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Stabilization of Soil Using Sodium Alginate Biopolymer

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Abstract: Soil stabilization refers to a variety of strategies and tactics used to strengthen a soil of problematic geotechnical characteristics and increase its capacity to support loads. Although several materials, including as bitumen, cement, and lime, are used to improve the qualities, they are not environmentally friendly. This study aims to investigate how sodium alginate, a naturally occurring polymer, can enhance the mechanical characteristics of alluvial soil. Compared to other traditional materials, this biopolymer has a lower carbon impact and is naturally biodegradable. To identify the optimum dosage needed for stabilization, four different variable proportions of sodium alginate with soil—0.5%, 1.0%, 2.0%, and 3.0% were utilized. Three key characteristics, such as the relationship between the optimal moisture content and 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 3.0% Sodium alginate has shown maximum improvement in the geotechnical properties of soil.
Keywords: Stabilization of soil, Sodium Alginate, Biopolymer, Geotechnical Properties of soil and Ecofriendly.

I. INTRODUCTION

Ground improvement techniques are essential in geotechnical construction, particularly for enhancing the engineering properties of weak or unstable soils to support structures. Traditional methods such as using cement, lime, and bitumen, although effective, are associated with high carbon footprints and significant environmental concerns. To address these issues, researchers are exploring sustainable, eco-friendly alternatives that minimize environmental impacts. One such alternative is sodium alginate, a naturally occurring biopolymer derived from seaweed. India, a leading producer of sodium alginate, benefits from this material's unique properties, including its viscosity and binding capabilities. Sodium alginate is widely used as a binder in industries such as pharmaceuticals and food due to its non-toxicity, water solubility, and environmental safety. In soil stabilization, sodium alginate demonstrates significant potential by forming cohesive matrices that reduce erosion, enhance strength, and improve load-bearing capacity. Various soil stabilization methods are employed to improve soil properties, categorized into mechanical, chemical, biological, and physical techniques. Mechanical stabilization relies on compaction and particle size alteration, while chemical stabilization uses agents like lime, cement, and polymers to enhance soil properties. Biological stabilization involves natural methods such as vegetation or microbial techniques, including Microbially Induced Calcite Precipitation (MICP), to bind soil particles and improve stability. Physical and thermal methods, like freezing or heating, are also used to alter soil properties for temporary or permanent stabilization. Biopolymers such as xanthan gum, guar gum, carboxymethyl cellulose, chitosan, and beta-glucans offer sustainable alternatives to conventional stabilizers. Among these, sodium alginate stands out due to its ability to form gels through ionic crosslinking with multivalent cations like calcium ions. This process creates a three-dimensional network that enhances soil strength, cohesion, and water retention, making it particularly suitable for arid regions. As a biodegradable, renewable, and non-toxic material, sodium alginate aligns with sustainable construction practices. Its application in soil stabilization not only improves soil performance but also significantly reduces environmental impacts, establishing it as a promising solution for modern geotechnical challenges.

II. NEED AND SCOPE OF THE STUDY

A. Need Of The Study

India, one of the fastest-growing economies, is rapidly expanding its physical infrastructure. As of December 31, 2022, the country's road network spans over 6.3 million kilometres, with continuous growth across construction sectors. However, many soils in India lack the mechanical properties needed for stable foundations, necessitating stabilization. Traditional methods using materials like cement and lime, though effective, contribute significantly to carbon emissions and are not environmentally sustainable.

This underscores the need for alternative materials that not only enhance soil properties but also align with sustainable development goals. Biopolymers present a promising solution, offering the potential to improve soil characteristics while minimizing environmental impact, thereby supporting eco-friendly construction and advancing the nation's sustainability objectives.

B. Scope Of The Study

This study explores the use of sodium alginate, an eco-friendly biopolymer, as a sustainable alternative to conventional soil stabilizers like cement and lime. With its lower carbon footprint and minimal dosage requirements, sodium alginate offers potential for improving soil strength, cohesion, and durability. The research aims to determine the optimum content of sodium alginate for various problematic soils through laboratory experiments and assess its cost-effectiveness for practical applications. It also investigates the long-term performance and durability of treated soils. A comparative analysis with traditional methods will evaluate sodium alginate's efficiency, environmental impact, and economic viability. The study aims to validate sodium alginate as a sustainable, cost-effective solution for enhancing geotechnical properties in modern construction.

C. Objectives Of The Study

The following objectives were concluded for the present study:

1) To find out Atterberg's limits of the soil and then classifying the soil as per IS code.
2) To determine the various engineering properties of soil like Optimum Moisture Content (OMC), corresponding Maximum Dry Density (MDD) and then performing Direct Shear test and Unconfined Compressive Strength (UCS) Test, CBR test & permeability test of the soil for comparing it with modified soil with Sodium alginate.
3) To determine the OMC, MDD, UCS, Direct Shear, CBR & Permeability test on the biopolymer treated soil with varying percentage of 0.5%, 1%, 2% and 3% by weight of soil.
4) To compare the results of the tests on treated soil with virgin soil and finding out the optimum dosage of Sodium alginate needed for the particular type of soil.

III. RESEARCH METHODOLOGY

1) To ascertain the different index qualities of the soil, the Atterberg's limits of the parental soil, the specific gravity of the soil, and wet sieve analysis will be performed first.
2) The heavy compaction test (Modified Proctor Test) will be used to determine the parental soil's Maximum Dry Density (MDD) and Optimal Moisture Content (OMC).
3) The specimens collected from the parental soil will undergo heavy compaction testing at OMC to determine the Unconfined Compressive Strength (UCS) and California Bearing Ratio (CBR) (both soaked and unsoaked).
4) After that, the soil will be combined with a specified amount of sodium alginate (0.5%, 1%, 2.0%, and 3.0%) using the dry mixing method. A heavy compaction test will then determine the OMC and MDD of the mixtures. At the OMC of the soil combined with the sodium alginate, the CBR (both soaked and unsoaked) and UCS tests will be conducted.
5) Direct shear test is performed on the soil combined with a specified amount of sodium alginate (0.5%, 1%, 2.0%, and 3.0%).
6) The optimum dosage of Sodium Alginate required for this specific type of soil will subsequently be determined by comparing the results.

IV. EXPERIMENTAL DESCRIPTION

1) Soil sample and additives**:** Soil is collected from Muzaffarpur district of Bihar. Sodium Alginate is procured from India Mart online platform site.
2) Compaction Test: The purpose of this test is to determine the amount of water needed to mix with soil to achieve the maximum dry density, thereby identifying the Optimum Moisture Content (OMC) for maximum compaction. In this study, the mould used had a weight of 2146 grams and a volume of 991 cubic centimetres. The rammer used weighed 4.90 kg and had a free-fall height of 450 mm. The soil was compacted in 5 layers of approximately equal mass, with each layer receiving 25 blows. After the compaction, a sample of soil was extracted from the mould to measure its moisture content. Using this value, the bulk density and dry density of the soil and its mixtures were calculated.
3) *California Bearing Ratio (CBR) Test*: This test, developed in 1929 by the California Division of Highways (US), calculates the ratio (expressed as a percentage) of the force required to penetrate a soil mass with a standard circular plunger (50 mm in diameter) at a rate of 1.25 mm/min, compared to the force needed for the same penetration in a standard material. The ratio is typically measured for penetrations of 2.5 mm and 5 mm. If the ratio at 5 mm is consistently higher than at 2.5 mm, the 5 mm ratio is used instead.

4) *Unconfined Compressive Strength (UCS) Test*: Unconfined Compressive Strength is the load per unit area at which a cylindrical soil specimen, without confinement, fails during an axial compression test. In this test, the specimens had a diameter of 38 mm and a height of 76 mm. Three specimens were prepared for each parental soil and its mixtures. They were loaded at a rate of 1.25 mm/min until failure or until an axial strain of 20 percent was reached. A graph of compressive stress versus strain was then plotted to determine the soil's maximum unconfined compressive strength.
5) Direct Shear Test: The Direct Shear Test is conducted to measure the shear strength parameters (cohesion and angle of internal friction) of soil. A soil sample is placed in a shear box and subjected to a normal load. Then, a shear force is gradually applied, and both the shear stress and displacement are recorded until the specimen fails along the shear plane. The test is usually carried out at a constant shear rate. Afterward, the shear stress at failure is calculated, and the Mohr-Coulomb failure criterion is used to determine the shear strength parameters. The test may be repeated with different normal loads to study the soil's behaviour under various conditions.

V. RESULT AND DISCUSSION

A. *Soil Properties*

Sl. No	Test Name	Value
1	Specific Gravity	2.70
2	Liquid Limit	34
3	Plastic Limit	19
4	Max. Dry Density	1.64
5	Optimum Moisture Content	17.8

Table 1 Physical Properties of Soil

B. *Optimum Moisture And Maximum Dry Density*

Sl. No	OMC	MDD
1	6.1	1.52
2	8.2	1.55
3	11.4	1.59
4	14.1	1.615
5	17.8	1.64
6	20.3	1.62
7	22.3	1.59
8	22.5	1.53

Table 2 OMC and MDD of soil

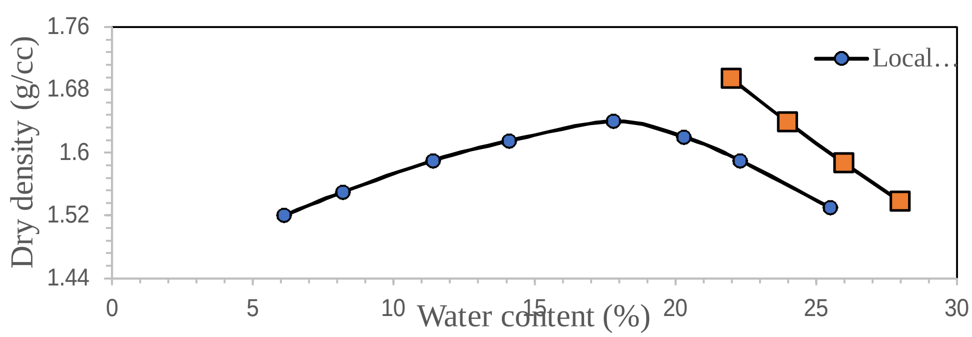
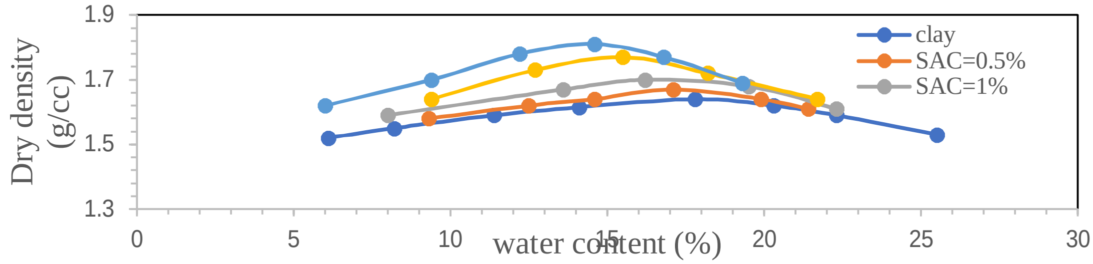


Figure 1

C. Comparison of the OMC and MDD Parental Soil and Mixes

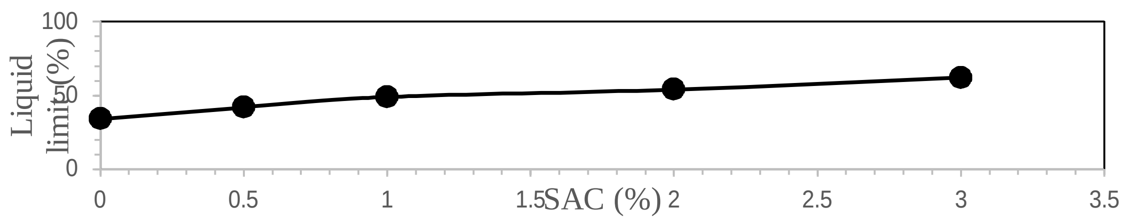
Sl. No	Soil Mix	OMC	MDD
1	Parent Soil	17.8	1.64
2	Parent Soil with 0.5% SAC	17.1	1.67
3	Parent Soil with 1.0% SAC	16.2	1.70
4	Parent Soil with 2.0% SAC	15.5	1.77
5	Parent Soil with 3.0% SAC	14.6	1.81

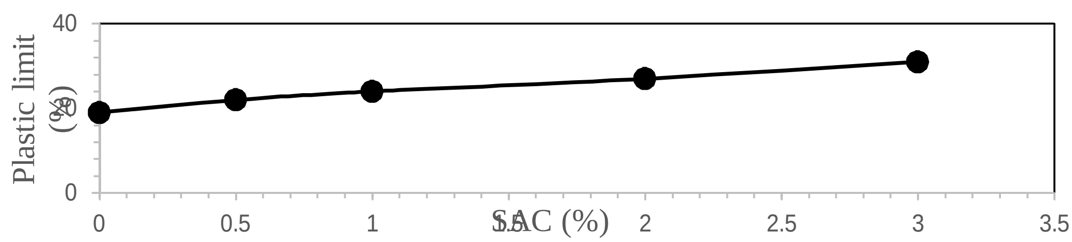


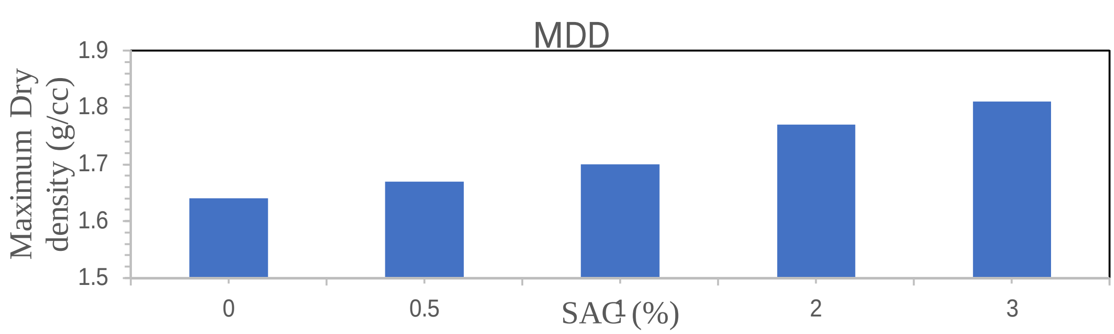
D. Liquid Limit and Plastic Limit at different value of SAC

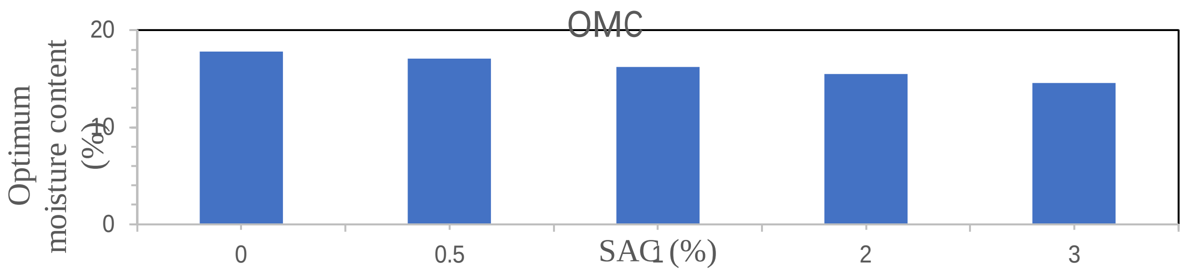
Sl. No	Atterberg Value	clay	SAC=0.5	SAC=1	SAC=2	SAC=3
1	LL	34	42	49	54	62
2	PL	19	22	24	27	31
2	PI	15	20	25	27	31

Table 3 Variation of Liquid Limit and Plastic Limit at different value of SAC





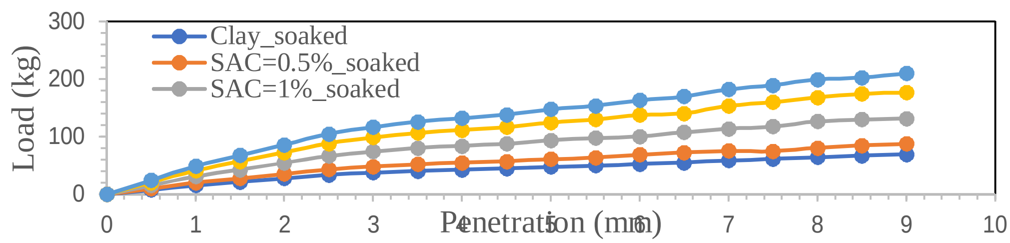




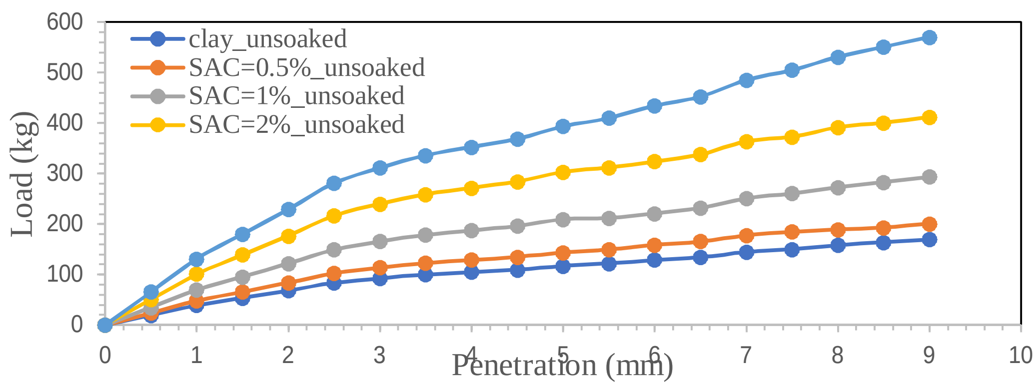
E. CBR Test Result

Sl. No.	SAC	CBR (soaked)	CBR (Unsoaked)	Load Soaked	load unsoaked
1	0	2.5	6.1	34.25	83.57
2	0.5	3.2	7.5	43.84	102.75
3	1	4.9	10.9	67.13	149.33
4	2	6.5	15.8	89.05	216.46
5	3	7.7	20.5	105.49	280.85

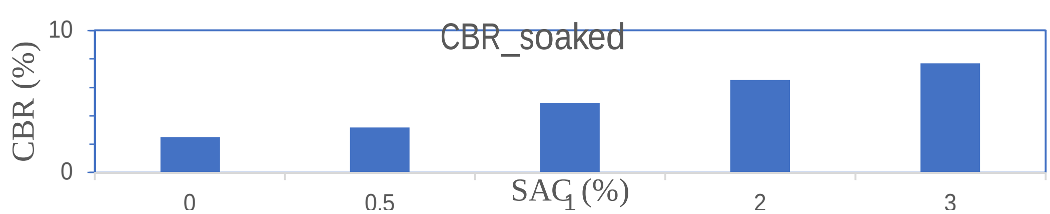
Table 4 Variation of CBR at different value of SAC



Load-penetration behaviour of soil mixed with SA under soaked condition



Load-penetration behaviour of soil mixed with SA under unsoaked condition



Variation of CBR with SAC for Soaked condition

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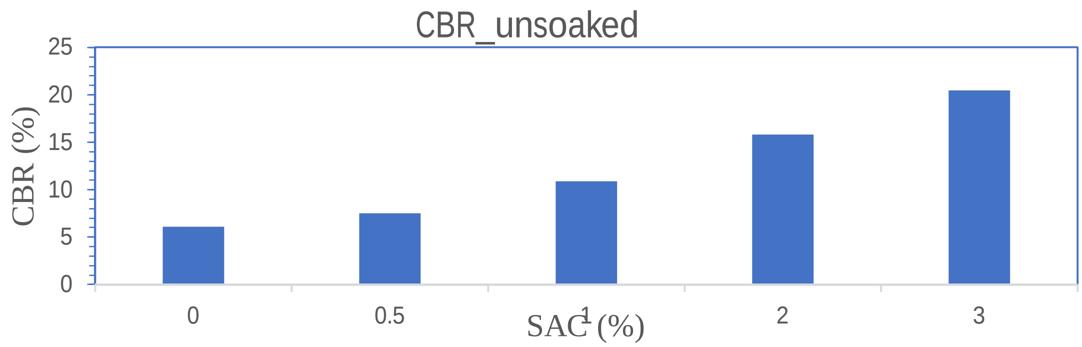
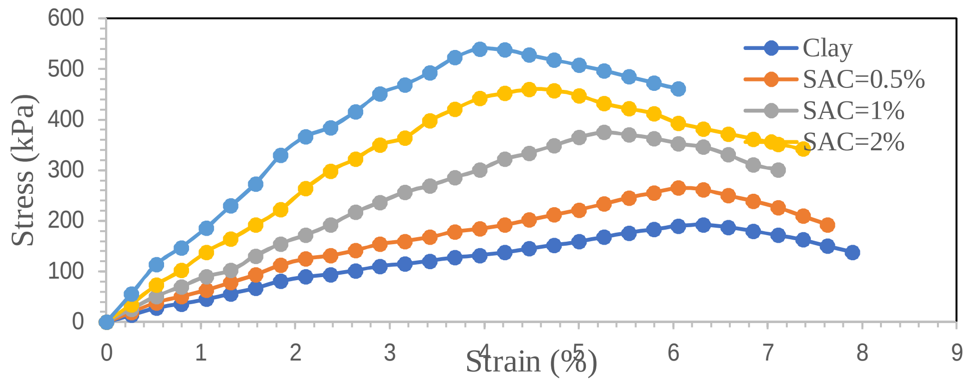


Variation of CBR with SAC in unsoaked condition

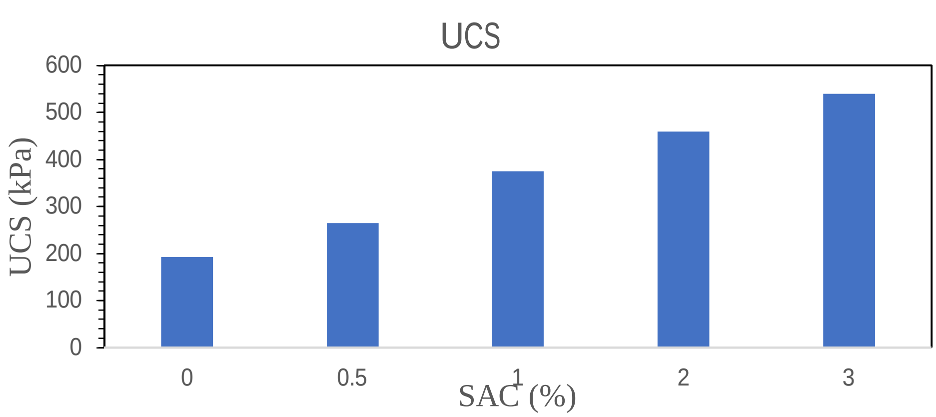
F. Performance of Soil-SA mix under UCS test

Sl. No.	SAC	UCS
1	0	192.6
2	0.5	265
3	1	375
4	2	460
5	3	540

Table 6 Variation of UCS at different value of SAC



Stress-strain behaviour of soil mixed



Variation of UCS with SAC

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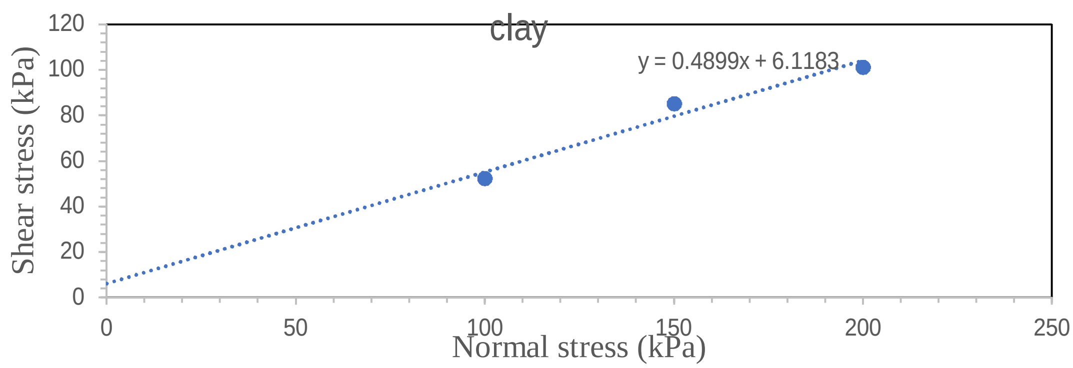
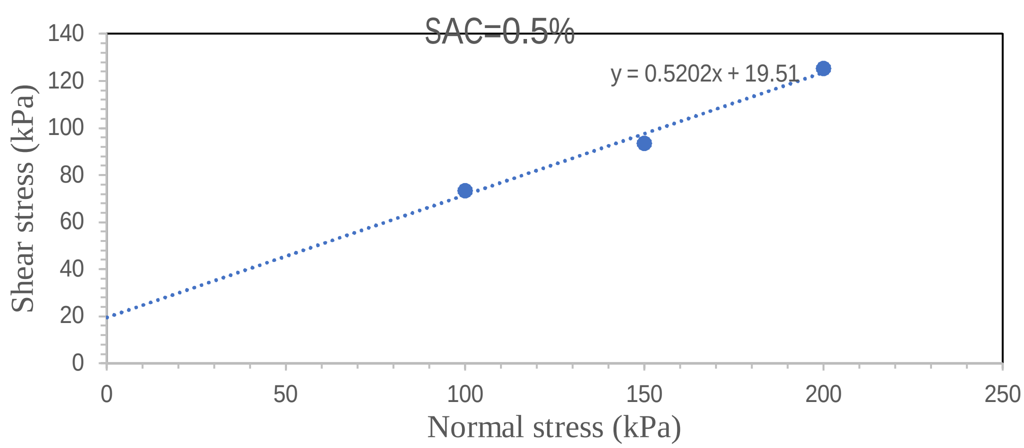
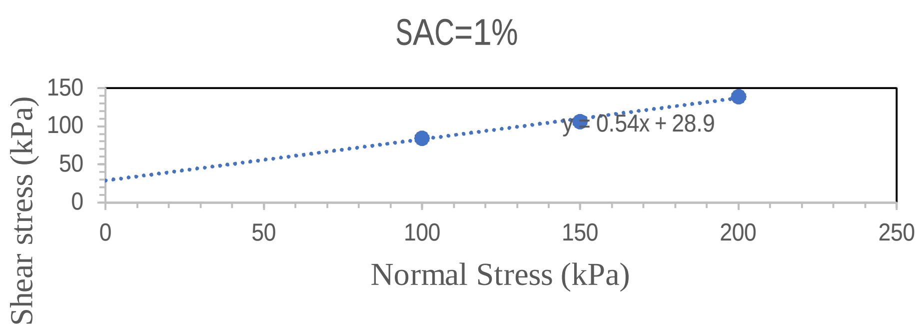
G. Performance of Soil-SA mix under Direct Shear Test



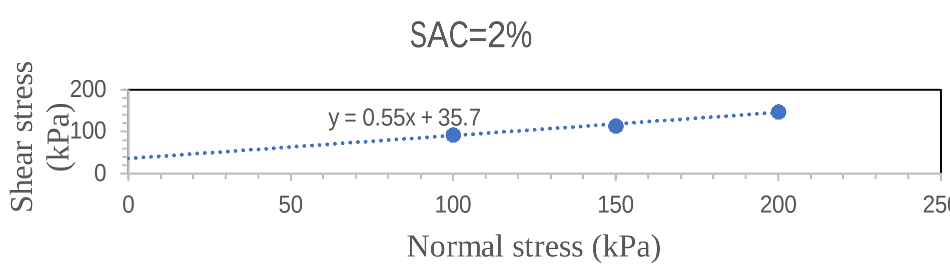
a) Clay alone



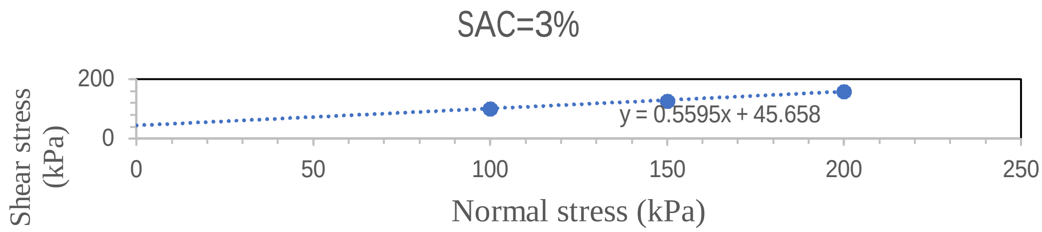
b) Clay+SAC=0.5%



c) Clay+SAC=1%



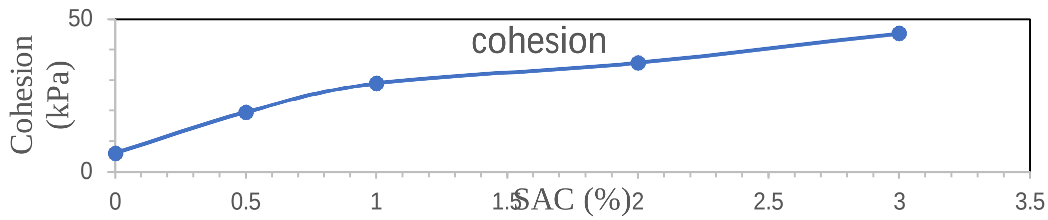
d) Clay+SAC=2%



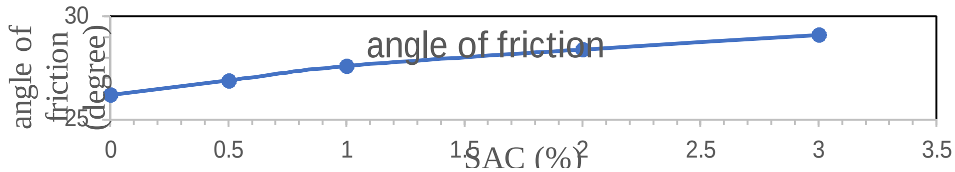
e) Clay+SAC=3%

H. C and φ at different value of SAC

Sl. No	SAC	C	φ
1	0	6.1	26.1
2	0.5	19.5	26.9
3	1	28.9	27.6
4	2	35.7	28.4
5	3	45.3	29.1



Variation of Cohesion with SAC



Variation of the angle of friction with SAC

VI. CONCLUSION

1) The liquid limit of soil increases significantly with the addition of sodium alginate (SA). It was around 34% for pure soil, while at 3% SAC, it increased to 62%.
2) The plastic limit also increases with SAC, rising from 19% for untreated soil to 31% at 3% SAC.
3) Adding sodium alginate shifts the compaction curve leftward and upward. The maximum dry density increases from 1.64 g/cc for untreated clay to 1.81 g/cc at 3% SAC, while the optimum moisture content (OMC) decreases from 17.8% to 14.6%.
4) The California Bearing Ratio (CBR) improves steadily with increasing SAC under both soaked and unsoaked conditions. Under wet conditions, the highest CBR value is achieved at 3% SAC, indicating enhanced load-bearing capacity. Unsoaked soils exhibit even greater CBR values for the exact SAC percentages, highlighting the effectiveness of SA in improving soil strength, particularly in dry conditions.
5) Untreated soil has a UCS of approximately 192 kPa, while at 3% SAC, the UCS improves by 2.8 times, reaching the highest peak stress among all samples.
6) Sodium alginate increases the cohesion and angle of internal friction of soil, as observed from the failure envelopes in the direct shear test (DST). This improvement is attributed to the cementitious bonds formed by SA, which enhance resistance to particle movement during shearing.

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