STABILIZATION OF SILTY CLAYEY SOIL USING SUGARCANE BAGASSE ASH, LIME AND MOLASSES

Rahul Sharma[1*], Mohammad Irshad Malik [2]

Abstract
The process of stabilizing soil entails the utilization of a wide variety of techniques and ways to enhance soil that may cause challenges in engineering and related sectors due to its poor strength as well as its tendency to shrink and swell. Stabilizing agents such as waste foundry sand (WFS), fly ash, waste from construction and demolition, rice husk ash, Sugarcane bagasse ash (SCBA), and sawdust ash are used to improve the geotechnical properties of the soil in order to alleviate the issues that have been brought to light. In this study, the efficacy of agricultural waste such as Sugarcane Bagasse Ash (SCBA) (at 5%, 10%, 15%, and 20% concentrations) coupled with lime (at 3%, 6%, 9%, and 12% concentrations) stabilized clayey soil with the addition of Molasses (at 5%, 10%, 15%, and 20% concentrations) is presented. The current research was conducted with the intention of developing a composite soil subgrade material for the purpose of designing the subgrade of flexible pavements. A number of different laboratory experiments, including Specific gravity, differential free swell, Liquid limit, compaction characteristics, and California bearing ratio (CBR) tests, were carried out on soil that had been amended with SCBA, Lime and molasses alone and in combination with each other in order to determine whether or not these ingredients were suitable for use as a subgrade material. The laboratory tests showed that the differential free swell and Liquid limit of Silty clayey soil dropped, Variation was seen in OMC and MDD values and CBR values increased on adding the optimal amount of SCBA (15%), Lime (9%) and molasses (10%) alone and in combination. Not only does the incorporation of SCBA, lime and molasses into the process of stabilization of silty clayey soil provide a solution to the difficulty of waste management, but it also offers a solution that is both cost-effective and environmentally friendly.

Keywords: Soil stabilization, silty clayey soil, Sugarcane Bagasse Ash, California bearing ratio, Optimum moisture content, Lime.

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Introduction

In civil engineering projects, different kinds of soil are used. Some soils need to be treated before they can be used for building. Problematic soils like silty and clayey soils can be found all over the world. Before they can support the weight of buildings, they must be removed and replaced or have their properties changed (Steinberg, 2000). Most buildings built on clayey soils settle a lot because the volume of the soil changes when the amount of water in the soil changes (Chen, 2012;). It's hard to accurately know about these changes because the surface physical and chemical forces control each clay particle and the size of the soil changes as it expands (Briaud et al., 2003). These surface physical and chemical forces work because of the small size of the particle and because a thin double layer forms around each clay particle. This double layer is also what causes these soils to swell and shrink (Aubeny and Lytton, 2004;).Soft soils, sometimes referred to as silty-clay soils, are a typical soil type that may be found in several areas of the world. Low shear strength, less durability, and extremely high compressibility are what define them. Because to their unique characteristics, they present a special challenge for construction projects because, if not correctly handled, they can result in a number of issues (Horpibulsuk et al., 2012; Zhan et al., 2015). Extensive settling is one of the most significant problems that are linked with silty-clayey soils. This issue might arise when the soil is unable to hold the weight of the structures that have been constructed on top of it (Lin and Cerato, 2012). This can result in the pavement cracking, the surface becoming uneven, as well as damage to buildings and other types of infrastructure. In addition, silty-clayey soils can cause structures to become unstable because of their tendency to shift and move over time, which can ultimately lead to structural damage and the possibility of the structure failing (Kampala and Horpibulsuk, 2013; Yao et al., 2020). Silty clay soils are particularly vulnerable to liquefaction during earthquakes, a condition in which the soil loses its firmness and rigidity, leading to the collapse of structures erected on it and potentially causing catastrophic damage and fatalities (Nguyen et al. 2018; Horpibulsuk et al., 2013). To deal with these problems, engineers have used a number of methods to enhance the geotechnical properties of silty-clayey soils. Some of these methods are soil stabilization, mechanical remediation, grouting, soil reinforcement, adding geo textiles, geo membranes, and graded aggregate materials (Bergado et al. 1996; B Atahi et al 2012). Despite this, soil stabilization is typically chosen as the method of choice because it is uncomplicated and economical. It requires the utilisation of a wide range of components and admixtures, such as chemicals, discarded materials, and pozzolanic materials, amongst others. Fly ash, waste from construction and demolition (also known as C&D waste), RHA, SCBA, BA, saw dust ash, and ground granulated blast furnace slag (GGBFS) are examples of popular pozzolanic materials that are utilised for the purpose of stabilising soil (Kenneth et al., 2001; Patil et al., 2012; Firoozi et al., 2017; Premlatha et al.,2018; Venkatesh et al., 2020; Heidemann et al., 2021). In the past, research studies have been carried out with the goal of locating efficient methods to stabilize poor soils by utilising admixtures, waste materials, chemicals, pozzolanic materials, and other such materials (Bhat and Lovell, 1994; Foundry Industry Recycling Starts Today, 2004; Abichou et al., 2005; Ashmawy et al., 2006; Guney et al., 2006; Kayal and Chakrabarti et al., 2008 Mgangira, 2006; Deng and Tikalsky, 2008; Singh and Prajapati, 2013; Taye and Araya, 2015; Sharma and Hymavathi, 2016; Sharma and Sharma, 2019; Bhardwaj and Sharma, 2022). The globe currently has a severe issue with how to dispose of the vast amounts of agricultural waste. Without sufficient care, agricultural waste is disposed of, which has an effect on the ecosystem. It disrupts ecosystems, pollutes the air and water, among other things. The problem of safely disposing of agricultural waste falls to the engineers. Multiple efforts have been made to boost soil strength by combining various chemical additions with lime and cement, but research must place a greater emphasis on the use of less expensive and readily accessible materials. This research investigates the use of agricultural waste in stabilizing. Engineers have been utilizing cement as a stabilizer to enhance the qualities of soil for some time now. Research has revealed that some agricultural waste contains properties similar to cement or lime in terms of binding the particles, and it can be utilized as a cement or lime substitute. One of those Agricultural wastes includes bagasse ash (made from sugarcane).

Bagasse, which is made up of tangled cellulose fibers, is the leftovers of a sugar mill. Economic, technological, and ecological considerations of commercial and industrial usage of agricultural waste products have been the topic of research. Bagasse, a fibrous waste product of the sugar industry, is burned simultaneously with the ethanol vapor. The pollution caused by this trash is already substantial. As a result, it's important to find fast ways to deal with the trash so that we can gauge how useful they are to the business world. As it possesses the right geomechanical qualities and is non-hazardous to the environment, it can be used in construction purposes specially in stabilizing soil.

According to the findings of the studies, implementing SCBA into diverse geotechnical applications has the potential to improve the strength of poor soils. It is anticipated that incorporating Sugarcane Bagasse Ash into clayey soil will greatly improve the engineering properties of the soil. Kharade et al.; (2014**);** used the partial replacement of soil with bagasse ash at the rates of 3%, 6%, 9%, and 12% is carried out in order to stabilize clayey soil and found out significant changes in compaction and CBR characterstics of soil. Osinubi et al., (2009); had investigated how lime-stabilized black cotton soil's compaction and strength parameters were affected by bagasse ash. The maximum CBR value was attained with a mixture of 4% bagasse ash. Gandhi (2012) Liquid limit (wL), Plastic limit (wP), Plasticity index (IP), Shrinkage limit (sL), Shrinkage index (sI), Free Swell Index, and Ps had been examined for the effects of adding bagasse ash (up to 10%), and it was discovered that all of these values decreased as the proportion of bagasse ash was increased. Reddy et al., (2017) did geotechnical tests on a mixture of 10%, 15%, 20%, and 25% black cotton soil, polypropylene fibres, and sugarcane bagasse ash. The OMC Test, the UCS Test, and the CB Ratio Test were all done. The UCS and CBR values go up when 1% of polypropylene fibre and 20% of sugarcane bagasse ash are added. J. Ochepo and K. J. Osinubi (2013) looked at the effect of compactive effort and time on the strength of lime-bagasse ash stabilized expanding clay from Gombe, Nigeria. The experiment looked at compression strength in the open. From the study, we can say the following things: The results show that UCS values go up when lime and bagasse ash are used to treat and cure the soil.

One of the most ancient construction materials utilised by man was lime, which has also been used for binding. since it was first utilised. According to Sherwood (1993), lime is predominantly composed of calcium oxide and hydroxide as its ingredients. Lime also imparts tensile strength to soil through the process of cation exchange. process. There is a point where lime gives it highest benefits which is called lime fixing point as it is the point at which Hilt and Davidson (1960) and Eades and Grim (1966) explained that lime gives the soil its maximal benefits, and this point is referred to as the lime saturation point. According to Thompson (1969a) and Brandl (1981), this point typically ranges from 3% to 10% (depending on the kind of soil), although it can go as high as 20%. It was discovered by Thompson, 1969b; Miller et al., 1970; and Tulloch et al., 1970 that soil–lime mixes require a significant increase in their tensile strength. According to the findings of Sharma et al. (2008), the incorporation of four percent lime and twelve percent rice husk ash into expansive soil improved the stress–strain behaviour of the composite by 127% and increased its CBR value by 191%, respectively. According to the findings of Al-Mukhtar et al., (2010), a lime content of 5 percent is enough for lowering plasticity and swelling in a material over a short period of time. Calcium aluminate hydrate (CAH) was discovered as the product of pozzolanic reaction by the use of X-ray diffraction analysis on samples with a lime percentage of more than 6%. Bozbey and Garaisayev (2010) analysed the influence that lime had on the geotechnical properties of exceptionally soft swelling soil that was readily accessible in the area. They found that the addition of lime upgraded the workability of the very soft soil as well as its swelling and compressibility. To investigate the influence that lime has on the geotechnical qualities of very expansive soil, Bozbey and Garaisayev (2010) employed readily available exceptionally expansive soil from the area to determine the influence of lime on its geotechnical qualities, and found that the addition of lime enhanced the highly expansive soil's workability, swelling, and compressibility. According to Ali and Zafar (2011), the introduction of lime to two highly plastic clays caused the composite to exhibit decreased flexibility as well as dispersion, shrinkage, and swelling potential as a result of the change. The authors also discovered that the increase in CBR of the clayey soil was closely connected to the quantity of lime that was supplied (but only up to 10 percent). Estabragh et al. (2013) analysed the impact that adding lime, cement, and coal ash had on the physicochemical and mechanical properties of expanding soil. According to the findings of the study, the combination of soil and lime led to a reduction in both the Ip and the MDD, but it led to a rise in both the shrinkage limit and the OMC. The researchers made this discovery after finding that the clay and lime together reduced both the Ip and the MDD.

According to the findings of Sharma and Hymavathi (2016), the addition of four percent commercial lime to black cotton soil caused the DFS of clayey soil to become equal to zero while simultaneously increasing the unconfined compressive strength (UCS) of silty soil. According to Lopez-Lara et al. (2017), treating expansive soil with 6% lime decreases the amount of swelling that the soil experiences. This occurs despite the fact that no surcharge is applied to the expansive soil. In their study, Kumar et al. (2018) proved the effect of including lime in varied quantities on Jamshoro soil, ranging from 0 to 25 percent. They found that the UCS and CBR values increased with increasing percentages of lime up to 5 percent, but not beyond that point.

Clayey soil that has weak geotechnical properties can benefit from utilising enzymes to stabilise the soil, which is yet another method for strengthening the strength of the soil (Shankar et al., 2009;) When compared to other substances, enzymes have a lower cost. With other soil stabilisation materials due to the fact that the quantity of enzyme required for the alteration of soil is very low (Scholen, 1995;). A number of different enzymes, including Terrazyme, permazyme, molasses, earthzyme, and eko soil, have been utilised in the past to increase the low strength of impoverished soils (Bergmann, 2000; Eujine et al., 2017; Bergmann, 2000; Pooni et al., 2019). Molasses is produced as a by-product of sugar cane and is collected from factories that process cane sugar (Tingle et al., 2007). Molasses is created in large quantities as a result of the strong demand for sugar and the huge production of sugar (Baby et al., 2016;). Because of the harmful nature of molasses, it produces dumping difficulties in the areas that are adjacent to the cane sugar sector (Isaac et al., 2003); Molasses has been the subject of a limited amount of research in the context of soil stabilisation (Suriadi et al., 2002; M'Ndegwa, 2011; Taye and Araya, 2015). These investigations were published in Suriadi et al., 2002; M'Ndegwa, 2011; and Taye and Araya, 2015. In an effort to enhance the structural strength of Burdekin sandy clay loam and Proserpine loamy sand, Suriadi et al. (2002) treated the soils with molasses alone and with gypsum. They found that the structural stability of both types of soil increased as a result of a decrease in dispersion and/or slaking (Rauch et al., 2003;). Molasses has been shown to have a beneficial effect on soft murum soil, and Shirsavkar and Koranne (2010) came to the conclusion that its usage in the construction of roads could result in cost savings. M'Ndegwa (2011) found that adding 8% cane molasses to clayey soil increased its tensile strength. This was discovered after the expansive soil was treated with sugar cane molasses to stabilise it. M'Ndegwa and Shitote (2012) demonstrated that incorporating sugar cane molasses into expansive soil at concentrations of up to 8% only resulted in a decrease in the plasticity index of the expansive soil from 39% to 26%. Molasses was added to the soil cement blend at a rate of 4%, which Taye and Araya (2015) found enhanced the CBR value from 1% to 64%. As a result, the plasticity of the composite was reduced from 53% to 19%. When Mahendran and Vignesh (2016) stabilised red soil with molasses, cement, and hypo sludge, they discovered that mix M9, which contained 5% molasses and 10% hypo sludge waste, had the highest UCS value. This combination was found to be the most effective. Pruthvi and Rao (2017) conducted research on the effect of adding molasses and lime to silt clay soil. They found that the cohesion value of the soil increased from 0.25 to 0.6, while the friction angle increased from 90 to 190. Both of these results may be attributed to the fact that the soil was treated with both of these amendments. It was also determined that in order to get the desired level of strength, the ratio of molasses to lime should be somewhere in the region of 7–10 percent. Vinodhkumar et al., (2018) carried out studies on clayey soil that had been mixed with molasses at various proportions, including LL, PL, and UCS tests. They claimed that adding 10% molasses increased the UCS value by up to 160 percent, and they recommended using molasses more frequently in subgrade modifications and other geotechnical applications. Kiran et al., (2018) conducted an investigational inquiry on expansive soil with molasses and areca nut fibres and published their findings.

1.Materials used

Soil

The soil used in this study came from Khairi, which is in the district of Balaghat in the Indian state of Madhya Pradesh (Fig.1). So that there wouldn't be any organic matter on the surface, the soil was taken from about 1.3m to 1.8m down. The soil was then taken to Chandigarh University's geotechnical engineering lab for more testing. The soil was t Under the Unified Soil Classification System, ASTM-D2487-11, the soil was found to have a lot of fine particles (silt and clay) (USCS). The soil falls into the category of "high plastic silt" on the plasticity chart (MH). Table 1 lists the different physical characteristics of soil.

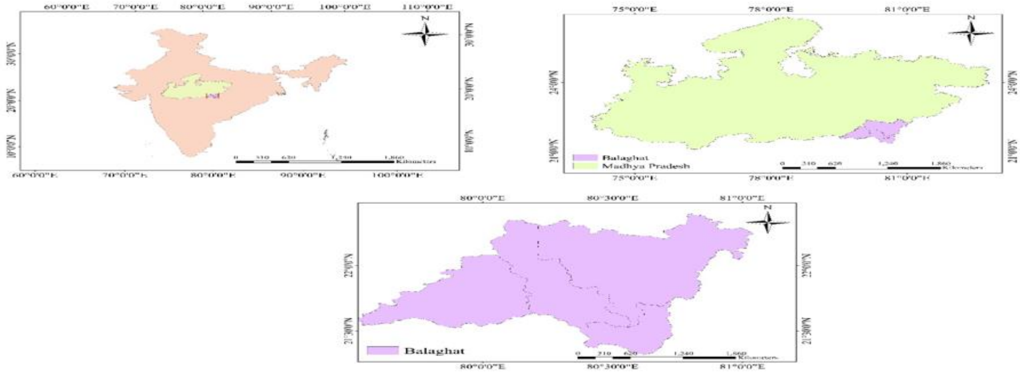

Fig.1 Location map of soil

Sugarcane Bagasse Ash

The remaining portion of the sugarcane after the juice has been removed is called as bagasse. It is a dry, pulpy, fibrous material. Both for manufacturing biofuel and as a building material, it is widely used. A sugar mill's raw bagasse is dried in an oven before being burned to ashes. The Morinda Coop. Sugar Mills Ltd. (roopnagar) provided the bagasse ash for the current investigation, which was then transported to Chandigarh University's geotechnical engineering lab for additional testing. A dry sieve technique was utilised in order to measure the distribution of the particles' sizes according to their particle size, as is seen above in Fig. 3. Table 1 lists the chemical composition of SCBA.

Table 1. Chemical composition of SCBA used in present study

Chemical composition	Percentage composition
Silica (SiO_2)	60.96
Alumina (Al_2O_3)	7.35
Iron Oxide (Fe_2O_3)	6.03
Calcium Oxide (Cao)	12.55
Magnesium Oxide (MgO)	2.50
Potassium Oxide (K_2O)	3.51
Sodium Oxide (Na_2O)	0.13

Lime

Limestone, the raw material used to make Lime, is essentially pure calcium carbonate. Lime's additive effects on soil structure are significant. Lime for the tests was purchased at a nearby hardware shop. Table 2 shows the chemical properties of Lime.

Table 2. Chemical composition of Lime used in present study

Chemical composition	Percentage composition
Silica (SiO_2)	45.6
Alumina (Al_2O_3)	18.7
Iron Oxide (Fe_2O_3)	8.66
Calcium Oxide (Cao)	10.7
Magnesium Oxide (MgO)	1.44
Potassium Oxide (K_2O)	2.53
Sodium Oxide (Na_2O)	2.32
Sulphur trioxide (SO_3)	1.88
Loss of ignition	5.37
Specific gravity	2.34

Molasses

Molasses is a thick, dark brown residue of the sugarcane industry that has a syrupy consistency. Molasses, if a spill is not cleaned up quickly after it occurs, has the potential to degrade the aesthetic quality of the surrounding environment. Molasses, which is a liquid sugar, has an effect on marine life, and water pollution occurs when waste or wastewaters enter river streams in sufficient amounts. Molasses is one of the substances that has this effect. Molasses is a product whose production frequently exceeds its demand; hence, it is essential to dispose of it and manage it in an appropriate manner. Molasses for the experiment came from

Morinda Co-Operative Sugar Mill Ltd (Roopnagar). The chemical properties of the Molasses used in the current study are shown in table 3.

Table 3. Chemical composition of Molasses used in present study

Chemical composition	composition
Colour	Black
Brix	83.2
Specific gravity	1.39
Viscosity	17500 mPa-s
Moisture	21.76%
Total sugar	47.85%
Invert sugar	10.31%
Sulphated sugar	15.60%
Ca	1.65%
Ph (1:1 at 20^{0}C)	5.5

2. METHODOLOGY

Each investigation followed the guidelines outlined in D854 by the American Society for Testing and Materials (ASTM) [11]. (Standard Test Methods for Specific Gravity of Soil Solids by Water Pycnometer), D4318 (Standard test methods for liquid limit of soils), D2487 (Standard practise for classifying soils for engineering applications (unified soil classification system)) and D698 Standard Test Methods for Experiments. were performed on clay soil that had been treated with molasses, lime, and SCBA. The liquid limit (LL) of clayey soils was calculated using various concentrations of molasses (M), sugarcane bagasse ash (SCBA), and lime (L). The DFS, another essential index characteristic for clayey soils, was also looked at. For several combinations of clayey soil and additions, the compaction test values of the clay, including the OMC and MDD, were also calculated. Additionally, the California bearing ratio (CBR) was computed for both the clay and the ideal mixture. The ASTM D1883-05 technique was used to calculate bearing capacity, a measure of soil strength. In the first stage of the investigation, the DFS and Liquid limit experiments on clayey soil with a variety of admixtures were carried out in order to determine the optimal percentages of materials (SCBA, Lime, and Molasses). These tests were carried out in order to determine the optimal percentages of these materials. The second part of this study investigates the compaction behaviour and California bearing ratio tests of clayey soil with and without the addition of the optimal amount of a number of different components.

The tests for the current study were carried out in the Geotech engineering laboratory of Chandigarh University in the state of Punjab, India. These tests were carried out in accordance with relevant ASTM and Indian Standards. The percentages of Sugarcane bagasse ash that were used in the current investigation were established based on a review of the relevant prior research. In accordance with IS:2720 (Part 5) 1985, IS:2720 (Part 8) 1983, and IS:2720 (Part 10) 1991, several laboratory experiments were performed on treated and virgin soil samples, respectively shown in Table 4. The material optimum combinations of various percentages of various admixtures in soil-bagasse -lime -molasses blends are listed in Table 5, which may be found below. Also, the particle size distribution of silty clayey soil and scba are shown in fig.2 and fig.3 respectively.

Table 4. Geotechnical properties of clayey soil and SCBA used in present study

Properties	Value (soil)	Value (SCBA)
Type	MH	-
Liquid limit (%)	60.49	-
Plastic limit (%)	20.90	-
Plasticity Index (%)	39.59	-
Specific gravity	2.06	1.95
DFS (%)	25.4%	-
OMC (%)	18.41	43%
MDD g/cm^3	1.649	1.41

Table 5. Optimum combinations of various admixtures used in this study

Materials	Proportions
C: SCBA	85:15
C: L	91:9
C: M	90:10
C: SCBA: L	76:15:9
C: SCBA:M	75:15:10
C: SCBA: L:M	66:15:9:10

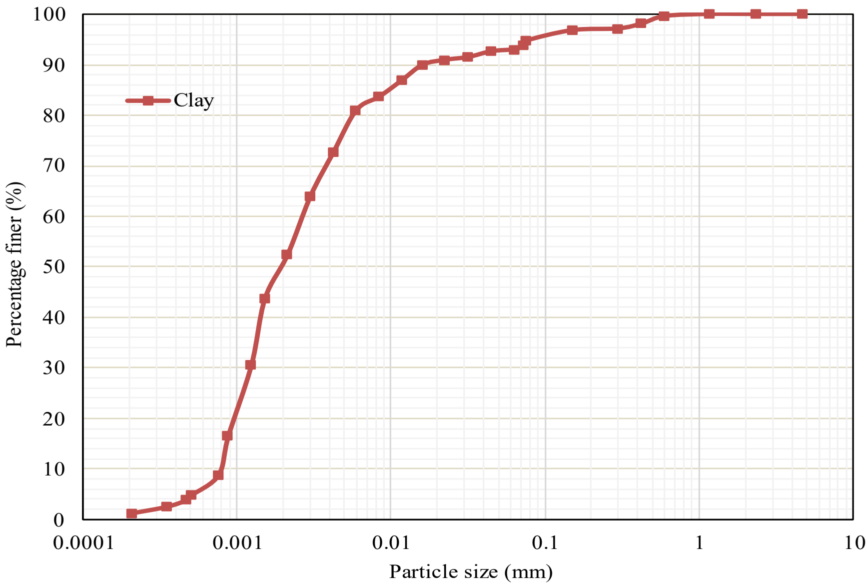

Fig. 2 Particle size distribution of Silty clay

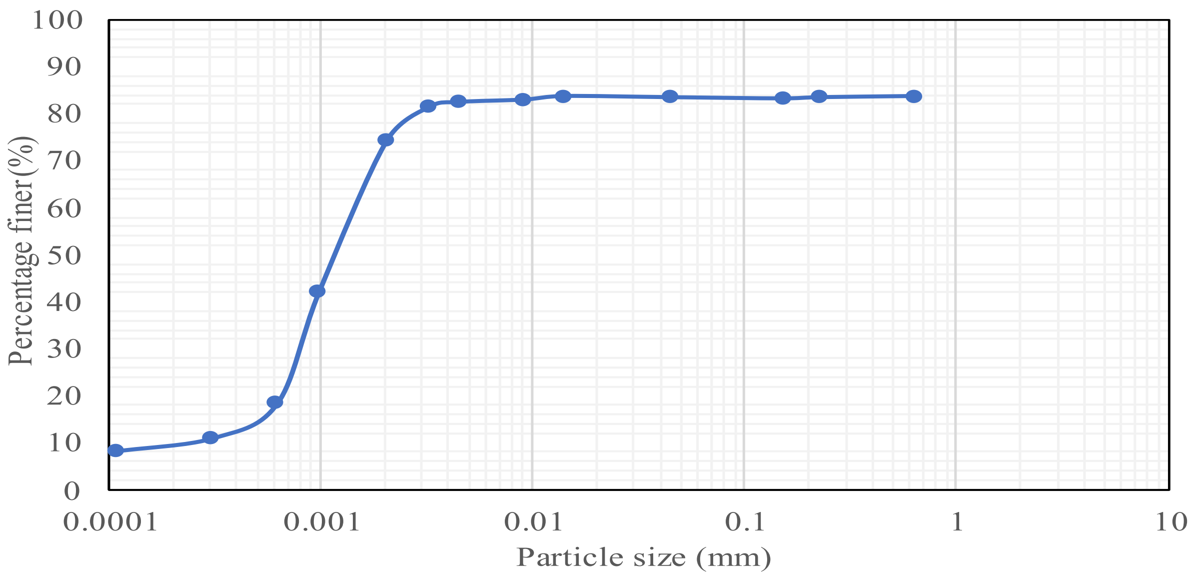

Fig. 3 Particle size distribution of Sugarcane Bagasse Ash

3. Results and discussions

Specific Gravity:

Clay: SCBA mixture

Figure 4 depicts the shifts that take place in the specific gravity of treated Silty Clay soil as a function of the amount of bagasse ash present. Following the addition of bagasse ash to the natural soil, the specific gravity dropped from 2.06 for the natural soil to 1.89 when there was 20% bagasse ash present. This suggests that the density of the minerals that make up the individual particles of soil is on the lower end. A greater value for specific gravity provides additional support for structures like roads and foundations. Few studies have previously seen similar phenomena in SCBA stabilised soils. (Surendra and Sanjeev, 2017).

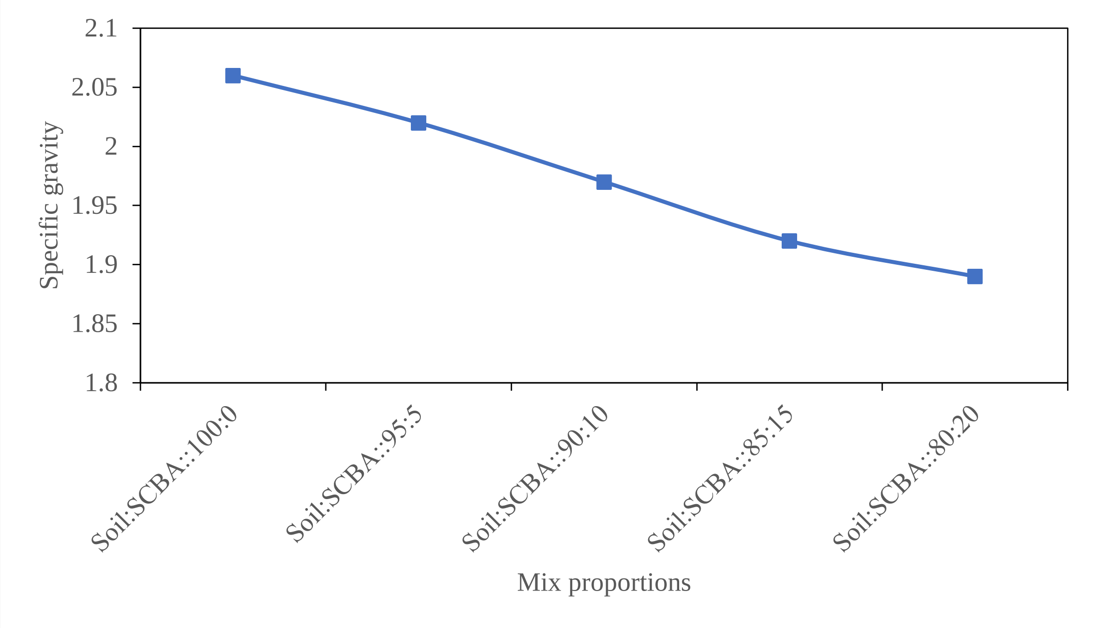

Fig. 4 Variation of Specific gravity with varying SCBA

Clay: Lime mixture

Figure 5 depicts the shifts that take place in the specific gravity of treated Silty Clay soil as a function of the amount of Lime present. Following the addition of Lime (3 to 12 percent) to the natural soil, the specific gravity increased from 2.06 for the natural soil to 2.52 due to high specific gravity of lime compared to soil and due to thicker particle size of the lime as compared to silty clay. Similar trends have been seen previously Nigussie, E., (2011).

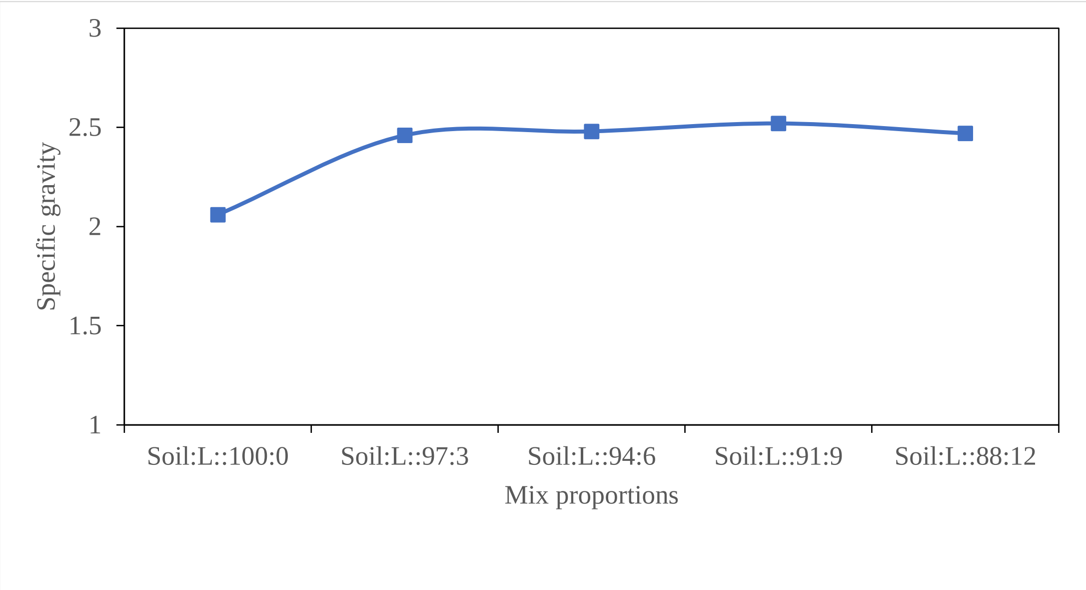

Fig. 5 Variation of Specific gravity with varying Lime

Clay: Molasses mixture

Figure 6 depicts the shifts that take place in the specific gravity of treated Silty Clay soil as a function of the amount of Molasses present. Following the addition of Molasses (5 to 20 percent) to the natural soil, the specific gravity decreased from 2.06 for the natural soil to 1.84 due to lower specific gravity of Molasses compared to Silty clay.

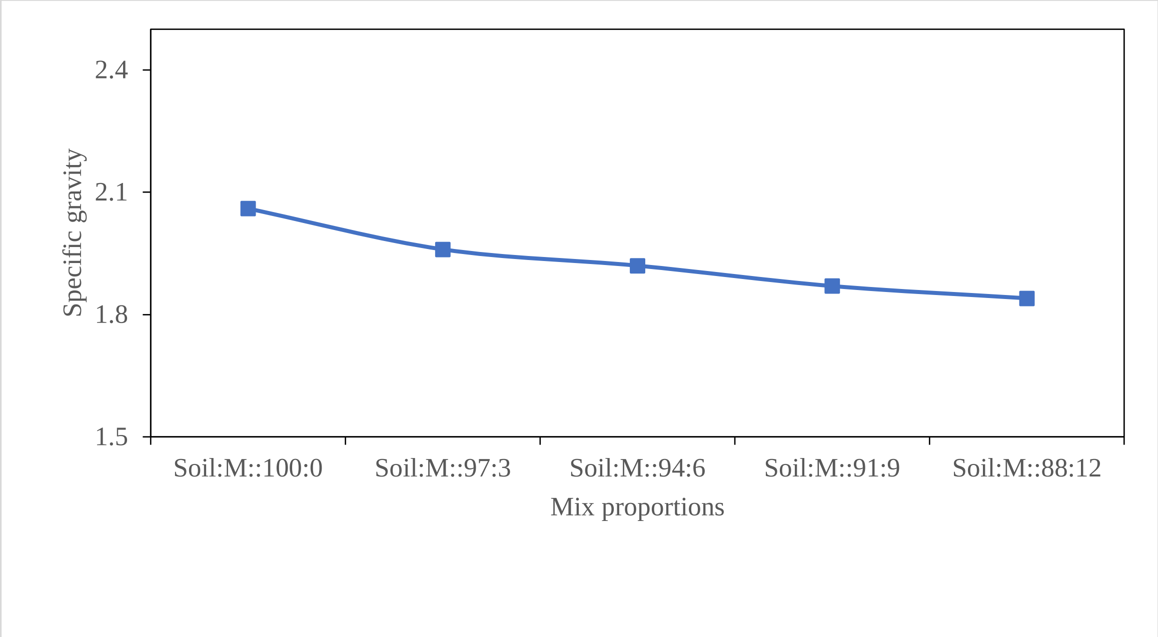

Fig. 6 Variation of Specific gravity with varying Molasses

DFS Test:

The differential free swell test, often known as the DFS test, examines the volume variations in clayey soil when tested with kerosene (or carbon tetrachloride, CCl4) and water as pore fluids (IS 2720 Part 40 (1977) It was discovered that the DFS value for silty clay comes out to be 25.4%, and the degree of expansion can be described as being high. As shown in Figure 7, 8and 9 As the blended content of SCBA, lime, and molasses grew, the DFS value dropped.

Clay: SCBA mixture

Differential free swell (DFS) tests were performed on soil-SCBA mixtures swelled. Different amounts of SCBA, 5, 10, 15, and 20% by weight, were added. When SCBA was added to the soil, the soil's free swell slowly went down up to 15% until it went from 25.4% to 3.41% at 20% SCBA content (Fig.3). Because SCBA is pozzolanic in nature and doesn't swell, it stopped the soil from swelling. Differential free swell went down when SCBA was added, as was found by a number of other researchers**.** Surjandari et al., the degree of swelling reduced itself when bagasse ash in increments of 5, 10, and 15% was added. The amount of swelling that was generated by a dose of 15% bagasse ash was the least, thus we can confidently state that this was the optimal dose. The quantity of swelling had a tendency to increase up by a minor value when given a dose of bagasse ash that was 20%.

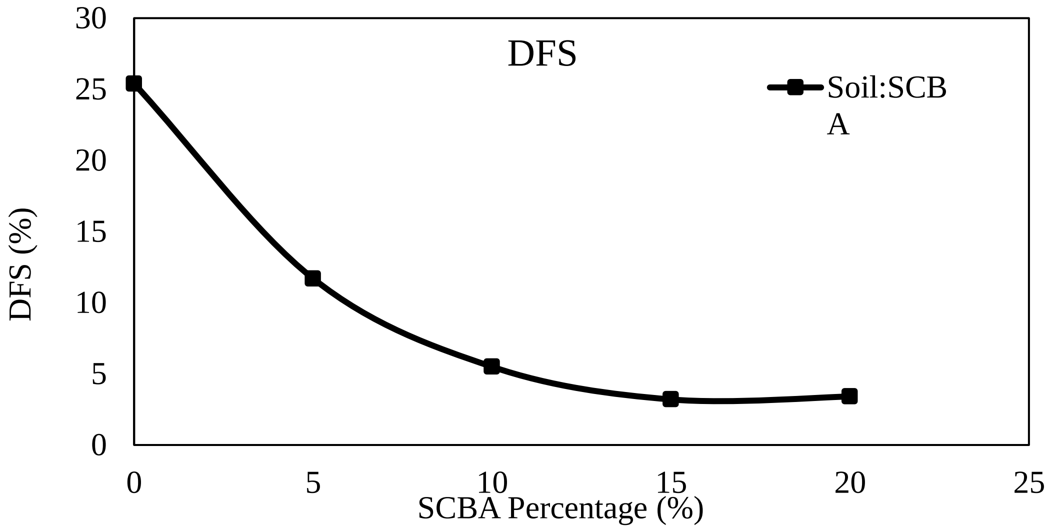

Fig. 7 Variation of DFS with varying SCBA

Clay: Lime mixture

The DFS value of clayey soil was lowered to 0 at 9% lime concentration. When the quantity of lime is raised over 9%, the DFS value increases, and hence 9 percent lime content is the ideal for clayey soil stabilisation. The decrease in DFS value induced by lime addition might be the result of other cations in calcium being replaced. Similar results have been seen in previous researches (Bozbey and Garaisayev, 2010; Estabragh et al., 2013)

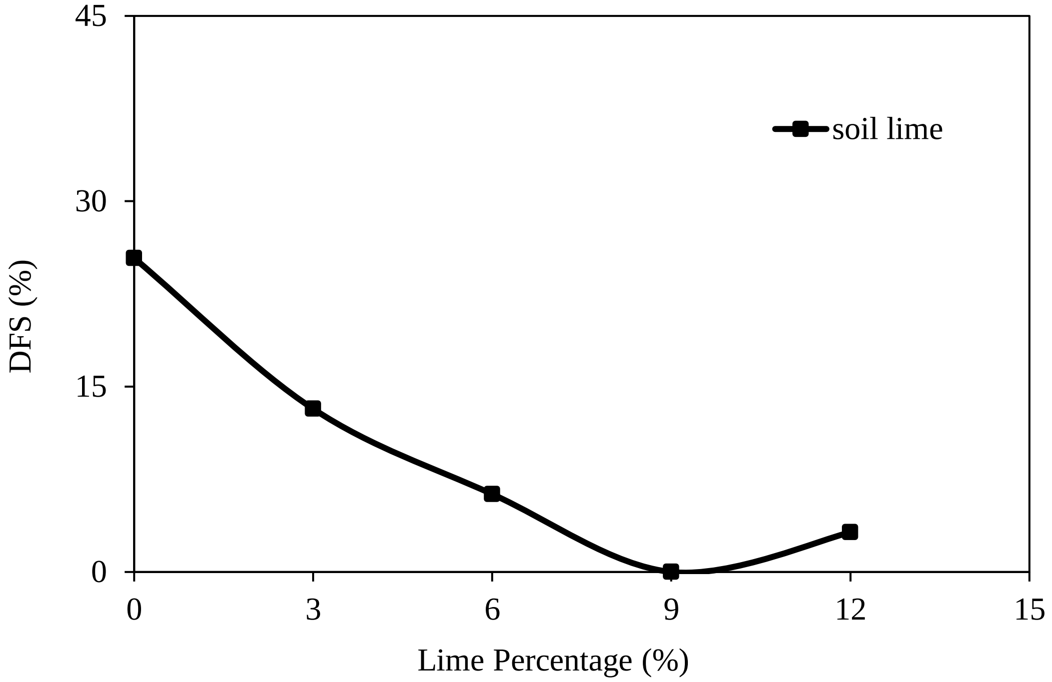

Fig. 8 Variation of DFS with varying Lime

Clay: Molasses mixture

At a molasses content of 10%, the DFS value of clayey soil dropped to zero, and there was no additional change in the DFS value despite adding more molasses to the clay soil. There is a potential that the presence of cementitious chemicals, such as calcium silicate hydrates, is to blame for the decrease in the DFS value that happened following the addition of the molasses. This is the case because there is a possibility that the presence of cementitious chemicals caused the decrease in the DFS value. Previous studies have revealed outcomes that are comparable to these. (O'Flaherty, 1974)

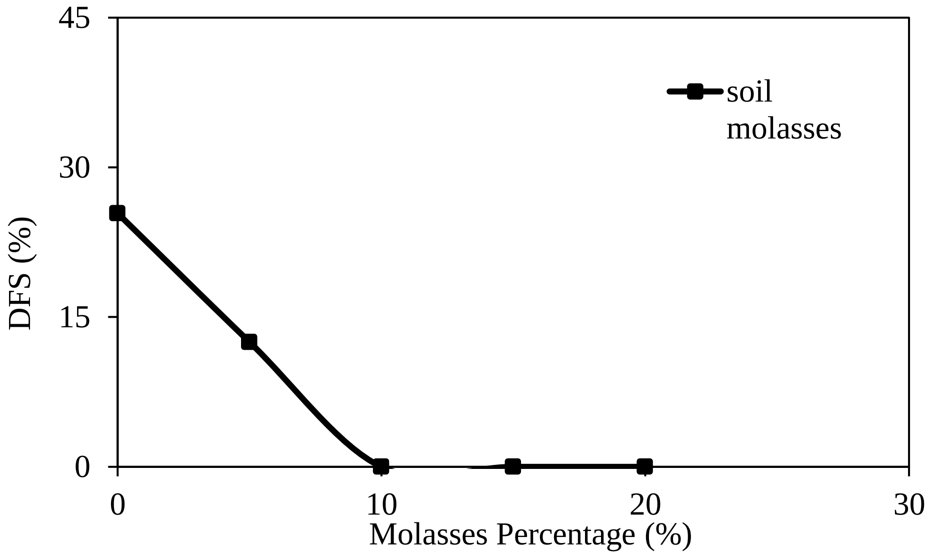

Fig. 9 Variation of DFS with varying Molasses

Liquid limit:

Clay: SCBA mixture

The silty clayey soil has high values for liquid limit (60.49 percent), plastic limit (20.90 percent), and plasticity index (39.59 percent). Because of these high values, the soil is classified as a highly compressible silty clay (MH) on the plasticity chart, Because of these abnormally high values, the soil is unfit for construction, which means that efforts to stabilize it are required. Incorporating Sugarcane Bagasse Ash into the soil helped to stabilize the soil, and the impact of this incorporation on the liquid limit was measured. IS:2720 (Part 5) 1985 was used to measure the liquid limit, of the soil and soil-SCBA mix.

The addition of 5% SCBA in silty clay soil reduces the Liquid limit from 60.49% to 56.2%. On further increasing the SCBA content to 10% the liquid limit follows the similar trend and decreases further to 49.1%. The trend continues up to 20 % and the liquid limit values reduces to 39.1%. It is possible to ascribe the overall decrease in the liquid limit for the combination of bagasse ash to the fact that the compounds created display cement-like characteristics owing to the calcium silicate with soil particles. This is the reason for the cementitious qualities of the compounds. This is the factor that contributes to the reduction in the liquid limit. Researchers have seen similar patterns in their data. (Sabat Ak 2012; Desai, C.S. 2014)

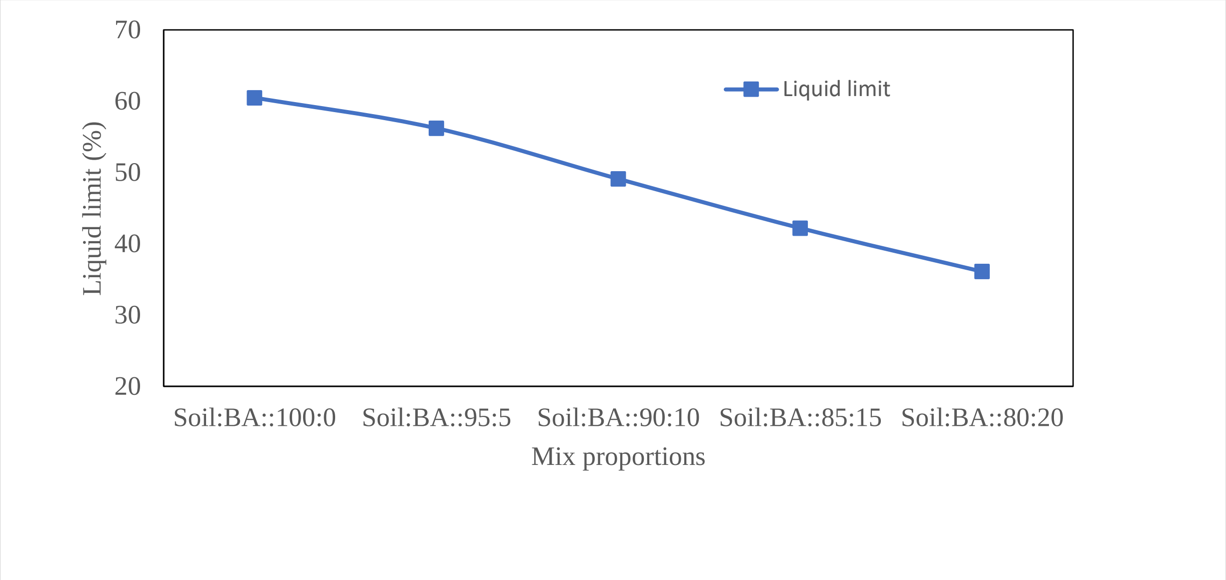

Fig. 10 Variation of Liquid limit with varying SCBA

Clay: Lime mixture

Clayey soil's liquid limit was lowered by the addition of three, six, nine and twelve percent lime, which in turn decreased the plasticity of the composite (Figure 11). This decrease in LL can be because cations are being released into the solution pore fluid, which ultimately results in an increase in the number of electrolytes that are absorbed by the pore water. This process results in a decline in the thickness of the diffuse double layer, which in turn has the effect of lowering the LL. In the past, experts have seen a tendency somewhat similar to this one in soils that have been stabilised with lime. (Nalbantoglu, 2006; Bozbey and Garaisayev, 2010; Harichane et al., 2011).

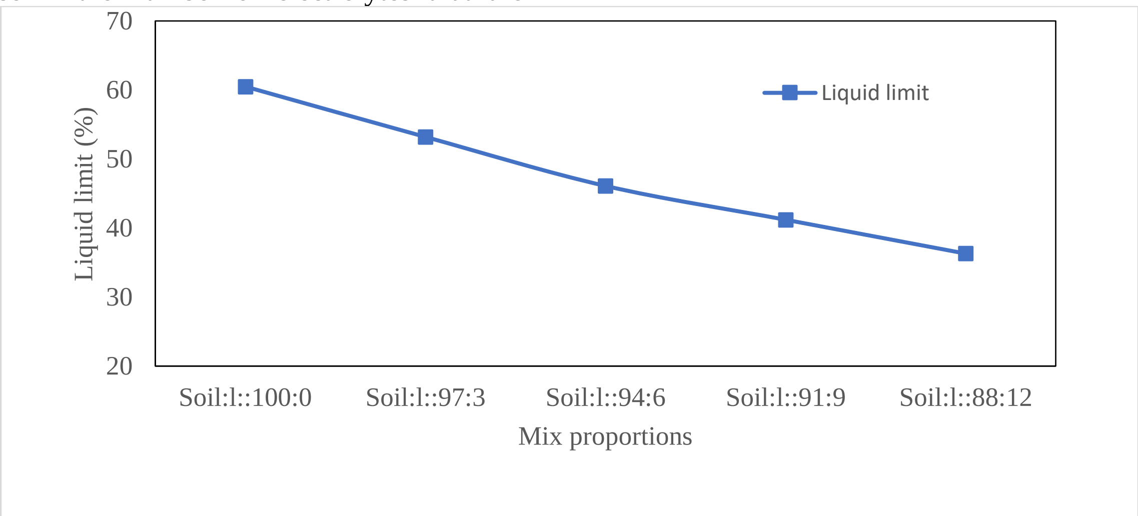

Fig. 11 Variation of Liquid limit with varying Lime

Clay: Molasses mixture

When molasses was added to clayey soil at concentrations of 5, 10, 15, and 20%, the liquid limit is reduced. The addition of molasses in quantities more than 10 percent did not show significant reduction and may thus be considered as an optimal content for soil stabilisation because it did not exhibit much reduction in plasticity index. Molasses may be responsible for a decline in the liquid limit because the cation exchange process that takes place in the mixture of molasses and soil results in a decrease in the thickness of the diffuse double layer, which ultimately leads to flocculation of the clay particles. Molasses may also cause a drop in the LL because of the cation exchange process. It's possible that this is what's behind the recent drop in consistency limitations. In addition, the process of flocculation leads to a decrease in the quantity of water that is absorbed by clay particles, which in turn results in a decrease in the liquid limit. This is because flocculation reduces the amount of water that is adsorbed by clay particles. A select group of researchers in the past (M'Ndegwa and Shitote, 2012; Taye and Araya, 2015; Kiran et al., 2018; Vinodhkumar et al., 2018) have reported seeing behaviour of molasses-stabilized soil that is analogous to that described here (Kiran et al., 2018).

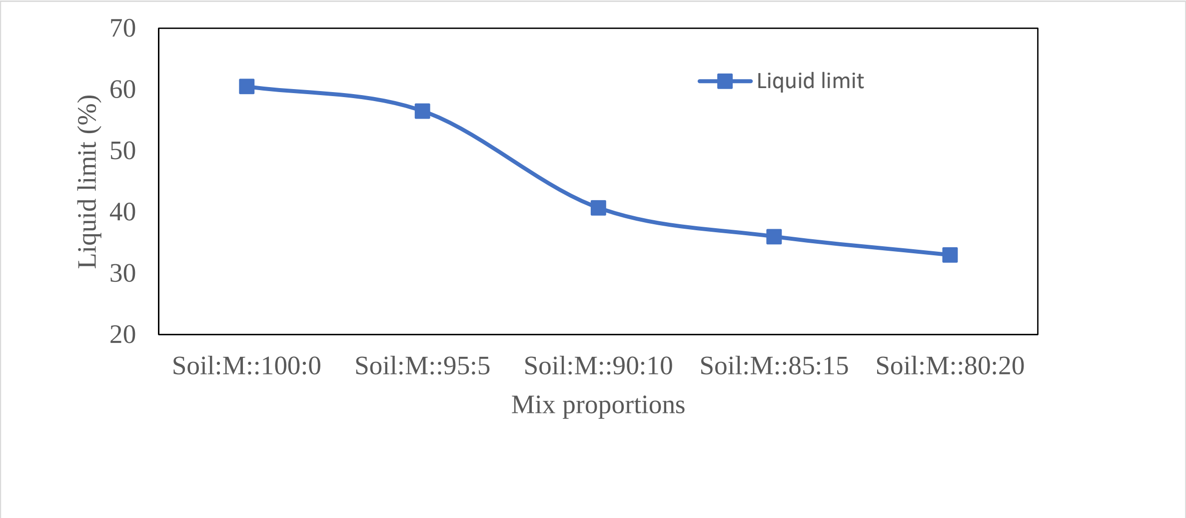

Fig. 12 Variation of Liquid limit with varying Molasses

Clay: SCBA: Lime mixture

The liquid limit of the composite was lowered as a result of the combined actions of SCBA (15%, agreed upon based on the results of the DFS test) and lime in varying percentages from 3 to12% (Figure 9). After adding lime content of up to

12 percent to clayey soil that already included 15 percent SCBA, the liquid limit of the composite showed a drop; however, after that point, there was not much change. Consequently, a C: SCBA: L ratio of 76: 15: 9 may be chosen as the optimal mix for the stabilization of the soil. It is possible that this is the result of the fact that the addition of SCBA and lime to clayey soil together brought about a reduction in the thickness of the double diffused layer which, in the end, resulted in a drop in the liquid index of the composite. Similar results seen in previous researches (Shimola, K 2018)

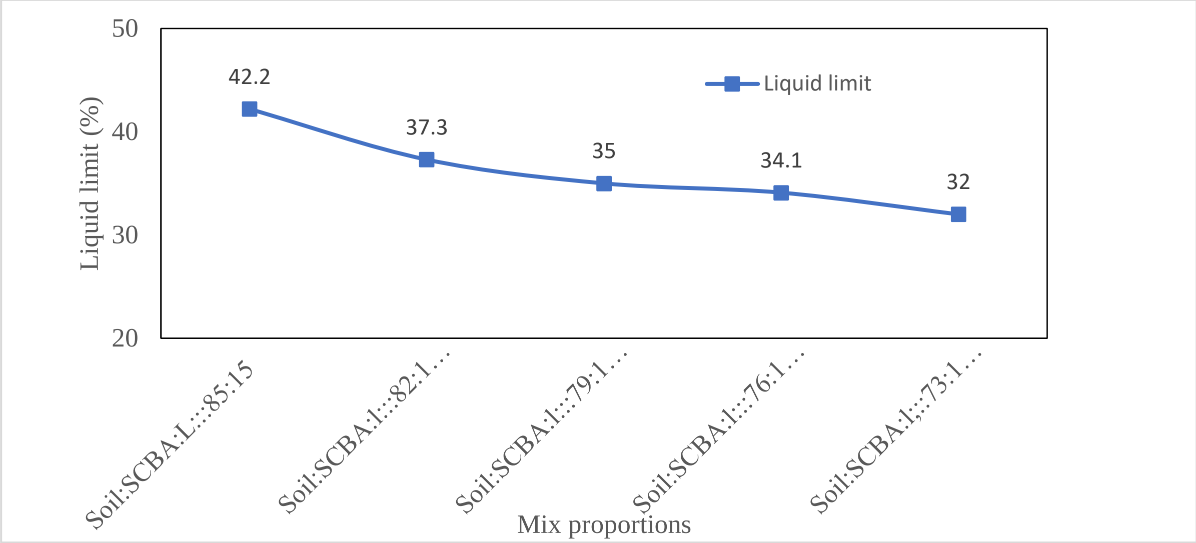

Fig. 13 Variation of Liquid limit with varying SCBA and Lime

Clay: SCBA: Molasses mixture

The liquid limit of the composite was lowered as a result of the combined actions of SCBA (15%, agreed upon based on the results of the DFS test) and Molasses in varying percentages from 5 to 20% (Figure 10). After adding Molasses content of up to 20 percent to clayey soil that already included 15 percent SCBA, the liquid limit of the composite showed a drop; however, after that point, there was not much change, as shown in fig. 14 hence the mixture of C: SCBA: M in ratio 75:15:10 may be considered as optimum for soil stabilization.

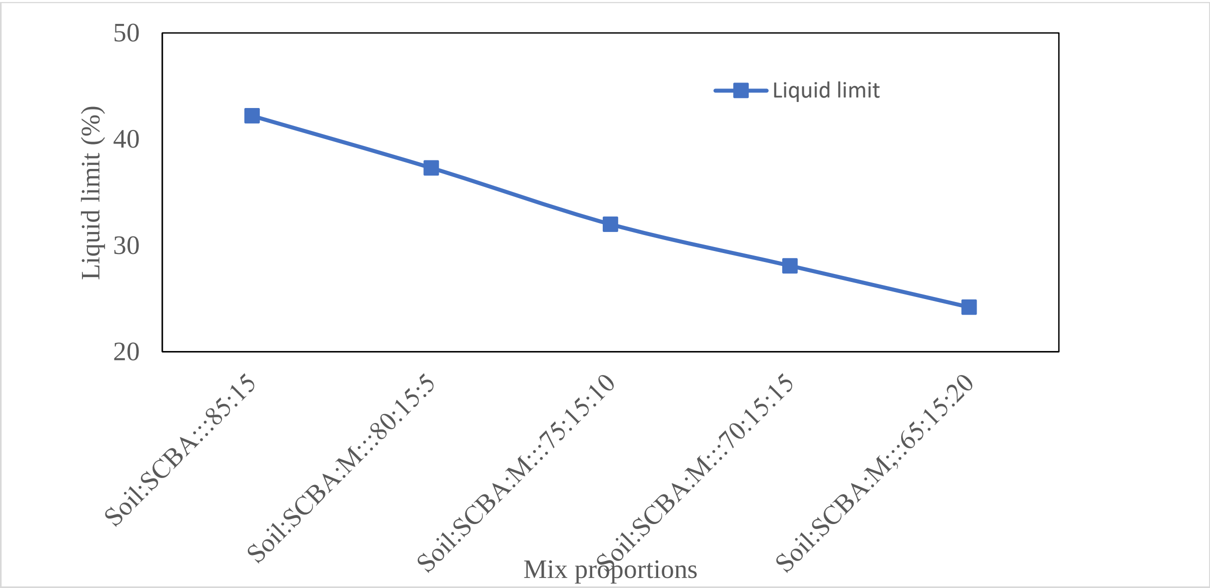

Fig. 14 Variation of Liquid limit with varying SCBA and molasses

Clay: SCBA: Lime: Molasses mixture

The incorporation of molasses at varying concentrations (five percent, ten percent, fifteen percent, and twenty percent), respectively to the C: SCBA: L:76:15:9 mixture [obtained from (Figure 15) reduced the total LL of the composite material (Figure 11). The malleability of the composite index reduced significantly after adding molasses up to 10% in the C: SCBA: L combination, and increasing the molasses concentration beyond 10% showed very little change in the composite's liquid limit, as shown in figure 15. As a result, 10% molasses may be considered optimal for clayey soil stabilisation, together with optimum levels of lime (9%) and SCBA (15%).

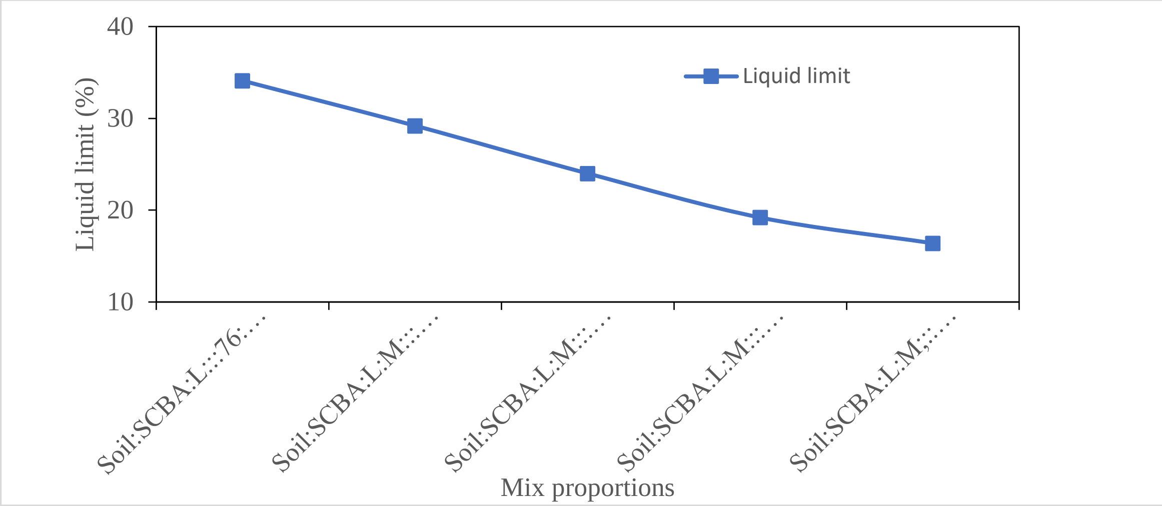

Fig. 15 Variation of Liquid limit with varying SCBA, Lime and Molasses

Compaction:

Clay: SCBA mixture

The optimum moisture content (OMC) and the max dry density (MDD) of a silty clayey soil were found out to be 18.4% and 1.649 g/cc. The OMC increased from 18.4% to 24.2% after SCBA was added in percentages ranging from 5% all the way up to 20%. The MDD value decreased from 1.649 to 1.486 g/cc when up to 20% SCBA was added. There are two potential causes that might be at play for the drop in the MDD value of silty clayey soil that takes place if there is a greater quantity of SCBA present in the soil. To begin, decrease in MDD occurs as the partial replacement of rather dense soils with lighter bagasse ash; the relatively less specific gravity value (1.95) of Bagasse Ash in comparison to that of virgin clayey soil (2.06); or it could also be attributable to coating of the soil by the bagasse ash, which results in big particles with more voids and hence reduced density. On the other hand, the increase in optimum moisture content (OMC) of the soil mixture can be attributed to the formation of calcium silicate hydrate (CSH) and calcium aluminate hydrate (CAH), the cementing agents, from the pozzolanic reaction of silica and alumina in soil and bagasse ash with calcium of the lime is what causes the increase in OMC as shown in fig.16 According to the findings of past experiments, a reaction quite similar to this one has been recorded when SCBA was added to the soil. (k Faria et al., Kharade et al., 2014; Das and Roy 2015)

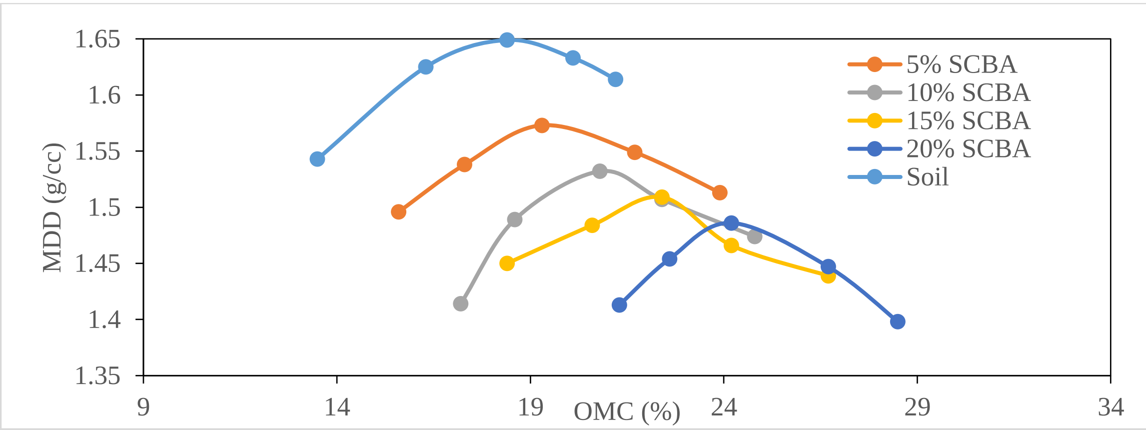

Fig .16 Variation of OMC and MDD with varying SCBA

Clay: Lime mixture

Silty clay's OMC and MDD were determined to be 18.4% and 1.649 g/cc, respectively. The OMC increased from 18.4 to 27% and the MDD value dropped when lime was applied to clayey soil in various ratios of 3, 6, 9, and 12%. Figure 17 shows that the value was reduced from 1.849 to 1.39 g/cc. The increase in OMC might be attributed to pozzolanic interaction between the clay portion of clayey soil and lime; the subsequent decrease in MDD could be attributed to particle aggregation to occupy larger areas. Another explanation for lime stabilised clayey soil having a lower MDD is because lime has a lower specific gravity than clayey soil. Only a few investigations have revealed similar tendencies in lime-stabilized soils. (Rahman, 1986; Manasseh and Olufemi, 2008; Sharma and Hymavathi, 2016).

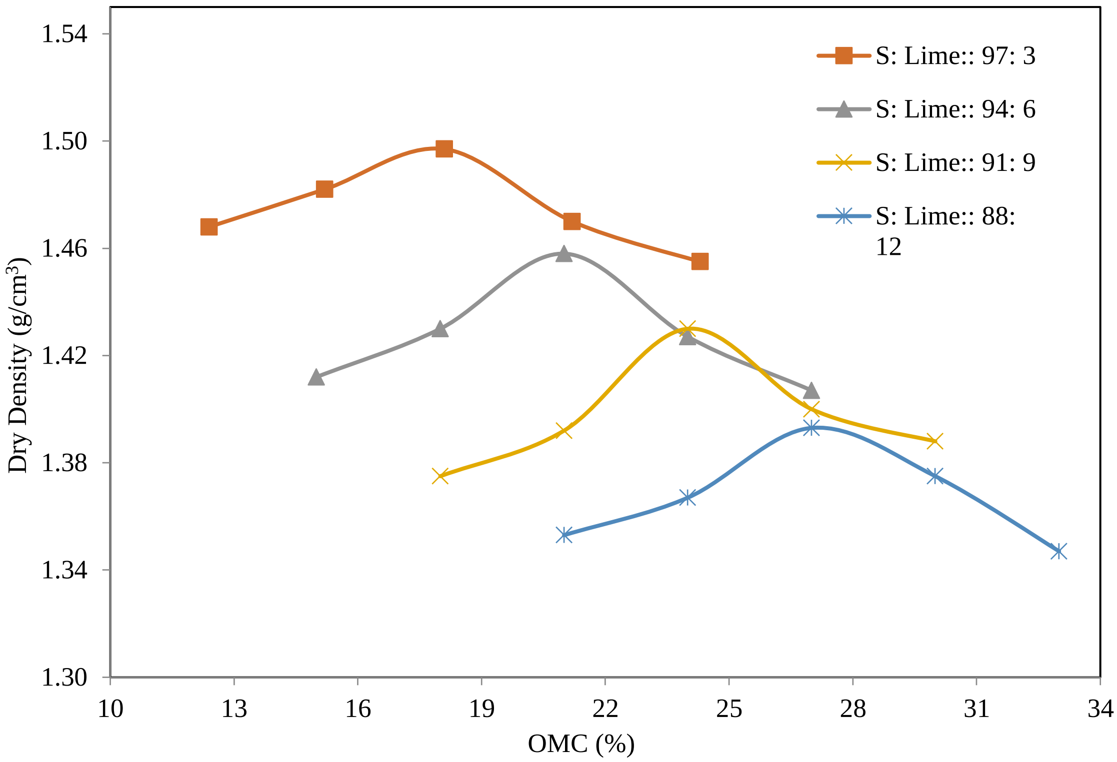

Fig .17 Variation of OMC and MDD with varying Lime

Clay: Molasses mixture

When molasses was added to clayey soil in varied ratios ranging from 5 to 20%, the OMC decreased from 18.4 to 8%, while the MDD value increased. Figure 14 shows a range of 1.649 to 1.789 g/cc as shown in fig.18 The increase in dry density may be attributable to the reason that positively charged molasses are drawn to negatively charged clay particles since clay particles have a negative charge, and molasses has adhesive properties that bind the soil particles together. The transformation of tiny particles into coarse particles, which brought about a decreased void ratio, may be responsible for the reduction in optimum moisture content that occurred following the addition of molasses. Molasses added to clayey soil produced outcomes that were comparable to those obtained without it. (Shirsavkar and Koranne, 2010; Taye and Araya, 2015)

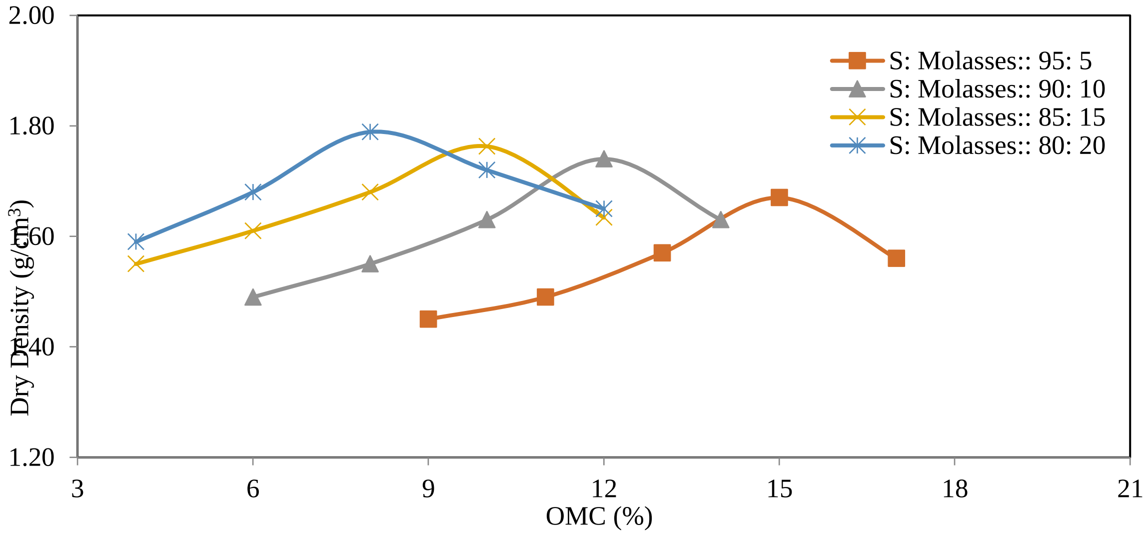

Fig .18 Variation of OMC and MDD with varying Molasses

Clay: SCBA: Lime mixture

The combination of SCBA and lime was added to clayey soil keeping Bagasse ash percentage constant at 15% with varying lime percentage (3% to 12%). The OMC value increased from 18.4 to 27% while the MDD decreased from 1.649 to 1.462 as shown in fig.19 The rise in OMC value can be linked to the pozzolanic reaction (which occurs between clay and lime) and the presence of Silica (which is present in SCBA). While decreasing MDD value is due to lower specific gravity of both SCBA and lime.

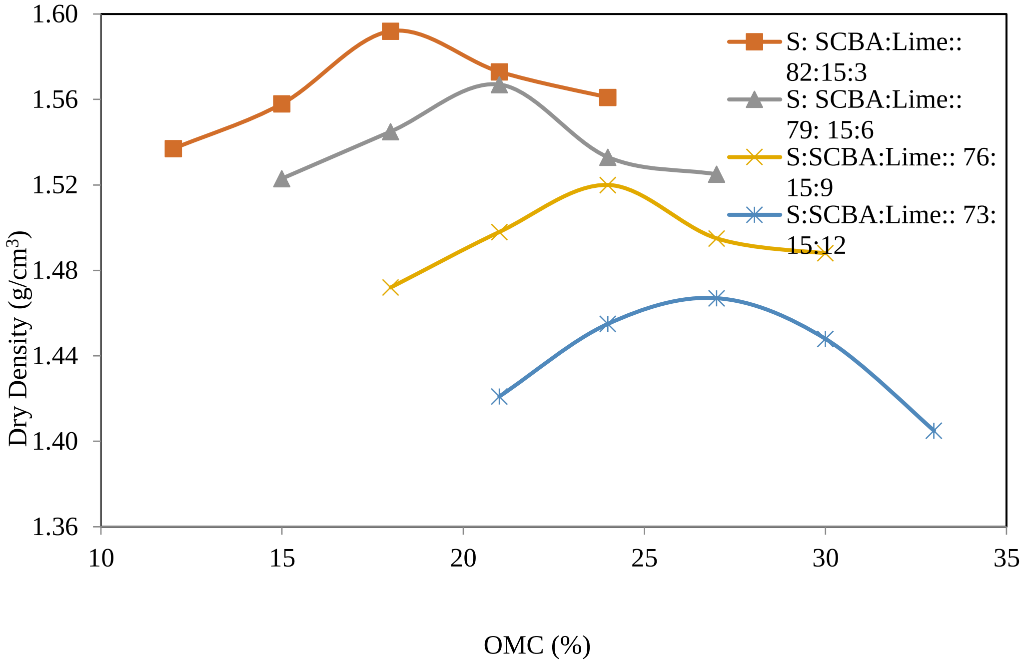

Fig .19 Variation of OMC and MDD with varying SCBA and Lime

Clay: SCBA: Molasses mixture

The combination of SCBA and lime was added to clayey soil keeping Bagasse ash percentage constant at 15% with varying molasses percentage (5% to 20%). The OMC decreases from 18.4 to 9% while MDD increases from 1.649 to 1.76 as shown in fig.20 It's possible that the shift of finer particles to coarser particles, which results in lesser void space, is to blame for the decrease in OMC value that occurs when molasses and SCBA are added simultaneously to clayey soil The rise in MDD value brought about by the addition of SCBA and molasses together. Perhaps as a result of the glue-like properties of molasses, which bind the particles of clay and SCBA together.

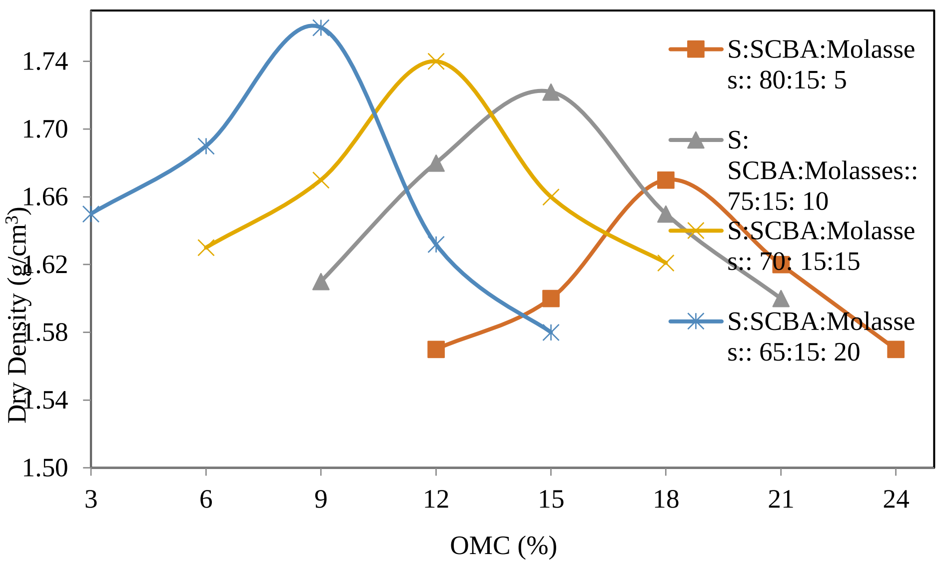

Fig .20 Variation of OMC and MDD with varying SCBA and Molasses

Clay: SCBA: Lime: Molasses mixture

Molasses was added to the combination of C: SCBA: L: 76:15:9 at increasing percentages (5, 10, 15, and 20%), which resulted in a decrease in the OMC value from 20.5 to 16.5 percent and an increase in the MDD value from 1.73 to 1.8 g/cc of the overall composite as shown in Fig. 21The decline in OMC value that results from introducing molasses to a mixture of C, L, and SCBA may be attributable to the coarser nature of SCBA and molasses. On the other hand, the increase in MDD value that occurs as a result of adding molasses to a mixture of C, SCBA, and L may be down to the greater specific gravity and the glue-like nature of molasses. Molasses to a C: SCBA: L mixture may be due to the rougher nature of SCBA and molasses

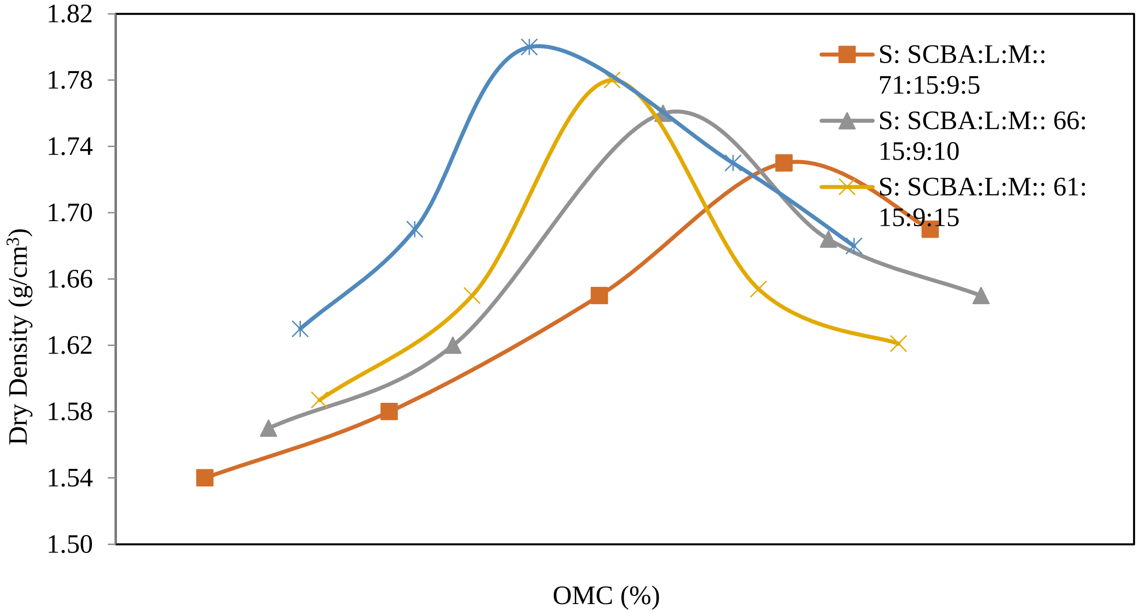

Fig .21 Variation of OMC and MDD with varying SCBA, Lime and Molasses

California bearing ratio (CBR):

The California bearing ratio test, often known as the CBR, is a tool that is utilised on a regular basis for the purpose of measuring the load bearing potential of subgrades that are utilised in the construction of flexible pavements. In accordance with the recommendations found in ASTM D1883-05 (2005), a number of CBR tests were carried out on both treated and untreated clayey soil while the soil was in a saturated state. Standard Proctor compaction tests showed that the samples were compacted to their MDD and their OMC after being subjected to the process. The samples were cured by being immersed in a tank of water for four days after a period of intense rain. To stimulate water penetration into the subgrade, this was done. According to the findings of the soaked CBR test, the CBR value of the clayey soil was found to be 1.98%. Soils with a CBR value of less than 5% are typically considered to be poor; therefore, it is not suggested in India to use such soil without first taking further efforts to raise its CBR value (IRC-SP-77 (2008). Pozzolanic reactions may occur when lime is applied to soil, and these reactions may both raise CBR right away and CBR over time. (FG Bell (1996).

Clay: SCBA mixture

The Soaked CBR test was performed on soil SCBA mix. The test results were plotted as load vs. penetration curves, and the CBR values for each composite were figured out (Figure 7). Figure 7 shows that the soaked CBR value of the soil before it was changed was 1.95. But when SCBA was added, the CBR value went up by a large amount. The CBR value was 3.25 when there was 5% SCBA content. It went up to 4.73 when there was 10% SCBA content, 5.02 when there was 15% SCBA content, and decreases to 3.54 when there was 20% SCBA content. This improvement could be due to a number of things, including the fact that There is pozzolanic interactions of bagasse ash with soil. Clay particles become agglomerated as a result, leading to the strength increase. The minor increases in strength could be attributable to a lack of calcium, which is essential for the production of CSH and the primary contributor to strength gains also the reason for the rise in CBR values could be cementation and Bagasse ash added to pozzolanic reactions in the form of frictional resistance. Similar trends have been seen in previous researches (Suman Manish et al., (2018), Saini Himani et al., (2019)

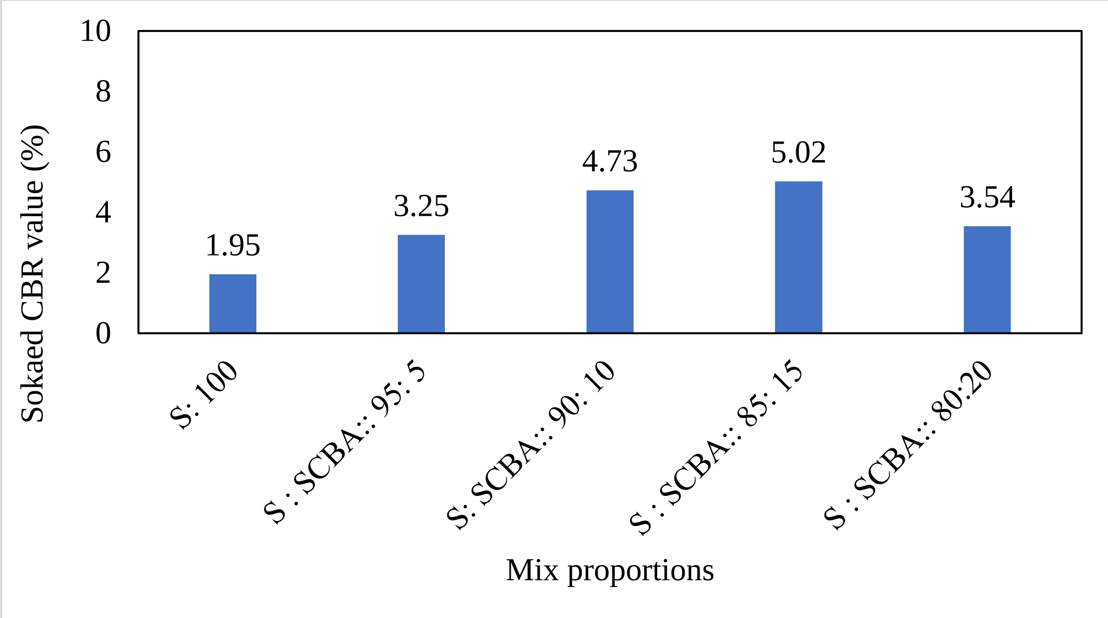

Fig. 22 Soaked CBR values of Soil and SCBA at different percentages

Clay: Lime mixture

In spite of the fact that virgin clayey soil had the lowest CBR. Due to the significant concentration of clay minerals which react with the binder, the CBR value rose when lime was added. Fig. 8 shows that the CBR value of clayey soil increased from 1.94 to 7.4% when different lime content was added from 3% to 12%, with CBR value increasing up to 9% of lime and further decreasing when mixed with silty clay. The aggregated soil particles' binding and covering are what give lime-stabilized clay its increased strength. The formation of a densely packed and compacted structure, which is indicative of the consumption of cementitious gel in the process of filling spaces and binding particles, is also a result of this increase in strength. A pattern that is very similar has been seen in the past. (F Zhu et al., (2019), Sharma et al., (2020), In addition, the CBR results of optimal combinations are investigated, and it is discovered that the CBR value of clayey soil experiences a significant rise as a consequence.

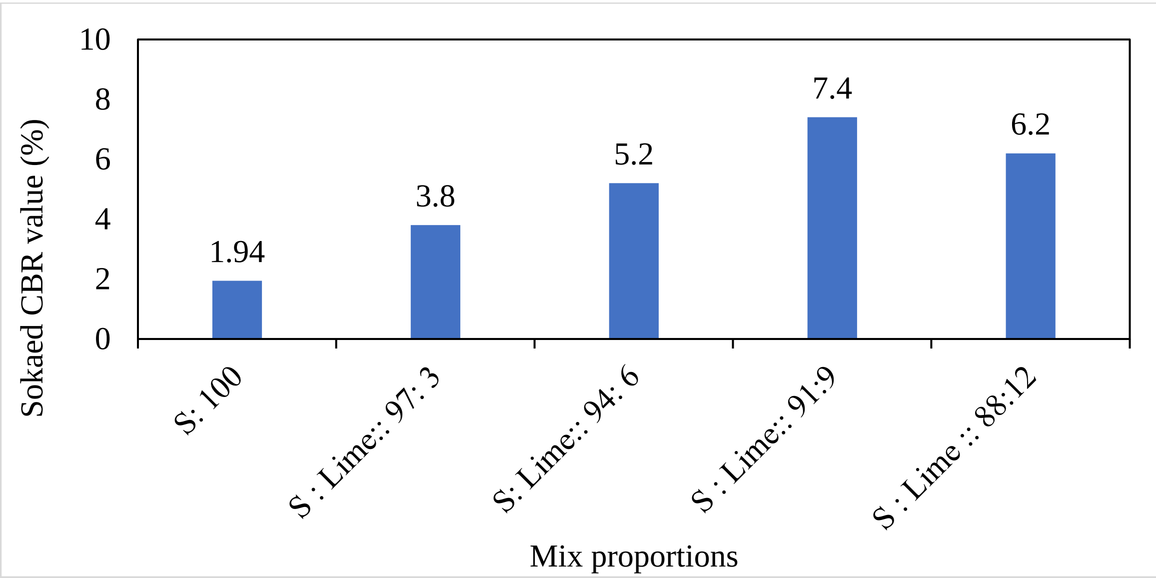

Fig. 23 Soaked CBR values of Soil and Lime at different percentages

Clay: Molasses mixture

When varying percentages of molasses content were combined with clayey soil (ranging from 5% to 20%), the CBR value increased from 1.94 to 6.8% (Fig. 17) Positively charged molasses particles may draw negatively charged tiny clay particles, increasing the silty clays CBR value. As a result, fine clay particles turn into more coarse particles, which can then resist larger compressive stresses. Molasses particles, which have a positive charge, may be attracted to tiny clay particles, which have a negative charge, according to a different hypothesis that might account for this phenomenon. A pattern that is very similar has been noticed in the past by a few studies. (SS Shirsavkar et al., (2010), M'Ndegwa JK (2011).

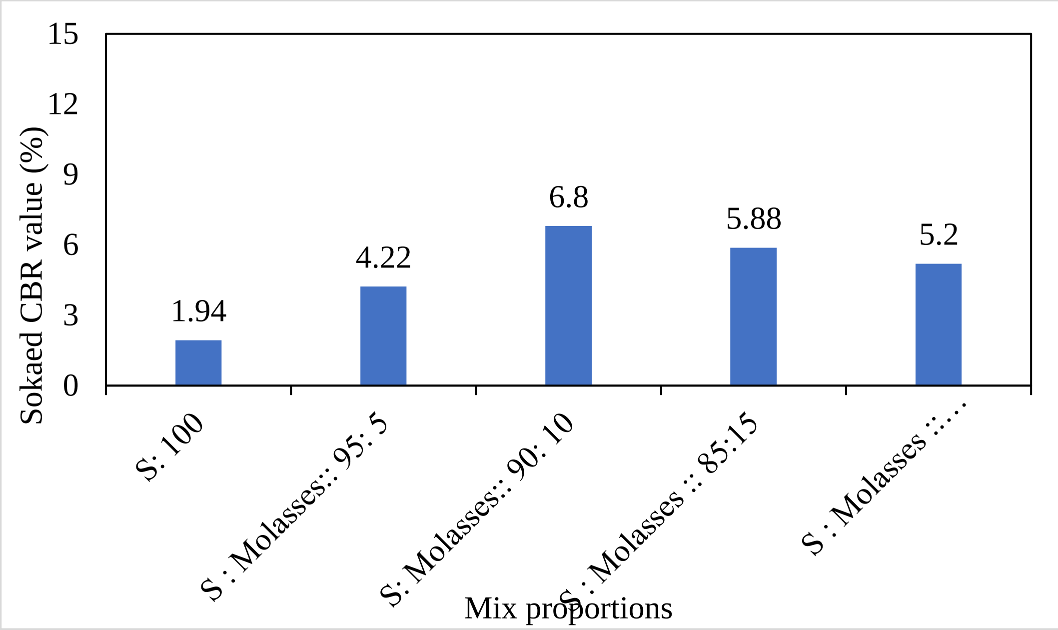

Fig. 24 Soaked CBR values of Soil and Molasses at different percentages

Clay: SCBA: Lime mixture

When SCBA Lime mix is added to clayey soil in different percentages with keeping SCBA fix at 15 % and varying percentages of lime from 3% to 12%. The CBR value tends to decline after reaching 9% lime content, having increased from 1.94 to 11.4 up to that point. After that, the value continues to trend downward. The rise in CBR value of silty clayey soil may be related to the inclusion of silica in SCBA, and the pozzolanic interaction between clay and lime particles causes the fine clay particles to stick together in a firmer structure, which results in an increase in the CBR value. In addition, the presence of silica in SCBA may also be linked to the pozzolanic reaction between clay and lime particles. Lime also contributes to this rise in CBR value of clayey soil. Consequently, the CBR value increases. Same results have been seen previously by various researchers. (L.C Dang et al., (2016).

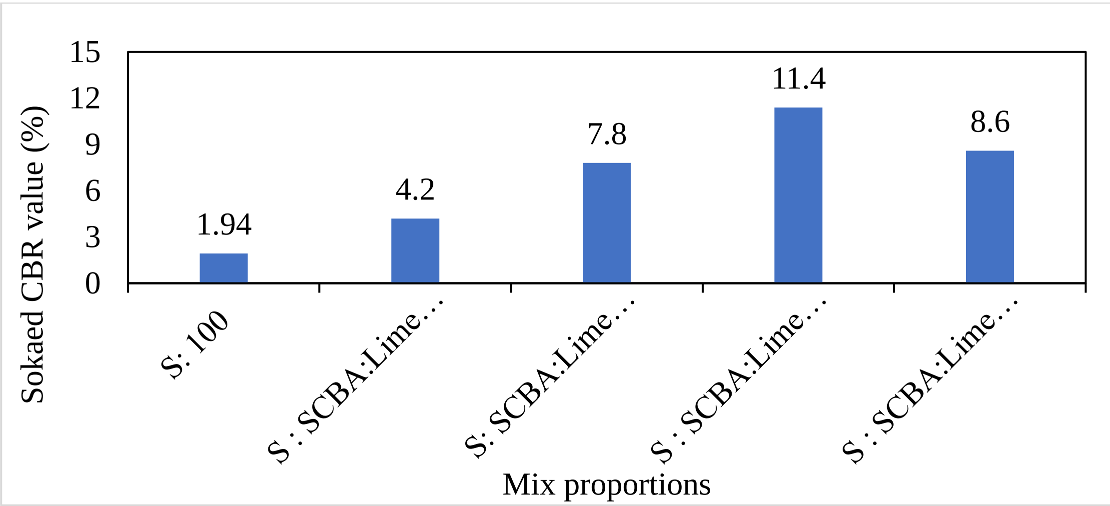

Fig. 25 Soaked CBR values of Soil SCBA and Lime at different percentages

Clay: SCBA: Molasses mixture

When SCBA Molasses mix is added to clayey soil, the CBR value enhanced from 1.94 to 6.24 up to 10% of molasses after which the value seems to be decreasing. The surge in CBR value of clayey soil with SCBA and molasses addition may be caused by the fact that the cation transfer process in the mixture speeds up as a result of the addition of molasses, and as a result, the CBR value of the resulting mixture both increases instantly and keeps growing over time. This increase in CBR value of clayey soil may also be attributed to the molasses-induced acceleration of the cation exchange process in the mixture.

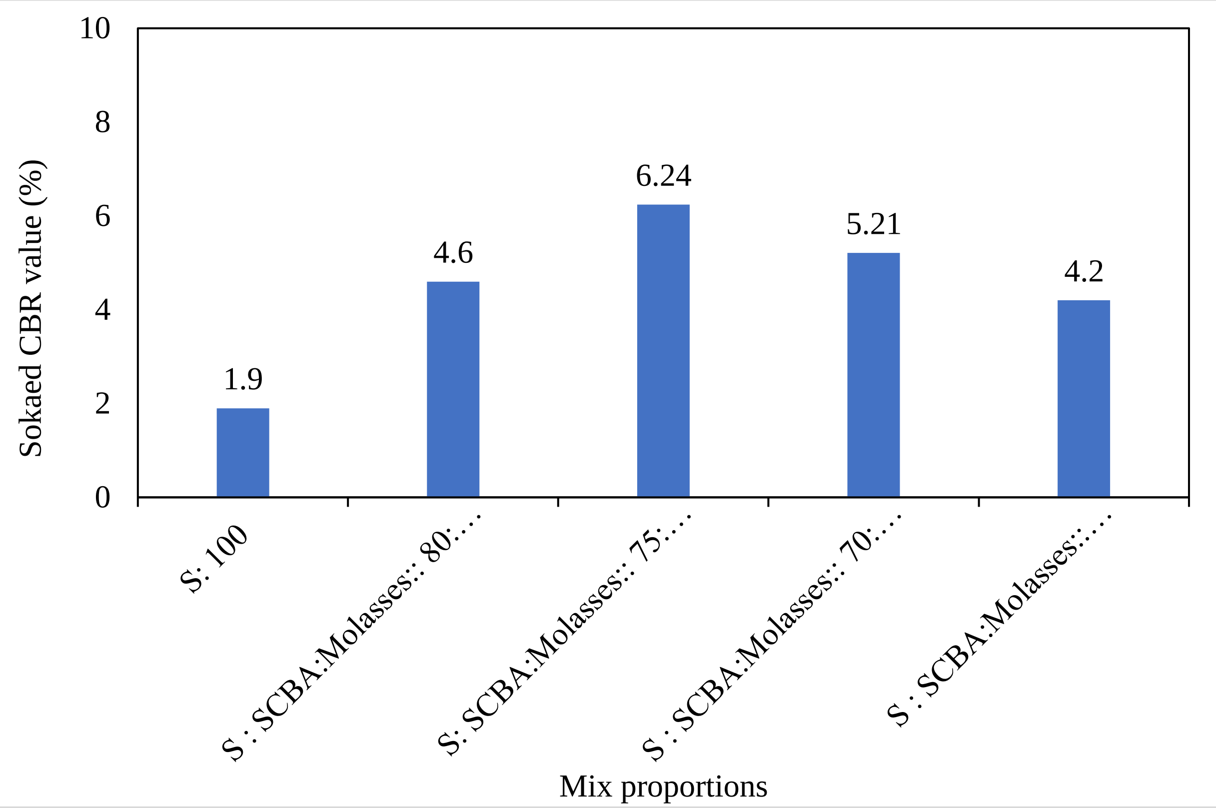

Fig. 26 Soaked CBR values of Soil SCBA and Molasses at different percentages

Clay: SCBA: Lime: Molasses mixture

For optimum combinations of SCBA, Lime and Molasses to the clayey soil, the percentages of SCBA and Lime are kept fixed at 15% and 9% respectively, while the Molasses percentages have been varied. The CBR values keep on increasing from 1.94 to 12.3. The production of CSH and CAH gels is sped up by the addition of molasses, which results in an increase in the bearing potential of clayey soil. The inclusion of silica in SCBA is responsible for the rise in value, and the pozzolanic reaction that occurs between the particles of clay and lime helps the tiny clay particles bind together in a more robust form after a few days have passed. increases the bearing potential of clayey soil However, the presence of silica in SCBA is what contributes to the increase in value.

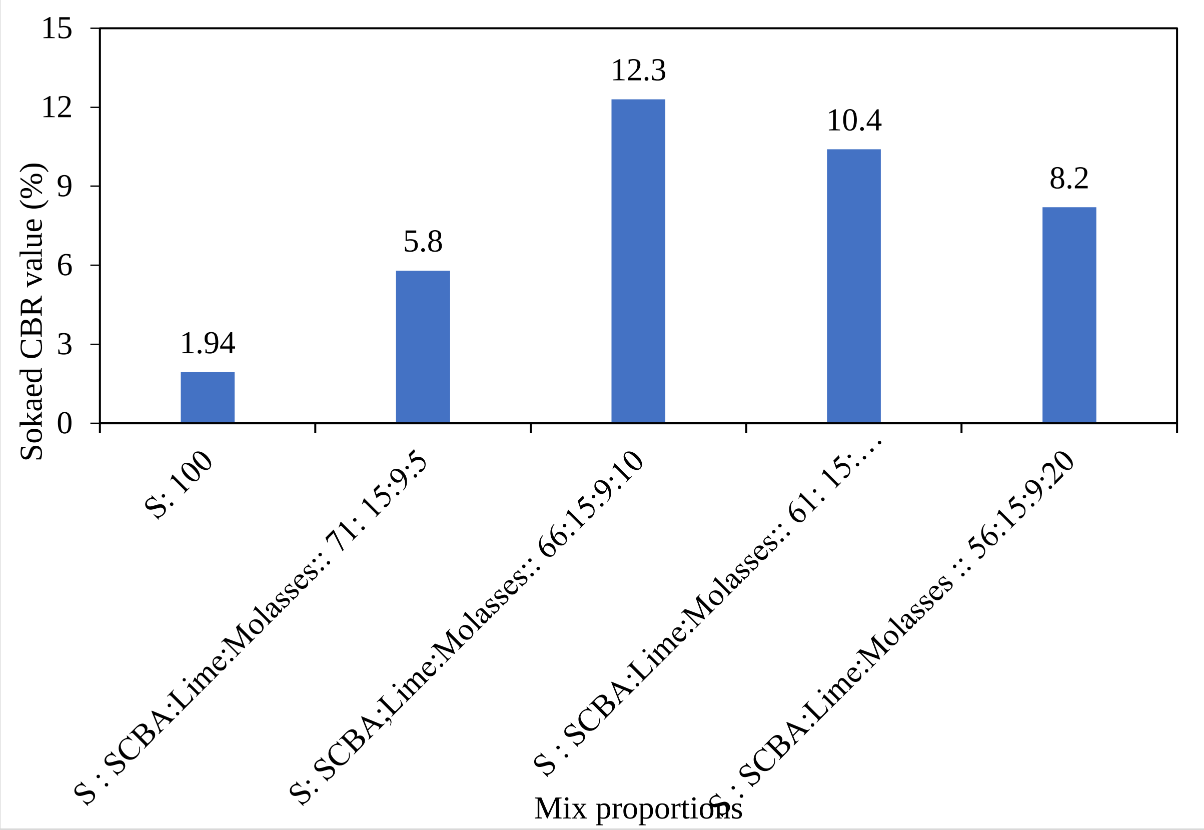

Fig. 27 Soaked CBR values of Soil SCBA, Lime and Molasses at different percentages

4. Conclusions

In order to improve the geotechnical qualities of clayey soil, research was conducted to examine the usefulness of SCBA as an agricultural waste, lime as a binder, and molasses as an enzyme. The following is a list of the most important takeaways from the aforementioned research:

1. The silty clayey soil had a specific gravity of 2.03. When 5% to 20% Sugarcane Bagasse Ash was added, the specific gravity decreased from 2.06 to 1.89. this is due to less weight of SCBA as compared to Silty clay, also this suggests that the density of the minerals that make up the individual particles of soil is on the lower end in a manner analogous to this, the addition of molasses results in an increase in specific gravity, but the addition of lime results in an increase owing to the higher particle weight.

2. After adding the optimal amount of lime (9 percent), the differential swell index of the clayey soil begins to decline. After this, however, it begins to once again increase. Clayey soil with a higher percentage of SCBA and molasses has a differential swell index that is lower and approaches 0 as the percentage of SCBA and molasses increases the addition of 15 percent SCBA and 10 percent molasses, respectively.

3. The liquid limit (LL) of the Silty clay comes out to be 60.49 which is a very high value and needs to be reduced. The LL of clayey soil is lowered by the incorporation with SCBA, Lime, and molasses as well as by the incorporation of all three of these admixtures together.

4. The addition of Sugarcane Bagasse Ash (SCBA) to soil changes the soil-SCBA mix's Optimum Moisture Content (OMC). The OMC grew from 18.6% to 24.2% with up to 20% SCBA.

5. The OMC value of clayey soil increased when SCBA and Lime are added alone and in combination, whereas it shows decrease when only Molasses is added. The MDD value of clayey soil decreases when SCBA and Lime are added by itself, while it increases when Molasses is added by alone. when SCBA was kept fixed and varying percentages of lime were added the OMC increased and MDD values decreased. In addition, when changing only the amount of Molasses used in different admixtures while maintaining the same proportions of SCBA (15%) and Lime (9%), the OMC value decreased while the MDD value increased.

6. Before the addition of SCBA, the silty clay had a CBR value of 1.95 when it was soaked, but it went up after adding SCBA up to certain percentage after which value drops. With 5% SCBA content, the CBR value was 3.25, with 10% SCBA content it was 4.75, with 15% SCBA content it was 5.02, and with 20% SCBA content it was 3.54.

7. The use of SCBA in conjunction with Lime, and Molasses, both independently and together, raised

the soaking CBR value of clayey soil, according to the findings of experiments done for all of the ideal combinations. The C: SCBA: L: M: 66:15:9:10 has the highest value of soaked CBR, followed by the C: SCBA: L: 76:15:9, the C: SCBA: M: 84:15:15.
8. These materials have the potential to be used to reduce DFS and liquid limit while also increasing the CBR, based on the findings of a thorough investigation that entailed spreading lime-mixed agricultural waste to clayey soil. The initial option is probably to use SCBA in combination with lime and molasses. when it comes to selecting the material that will be used because it is widely accessible.

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