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Stabilization of Soil Using Guar Gum Biopolymer

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Abstract: Soil stabilization in a broader sense refers to various methods and techniques employed to improve the geotechnical properties of a problematic soil to enhance its load bearing capacity. Many materials like cement, lime, bitumen etc. are employed to improve the properties but they are not ecofriendly as such. In this study, an effort has been made to study the effect of natural occurring polymer, Guar Gum to improve the mechanical properties of soil rich in clayey minerals. This biopolymer is biodegradable in nature and have less carbon footprint than other conventional materials. Five different varying proportion (0.5%, 1.0%, 1.75%, 2.50% and 3.25%) of Guar Gum with soil has been used to find the optimum dosage required for stabilization. Three major properties like Optimum Moisture Content -Maximum Dry Density relation, California Bearing Ratio Test (both unsoaked and soaked) and Unconfined Compressive Strength Test were studied on the soil and mixes. From the results it was concluded that soil with 1% Guar Gum has shown maximum improvement in the geotechnical properties of soil.
Keywords: Stabilization of soil, Guar Gum, Biopolymer, Geotechnical Properties of soil and Ecofriendly

I. INTRODUCTION

Soil stabilization technique is employed to improve the geotechnical properties of the problematic soil so as to increase its load bearing capacity and to improve the durability of construction. For this, various conventional methods like use of cement, lime, bitumen etc. are employed to improve these properties. These materials are however not ecofriendly and have more carbon footprint in the environment. To promote sustainable development and to reduce the impact of construction projects on environment, new ecofriendly materials are now being studied to replace these materials. One such material is Guar Gum, which is a naturally occurring polymer also referred as Biopolymer It is extracted from the seeds of the Guar Plant. India is world's leading producer of Guar Gum.

Guar Gum has binding property and is viscous in nature. This property of Guar Gum can be utilized for the binding effect on dispersive soils just like other binders. Guar Gum is a water soluble, non-ionic biopolymer and remains stable in solution of pH range of 5-7. These are mostly used as a thickener in food industry, as a binder agent in pharmaceutical industry etc.

A. Methods of Soil Improvement

These can be broadly classified into three categories:

1) *Mechanical:* This method incorporates improving the soil properties by means of physical processes like to alter the property by changing the constituents of the soil by either addition or removal of certain particles in it, or by making soil dense with the help of compaction. The primary objective of this stabilization is to make soil resistant to deformation and displacement under loads. For this particle size analysis of soil is carried out to determine the various fractions of sizes of the particles present in it and then according to the demand of desired property removal or addition of certain particles is done or compaction is incorporated.
2) *Chemical:* This method employs use of certain chemicals to improve the properties of problematic soils. Here the enhancement of the properties takes place by the chemical reaction taking place between the soil particles and the chemical substances. Examples of chemical stabilizers include cement, lime, bitumen, calcium chloride, sodium silicate, sodium chloride etc. Usage of polymers both natural or artificial have also improved the properties of soils by chemical reactions between the particles and polymer molecules.
3) *Biological:* This method employs afforestation in a barren area where the roots of the plants help in binding the adjacent soil particles with it and thus reducing the chances of erosion of top soils and also providing a greater stability to the soils especially in the sloping areas from being washed off or being eroded. Many studies have been going on to find out the effect of calcite precipitation induced by microbial activity on the strength/stiffness and permeability of the soils also known as Bio cementation.

4) *Soil Stabilization Using Biopolymers:* Biopolymers refers to the natural polymers generated by the cells of a living organism. These biopolymers form a long chain consisting of monomeric chains which imparts to their heavy molecular weight. In recent studies researchers have found out the binding properties of some of these biopolymers with the soil particles which has greatly influenced the mechanical properties of the soils. These biopolymers are biodegradable in nature. Since these polymers are naturally occurring, their application in the field of soil stabilization proves to be beneficial with respect to the environmental concern over the conventional method of stabilization. These biopolymers have less carbon footprint than the other chemical stabilizers and hence helps in the sustainable development of the construction industry.

B. *Biopolymers used in soil Stabilization*

1) *Guar Gum:* This is a polysaccharide biopolymer extracted from the guar beans that has thickening and stabilizing properties. These biopolymers are mainly grown in India, Pakistan, USA, Australia and Africa. India is one of the largest producers of these biopolymers and contribute to about 80% of the world production. This is a water soluble, non-ionic biopolymer and remains stable in solution of pH range of 5-7. These are mostly used as a thickener in food industry, as a binder agent in pharmaceutical industry and also in other industries.
2) *Xanthan Gum:* This also belongs to polysaccharide biopolymer and is produced by the fermentation of glucose and sucrose. It serves as an effective thickening agent, emulsifier and stabilizer which prevents the separation of ingredients. Common application of this biopolymer is in food industry, oil industry, cosmetics industry etc.
3) *Alginate:* It is also known as Sodium Alginate, which is derived from the brown seaweeds. It is a linear unbranched polymer comprised of combination of manuronic acid and guluronic acid. Various properties of these biopolymer include film forming ability, Ionic crosslinking, gelling etc. It is used in waterproofing fabrics, pharmaceutical industries, dye printings etc.
4) *Carboxymethyl Cellulose (CMC):* These are synthesized by the alkali catalysed reaction of cellulose with chloroacetic acid. These exhibit property of thickening, viscosity modifier, stabilizing emulsions etc. It is used in medical applications, Food science, culinary uses etc.
5) *Beta 1, 3/1, 6 Glucan:* This polymer is extracted from yeast, fungi, cellulose, cereals and some other bacteria. It dissolves in water and creates a gelatinous solution. It finds its application in Medical Industry and further it's been used to study its effect on stabilization of soil in civil engineering.
6) *Chitosan:* This polysaccharide is extracted from chitin shells of shrimp and other crustaceans. This polymer is biocompatible, biodegradable and non-toxic in nature. It finds its use in medical industry, biotechnology, agriculture etc.

C. *Advantages of using Guar Gum are as follows*

1) It is eco-friendly material which is derived from renewable sources and are also biodegradable in nature. Unlike the conventional stabilizers it has less carbon footprint than cement, lime etc.
2) It has a tendency to form a cross linking network, which further enhances soil cohesion by forming bonds with soil particles. This phenomenon gives ability to soil to resist deformation.
3) This biopolymer has water retention capability due to its hydrophilic nature which is valuable in arid regions which are prone to drought.
4) These biopolymers can reduce erosion due to its binding properties and will hence enhance the slope stability of the soils.
5) Unlike synthetic biopolymers, it degrades over time and hence will reduce their impact on the environment.

II. LITERATURE SURVEY

1) Acharya et al. 2017 In this, authors conducted test on two dam locations, for the slope stability using Guar Gum for treatment at Grapevine Lake & Joe Pool Lake, Texas which was originally constructed with expansive soils. Slope Stability was assessed using the Fast Lagrangian Analysis of Continua in three Dimensions Software. After the tests were conducted, it was observed that biopolymers significantly improve the stability of slopes constructed with expansive soils. Biopolymer treated soils showed moderate improvement in shear strength and effectively mitigated the shrinkage characteristics of the native expansive material. It would help in prevention of moisture infiltration into the slope preventing shallow slope failures. They concluded that the easy availability, low acquisition and treatment cost, smaller carbon footprint compared to other stabilizers like lime and cement are tangible benefits of using Biopolymers as Soil Stabilisers.

2) (Ayeldeen et al., 2017) In this, author aimed to investigate the enhancement of mechanical properties of collapsible soil using xanthan gum and guar gum as biopolymers. The experiments were focused on three major soil properties mainly companion characterisations, collapsible potential and shear parameters. The experiments were performed at two curing periods that is soon after mixing with biopolymers and after one week of curing period. A finite element model was built using software Plaxis 2D 8.2 to predict behaviour of treated collapsible soil after and before inundation. It was observed that MDD reduced with increasing concentration of both biopolymers and the reduction was more in case of Guar Gum than Xanthan Gum while the OMC value increased for both the cases. The efficiency of biopolymer reducing the collapse potential for the wet mix was about 2-3 times more than dry mixing. It was observed that despite the reduction in density, with increased concentration of biopolymers, shear resistance of treated soil has improved. Numerical model concluded that stabilizing soil with biopolymer reduces the settlement during and after inundation under the footings and also improves the soil bearing capacity.
3) (Das et al., 2015) In this study, Compaction tests were done to obtain the optimum moisture content and maximum dry density and also unconfined compressive tests were conducted on samples of pond ash without and with various percentage of xanthan gum (1%,2%,3%) and guar gum (0.5%,1%,2%). Based on the limited study conducted on the pond ash collected from Rourkela Steel Plant, Rourkela, Orissa, it was observed that OMC of the biopolymer modified pond ash was more than the virgin pond ash while MDD decreased with increasing content of biopolymers. It was also observed that strength increased with increase in percentage of gum and have better strength when it was sundried. With the same percentage of gum, it was concluded that pond ash stabilized with Guar Gum has better strength compared to that of Xanthan Gum. Specific Gravity of the pond ash stabilized with biopolymers increased with addition of biopolymers.
4) (Keshav et al., 2021) This study illustrated use of xanthan and guar gum for soil stabilization. UCS and one-dimensional consolidation tests were performed on both treated and untreated soil samples. Soil was classified as MH group soil. Xanthan and Guar Gum were added in a ratio of 0.5, 1.0 and 1.5% of expansive soil. The samples were cured for 0, 7 and 28 days and then UCS test were performed. The Results indicated that Xanthan gum addition has showed increase in strength to 630% at the optimum value of 1% for 28 days while Guar Gum has shown an increase of 100% at an optimum value of 1.5% at 0 days. As the curing period for Guar Gum has been increased there has been decrease in the strength due to solubility of the gum. At last author put forward of adding cementitious material along with xanthan gum to increase durability of soil.
5) (Mohan & Adarsh, 2022) In this, Authors conducted test on soil sample collected from kuttanad region of allapuzha district in kerala which was classified as inorganic clay of high plasticity for its stabilization using Guar Gum biopolymer. Guar Gum was added in varying contents of 0.5, 1.0, 1.5, 2.0, and 2.5% by dry weight of soil taken. Guar Gum was added in solution form. The samples prepared for testing were cured from 7 to 28 days before testing. It was observed that as the guar gum percentage varied from 0.5% to 2.5%, MDD value reduced from 15.0 kN/cubic metre to 13.2 kN/cubic metre, and the corresponding OMC increased from 21.5% to 23.4%. UCS trend was found to be increasing till 1.5% and then the value further decreased. Hence 1.5% Guar Gum content has found to be the optimum dosage for this stabilization. CBR strength increased until 1.5% GG content and then it reduced slightly. This trend has been seen for all curing periods. It has been concluded that the UCS strength of soil improved by 1.8 times and the CBR strength of soil improved by 4 times than the untreated soil.
6) (Puppala & Pedarla, 2017) In this article, four research studies involving stabilisation to mitigate expansive soil behaviour at both shallow and deep depths have been analysed. In the first study, the role of clay minerals in the durable performance of stabilised soils is explained and a novel mix design method by accounting for clay mineral percent in the design is developed. Second study involves mitigation of surficial slope failures. The soils at the site were treated with four stabilisers and among the treatment, 8% lime + 0.15%fibers and 8%lime treated soil were the top two treatments. In the third shallow stabilisation, biopolymers were used to improve the stability of slopes. Treatment showed moderate improvement in the shear strength but effectively mitigated the shrinkage characteristics of the native material. The Final research study focused on deep soil treatments and the performance of Deep Soil Mixing columns in expansive soils was studied and evaluated. Overall performance of DSM Treated sections has provided successful treatment in mitigating the swell-shrink movements related to moisture changes.
7) (Ramani Sujatha et al., 2020) This study investigated the viability of using Guar Gum for improving geotechnical properties of clay soil. It was found that the treated soil behaved like clay in stiff consistency, failing at higher loads and lower strains with higher stiffness modulus. The soil was collected from Coimbatore, Tamil Nadu and was classified as highly compressible silt clay mixture. Guar Gum was used in ratio of 0.5%, 1%, 1.5% and 2% by weight of soil. It was added to soil in Gel Form. From the various experimental tests done it was found that Permeability of the treated soil decrease exponentially as a result of reduction in pore size by the formation of gel plugs. pH of soil showed very marginal change which indicates the compatibility

of its application in various areas like landfill liners. It was found that the modification in various properties of soil matrix primarily lies on the ability of guar gum to dissolve in water to form highly viscous gel and form strong hydrogen bonds that hold the soil matrix together. With aging soil guar matrix grows stronger and stiffer, improving its toughness and hence improving its strength and reducing its compressibility.

8) (Swain et al., 2018) In this study, stabilisation of dispersive soil collected from NIT Rourkela was done with two biopolymers xanthan gum and guar gum. The content percentage taken for xanthan gum was 1%, 2%, 3% and for guar gum it was 0.5%, 1.0%, 2.0% by weight of soil. Soil was classified as CL-ML (organic clay with high plasticity) or (inorganic silt with low plasticity). Crumb test and Cylinder Dispersion test were carried out for erosion control while Compaction tests and Unconfined Compression Tests were carried out for strength tests. It was found that Xanthan Gum and Guar Gum have been effective in stabilising the dispersive nature of the soil. OMC of the bio treated sample increased while MDD reduced with increase in concentration of biopolymers. UCS of guar gum samples indicated higher value than xanthan gum samples. The SEM analysis inferred that minerals of biopolymers has modified the dispersive soil and are bonded by the gum layer which in fact decreases the dispersivity of the soil. No difference was observed between XRD pattern of dispersive soil and Bio treated dispersive soils.

9) (Toufigh & Ghassemi, 2020) It studied the efficiency of three biopolymers, xanthan gum, guar gum and carboxymethyl cellulose (CMC) with 0.5%, 1% and 1.5% concentrations for soil treatment against dust generation. Three soil samples were collected from the locations that generate most dust in Iran. Biopolymers were added in solution form. It was observed that the addition of biopolymers largely increased the moisture retention capacity of the samples even under wet-dry cycles. Biopolymer treated samples exhibited higher surface strength compared to untreated samples. SEM analysis showed that biopolymers formed a cross linking network which led to a denser and integrated structure of particles which enhances the dust resistance, improved the moisture retention capacity, and increased the surface strength and compressive strength. It was concluded in Taguchi analysis that CMC had better performance in comparison with xanthan gum and guar gum and has a promising potential as an alternative material for dust control.

10) (Vydehi & Moghal, 2022) In this study, experiments were performed for the stabilisation of lean clay collected from the NIT Warangal campus with Guar Gum biopolymer at varying dosages of 0.5%, 1.0%, 1.5%, 2.0% and 2.5% by dry weight of soil. It was observed that with the increase in dosage of GG, liquid limit and plasticity index values increased and it was attributed to increase in viscosity of the solution of biopolymer. The hydrophilic nature of Guar Gum causes more absorption of water which leads to increase in OMC and corresponding reduction in the MDD values of the soil biopolymer mixtures. The compressibility values increased at higher gum dosage, which was attributed to the increase in repulsion between negatively charged clay particles and the hydroxyl group of guar gum. Cross linking of soil particles and the development of hydrogen bonds are the key factors affecting the compressibility characteristics of soil biopolymer mix.

III. RESEARCH METHODOLOGY

1) First the Atterberg's limits of the parental soil, determination of specific gravity of soil and wet sieve analysis will be carried out to determine the various index properties of soil.
2) Optimum Moisture Content (OMC) and Maximum Dry Density (MDD) of the parental soil will be obtained by carrying out heavy compaction test (Modified Proctor Test).
3) California Bearing Ratio (CBR) test (both unsoaked and soaked) and Unconfined Compressive Strength (UCS) test will be performed at OMC obtained from the heavy compaction tests on the specimens prepared from the parental soil.
4) The soil then will be mixed with predetermined dosage of Guar Gum (0.5%, 1%, 1.75%, 2.50% and 3.25%) by dry mixing method and then OMC, MDD of the mixes will be found out by heavy compaction test. CBR test (both unsoaked and soaked) and UCS test will then be followed at OMC of the soil mixed with the Guar Gum.
5) The results obtained will then be compared with each other to obtain the optimum dosage of the Guar Gum needed for this particular type of soil.

A. *Methods Adopted as per IS Code*

1) Determination of Atterberg's limit of soil: liquid limit and plastic limit as per IS:2720 part 5
2) Determination of Specific Gravity of Soil as per IS:2720 part 3.
3) Wet Sieve Analysis of Soil as per IS:2720 part 4.
4) Determination of OMC and MDD of Parental Soil and Mixes by heavy compaction test as per IS:2720 part 8.
5) Determination of Load Penetration Curve of Parental Soil and Mixes by use of CBR Test as per IS:2720 part 16.
6) Determination of UCS of Parental Soil and Mixes as per IS:2720 part 10

IV. EXPERIMENTAL DESCRIPTION

A. Materials

Soil was collected from Mahoba district in Uttar Pradesh. Guar Gum was acquired from India Mart by Arboreal Bioinnovations Pvt. Ltd.

B. Heavy Compaction Test

The purpose of this test is to find out the water required to mix with the soil so as to achieve maximum dry density. Hence it gives Optimum Moisture Content required to achieve Maximum Dry Density. The mould used in this research work had weight 2146 gm and volume 991 cubic centimetres. Weight of rammer used in this test has weight of 4.90 kg and freefall height of 450 mm. The soil in the mould was placed in 5 layers of approximately equal mass with each layer subjected to 25 number of blows. After the test, some amount of soil from mould was extracted out to find out the moisture content of the soil. After the moisture content has been obtained, Bulk Density and Dry Density of the soil and mixes has been obtained.

C. California Bearing Ratio (CBR) Test

This test was developed in 1929 by California Division of Highways (US). It is the ratio expressed in percentage of force per unit area required to penetrate a soil mass with a standard circular plunger of 50 mm diameter at the rate of 1.25 mm/min to that required for corresponding penetration in a standard material. The Ratio is usually determined for penetration of 2.5 mm and 5 mm. When the ratio at 5 mm is consistently higher than that at 2.5 mm, the ratio at 5mm is used.

D. Unconfined Compressive Strength (UCS) Test

Unconfined Compressive Strength is the load per unit area at which an unconfined cylindrical specimen of soil will fail in the axial compression test. In this test specimen had diameter of 38 mm and height of 76 mm. Three specimens were prepared for each of the Parental Soil and Mixes and were loaded at a rate of 1.25 mm/min as long as the sample failed or until an axial strain of 20 percent is reached. Then the graph was plotted between compressive stress and strain to get the maximum unconfined strength of the soil.

V. RESULTS AND DISCUSSIONS

The experimental programme was conducted to determine the optimum dosage of the Guar Gum needed to stabilize the soil. All the engineering properties obtained from the results are compared below:

A. Soil Properties

Table I. Properties of Soil and Classification (As per IS 2720: 1993, Reaffirmed Year:2021)

S. No.	Test Name	Obtained Values
1	Liquid Limit	36.68%
2	Plastic Limit	22.03%
3	Plasticity Index	14.65%
4	Classification of soil as per IS	CI
5	Specific Gravity	2.66
6	Percentage Finer of 0.075mm	93.54

B. Optimum Water Content and Maximum Dry Density Relation

It was observed that OMC of the mixes first decreased up to soil with 1% Guar Gum and then began to increase and has got maximum value at soil with 3.25% Guar Gum. MDD shows a decreasing variation and has a least dry density at soil with 3.25% Guar Gum.

Table II. Comparison of the OMC and MDD Parental Soil and Mixes (Heavy Compaction Test)
(As per IS 2720: 1980 Part VIII, Reaffirmed Year:2011)

Soil Mix	OMC (%)	MDD (g/cc)	Comparison of MDD (%)
Parent Soil	13.92	1.90	-
Parent Soil with 0.5% Guar Gum	13.58	1.87	-1.58%
Parent Soil with 1.0% Guar Gum	13.22	1.82	-4.21%
Parent Soil with 1.75% Guar Gum	13.74	1.80	-5.26%
Parent Soil with 2.50% Guar Gum	13.84	1.75	-7.89%
Parent Soil with 3.25% Guar Gum	14.86	1.69	-12.43%

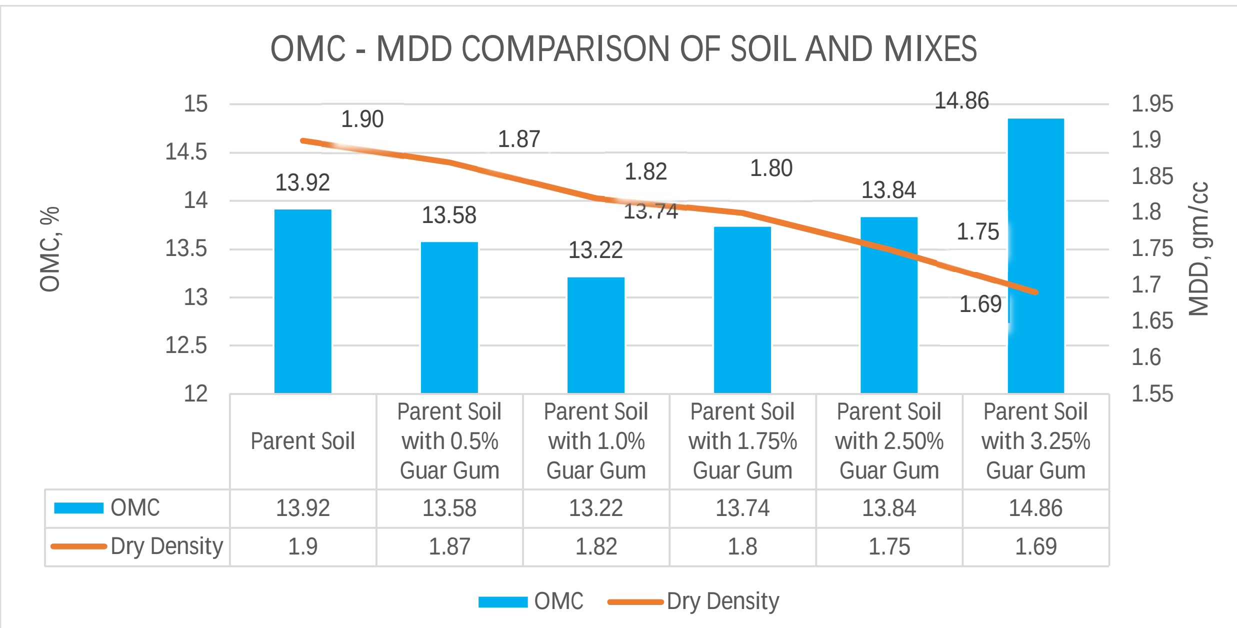

Figure 1: Comparison of OMC -MDD Relations

C. Unsoaked CBR Test Results

Unsoaked specimens for CBR test were prepared for the soil and mixes at OMC obtained from Heavy Compaction Test. A surcharge weight of 10 kg was applied in form of four 2.5 kg plates placed on mould to produce base material effect. CBR values at 5.0 mm penetration were found to be consistently greater than 2.5 mm penetration after test repetition. Hence CBR values at 5.0 mm were considered. CBR values obtained were greater than the CBR values of Parent Soil. However, it does not have any linear relation i.e., the values were not increasing as Guar Gum content was increasing. Maximum CBR value was obtained at soil with 1.0% Guar Gum. Following are the comparisons drawn:

Table III. Comparison of the unsoaked CBR values of Parent Soil and Mixes

S. No.	Soil Description	CBR value at 5.0 mm penetration of Mould 1 (%)	CBR value at 5.0 mm penetration of Mould 2 (%)	Average CBR value of the two Moulds at 5.0 mm penetration (%)
1	Parent Soil	10.41	8.99	9.70
2	Parent Soil with 0.5% Guar Gum	13.48	12.49	12.99
3	Parent Soil with 1.0% Guar Gum	13.54	13.83	13.69
4	Parent Soil with 1.75% Guar Gum	12.90	13.59	13.25
5	Parent Soil with 2.50% Guar Gum	12.67	12.90	12.79
6	Parent Soil with 3.25% Guar Gum	10.41	9.66	10.04

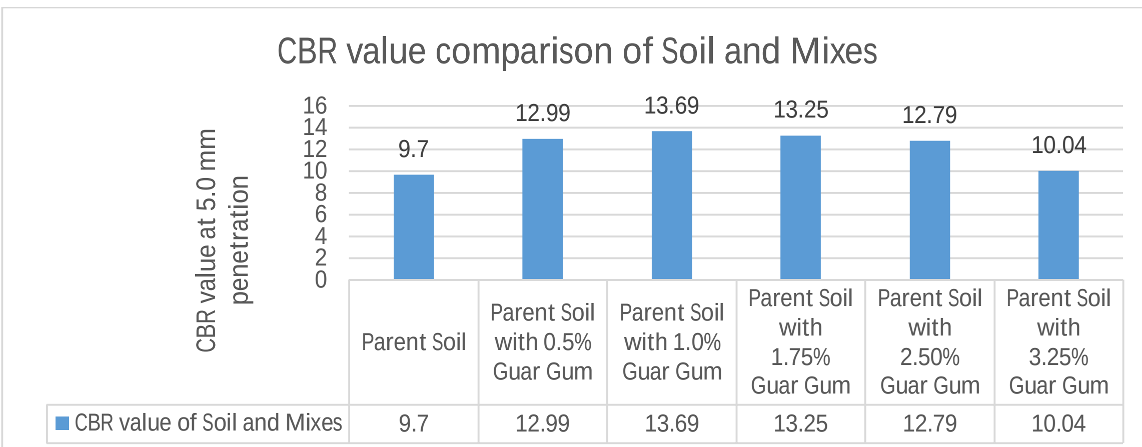

Figure 2: Comparison of Unsoaked CBR results

Table IV. Percentage variation in CBR values

S. No.	Soil Description	Percentage increase in Unsoaked CBR values in compare with Parent Soil
2	Parent Soil with 0.5% Guar Gum	33.92
3	Parent Soil with 1.0% Guar Gum	41.13
4	Parent Soil with 1.75% Guar Gum	36.60
5	Parent Soil with 2.50% Guar Gum	31.86
6	Parent Soil with 3.25% Guar Gum	3.51

D. Soaked CBR Test Results

Specimens were prepared and kept immersed in water for 96 hours. A surcharge load of 10 kg was applied to it to produce effect of base material and pavement load. Here also CBR values at 5.0 mm penetration was found to be consistently greater than 2.5 mm penetration. Hence CBR values at 5.0 mm were considered. CBR value at soil with 1.0% Guar Gum showed maximum improvement. Following are the test results obtained.

Table V. Comparison of the Soaked CBR values of Parent Soil and Mixes

S. No.	Soil Description	CBR value at 5.0 mm penetration of Mould 1 (%)	CBR value at 5.0 mm penetration of Mould 2 (%)	Average CBR value of the two Moulds at 5.0 mm penetration (%)
1	Parent Soil	5.13	4.80	4.97
2	Parent Soil with 0.5% Guar Gum	7.81	8.16	7.99
3	Parent Soil with 1.0% Guar Gum	7.63	8.79	8.21
4	Parent Soil with 1.75% Guar Gum	6.94	6.83	6.89
5	Parent Soil with 2.50% Guar Gum	5.84	4.22	5.03
6	Parent Soil with 3.25% Guar Gum	3.36	3.07	3.22

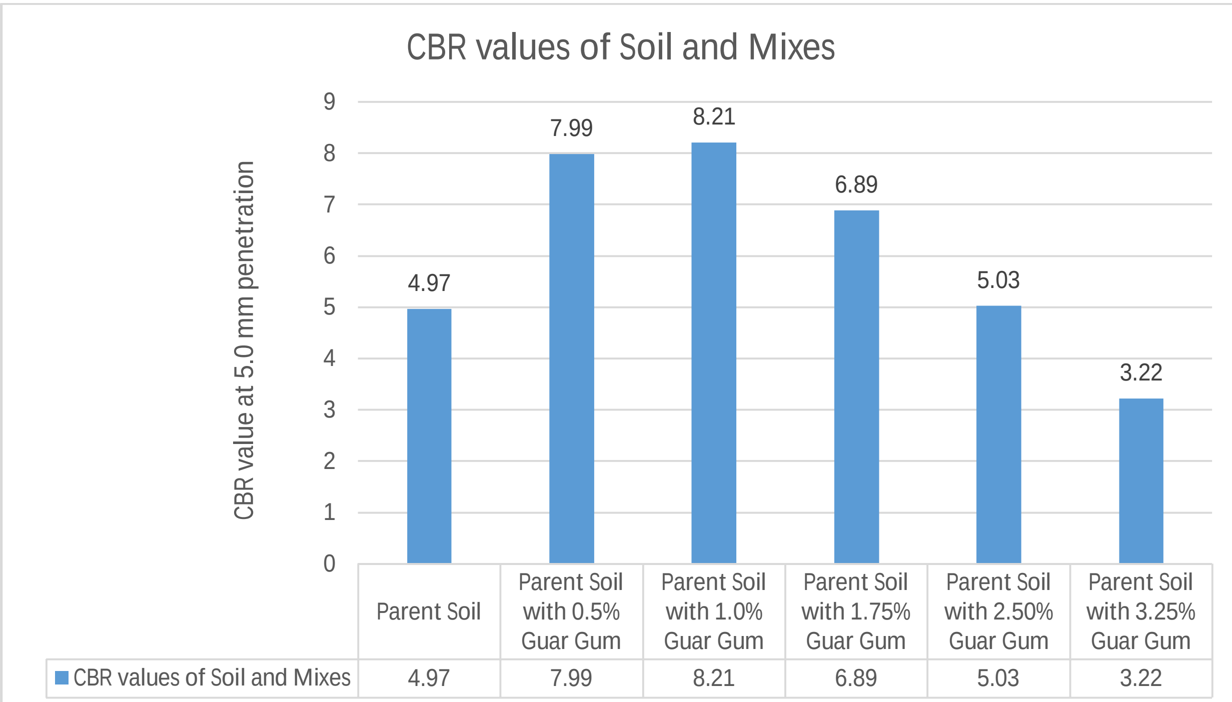

Figure 3: Comparison of Soaked CBR values

Table VI. Percentage variation in CBR values

S. No.	Soil Description	Percentage increase in Soaked CBR values in compare with Parent Soil
2	Parent Soil with 0.5% Guar Gum	60.76
3	Parent Soil with 1.0% Guar Gum	65.19
4	Parent Soil with 1.75% Guar Gum	38.63
5	Parent Soil with 2.50% Guar Gum	1.21
6	Parent Soil with 3.25% Guar Gum	-35.21

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E. UCS Test Results

Unconfined Compressive Strength was performed on Parent soil and each mix. Three Specimens were tested for each category. Rate of loading was 1.25 mm/min. Average of the maximum of three values has been taken as UCS value. All the mixes showed improvement in the strength and maximum result was obtained at soil with 1.0% Guar Gum.

Table VI. UCS values of Soil and Mixes

S. No.	Soil Description	Unconfined Compressive Strength (q_u), kg/cm^2
1	Parent Soil	1.34
2	Parent Soil with 0.5% Guar Gum	2.54
3	Parent Soil with 1.0% Guar Gum	2.87
4	Parent Soil with 1.75% Guar Gum	2.81
5	Parent Soil with 2.50% Guar Gum	2.41
6	Parent Soil with 3.25% Guar Gum	2.32

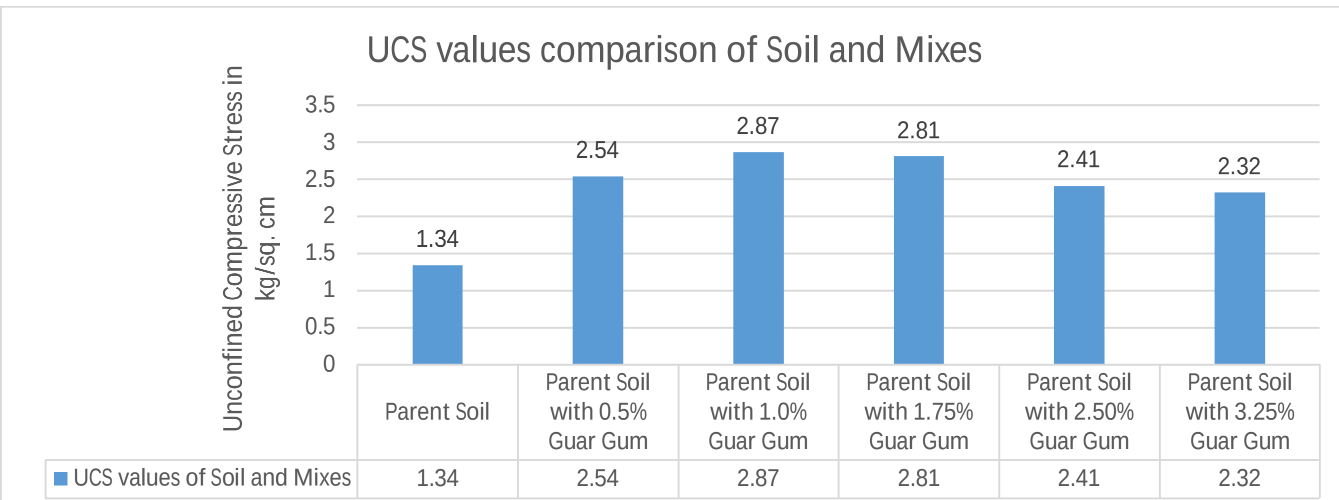

Figure 4: Comparison of UCS values

Table VI. UCS values of Soil and Mixes

S. No.	Soil Description	Percentage increase in UCS values in compare with Parent Soil
2	Parent Soil with 0.5% Guar Gum	89.55
3	Parent Soil with 1.0% Guar Gum	114.18
4	Parent Soil with 1.75% Guar Gum	109.70
5	Parent Soil with 2.50% Guar Gum	79.85
6	Parent Soil with 3.25% Guar Gum	73.13

VI. CONCLUSIONS

After performing all these tests following conclusions can be drawn out:

1) OMC values first shown a decreasing trend up to 1.0% Guar Gum content and then began to increase in all other categories of mixes.
2) MDD values shows a decreasing trend as the content of Guar Gum increases.
3) OMC and MDD value at 1.0% Guar Gum content is 13.22% and 1.82 gm/cc respectively.
4) Unsoaked value of CBR was achieved its maximum value at 1.0 % Guar Gum content with about 41.13% increase from the value of Parent Soil.
5) Unsoaked CBR value of soil with 1.0% Guar Gum content is 13.69%.
6) Soaked CBR value was also achieved maximum at 1.0% Guar Gum content with about 65.19% increase from the value of parent soil.
7) Soaked CBR value of soil with 1.0% Guar Gum content is 8.21%
8) All the UCS values of the mixes obtained were higher than the parent soil with maximum value at soil with 1.0% Guar Gum content.
9) UCS value of soil with 1.0% Guar Gum content is 2.87 kg/ sq. cm.
10) Optimum dosage of Guar Gum required for the maximum improvement in engineering properties of the soil from the test carried was 1% Guar Gum Content.

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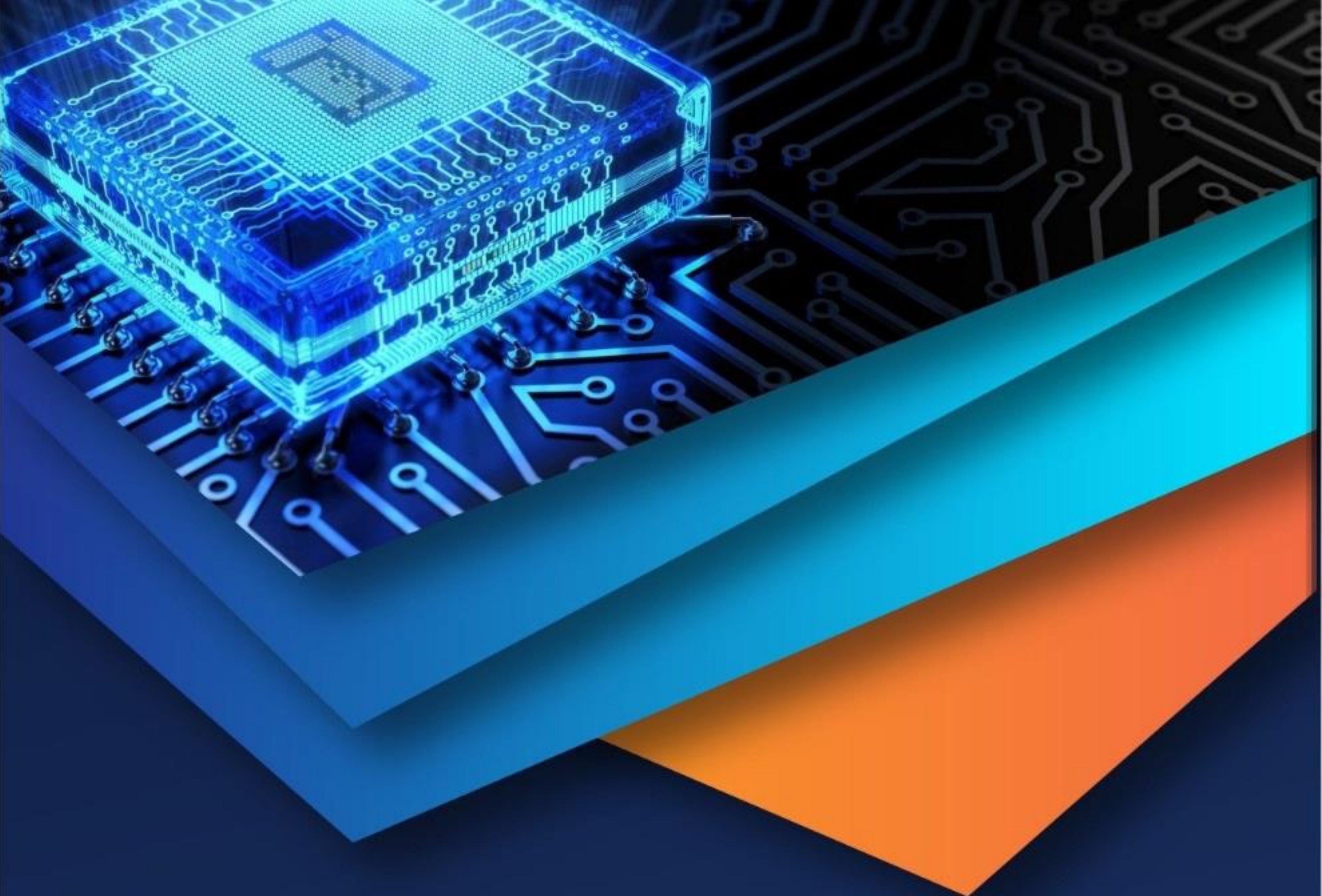

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