron Microscope analysis was also conducted to analyze the micro structural changes in the treated and untreated soil specimen. Polymer stabilizer was proved to be effective on poor soil as significant enhancement in the engineering properties and index properties of soil was observed.

Keywords: Soil Stabilization, Polymer Stabilizer, California Bearing Ratio, Unconfined Compressive Strength, Scanning Electron Microscope.

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ABSTRACT: In the present scenario soil stabilization has become a vital term in the field of geotechnical engineering due to the construction of heavy structures such as high rise buildings, large dams, underground structures etc. These structures impose immense pressure on soil. Most of the time engineers are not lucky enough to get the soil strata having sufficient strength to sustain this pressure, especially in case of highly cohesive soil which undergo huge variation in strength in dry and wet conditions. Thus it becomes essential to choose an alternative solution to enhance the geotechnical properties of poor soil. In this paper, an attempt has been made to find a solution to these problems by conducting a detailed laboratory investigation on the soil sample stabilized with polymer stabilizer. The geotechnical properties of the stabilized soil are determined and attempt has also been made to understand the stabilization mechanism of the polymer stabilizer. The locally available black cotton soil due to its high shrinkage and swelling characteristics is selected in the present study. Most of the area in the central region covered with the black cotton soil. This soil is highly cohesive and contains enormous amount of montmorillonite, which makes it erratic for any construction project. The polymer stabilizer is used in conjunction with cement to improve its efficiency with the soil particle. The soil sample was treated with different doses of polymer stabilizer and cement. The results obtained from the geotechnical tests conducted on black cotton soil treated with polymer stabilizer were analyzed. The various tests such as Liquid Limit, Plastic Limit, Differential Free Swell, Unconfined Compressive Strength, and California Bearing Ratio were performed on each sample. Scanning Electron Microscope analysis was also conducted to analyze the micro structural changes in the treated and untreated soil specimen. Polymer stabilizer was proved to be effective on poor soil as significant enhancement in the engineering properties and index properties of soil was observed.

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INTRODUCTION:

Soil stabilization is a process to alter any property of the given soil. It is required when the bearing capacity or the strength of soil available at the construction site is not as per requirement or specification. In that case these properties are enhanced by using different mechanical or chemical means soil stabilization. The importance of soil stabilization is increasing day by day because of the construction of massive structures, such as multistory building, large span bridges, huge dams etc. Polymer stabilization of soil is also considered as one of the important and effective way to improve the properties of soil.

Polymer is simply a long chain of monomers which is connected to each other by a sufficiently strong and flexible wonder wall forces. According to J. S. Tingle (2007) the polymer stabilizer creates polymer coating around the soil particle which eventually connects soil particle with each other by a flexible bond. Thus a soil polymer matrix is formed which can safely resist high intensity load. It is found from the previous research work that with soil it slightly behaves as an inert material, hence it should be used in conjunction with any binding agents such as cement lime etc. to enhance the reaction with soil. Since polymer stabilizes the soil by coating the soil particles, thus for fine soil its efficiency reduced.

A variety of natural polymers, such as lignosulfonates and synthetic polymers are marketed, but the constituents of the polymers are typically undisclosed by suppliers. Due to which the exact physical or chemical reactions that take place between the soil and polymer is not available. However, it is known that the polymers consist of hydrocarbon chains, and it is thought that these chains become entwined within the soil particles thus producing a stabilizing effect. In effect, the polymers act as a binder to glue the soil particles together reducing dust, and even stabilizing the entire soil matrix (Brown et al., 2004).

In this paper the geotechnical properties of polymer soil stabilizer is analysed with the help of detailed geotechnical investigation. In Madhya Pradesh most of the area is covered with black cotton soil, which is highly cohesive and expensive in nature. The black cotton soil possesses a lot of problem to any structure constructed over it due to its highly shrinkage and swelling properties. The use of polymer in this research paper is an effort to find out a most feasible solution to this problem. The polymer stabilizer is used in conjunction with cement to improve its efficiency with the soil particle. The soil sample was treated with different doses of polymer stabilizer and cement. The noteworthy results are observed from the geotechnical tests conducted on black cotton soil treated with polymer stabilizer.

1. LITERATURE REVIEW:

Polymer stabilizers are typically vinyl acetates or acrylic co-polymers suspended in an emulsion by surfactants. It is reported that polymers typically used in soil stabilization have excellent tensile and flexural strength, producing physical bonds with excellent strength. As with asphalt cement, the polymers are resistant to water, providing excellent waterproofing of the coated particles and reducing susceptibility to moisture [Rauch et al. (2003)].

Sinha et al. (1957) performed Tests on silty clay loam using lignins in his study he observed slight increase in the soil strength. In his study several forms of lignins were used which produces almost similar results with relatively insignificant increases in strength. However, Sinha et al. (1957) concluded that lignins could be more effective on granular soils than fine-grained soils.

According to Ingles (2003) Polymers improve the soil by providing physical stabilization through the use of binding agents. Polymer can be easily modified; therefore, a range of polymer combinations can be prepared to modify soils. Many different polymers have been proposed as soil stabilizers, including cationic, anionic and non anionic.

J. S. Tingle (2007) had conducted detailed microscopic investigation on Polymer stabilizers like X Ray Diffraction (XRD), Scanning Electron

Microscope (SEM), Fourier transform infrared spectrometer (FTIR), gel permeation chromatography (GPC) etc. from these analysis he found that the polymer stabilizer coats the soil particles and form strong physical bonds. Polar components present in the polymer may adsorb strongly to the soil particle surfaces and promotes adhesion. Depending on the specific polymer composition, ion exchange between the polymer and soil matrix may occur.

Susan and Mitchell (2007) conducted UCS test on clay soil treated with different stabilizer such as cement, micro fine cement, polymer, super plasticizers, calcium carbide etc. They compared the unconfined compressive strength of the clay soil treated with different stabilizers after 3 days curing period. The results were not very appropriate when the soil was treated with the polymer only. However there was considerable improvement when the soil was treated with cement in addition to polymer. This was due to the acceleration caused by the cement stabilizer in the rate of strength gain of soil treated with polymer. From there experimental results it was also concluded that soil treated with polymer only, showed somewhat lesser strength as compared to cement and polymer treated soil.

Jin Liu (2009) determined Water-stability of soil aggregates using two different soil stabilizers: S-type and E-type. Various concentrations of the two soil stabilizers were tested in soil aggregates that were bigger than 5 mm but smaller than 10 mm. testing the aggregates using the static water-measure method showed that the water-stability index, *K*, increased with the concentrations of soil stabilizers. S-type soil stabilizer in concentrations ranging between 20% and 40% resulted in *K*-values between 64.0% and 83.8%, and E-type polymer emulsions in concentrations between 3% and 7% resulted in *K*-values between 90.1% and 99.7% respectively. The soil aggregates admixed with water resulted in a *K*-value of 11.5%, which was tested as a control. He also analysed the collapse characteristics of these modified aggregates, in which S-type soil stabilizer in low concentrations follows a gradual collapse pattern, while S-type stabilizer in high concentrations and E-type stabilizer in low concentrations follow an explosive collapse pattern.

1.1 Projects under taken in India using polymer stabilizer:

PWD Rajasthan has undertaken some pavement construction works using Renolith in 2001[S. Jayalakshmi (2012)]. Renolith technology has been used in some projects by the Public Works Department of Arunachal Pradesh State in India and reported cost reduction of about 20 to 30% in different pavement construction projects. In Nagaland, a stretch of road leading New Secretariat road in Kohima has been constructed using Renolith. No failure has been observed for last two years and certified to meet to all necessary standards and specifications set by Nagaland PWD [PWD Arunachal Pradesh (2007)]. Some other pavement construction projects which have been completed using renolith with considerable success are as follows [S. Jayalakshmi (2012)]:

1. Lumla township roads under CRF and Zimithang ring road under RIDF.
2. Dirangdzong-Namthung-Sangti road under CRF and Nafra-Nakhu road under NLCPR.
3. Lhou to Mukto road under NLCPR.
4. Shergaon-Doimara road.
5. Road from PWD IB to Bali at Seijosa under RIDF.

2. Material used:

2.1.Soil Sample:

The locally available black cotton is used as a soil sample, which was treated with different doses of polymer stabilizer. The black cotton soil is abundantly available in the central region. This soil is highly cohesive and contains enormous amount of montmorillonite, the black cotton soil contains high amount of Montmorillonite which render its high degree of expansiveness on wetting and shrinkage on drying. The chemical properties of the black cotton soil are given in table 1.

Table-1: Properties of untreated black cotton soil.

S. No.	Tests	Values
1	Specific gravity	2.40
2	Atterberg limits Plastic limit % Liquid limit % Shrinkage limit % Plasticity index	 28 54 25 26
3	Differential Free Swell (%)	35
4	Standard Proctor Compaction properties Maximum Dry unit weight Optimum Moisture content (OMC)%	 1.61 24
5	Modified Proctor Compaction Test Maximum Dry unit weight (Kg/cm^3) Optimum Moisture content (OMC)%	1.69 19
6	California Bearing Ratio	2.62
7	Unconfined Compressive Strength (Kg/cm^2)	6.12
8	Indian Standard soil classification	CH

2.2 Polymer Stabilizer:

The polymer soil stabilizer used in this study was Renolith. The chemical properties of the polymer stabilizer are shown in table 2.

Table 2: Properties of polymer stabilizer

S. No.	Properties	Values
1.	Boiling Point	100 °C
2.	Specific Gravity @25°C	1.00 – 1.02
3.	Viscosity @25°C	1,200 – 2,000 cps
4.	Solubility in water	Miscible in water
5.	pH value @25°C	11.0 – 12.5
6.	Appearance/ Colour	Milky white
7.	Evaporation Rate	Same as water
8.	Melting point	Liquid
9.	Reactivity data	Stable
10.	Materials to avoid	Caustics and strong bases
11.	Hazardous content	None

2.3Cement:

The soil sample is also treated with cement in addition with polymer stabilizer. For this purpose Portland Pozzolona Cement (PPC) is used which is normally available in market. The properties of cement used are given in Table-3.

Table- 3: Properties of cement.

Sl. No.	Property	Value
1	Average Specific Gravity	3.1
2	Initial Setting Time	27 min
3	Final Setting Time	558 min
4	Fineness: Passing 90μ sieve	96%

As per the literature available most suitable range of cement content for the stabilization black cotton soil with polymer stabilizer is 5-7% by weight of soil. In present study the variation of cement content is done on the higher side as well as on the lower side of cement content recommended by manufacturer. Cement is varied from 2-8% by weight of soil.

3. LABORATORY TESTS:

The proportion of cement in the soil specimen was varied from 2% to 8% by weight of soil sample and for each variation of cement in the soil sample; the proportion of renolith was varied from 0% to 8% by weight of cement. The percentage of renolith and the percentage of cement used for different samples are illustrated in Table- 4.

As given in Table- 4, 20 samples were prepared with different contents of cement and polymer stabilizer. Following tests were performed on each sample in the laboratory:

1. Liquid Limit.
2. Plastic Limit.
3. Differential Free Swell.
4. Scanning Electron Microscope
5. Unconfined Compressive Strength Test.
6. California Bearing Ratio.

Table- 4: Variation in the doses for the testing of soil sample:

Cement (%)	**Renolith (%)**				
	0	**2**	**4**	**6**	**8**
2	Sample No.-1	Sample No.-2	Sample No.-3	Sample No.-4	Sample No.-5
4	Sample No.-6	Sample No.-7	Sample No.-8	Sample No.-9	Sample No.-10
6	Sample No.-11	Sample No.-12	Sample No.-13	Sample No.-14	Sample No.-15
8	Sample No.-16	Sample No.-17	Sample No.-18	Sample No.-19	Sample No.-20

3.1 Liquid Limit: Liquid limit test is conducted after 24 hours of mixing the stabilizer into the soil sample. The liquid limit of untreated black cotton soil was 54. The results of soil sample treated with different contents of soil stabilizers are given in the Table- 4.2. The result shows that there is considerable decrease in the value of liquid limit with increase in the stabilizer content. The decrement in the value of liquid limit is illustrated in Figure- 1.

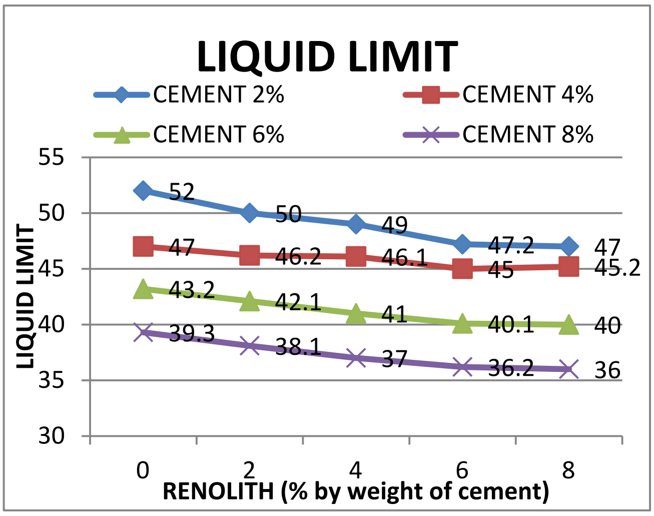

Figure- 1: Variation in the Liquid Limit for different contents of cement and polymer stabilizer for 1 day curing.

3.2 Plasticity Index:

The plasticity index of soil sample decreased with increase in the polymer and cement content. Fromthe test results, it is clear that the stabilizer is effective in controlling the plastic properties of black cotton soil. The variations in the values of plasticity index for different combination of cement and polymer stabilizer are shown in Fig.-2.

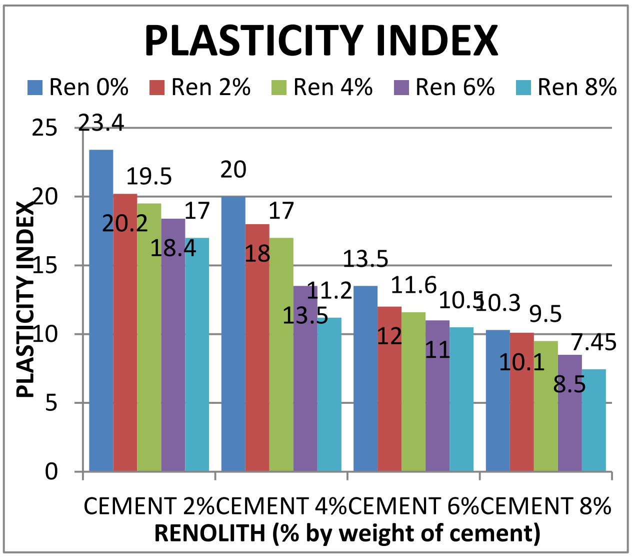

Figure-2: Variation in Plasticity Index.

3.3 Differential Free Swell Index:

Differential free swell index test was conducted primarily to check the variation in the amount of swell in the soil sample treated with cement and polymer stabilizer. For higher doses significant reduction in swelling is observed. The value of DFS for different proportion of cement and polymer stabilizer is shown in Figure- 3.

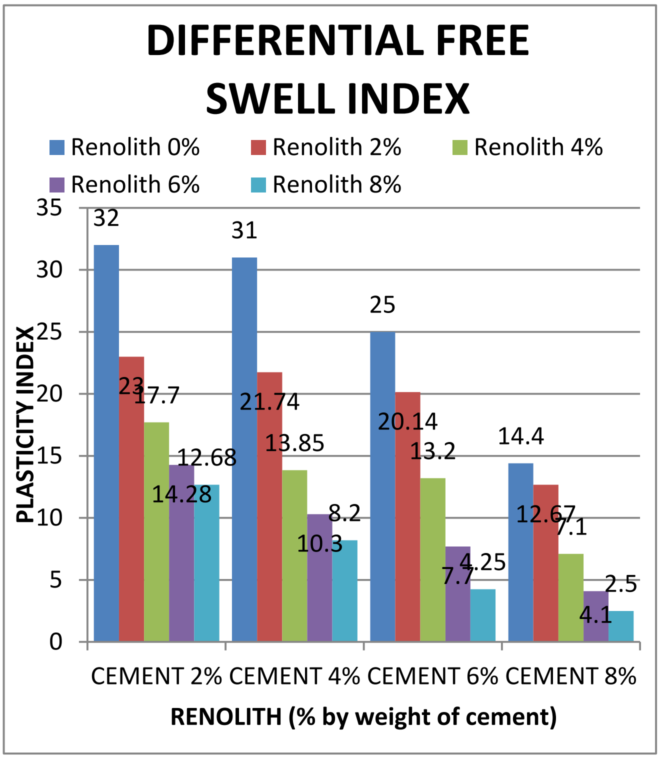

Figure- 3: Variation in Differential Free Swell Index with the combination of cement and stabilizer.

3.4 California Bearing Ratio Test:

The CBR test was performed on untreated black cotton soil and on the soil samples with variation in percentage for cement and polymer stabilizer as given in Table- 4.1. The specimens were prepared as per the relevant IS Code. The untreated black cotton soil gave the soaked CBR Value as 2.63. The Load Vs Penetration Curve for untreated soil is shown in Figure- 4.

The values of soaked CBR with all variation of cement and polymer stabilizer content are illustrated in Figure- 5.

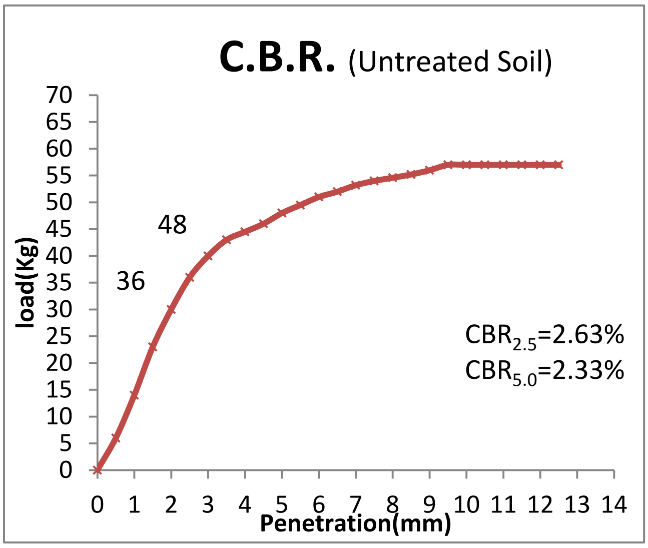

Figure- 4: Load Vs Penetration curve for untreated soil.

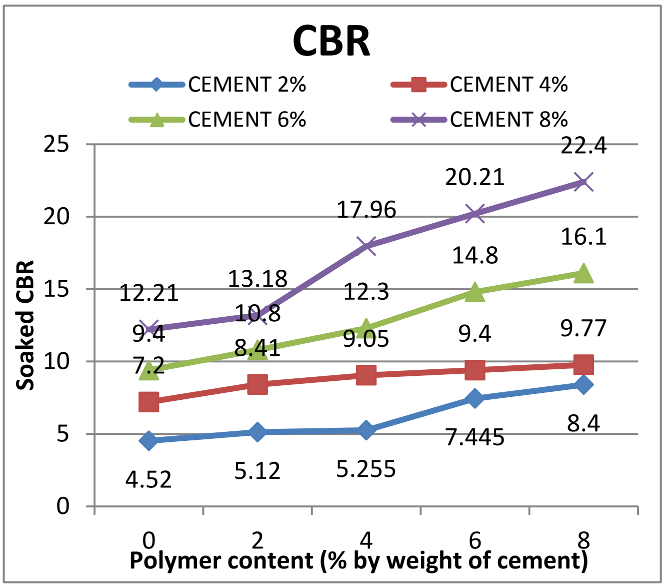

Figure- 5: Variation in the CBR value for different contents of cement and polymer stabilizer for 1 day curing.

3.5 Unconfined Compressive Strength:

Unconfined Compressive Strength Test was conducted on the soil sample at optimum moisture content as determined from the compaction test. The specimen were prepared by heavy compaction and allowed to cure for 1day and 7day. The UCS value of untreated soil was 612 KPa. The cement and polymer content is varied in same proportion as done in CBR test.

The variation in UCS value for different dosage of cement and polymer content is for 1 day curing and 7 day curing is illustrated in Figure-6 and Figure- 7 respectively.

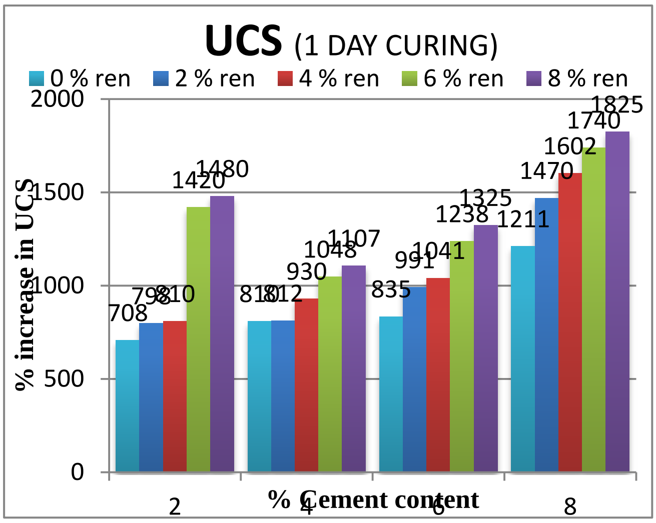

Figure- 6: Variation of UCS with all combinations of cement and polymer for 1 day curing.

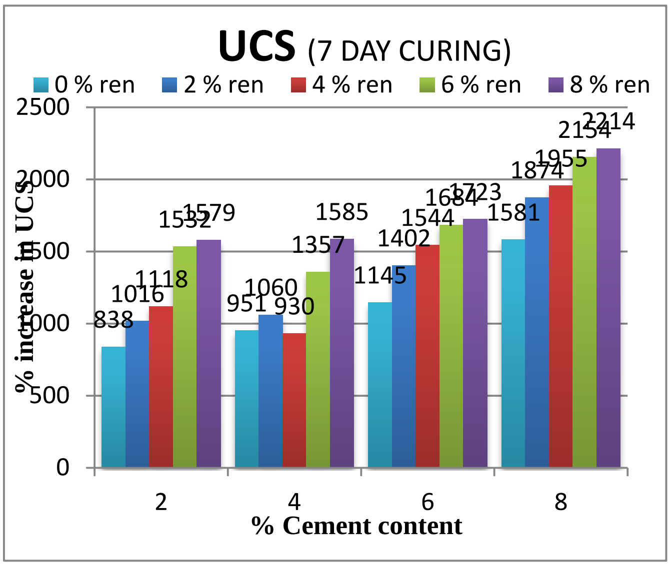

Figure- 7: Variation of UCS with the combinations of cement and polymer stabilizer for 7 day curing.

In most of the cases the maximum percentage increase in the UCS was observed for 6 to 8% of polymer stabilizer content. Hence it can be concluded from the percentage variation of UCS value that the polymer stabilizer gives enhanced performance at higher dosage of cement and polymer stabilizer. For cement there is a continuous increase in the UCS value with increase in the cement content. The quantity of cement to be used will depend upon the strength properties of soil required in the field.

3.6 Scanning Electron Microscope:

The scanning electron microscope test was conducted check the microstructural as well as chemical changes in the treated soil with respect to untreated soil sample.Figure-8(a) shows the microstructure of untreated soil sample. Figure-8(b) shows the cement used to treat the soil in conjunction with polymer. Figure- 8(c) shows the microstructure of soil treated with cement after 7 day curing period. The microstructure of soil treated with cement and polymer with 7 days curing period is shown in Figure- 8(d).

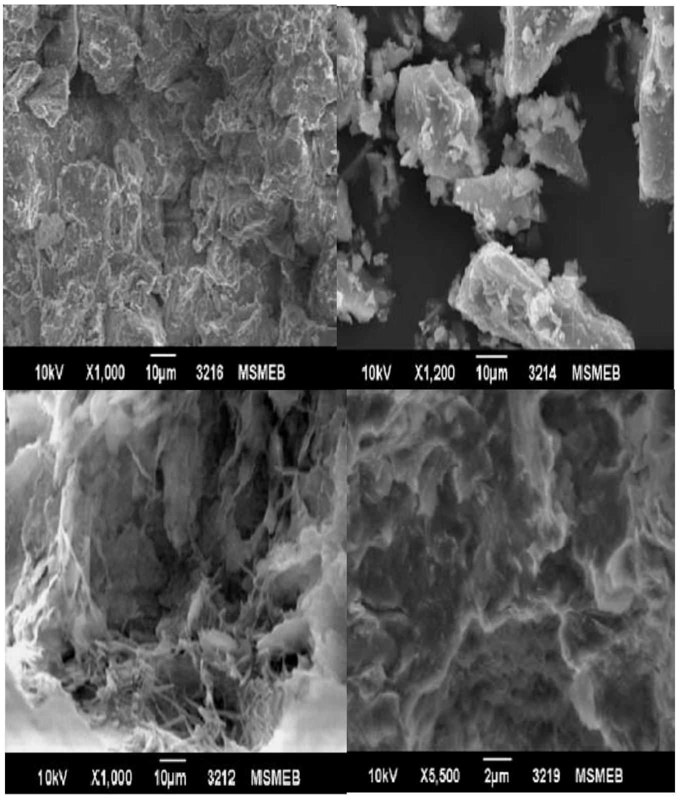

Figure-8: SEM images of treated and untreated soil.

4. CONCLUSION:

The addition of polymer caused a significant modification in engineering properties. The polymer addition showed considerable improvement in strength, CBR, as well as swelling characteristics. The increase in these engineering properties was due to polymer bonding on the surface of the soil particles. The conclusions drawn from the results obtained are as follows.

4.1 Liquid Limit:

The liquid limit of untreated black cotton soil was 54. For the polymer treated soil sample the liquid limit of soil sample decreased considerably to a value of 36. The percentage decrease observed in the liquid limit was up to 33.2% for the polymer treated soil as compared to untreated soil.

4.2 Plasticity Index:

The plasticity index of the polymer treated soil is decreased with increase in content of stabilizer. This proves that the polymer is highly effective in reducing the plastic characteristics of black cotton soil. The plasticity index of untreated black cotton soil sample was 26, while plasticity index of black cotton soil treated with polymer varied from 23.4 to 8.5. Maximum decrease of 67% is observed in the plasticity index when it is treated with higher dosage of polymer stabilizer.

4.3 Differential Free Swell Index:

There is a considerable decrease in the differential free swelling property of the soil sample. Initially the DFS for the untreated soil is 37.5%. While with increase in the dosage of polymer stabilizer, it decreased up to 2.5%. Hence, it can be concluded that the polymer stabilizer can be very effective in preventing the swelling properties of black cotton soil.

4.4 California Bearing Ratio:

The CBR test conducted on black cotton soil showed significant improvement in soaked CBR value when the cement and polymer stabilizer content is increased. The CBR value for the untreated soil was 2.63. The maximum percentage increase in CBR value for treated soil sample was 772%. The CBR values of the soil sample treated with polymer stabilizer enhanced by 2 to 8 times the value of untreated soil.

The CBR values of soil sample increased considerably by mixing the soil sample with higher percentage of polymer stabilizers as recommended by the manufacturer. This confirms the basic mechanism of stabilization that, the clay of soil needs comparatively higher amount of polymer stabilizer due to higher surface area. The increased polymer bonding among the soil particles increases the engineering properties of soil.

4.5 Unconfined Compressive Strength:

The UCS test was conducted on soil specimens for two different curing period i.e. 1day and 7 day. For untreated soil sample the UCS value was 672 KPa, which is enhanced from 712 KPa to 2214 KPa with increase in the contents of cement and polymer. The strength increase was probably due to the polymer coating around the surface of the soil particles causing increase in the shear strength of soil sample due to inter-particle bonding.

4.6 Scanning Electron Microscope:

In SEM analysis some microstructural changes were observed between treated and untreated soil sample which is probably due to the formation of polymer coating around the soil particle.

5. SCOPE FOR FUTURE WORK:

1. Further research work and laboratory test can be conducted to evaluate the performance of polymer stabilizer on different types of soil.

2. Curing period of treated soil sample can be further increased to check the long term effect of soil stabilizer.
3. A detailed microscopic investigation could enhance understanding of the soil-polymer interaction and overall system behavior. A fundamental understanding of this interaction would assist with preparing specifications for industry use of polymer as a soil amendment.
4. For successful field-scale implementation, further enhancement of standards and methods is needed by conducting large scale experimental research project assisted by field testing program.

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