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POZZOLAN EFFECT ON THE MECHANICAL PROPERTIES OF SCBA BLENDED CEMENT TREATED SOIL

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ABSTRACT. *The recent agricultural and industrial waste reduction research has focused on monetary, sustainable environment, and technological considerations. Discarded raw materials such as rice husk ash, fly ash, coir fiber and silica fumes were widely explored and successfully utilized as blending elements for cement. Current studies have proved that Sugarcane Bagasse Ash (SCBA) produced from sugar production has a pozzolanic reaction due to the high substance of amorphous silica in this raw material. This research would boost the insight of potential blending agents that can reduce the cost and stabilize problematic soil. This study intends to evaluate the effect of SCBA blended cement on improved soil's mechanical properties, including the shear strength and the compressibility of the treated soil. Unconfined Compressive Strength test was conducted to attain the compressive behavior, while the One-Dimensional test was performed to examine the compressibility behavior. The tested samples with SCBA show a beneficial effect in terms of both compressive strength and compressibility. This study proved that SCBA could be applied at least as a partial substitute to the Portland cement.*

KEYWORDS. Sugarcane bagasse ash, pozzolanic reaction, compressive strength, compressibility

INTRODUCTION

Soft soil is usually categorized as soil with poor shear strength and highly compressible and low permeability [1]. Generally, construction challenges in this type of soil are unsatisfactory bearing capacity, extreme post-construction settlement and uncertainty in excavation and embankment construction [2,3]. To enhance the strength and engineering properties of the problematic soil, numerous stabilization techniques with the addition of materials such as sugarcane bagasse ash [4,5], rice husk ash [6,7], cement [8,9], fly ash [10,11], and other additives [12,13] are often used.

Lime and cement are the most common stabilizers used to improve soil properties. However, these manufactured stabilizers are cost-consuming and not environmentally friendly. WBCSD [14] reported cement contributed roughly 5%-8% of global Carbon Dioxide production and is projected to rise to 1.2% every year till it reaches 4.4 billion tons around 2050.

With the escalating request from the whole world for more sugar and ethanol-producing in recent eras, undesirable waste has significantly risen. However, the waste can be used as fuel to stoke boilers that generate steam for electricity production. This incinerating process's finishing product is sugarcane bagasse ash (SCBA). Bagasse is a discarded product from sugar factories after the process of extraction of liquid from sugarcane. SCBA is a pozzolan material that contains a high amount of siliceous and aluminous material [15]. According to Frías *et al*. [15] pozzolan may possess a bit or no cementitious amount. But with the existence of water, it will react chemically along with calcium hydroxide at a typical temperature to produce composites having cementitious properties.

Besides that, the previous research demonstrated the silica content amount in the SCBA is higher than in other additives [16,17]. Therefore, the SCBA has a vast potential alternative to be used as a partial cement substitute compared to other waste materials. Numerous types of research have been performed by using SCBA as partial or total substitution of Portland cement as inert material in compacted soil blocks [18], road constructions [19], soft soil improvement [20,21] and others [22,23].

Abbasi and Zargar [24] reported that workability, mechanical strength, and concrete durability are improved by replacing cement with SCBA. According to Kantinaris [25] SCBA can be used in commercial cement and composite manufacturing. Saini *et al.* [26] and Kharade *et al*. [27] investigated the utilization of SCBA in stabilizing expansive soil. Their studies indicated that the compressive strength of soft soil improves slowly with the rise of the percentage of SCBA up to 5% and 6% without any extra chemical or cementing substance. However, an additional percentage of SCBA can initiate a decrease in UCS value. These actions are credited to the accessibility of an unsatisfactory volume of water necessary for pozzolanic reactions at elevated bagasse ash quantities.

One of the essential relationships observed in the soil stabilization of problematic soil samples is the variation of Maximum Dry Density and Optimum Moisture Content. In addition, stabilized peat by the utilization of SCBA to substitute cement in this soil has been investigated by several researchers. The findings indicated that the mechanical properties in the modification improved peat by applying SCBA were noticeably increased [27].

An increase in Optimum Moisture Content (OMC) and a decrease in Maximum Dry Density (MDD) values have been reported by [21,28,29] when SBCA was used as an additive. The rise in OMC was ascribed to the addition of water content during the hydration process, while the decrease in MDD value was credited to the lightweight SCBA in contrast with the soft soil used. The statement demonstrates that SCBA can be utilized as a soil enhancement means to reduce the settlement behaviour of strengthened soil.

Abu Talib *et al*. [3] and Kamaruidzaman *et al*. [20] reported in their study regarding a substantial lessening of the void ratio for ideal peat-cement-SCBA mixtures as contrasted to natural peat. The finding shows that the stabilized peat of secondary compression index/ compression index ratios (C_α/C_c) declined radically compared to untreated peat. This condition indicated that the stabilized soil mixture effectively decreased the secondary compression.

This article represents the findings of a thorough study on the mechanical properties of stabilized local soft soil in Pulau Pinang featuring Sugarcane Bagasse Ash (SCBA) and cement, which include the shear strength properties and the compressibility of the treated soil. The Unconfined compressive Strength Test was performed to attain the compressive behaviour, while the One-Dimensional Test examined the compressibility behaviour. The subsequent sections represent the experimental process, the findings of numerous tests performed on stabilized modification soils and finally followed by the conclusions.

METHODOLOGY

The problematic soil utilized in this experiment was obtained from the construction site located at Bukit Tengah, Pulau Pinang. The disturbed soil sample was collected at a depth of 2.0 m to avoid the inclusion of organic material. The soil is greyish-black in colour. The Cone Penetrometer Test was performed to classify the soils by following the British Standard 1337 Part 2.

Table 1 shows the physical properties of natural soil. The natural soil was classified as SILT of Intermediate Plasticity (MI) according to the USCS classification system. The natural Moisture Content and Dry Densities were 24% and 1.553 g/cm^3, correspondingly. A Standard Proctor Test was performed on untreated soil to obtain the compaction characteristics of MDD and OMC. The test was performed according to British Standard 1337 Part 4. The Unconfined Compressive Strength (UCS) value obtained from the soil was 18.7 kN/m^2, categorized as very soft and problematic soil.

Table 1. Physical and mechanical properties of natural soil

Soil Characteristic	Value & Description
Moisture Content, MC (%)	24
Percentage of fines soil (%)	1.5
Optimum Moisture Content, OMC (%)	48.5
Maximum Dry Density, MDD (g/cm^3)	1.553
Unconfined Compressive Strength, UCS (kN/m^2)	18.7
Specific Gravity (G_s)	2.55
Liquid Limit, w_L (%)	42.24
Plastic Limit, w_P (%)	26.63
Plasticity Index, I_P (%)	15.61
Soil Classification	SILT of Intermediate Plasticity (MI)

The sugarcane's scientific name is "Saccharum Officinarum" which is typically used for making raw sugar. Figure 1 shows the location of the sugar cane fields. The efficacy of a pozzolan is primarily associated with its silica substance and the crystallinity of silica. Amorphous or partially crystalline silica is essential for developing pozzolanic reactions together with calcium hydroxide.

The burning requirements, such as the optimum temperature and the appropriate burning time, were monitored to produce high-quality SCBA. Besides that, a proper kiln or furnace was used to burn sugarcane bagasse. According to the earlier research, burning the bagasse in a furnace with a high-level temperature between 500 °C to 800 °C will generate good quality amorphous silica. However, the crystallinity in SCBA after the temperature of burning activities greater than 800 °C will produce poorer pozzolanic properties [30,31]. In this research, the baggage ash was obtained from burning sugarcane baggage in a furnace of 800^{o}C.

Particle breaking of SCBA is an essential procedure to monitor the particle size of the material as it will modify the crystalline compounds and pozzolanic activities. The most appropriate size of SCBA to be adopted in this study is equivalent to the size of cement used, which is 2µm. The percentage SCBA used is 3%, 6%, and 9% for each blended sample. These percentages of SCBA are selected based on previous studies [5,27].

Figure 1. The location of the sugarcane fields

OPC Type I has been used in this research because it was suitable for various general purposes in construction and had an outstanding binding property that provides better strength to any structural or infrastructural components. Table 2 represents the chemical properties of soil, OPC, and SCBA. The higher value of silica and oxygen elements in SCBA shows good potential to serve as good pozzolanic material. Two samples of untreated soil and cement-treated soil mixed with SCBA were tested for three main properties: physical, mechanical, and chemical. The percentages of cement used were 3%, 5%, and 10%.

Table 2. Chemical properties of soil, OPC and SCBA

Element	Soil (%)	OPC (%)	SCBA (%)
Carbon, C	21.181	6.851	5.496
Oxygen, O	52.783	41.018	38.029
Magnesium, Mg	0.352	0.451	0.451
Aluminum, Al	8.251	1.077	0.358
Silica, Si	13.235	5.459	11.567
Iron, Fe	2.100	1.371	0.520

A sequence of laboratory experiments was performed on untreated and treated soil to accomplish this study's objectives, including the Unconfined Compressive Test (UCT) and One-Dimensional Consolidation (Oedometer) test. The tests had been conducted for soils with and without SCBA. To prepare the remolded sample, the soil was weighed and added with specific percentages of cement (3%, 5%, and 10%) and SCBA (3%, 6%, and 9 %) inside the plastic bag in the dry form.

For the UCT test, the sample was tested on three curing days: days 0, 3, and 7. Later, water was combined into the mixture and was carefully mixed until a consistent color was observed. The water added refers to the value of natural moisture content. Table 3 demonstrates the design mix of the samples to be tested on the mechanical properties and chemical properties.

Table 3. Design mix of the samples

Curing Day	OPC (%)	SCBA (%)
0	3	0
3		3
7		6
		9
0	5	0
3		3
7		6
		9
0	10	0
3		3
7		6
		9

The sample's design mix is prepared using data in Table 3. The blended soil samples were compressed in a cylindrical mold with a diameter of 38 mm and a height of 76 mm until the desired density and moisture content of 1.553 g/cm^3 and 24% were achieved. Then the compacted soil was extruded, wrapped with clear plastic, and stored in a desiccator for curing processes. After that, the UCS tests were performed in the laboratory as per British Standard 1337 Part 7 on each sample to obtain the strength for different percentages of cement, SCBA, and curing period, respectively.

The estimation of the rate amount of consolidation settlements is crucial for any structure built on a compressible soil layer. Hence, the One-Dimensional Consolidation test (according to British Standard 1377 Part 5) was conducted to determine the effect of SCBA (3%, 6%, 9%, and 12%) based on the dry density of soil as an additive on the consolidation settlement parameter of cement-treated soil. This study tested soil samples with 3%, 5% and 10% cement.

The ash-cement-soil mixture was compacted in a cylindrical mold until the required density of 1.553 g/cm^3 was attained. Then, the ring with a diameter of 50 mm and a height of 20 mm was pressed into the soil. The top and bottom of the ring were trimmed using a palette knife so that the ring's top and bottom were clean. The soil samples were submerged in the water for 24 hours before the test was conducted.

RESULT AND DISCUSSION

Effect of SCBA on UCS

The UCT tests were conducted 2 hours after the sample was prepared. The experimental results of the strength of the treated soils with different proportions of cement (3%, 5%, and 10%) and SCBA are shown in graphs Figure 2 to Figure 4. Based on the findings, the shear strength of the treated soil improved as the percentages of SCBA increased.

The SCBA contains a high-level quantity of silica and acts as a fine pozzolan. This indicates that adding SCBA can enhance the compressive strength of the soil samples. It can hydrate when there is liquid and react with the remaining calcium hydroxide of cement to produce pozzolanic compounds, hence further enhancing the soil strength [32]. The result justifies that the SCBA containing a high amount of silica is suitable for blending components for cement.

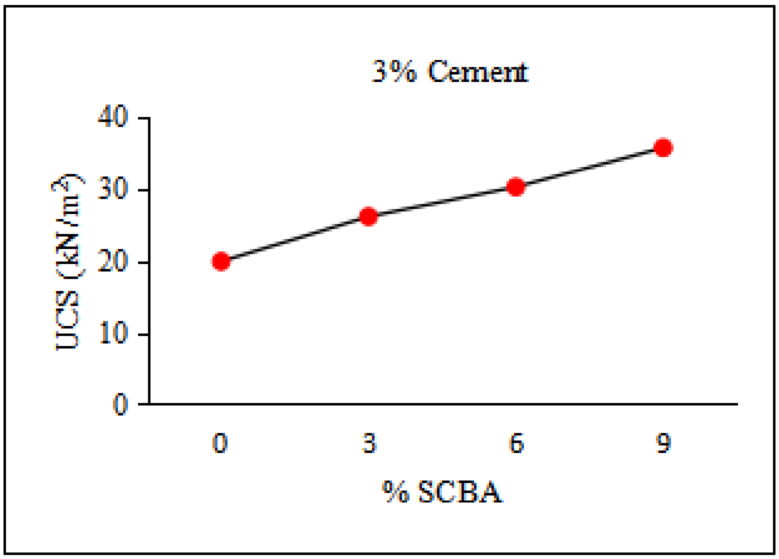

Figure 2. Effect of SCBA on UCS (3% Cement)

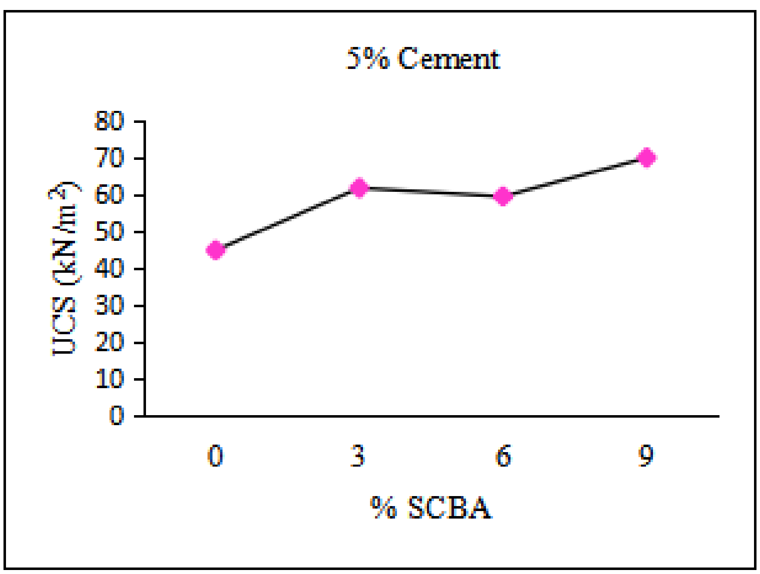

Figure 3. Effect of SCBA on UCS (5% Cement)

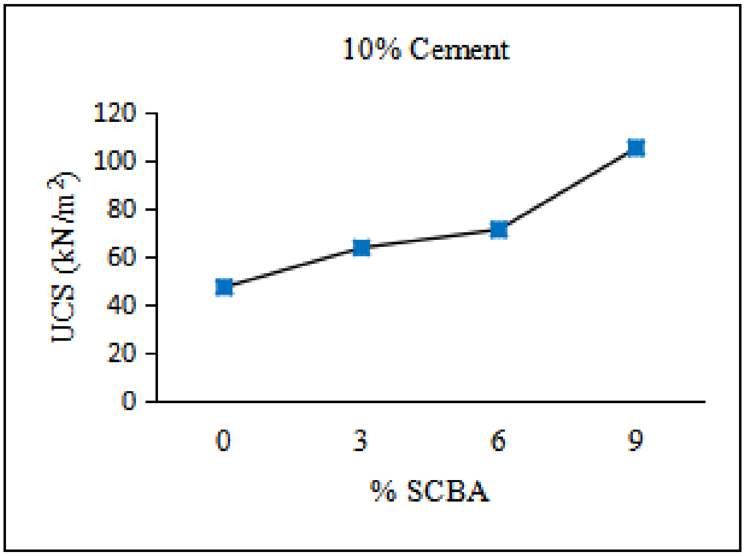

Figure 4. Effect of SCBA on UCS (10% Cement)

For each percentage of cement, the samples with the highest UCS values were those with the addition of 9% SCBA. This finding is supported by a previous study that the UCS value of the treated soil is more significant when the percentage of the ash is higher but up to optimal limit replacement for SCBA [29,33]. The results of a 5% cement mix with 9% SCBA are higher than 10% cement alone, indicating that the SCBA can be employed as a partial substitution for cement. However, in this study, the optimum limit of the SCBA is unknown.

Effect of Cement on UCS

The successful soil stabilization using pozzolanic material is only accomplished by mixing the waste material with the Portland cement. The OPC will activate the chemical reaction with the help of water. Then, the blended material becomes hardened and durable as the cement hydrates and strengthens. Figure 5 shows the effect of cement on Unconfined Compressive Strength.

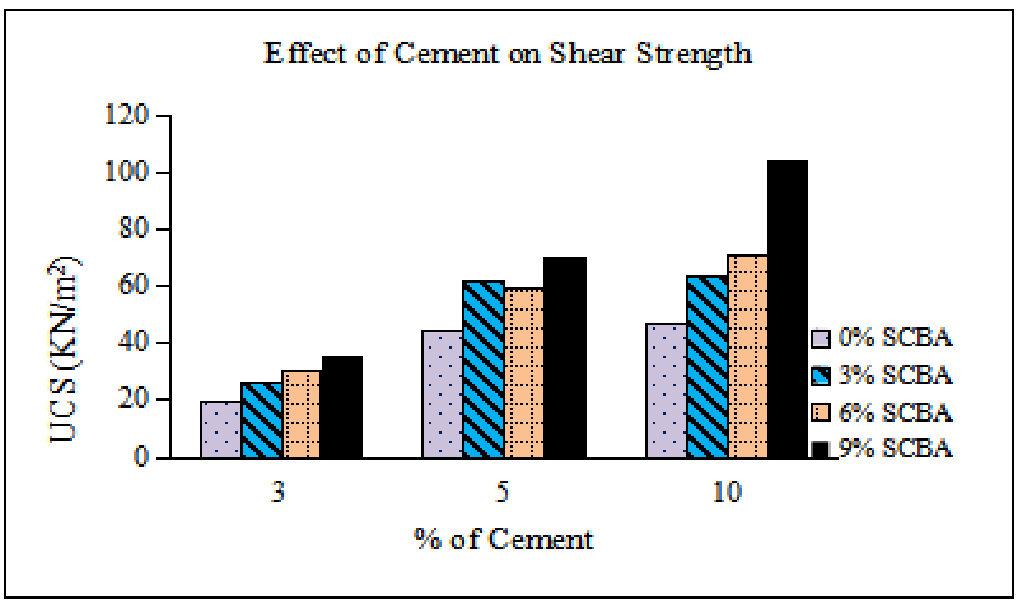

Figure 5. Effect of cement on UCS

In this experiment, the cement utilized as an additional additive with SCBA to enhance the soil properties were 3%, 5%, and 10%. The graph shows, once 3% of the cement added to the mix of different percentages of SCBA (0%, 3%, 6%, and 9%), the strength improved to 7%, 40.3%, 62.4%, and 91.9% respectively. The test then proceeds to the new samples with the addition of 5% of cement. The result indicates that the strength value of stabilized soil increased to 140.3%, 231.25%, 218.82%, and 275.3%, correspondingly. These strength increments were demonstrated to be three times greater than untreated soil.

When a similar test is repeated to 10% of cement, the strength of treated soil increases tremendously by 153%, 240.9%, 281.7%, and 464%, correspondingly. The result demonstrates that when the percentage of cement increases, the compressive strength increases likewise. The outcomes indicate the amount of cement added influences the soil strength. The more adhesive added, the higher strength of the mixture.

The result above was in line with Xiao & Lee [8] study where when the cement, additive, water, and soil combine, primary hydration will occur. Then, the secondary pozzolanic reaction will take over when the pore chemistry in the soil structure attains an alkaline form. This process is due to early strength improvement due to developing earlier cementitious products and drying up the soil-cement mix.

Effect of Curing Time on UCS

Unconfined Compressive Strength (UCS) values blended Cement-SCBA-Soil sample for 3% SCBA and different percentages of cement (3%, 5%, and 10%) were evaluated by examining the effect of curing time as illustrated in Figure 6. The blended Cement-SCBA-Soil sample was cured for 3 and 7 days. The curing sample was compared with an immediately blended soil sample from 0-Day curing time to see the results of the curing period on the soil samples. The UCS values for 0-Day curing were 26.1, 61.6, and 63.4 kN/m^2. When the sample was cured for 3-Days, the UCS increased to 52.8, 66.3, and 89 kN/m^2. Later, when the samples were cured for 7-Days, the UCS value also rose to 70.3, 83.3, and 161.9 kN/m^2 correspondingly. This situation signifies the effect of continuing the hydration process over time.

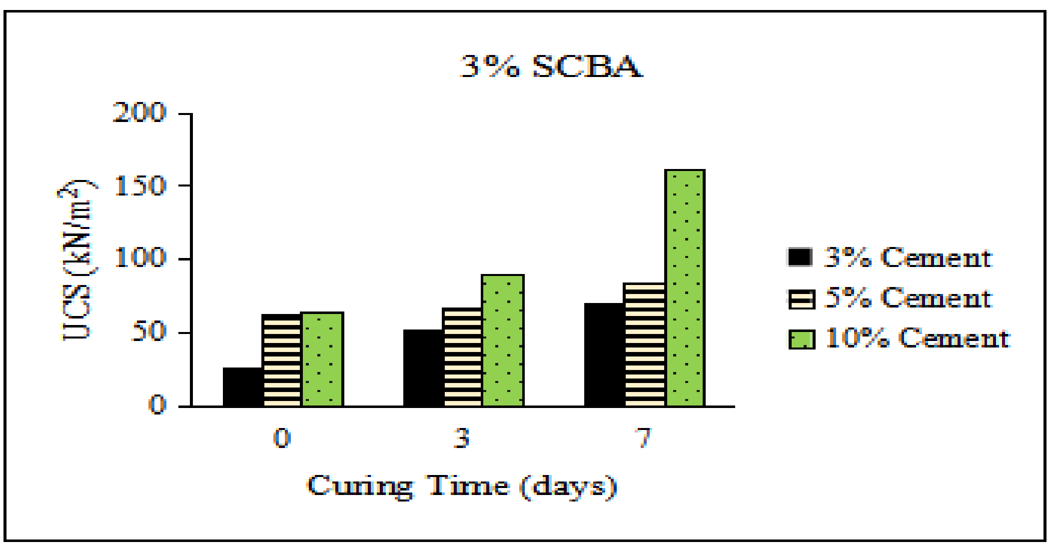

Figure 6. Effect of Curing on UCS of 3% SCBA

Figures 7 and 8 show the effect of curing time on UCS blended Cement-SCBA-Soil samples for 6% and 9% of SCBA and different percentages of cement (3%, 5%, and 10%). Similar to the previous SCBA 3% sample result, the UCS values significantly improved when the curing time was extended from 3 to 7 days. The result demonstrates drastic escalations of the UCS amount for cement by 10% with 7-Days curing. Testing results indicated that the additions of 3 and 7 days of curing time for the cement-SCBA-soil sample improved the structure of the admixtures leading to an elevated amount of strength compared to 0-Day curing.

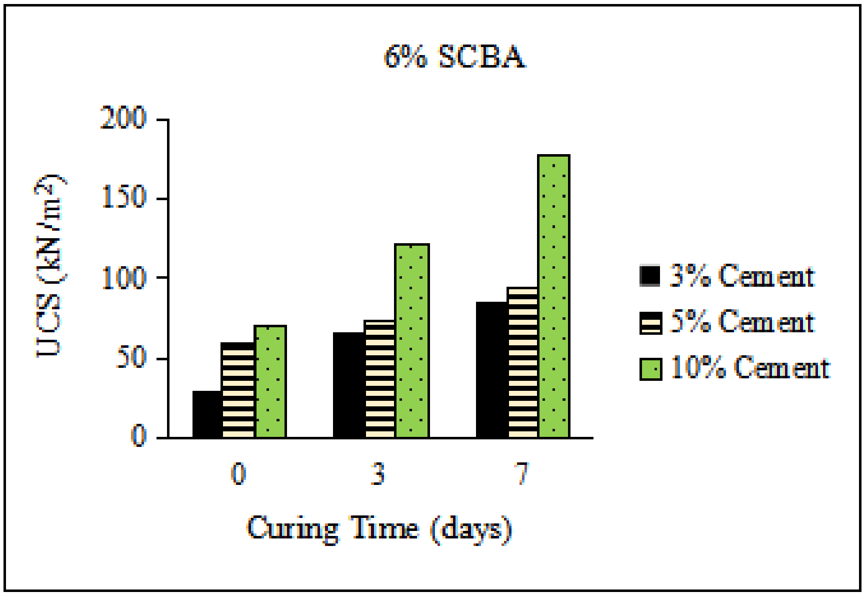

Figure 7. Effect of Curing on UCS of 6% SCBA

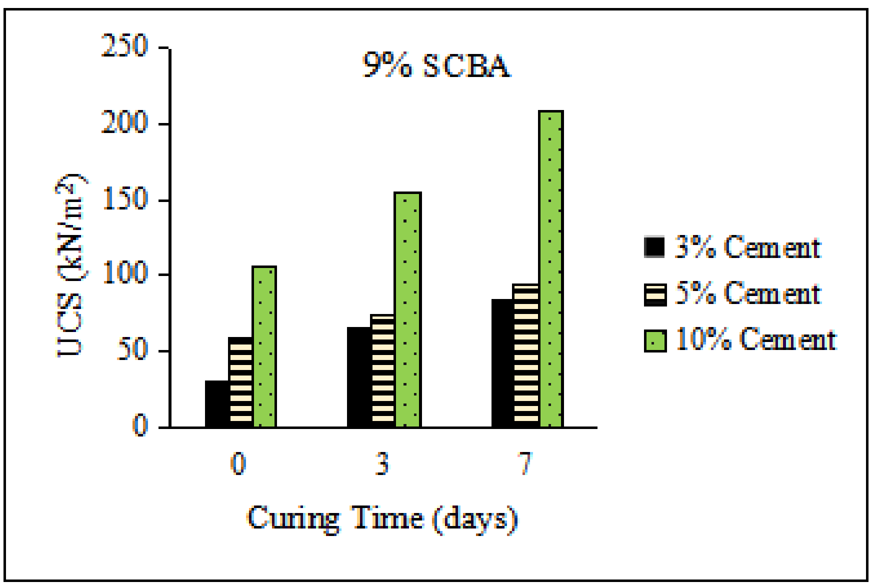

Figure 8. Effect of Curing on UCS of 9% SCBA

For the sample with the lowest percent of OPC and SCBA, the strength increases from 19.9 kN/m^2 on Day 0 to 52.4 kN/m^2 on Day 7. The increase of the UCS is about 1.6 times from Day 0 to Day 7. Comparable to samples with the highest percent of OPC and SCBA, the strength improves drastically from 104.9 kN/m^2 on Day 0 to 208.9 kN/m^2 on Day 7. The result shows an increment of about 100% before curing and after 7-Days of curing. The hydration and pozzolanic processes of soil, cement, and SCBA occur from time to time. The enhancement of strength increases as the hydration and cementation reaction increases with the curing time [34,35].

The result illustrates the strength of the soil improved as the curing period increased due to the reaction between soil, cement, and SCBA. The pozzolanic behaviour was maximized between 3 and 7 days of curing. This condition explains by Abu Talib *et al*. [3] that the extreme escalation in the UCS earlier seven days of curing was primarily anticipated to the hydration reaction of the cement, the mixture of the filling effect of both silica plus SCBA, and as well as pozzolanic reaction.

Effect of SCBA on Consolidation Characteristic

Typically, soil subjected to vertical stresses will cause volume change through the rearrangement of soil grains. The total volume change is associated with the difference in the quantity of water in the soil. Water dissipated from the soil voids contributes to the deformation or settlement. This process takes time and varies with the permeability of the soil. The permeability is affected by particle distribution of the soil as the finer the soil particle, the lower the permeability [36].

The One-Dimensional Consolidation test was performed to obtain the consolidation characteristics of the soil. Figure 9 and Figure 10 present the relationship between stress (σ) applied and the coefficient of volume compressibility (mv) of 3% and 5% of OPC, respectively. The results depicted that the untreated soil has the highest volume of compressibility compared to the treated soil. The cement-treated soil with SCBA shows significant improvement in reducing the compressibility of the soil. The existence of OPC and SCBA has proven to uphold the soil particles simultaneously and strengthen the saturated soil.

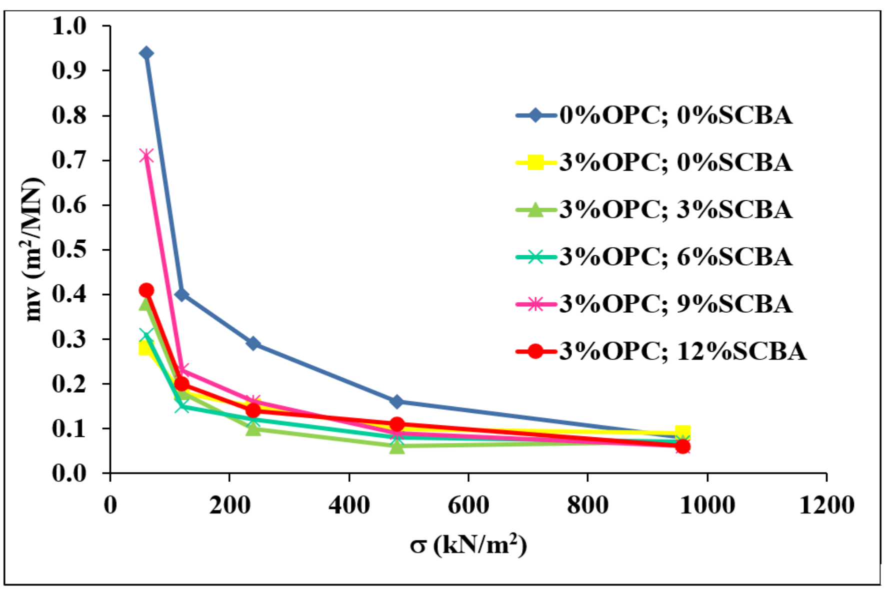

Figure 9. Change of m_v with stress for 3% OPC

The One- The test findings reveal that the soils with 3% SCBA for 3% and 5% OPC had the lowest volume of compressibility at the early loading stages. Meanwhile, at the subsequent loading stage, soil with 12% of SCBA has the lowest volume of compressibility for both 3% and 5% OPC. However, this is not obvious as other SCBA contents have a relatively small difference in the m_v value.

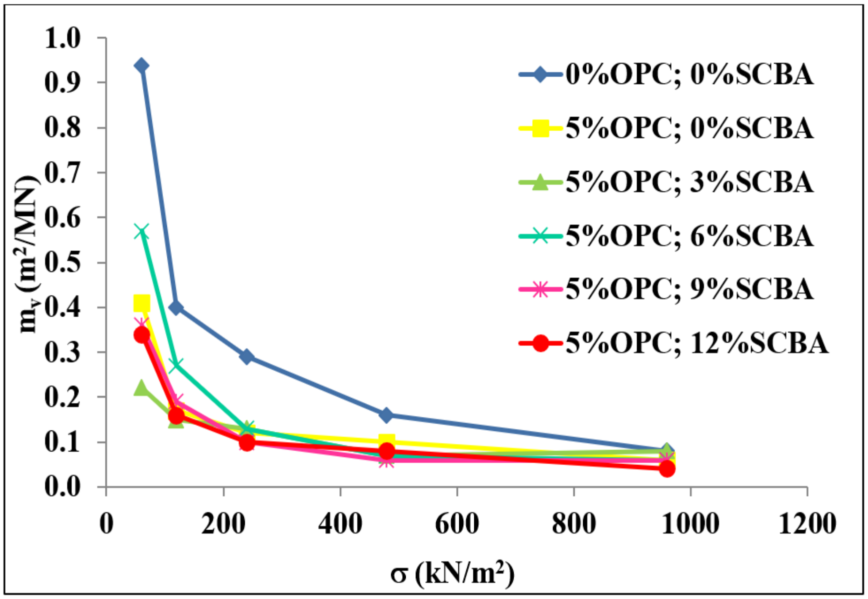

Figure 10. Change of m_v with stress for 5% OPC

In summary, the improvement of the soil strength is attributed to the inclusion of fine particles of SCBA in the soil mixture. Where the chemical reacts among the stabilizer and the soil, this process will enhance the sample's durability and mechanical properties. The SCBA was pozzolanic material with a high amount of silica which is suitable for partial blending components for cement. This partial replacement will reduce the problem of waste disposal (SCBA), environmental pollution from the emission of CO_2 (cement), and water pollution.

The result from the study shows that the addition of SCBA enhanced the structure of the blend materials and prominent to a more excellent value of strength. The primary hydration happens after the cement and water react to gain initial strength due to the composition of cementitious products. The process continues with secondary hydration, where the pozzolanic reaction fills pores in the soil system with fine particles from SCBA.

The statement was supported by the result in this study, where when the amount of cement used was the same, and the percentage of SCBA increased, the strength likewise kept on escalating. This condition occurs because of the pozzolanic result and decreasing capillary openings. Thus, from the justification, the amount of cement could be reduced and replaced by partial SCBA to get better results than the cement alone. Besides that, it is worth noticing that the blended Cement-SCBA-Soil sample mixtures achieved compressive strength superior to initial untreated soil, mainly when the 10% cement and 9% of SCBA with seven days curing time are used.

Furthermore, the volume of compressibility of Cement-SCBA-Soil reduced compared to the natural untreated soil. The result indicated that using SCBA as partial cement reinforcement enhances the stiffness of the soil matrix and can be used to overcome difficulties in construction such as excessive settlement and lead structural damage to the building frame or loss of functionality. Therefore, the blend of SCBA and cement as a partial substitute for cementing the stabilization of problematic soil appears to be a favorable option after pondering economic, energy utilization, pollution, and sustainability concerns.

CONCLUSION

The utilization of waste materials due to industrial and agricultural activities has become a great concern to the developing country. These unwelcome wastes have affected the atmosphere because of the challenge of management and disposal. In this research, the effect of SCBA has been studied on Compressive Strength and Soil Compressibility. The higher the percentages of SCBA used, the better the soil compressive strength. Furthermore, the strength value of the stabilized soil improved as the curing period increased. Additionally, the compressibility of cement-treated soil was reduced with the addition of SCBA. Adding 3% of SCBA to the cement-treated soil seems to be the optimum value, at least at a small loading stage. Using SCBA as a partial substitute for OPC gives positive results in stabilizing the soil. However, no optimum amount of SCBA was found in the study. Therefore, future studies may consider higher content of SCBA, which is larger than the maximum amount used in this study. In conclusion, SCBA could be used as an alternative additive to improve soil behaviour in strength and compressibility with or without cement. Consequently, applying bagasse ash waste in the ground improvement has excellent potential for the future to solve specific waste disposal problems.

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