Soil improvement with sugarcane bagasse ash: technical-economic viability for tertiary roads

Mejoramiento de suelos con cenizas de bagazo de caña: viabilidad técnico-económica para vías terciarias

Melhoramento do solo com cinza de bagaço de cana: viabilidade técnico-econômica para estradas terciárias

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Abstract

Introduction: Economic evaluation of soil subgrade improvement using sugarcane bagasse ash case study: Propal Road - La Cabaña Sugar Mill", developed at the Pontifical Javeriana University of Cali in 2022.

Problem: Tertiary roads in Colombia are essential for mobility in rural areas and for the sugar industry, which generates waste such as sugarcane bagasse ash (SGBA).

Objective: To present the results of the economic and technical feasibility study of using sugarcane bagasse ash for soil improvement in tertiary roads.

Methodology: Characterization tests of natural soil state and modified Proctor, expansion index, CBR, and unconfined compression for stabilized soils at percentages of 5, 10, 15, and 20% of SGBA are carried out.

Results: The mechanical properties of the soil improve with additions of ash between 5% and 15%; however, the utilization of 15% of SGBA is proposed to favor the disposal of a significant volume of this waste.

Conclusion: The technical and economic feasibility of using SGBA as a promising solution to improve tertiary roads in Colombia is demonstrated.

Originality: Viability of implementing sugarcane bagasse ash on rural roads of sugar mills and agricultural areas with production of this type of waste.

Limitations: Similar studies should be carried out for each region to confirm the appropriate percentage for subgrade stabilization using SGBA.

Keywords: stabilization, ash, sugarcane, improvement, tertiary roads

Resumen

Introducción: evaluación económica del mejoramiento de subrasante de suelos utilizando ceniza de bagazo de caña de azúcar, estudio de caso: Camino Propal - Central La Cabaña", desarrollado en la Pontificia Universidad Javeriana de Cali en el año 2022.

Problema: las vías terciarias en Colombia son fundamentales para la movilidad en las zonas rurales y para la industria azucarera, que genera residuos como la ceniza de bagazo de caña (SGBA).

Objetivo: presentar los resultados del estudio de factibilidad económica y técnica del uso de ceniza de bagazo de caña para el mejoramiento de suelos en caminos terciarios.

Metodología: se realizan pruebas de caracterización del estado natural del suelo y Proctor modificado, índice de expansión, CBR y compresión libre para suelos estabilizados en porcentajes de 5, 10, 15 y 20% de SGBA.

Resultados: las propiedades mecánicas del suelo mejoran con adiciones de ceniza entre 5% y 15%; sin embargo, se propone la utilización del 15% de SGBA para favorecer la disposición de un volumen importante de estos residuos.

Conclusión: se demuestra la factibilidad técnica y económica de utilizar el SGBA como una solución prometedora para mejorar las vías terciarias en Colombia.

Originalidad: viabilidad de implementar ceniza de bagazo de caña en caminos rurales de ingenios azucareros y zonas agrícolas con producción de este tipo de residuos.

Limitaciones: se deben realizar estudios similares para cada región para confirmar el porcentaje apropiado para la estabilización de la subrasante utilizando SGBA.

Palabras clave: estabilización, ceniza, caña de azúcar, mejoramiento, caminos terciarios.

Resumo

Introdução: avaliação econômica da melhoria do subleito do solo com cinza de bagaço de cana-de-açúcar, estudo de caso: Camino Propal - Central La Cabaña", desenvolvido na Pontifícia Universidade Javeriana de Cali em 2022.

Problema: as estradas terciárias na Colômbia são essenciais para a mobilidade nas áreas rurais e para a indústria açucareira, que gera resíduos como a cinza do bagaço de cana (SGBA).

Objetivo: apresentar os resultados do estudo de viabilidade econômica e técnica da utilização da cinza do bagaço de cana-de-açúcar para melhoria de solo em estradas terciárias.

Metodologia: são realizados ensaios de caracterização do estado natural do solo e Proctor modificado, índice de expansão, CBR e compressão livre para solos estabilizados em percentuais de 5, 10, 15 e 20% de SGBA.

Resultados: as propriedades mecânicas do solo melhoram com adições de cinzas entre 5% e 15%; Contudo, propõe-se a utilização de 15% de SGBA para favorecer a destinação de um volume significativo desses resíduos.

Conclusão: a viabilidade técnica e económica da utilização do SGBA é demonstrada como uma solução promissora para melhorar as estradas terciárias na Colômbia.

Originalidade: viabilidade de aplicação da cinza do bagaço de cana em estradas rurais de usinas de açúcar e áreas agrícolas com produção deste tipo de resíduo.

Limitações: Estudos semelhantes devem ser realizados para cada região para confirmar a percentagem adequada de estabilização do subleito utilizando SGBA.

Palavras-chave: estabilização, cinzas, cana-de-açúcar, melhoria, estradas terciárias.

1. INTRODUCTION

Colombia has a road network with an approximate length of 215,988 kilometers, of which around 154,207 kilometers are tertiary roads [1], rural roads where no more than 150 vehicles travel per day [2], and despite efforts to improve their conditions for drivability, they remain precarious [3] with minimal paving in rural areas [4]. The National Planning Department in Colombia has project guidelines [5] with solutions for improving this category of road, such as stabilizing the base material using cement, bituminous materials, or mechanical stabilization, double surface treatment or asphalt slurry, "placa huella" (a type of paving), among others, along with minor drainage works and road structures.

Mobility within the 13 sugar-producing plants of the 12 sugar mills in Colombia is facilitated through tertiary roads connecting 50 municipalities across the departments of Valle del Cauca, Cauca, Risaralda, Caldas, and Quindío [6]. Annually, as a byproduct of sugarcane cultivation in this country, around 6.4 million tons of sugarcane bagasse are generated and incinerated. According to [7], for every ton of bagasse incinerated, 25 kg of ash are produced, which in the best-case scenario is disposed of in sanitary landfills [8] [9]; in other situations, it is used for filling excavations or employed as agricultural fertilizer.

This issue has led the Sugarcane Research Center, Asocaña, to propose sustainability strategies with the aim of having the sugar industry contribute to improving people's quality of life and, consequently, the country's development [10]. In this context, it is crucial to propose ecological alternatives that mitigate the environmental problems associated with this sector. Therefore, the objective of this article is to present the results of the economic and technical feasibility study of using sugarcane bagasse ash for soil improvement in tertiary roads of the Propal La Cabaña Sugar Mill, surrounded by tertiary roads, a solution that could be applicable to tertiary roads across the country. To this end, the behavior of a control soil sample of subgrade material was compared with subgrade material, modified with sugarcane bagasse ash (SGBA) added in percentages of 5%, 10%, 15%, and 20%.

This alternative was based on evidence of the behavior of sugarcane bagasse ash, which has demonstrated advantages as a pozzolanic material [11], offering an option for stabilization using lime and cement, thereby improving the geotechnical properties of subgrade materials in roads [12]. This residue has been used as a total or partial substitute for cement and lime [13] [14], contributing to soil shear strength and durability [15], and plays an important role in the circular economy [8] by being reintegrated into the production chain.

1.1 Background of the use of sugarcane bagasse ash (SGBA) in soil improvement

Sugarcane is the most extensive crop globally, with India and Brazil being the main producers [15]. Likewise, in Colombia, sugarcane processing contributes 0.7% to the country's gross domestic product [10], generating waste from this activity. Therefore, a sustainable response to crop processing is the use of sugarcane bagasse ash.

The massive generation of sugarcane bagasse ash by producing countries becomes a global issue since its indiscriminate use as a fertilizer [16] contaminates soil and water bodies, thus posing a serious environmental problem [17] [18]. Previous studies indicate the possibility of applying ash in specific areas, such as a substitute for Portland cement [9] [19], clay replacement, adsorbent, soil treatment, and stabilization, as filler in asphalt mixes, among other uses [18].

For this study, subgrade stabilization in pavements represents a challenge for road improvement due to the inherent variability of soils [15]. The compaction characteristics of soil stabilized with sugarcane ash are inherently linked to the plasticity nature of the soil. In soils with medium plasticity, the introduction of this stabilizer leads to a reduction in maximum dry density and an increase in the optimum moisture content, as demonstrated in the study by [20]. The implementation of ash in the soil at percentages between 2.5% and 12.5%, for example, led to a decrease in the plasticity index [20] and overall improvement in the geotechnical properties of various subgrade materials [15] [8].

On the other hand, it has been found that the incorporation of 10% sugarcane bagasse ash along with 10% lime results in significant improvements in the mechanical and durability properties of compacted soil blocks [11] [21].

Given the abundance of materials required in geotechnical projects, the reuse of biomass ash as a new recycled material in such projects is attractive [22], which is why applications of wood ash and sugarcane bagasse ash are found as pozzolanic materials and wood ash as reinforcement material for road pavements and subgrades [23] [24], [25] [26] [22].

2. METHODOLOGY

This research follows a descriptive experimental methodology that begins with a literature review and continues with the collection and characterization of samples from both natural soil and sugarcane bagasse ash. Consequently, a sample representative of 100 meters of roadway was collected (Figure 1). Material characterization was conducted using, as necessary, standards from the National Roads Institute (Invías) or the American Society for Testing and Materials (ASTM). The percentages of sugarcane bagasse ash used were 5%, 10%, 15%, and 20%, and specific mechanical tests included resistance analysis, compaction, and California Bearing Ratio (CBR) (Table 1).

Table 1. Soil characterization

Test	Standar	A	B	C	D	E	Total
Humidity	INV E-122-13; ASTM D2216-19	X					3
Sieve analysis	INV E-213-13, ASTM D6913/D6913M-17	X					1
Atterberg Limits	INV E-125-13, INV E-126-13; ASTM D4318-17	X	X	X	X	X	5
Modified Proctor	INV E-142-13, ASTM D1557-12	X	X	X	X	X	5
Soil expansion index	ASTM D4829-21						
CBR	INV E-148-13, ASTM D1883-21	X	X	X	X	X	30
Unconfined compression	INV E-152-13; ASTM D2166/D2166M-16	X	X	X	X	X	45
Preparation of compacted samples	INV E-104-13	X	X	X	X	X	75

Note: A: Natural soil; B: Soil + 5% SGBA; C: Soil + 10% SGBA; D: Soil + 15% SGBA; E: Soil + 20% SGBA

Source: own work

Figure 1. a) sugarcane bagasse ash analyzed in the scanning electron microscope b) natural terrain
Source: own work

For the cost analysis of implementing the alternative on the Propal - Ingenio La Cabaña road, a comparison was made between conventional maintenance and the projected maintenance required on the road improved with sugarcane bagasse ash [27], following an approach to economic analysis of life cycle costs [2], considering:

- Estimation of the cost of sugarcane bagasse ash production.
- Estimation of stabilization works costs, including the transportation of stabilizers and the construction process.
- Estimation of necessary works to maintain the road with acceptable levels of trafficability and service, which implies costs associated with routine periodic maintenance, vehicle operation costs, costs for delays or disruptions [2] (National Roads Institute, 2007), [29], [30] [31].

3. RESULTS

The moisture content of sugarcane bagasse ash yielded an average value of 1.87%. Regarding the natural soil, the specific gravity was 2.69, and the average moisture content was 18.32%, with liquid limit, plastic limit, and plasticity index of 52, 23, and 29, respectively. It can be observed that the Atterberg limits change with the addition of sugarcane bagasse ash (Table 2).

Table 2. Results of Atterberg limits for soil amended with SGBA.

No. Muestra	% SGBA	Liquid Limit (LL)	Plastic Limit (PL)	Plasticity Index (PI)
1	5	51	22	29
2	10	52	21	31
3	15	49	20	29
4	20	49	19	30

Source: own work

Furthermore, the ash added in percentages above 15% changes the classification of the soil from high plasticity clay to low plasticity clay (Table 3).

Table 3. Soil classification.

No. Sample	% SGBA	Classification SUCS	Classification AASHTO	Description
Natural soil	0	CH	A-7-6	High plasticity inorganic clay
1	5	CH	A-7-6	
2	10	CH	A-7-6	
3	15	CL	A-7-6	Inorganic clay of low plasticity
4	20	CL	A-7-6	

Source: own work

Regarding the maximum dry density obtained in the standard Proctor test (Table 4), in the natural soil it approached 1.83 g/cm^3 (Table 4), with a decrease in the Proctor response observed in the soil with the addition of ash. This finding is significant for meeting specifications in road construction.

Table 4. Proctor standard results for natural and modified soil.

# Strokes	% SGBA	Maximum dry density (g/cm^3)	Humidity (%)
12	0	1.66	19.10
26		1.76	17.80
56		1.83	17.30
12	5	1.59	18.70
26		1.71	18.20
56		1.78	15.20

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# Strokes	% SGBA	Maximum dry density (g/cm³)	Humidity (%)
12	10	1.64	24.40
26		1.60	21.50
56		1.57	21.10
12	15	1.59	22.00
26		1.62	20.60
56		1.71	19.70
12	20	1.48	20.50
26		1.52	19.40
56		1.54	16.30

Source: own work

As for the bearing capacity, the natural soil presents CBR values of 8.70 and 5.70 at 100% and 95% of maximum dry density respectively. With the inclusion of 20% sugarcane bagasse ash, these values increased to 12.40% and 5.80%, respectively. Table 5 shows the response of the natural soil and the increase in CBR with additions of sugarcane bagasse ash at 5%, 10%, and 15%. The increase in CBR of a soil indicates an improvement in its strength and load-bearing capacity.

Table 5. CBR results for natural and modified soil.

# Strokes	% SGBA	CBR 100% de MDD	CBR 95 % MDD
12	0	3.50	1.95
26		3.90	3.35
56		8.70	5.70
12	5	3.35	2.50
26		5.75	4.40
56		9.70	7.40
12	10	8.00	6.40
26		8.70	6.40
56		11.40	11.20
12	15	6.30	6.20
26		9.10	8.00
56		12.20	10.40
12	20	6.30	6.50
26		10.00	10.00
56		12.40	5.80

Note: MDD maximum dry density in g/cm³

Source: own work

In terms of the unconfined compression response of the natural soil, the soil exhibits a strength value of approximately 464.15 kPa (as shown in Table 6), showing characteristics similar to other soils in Cauca and Valle del Cauca [32]. This favorable behavior is also observed in soils treated with 5%, 10%, and 15% sugarcane bagasse ash. Additionally, it was observed that the maximum axial deformation of the natural soil was 1.44%, while for the modified soils, it ranged between 2.4% and 5.6%.

Table 6. Unconfined compression results for natural and modified soil

% SGBA	# Strokes	Maximum compression strength (kPa)	Maximum percentage of deformation
0	12	252.73	1.44
	26	436.56	
	56	464.15	
5	12	552.57	3.4
	26	416.53	
	56	677.74	
10	12	177.37	5.4
	26	287.55	
	56	498.40	
15	12	149.02	5.6
	26	170.20	
	56	397.28	
20	12	161.09	2.4
	26	227.65	
	56	39.45	

Source: own work

Figure 2 illustrates the soil behavior when adding different percentages of SGBA. Although the maximum unconfined compressive strength is achieved when adding 5% of SGBA, the maximum CBR value is achieved when adding 15% of SGBA at 95% of maximum dry density. This indicates a clear difference in the optimal percentage of SGBA addition for achieving maximum strength (5%) compared to maximum CBR (15%).

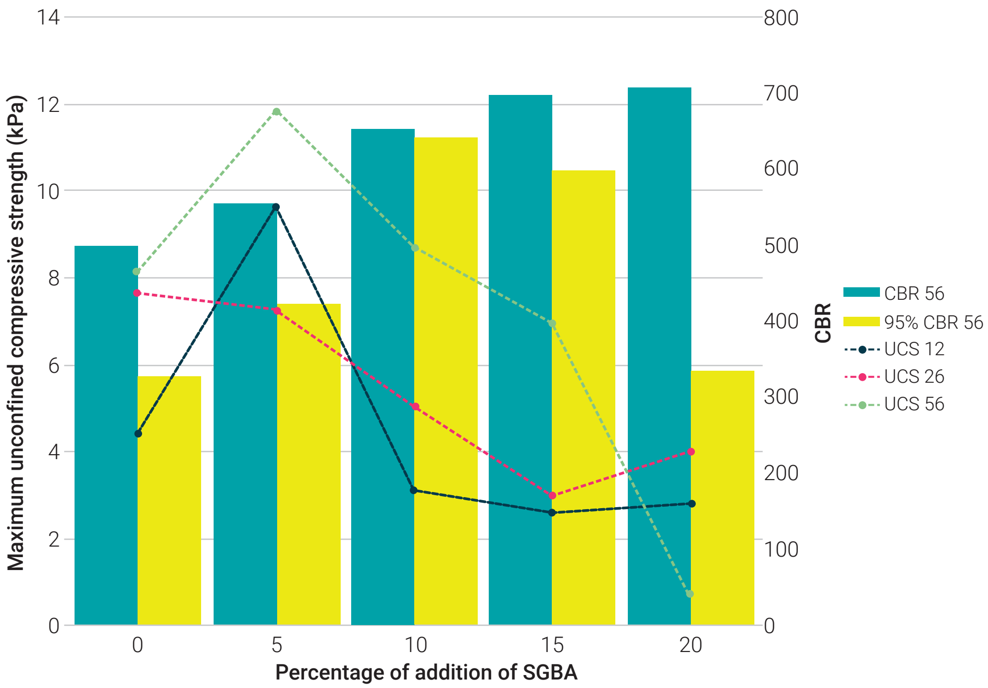

Figure 2. Comparison of CBR and unconfined compression behavior.
Source: own work

Although the mechanical properties of the soil improve with additions of ash between 5% and 15%, it is proposed to utilize 15% ash in these roads. This approach not only enhances soil properties but also facilitates the disposal of a significant volume of this residue, contributing to circular economy waste management solutions.

As an example, in this study, the cost for stabilizing a section with a thickness of 20 cm, length of 100 m, and width of 8 m was estimated (Table 7). The machinery included in the analysis consists of a motor grader for road cleaning and scarification activities, a vibratory compactor for material compaction, and a water tank for irrigation.

The estimation of ash quantity, considering 95% of maximum dry density, which in this study corresponds to 1800 kg/m³, resulted in a required granular material quantity of 288,000 kg, equivalent to 85% soil, and 50,823.53 kg corresponding to 15% ash. The ash production value was provided by Ingenio La Cabaña and will vary from one sugar mill to another. The total ash to be transported corresponds to 31.1 m³, considering an average ash density of 1634.2 kg/m³.

Once the soil is stabilized, road reformation is proposed by spreading a granular material with a thickness of 5 cm.

Table 7. Cost assessment of stabilization with SGBA

Stabilization with SGBA				
Description	**Un.**	**Qt.**	**Unit Value**	**Total value**
Sugarcane bagasse ash	kg	50823.53	$ 38.00	$ 1,931,294.14
Material transportation and placement	m³	31.10	$ 20,000.00	$ 622,009.35
Motor grader (initial scarification of 20 cm gravel layer)	hr	0.30	$ 113,504.00	$ 34,051.20
Motor grader (SGBA spreading)	hr	0.20	$ 113,504.00	$ 22,700.80
Subtotal:				$ 2,610,055.49
Road compaction				
Description	**Un.**	**Qt.**	**Unit Value**	**Total Value**
Motor grader (spreading and leveling of river material)	hr	0.30	$ 113,504.00	$ 34,051.20
Material transportation and placement, 5 cm thickness	m³	40.00	$ 32,260.00	$ 1,290,400.00
Water tank for irrigation	hr	0.5	$ 6,000.00	$ 3,000.00
Vibrocompactor	hr	0.1	$ 110,000.00	$ 11,000.00
Subtotal:				$ 1,338,451.20
Total value:				$ 3,948,506.69
Value/m³:				$ 24,678.17

Source: own work

The cost assessment for the conventional unpaved road was estimated considering the spreading and compaction of 20 cm thickness of material over the existing soil, where the cost of the unpaved road per cubic meter is $32,560.32 (Table 8). Regarding the number of periodic maintenance operations, these were estimated based on information found in previous studies [2].

Table 8. Cost assessment of the road in the unpaved condition.

Road compaction				
Description	**Un.**	**Qt.**	**Unit Value**	**Total value**
Motor grader (spreading and leveling of granular material)	hr	0.3	$ 113,504.00	$ 34,051.20
Material transportation and placement, 20 cm thickness	m³	160	$ 32,260.00	$ 5,161,600.00
Water tank for irrigation	hr	0.5	$ 6,000.00	$ 3,000.00
Vibrocompactor	hr	0.1	$ 110,000.00	$ 11,000.00
Subtotal:				$ 5,209,651.20
Total value:				$ 5,209,651.20
Valor/m³:				$ 32,560.32

Source: own work

For the improved soil case, it is estimated that preventive maintenance should be carried out semi-annually, while for the conventional unpaved road, according to historical records from Ingenio La Cabaña, this maintenance is performed at least every two months using the machinery available in the mills (Table 9). Considering that there is no reported historical information on costs due to delays, these are not incorporated into this cost analysis.

Table 9. Comparison of costs over a period of 5 years considering maintenance.

Year	Activity	Stabilized gravel with SGBA	Conventional gravel pavement
1	Initial rehabilitation plus routine maintenance	$ 7,897,013.38	$ 62,515,814.40
2	Initial rehabilitation plus routine maintenance	$ 7,897,013.38	$ 62,515,814.40
3	Initial rehabilitation plus routine maintenance	$ 7,897,013.38	$ 62,515,814.40
4	Initial rehabilitation plus routine maintenance	$ 7,897,013.38	$ 62,515,814.40
5	Initial rehabilitation plus routine maintenance	$ 7,897,013.38	$ 62,515,814.40
Total		$ 39,485,066.91	$ 312,579,072.00

Source: own work

The results indicate a higher long-term cost with maintenance for the conventional unpaved road due to the high frequency of interventions required to maintain road operation. On the other hand, the stabilized unpaved road with SGBA only requires semi-annual maintenance with scarification and spreading of river material.

4. DISCUSSION

Certain agro-industrial residues may possess suitable mechanical properties and significant potential for reuse in various applications, especially in the construction sector [8]. However, a substantial fraction of these residues is disposed of in landfills, leading to environmental pollution. This is of particular concern as improper waste management can result in environmental damage, such as soil and water contamination [33] [18] [17], and landscape disturbances, among others.

Therefore, it is imperative to efficiently manage waste by providing solutions to reduce this environmental impact, through actions that contribute to achieving the objectives set towards sustainable development and the circular economy [8]. Such is the case with the controlled management of waste from industry and agriculture, such as sugarcane bagasse ash, which has been the subject of recent research motivated by economic, environmental, and technical considerations [34], as this residue contributes to improving the response of unconfined compression, favoring the geotechnical properties of stabilized soil [8], precisely due to the cementitious properties of the ash.

Considering that infrastructure may sometimes encounter soils with low bearing capacity, unsuitable for supporting both the load of pavement layers and vehicular traffic, compromising road stability [15], the utilization of sugarcane bagasse ash emerges as a viable solution.

Essentially, the use of sugarcane bagasse ash as a subgrade stabilizer emerges as a preventive measure against air, soil, and water pollution resulting from improper disposal of this residue [15]. Moreover, it addresses the growing concern for the environment and the interest in reducing construction costs, which have driven the adoption of recycled materials over conventional ones in engineering projects, provided they offer favorable outcomes from both an economic and technical perspective [22].

5. FUTURE WORK

Despite the inert condition of sugarcane bagasse ash, it is proposed to conduct studies on contaminant transport in soils to assess the mobility of sugarcane bagasse ash under different precipitation conditions. This is done to adjust the frequency of preventive maintenance to the operational levels of this stabilizer.

Likewise, it is recommended to continue the research considering dynamic tests to better understand the behavior of the material at different temperatures, humidity percentages and pressure. On the other hand, construction and monitoring of a pilot section is recommended to evaluate the behavior of the treatment under real road conditions.

6. CONCLUSIONS

The test results indicate that untreated soil with no added SGBA is classified as high plasticity inorganic clay (CH) under the Unified Soil Classification System (USCS) and as A-7-6 under the AASHTO classification. The soil with 5% and 10% SGBA maintains the same classification as the blank sample, being classified as high plasticity clay (CH) under USCS and A-7-6 under AASHTO. This suggests that the addition of up to 10% SGBA does not significantly alter the soil's plasticity characteristics.

However, samples with 15% and 20% SGBA show a change in classification. They are now classified as low plasticity clay (CL) under USCS, but remain A-7-6 under

AASHTO. This indicates that higher percentages of SGBA significantly reduce the soil's plasticity. There is a clear transition from high plasticity (CH) to low plasticity (CL) between 10% and 15% SGBA addition, indicating a critical threshold around 15% SGBA, beyond which the plasticity characteristics of the soil change noticeably.

Despite changes in the USCS classification, all samples are consistently classified as A-7-6 under AASHTO. This consistency suggests that the overall soil characteristics affecting the AASHTO classification are less sensitive to the addition of SGBA. The addition of SGBA can modify the plasticity of the soil, with significant changes observed at higher percentages (15% and above). This can be beneficial for soil stabilization purposes, where lower plasticity is often desired.

For projects requiring specific soil characteristics, the percentage of SGBA added must be carefully controlled. For instance, if lower plasticity is required, adding 15% or more SGBA could be effective. The transition from high to low plasticity with increased SGBA addition is a key finding, providing valuable insights for soil improvement strategies.

The results also indicate that as the percentage of SGBA increases, there is a general decrease in the maximum dry density. This trend remains consistent across varying numbers of compaction strokes (12, 26, and 56 strokes). For instance, when comparing rows with the same number of strokes, the maximum dry density typically declines with higher percentages of SGBA.

The CBR test results demonstrate the beneficial impact of adding SGBA on the soil's CBR values, signifying enhanced soil strength and bearing capacity. Moreover, these findings underscore the significance of compaction energy and density level in shaping soil performance. Such insights can inform soil modification and stabilization techniques, especially in road construction and infrastructure projects, with the goal of improving soil properties and ensuring sufficient pavement support.

The optimal SGBA addition varies based on the desired strength parameter. Specifically, to achieve maximum CBR on soil compacted with 56 strokes of energy, the optimal SGBA addition is 15% at both optimum moisture content and 95% of optimum moisture content. Conversely, for achieving maximum Unconfined Compressive Strength (UCS), the optimal SGBA addition is 5%, particularly notable in samples compacted with 56 blows. This difference emphasizes a clear contrast in the ideal percentage of SGBA addition between maximizing strength (5%) and maximizing CBR (15%).

This study supports the effectiveness of utilizing SGBA for soil stabilization and enhancement, presenting it as a cost-effective, sustainable, and efficient alternative to traditional maintenance practices. This approach not only yields positive environmental outcomes but also presents a viable solution for SGBA-producing companies. By enhancing the physical and mechanical properties of soil used as subgrade for tertiary roads, it offers promising solutions, particularly relevant for countries like Colombia.

Utilizing SGBA, a byproduct of sugarcane processing, can serve as an environmentally friendly approach to enhancing soil properties while simultaneously reducing waste.

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