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# Improvement of Mechanical Properties by Waste Sawdust Ash Addition into Soil

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## ABSTRACT

The objective of this paper is to utilize waste sawdust ash in a beneficial way for geotechnical purposes. The amount of sawdust generated every year constitutes up to 10-13% of the total volume of wood log. Such an enormous amount serves as waste material for landfill and is not utilized. Effective utilization of waste sawdust ash to enhance the engineering properties of soil could result in a solution of the landfill problem, which was the objective of this study. Permeability and direct shear tests were conducted to analyze the impact of waste sawdust ash on the properties of soil. After noticing the behavior, the optimum quantity of (12%) SDA was selected and further compaction and shrinkage limit tests on soil with 12% SDA were conducted. Dry density of the soil was improved by 7.8%, permeability was reduced by 71.8% and shrinkage limit was increased. Further, there was an increase of 22.14% in the friction angle with the addition of 12% sawdust ash and shear strength parameters were improved significantly. Overall, SDA had a positive effect on the geotechnical properties of the soil and it can be used as admixture in soil. This will not only solve the waste disposal problem, but will also improve the strength characteristics of soil.

**KEYWORDS:** SDA (sawdust ash), Direct shear test, Cohesion, Permeability, Friction.

## INTRODUCTION

Sawdust is the term given to the product formed after grinding of wood log. It occurs in various sizes and shapes depending upon the way it is cut. In World War I, it was a primary source of potassium. It occurs in abundant quantities in the universe as the wood is cut for human purposes, especially in mills and when it is processed in a fine powdered form. About 10-13 % of the total volume of wood log is processed into sawdust. Such a proficient amount of sawdust waste is mostly fed to landfill disposal. This paper aims at finding a useful way to modify the geotechnical properties of soil for better field construction by using sawdust ash. Hence, a two-fold benefit is obtained.

Infrastructure projects such as highways, railways, water reservoirs, reclamation... etc. require soil material in very large quantities. Usually, large areas are covered with highly plastic and expansive soil. Extensive laboratory tests have been carried out by various researchers and have shown promising results for application of such expansive soil after stabilization with additives.

Research has already been carried out on the use of SDA as partial replacement in concrete (Raheem, 2012). Doubtlessly, it has been found that it can act as a significant pozzolan in concrete. Similarly, the effects of different raw wastes on geotechnical properties of soil are also available in literature. The effects of fly ash on the geotechnical properties of an expansive soil has been tested by observing the compaction properties and swelling behavior of the soil which were found to

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be positive. Similarly, investigation has been conducted on the stabilization of expansive soils using fly ash (Bhuvaneshwari et al., 2005). *In situ* density test by core cutter, natural moisture content and light cone penetration tests were carried out. The tests indicated that the workability is maximum with 25% fly ash. Maximum dry density was attained for 25% fly ash. Fly ash is also being used as stabilizer of soil and many research papers in this field are easily available in literature. Modern day applications for ash include the use of coal ash in fills and embankments, pavement and sub-base courses, road material, sub-grade stabilization, landfill deposition, soil improvement, land reclamation and water pollution control.

Hansson (2008) examined the effect of deep stabilization of soil with fly ash for his master thesis. He performed unconfined compression and triaxial compression tests to check the suitability of soil with fly ash. It was found that class H coal ash is a product of hard coal combustion. The combustion takes place in a circulating fluidized bed boiler at approximately 800°C. A more effective and stronger material is obtained if lime and cement are used with fly ash in soil. Hansson also deduced that if the soil with fly ash is left to be cured, then the strength is slightly higher after 56 days than after 7 days, implying that some pozzolanic reactions take place. Strength characteristics of fly ash mixed with lime stabilized soil were studied, claiming that increasing fly ash content up to 15% in the soil samples showed a significant change in the unconfined compressive strength. The test revealed that the optimum content of admixture for achieving maximum strength is approximately 15% fly ash mixed with 4% lime of the dry weight of the soil (Sahoo, 2010).

Nigerian clayey soils have shown remarkable improvement by incorporation of sawdust ash. Reduction of plasticity and increase of maximum dry density have been reported by Fajobi et al., who have recommended its usage in places where reduction of swelling and shrinkage is of prior importance. Further, the use of sawdust ash as highway pavement material has been tested. It has been shown that an increase took place in particle size distribution of lateritic soil and maximum CBR of 19.4% (soaked) and 24.1% (unsoaked), which falls under AASHTO classification under A-2-7 (Joseph et al., 2013). Geotechnical properties of south-western Nigerian soil were again tested by Ogunribido (2012) who has proven that sawdust ash is an effective soil stabilizer for lateritic soil and that road quality can be enhanced by its addition into soils. He further showed that shear strength is increased from 50.92 to 71.07 $kN/m^2$ and that unconfined compressive strength is increased from 101.4 to 142.14 $kN/m^2$ hence overcoming the problem of road failure in Nigeria. Similarly, Kanaka (2012) has effectively shown the positive impact of sawdust on marine clays, through proving that liquid limit of soil decreases at 20% saw dust, free swell index of soil decreases moderately at 20% saw dust, addition of a small percentage of gypsum reduces the hardening process and saw dust can potentially stabilize the expansive soil solely.

This laboratory trial was conducted with a view to use sawdust to improve the engineering properties of soil. Soil is a critical factor in stability of civil engineering constructions. Many structural failures have been attributed to shear failure of soil. The current practice with saw dust is its usage as fuel for domestic cooking and for sand filling ditches where it causes environmental problems. Therefore, converting wood dust into sawdust ash has a two-fold benefit. First, environmental pollution is controlled; and second, it creates jobs for unemployed by agents who would bring SDA to site where soil is to be compacted. Above all, it will also cause a reduction of cost employed for soil compaction by decreasing the amount of effort required for the compaction process.

## MATERIALS AND EXPERIMENTAL PROCEDURE

### Procurement of Sawdust and Soil Sample

The soil sample was collected from *a local area of*

*'Tarnab farm'*, KPK, Pakistan within a 2000cm distance from a low running stream. It was obtained by digging at a depth of 37.5 cm from ground surface. Visually, soil was slightly wet due to a high water-table which exists in the mentioned location. Sawdust was obtained from the wood of locally available Diyar and Lasani (recycled form of wood, Figure 1) for tests. Sawdust was procured from a local milling industry where wood was being processed. Sawdust was chosen because of its abundant availability and with the aim to effectively utilize it for ground improvement purposes to avoid it being dumped into landfill sites.

**Properties of Materials**

Soil was obtained in wet form. It had 50.22% clay, 8.5% silt and 30.3 % sand. The gradation shows that the soil has a greater portion of clayey grains and hence it is significantly a clayey soil. Soil had a liquid limit of 19.6%, a plastic limit of 29%, a plastic index of 9.4% and a shrinkage limit of 29.15%.

Sawdust ash is a pozzolanic material as confirmed by Raheem et al. (see Table 1). The chemical composition proves that sawdust ash has sufficient amounts of silica and alumina. Silica content gives the ash its pozzolanic properties which makes it a useful cementitious material. Particle gradation analysis showed that sawdust ash had 97.4% sand, 2% clay and 0.6% silt. This shows that it represents the characteristics of sandy soil, since it has a higher portion of sand. According to AASHTO classification system, it is classified in category A-1.

**Sample Preparation**

After collecting the waste sawdust leftover by wood processing, sawdust was left for 24 hours in an open area to sun-dry it, in order to remove its moisture content and to facilitate its easy burning to ash. An incinerator was used to burn the sawdust to ash by pouring all the dried sawdust contents into a container and 4-5 hours were given for complete combustion. After verifying the product as obtained in Figure 2 and grinding it into powder to increase the surface area, the samples were prepared for laboratory tests. Permeability and shear tests were conducted to observe the difference in soil's behavior by addition of sawdust ash. The optimum selection was chosen from the lab results and verification of results was checked by further shrinkage limit and compaction tests.

**Table 1. Chemical composition of sawdust ash (Raheem et al., 2012)**

| Chemical elements present | Percentage composition |
|---|---|
| $SiO_2$ | 65.42% |
| $Al_2O_3$ | 5.69% |
| $Fe_2O_3$ | 2.16% |
| Cao | 9.82% |
| MgO | 4.23% |
| $SO_3$ | 1.06% |
| $Na_2O$ | 0.04% |
| $K_20$ | 2.38% |
| $CaCO_3$ | 7.89% |
| $SiO_3$+ $Al_2O_3$ | 71.1% |

**Permeability**

Permeability test chosen was the falling head permeability test, since the soil had a major portion of clayey matter .Variation in head and volume collected in graduated cylinder was measured for noted time intervals. The mould had a diameter of 10 cm with 11.46 cm height. Moreover, the mould was nearly filled with the soil sample so that the area of mould can be said equivalent to the area of soil. The test was conducted on soil samples with 2% SDA, 6% SDA, 10 % SDA and 12 % SDA. The results obtained were as follows (see Figure 1).

Results indicated that the control soil sample with no sawdust ash had a coefficient of permeability equal to 0.2064 cm/sec, which decreased to 0.1200/sec with the addition of 2% sawdust ash. With further 4% addition of SDA (i.e., 6% SDA) to the soil sample, permeability decreased by 7.83%. This may be attributed to the increase of voids after uneven mixing of ash in soil. However, when SDA is increased to 10%

of the mass of soil, permeability decreases by 46.6% compared to virgin soil, while there is a slight drop in permeability if compared to soil with 6% ash. Clearly, the optimum reduction in permeability occurs at 12% SDA soil specimen, where the coefficient of permeability decreases by 97.1% compared to the virgin soil. This can be attributed to fineness and packing density of SDA which resists the flow of water through its grains. Also, the ash has little affinity for water and water does not flow easily into the closely packed pores of ash. This reduction in permeability is of prime importance in determining the suitability of soil for construction on it. Less permeability can reduce the chances of seepage through the soil to concrete foundations; hence enhancing its bearing capacity.

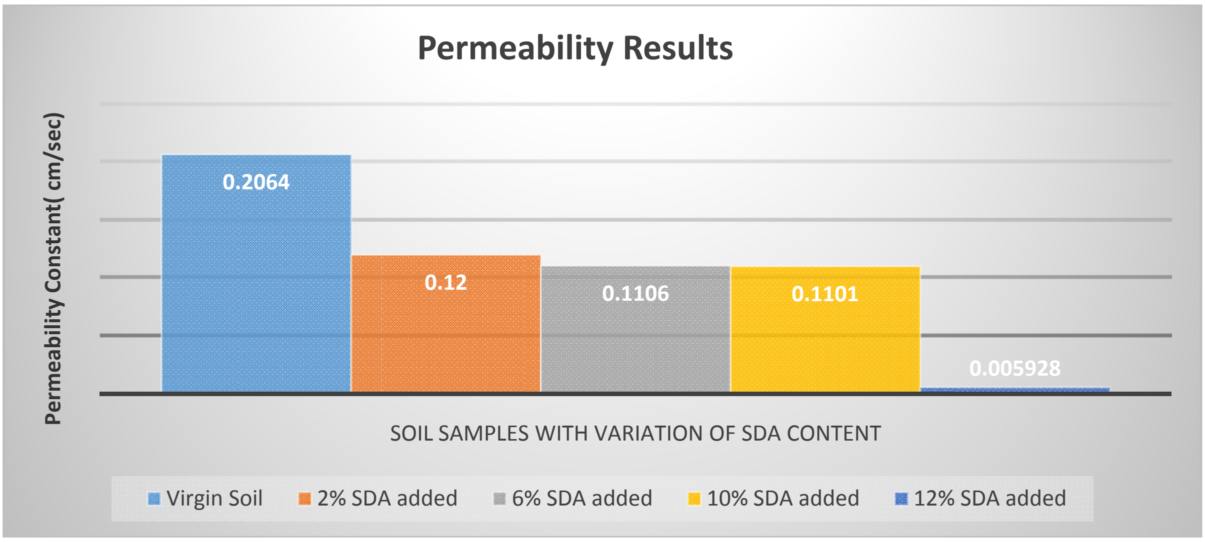


**Figure (1): Bar chart for permeability test**

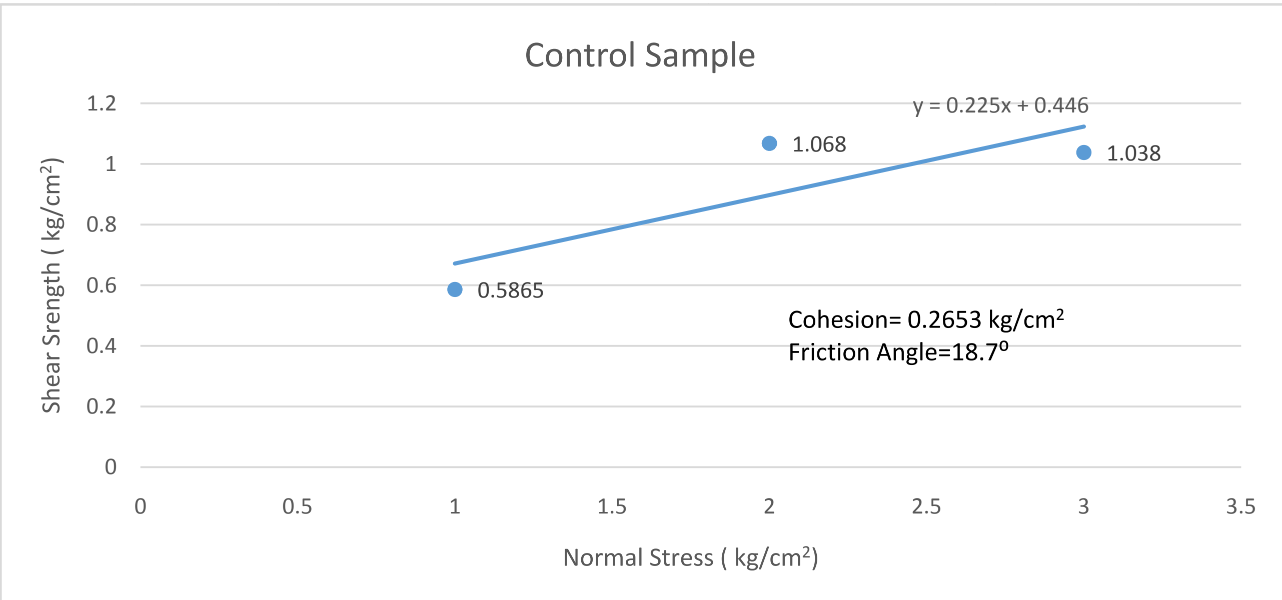


**Figure (2): Shear test result for control soil specimen**

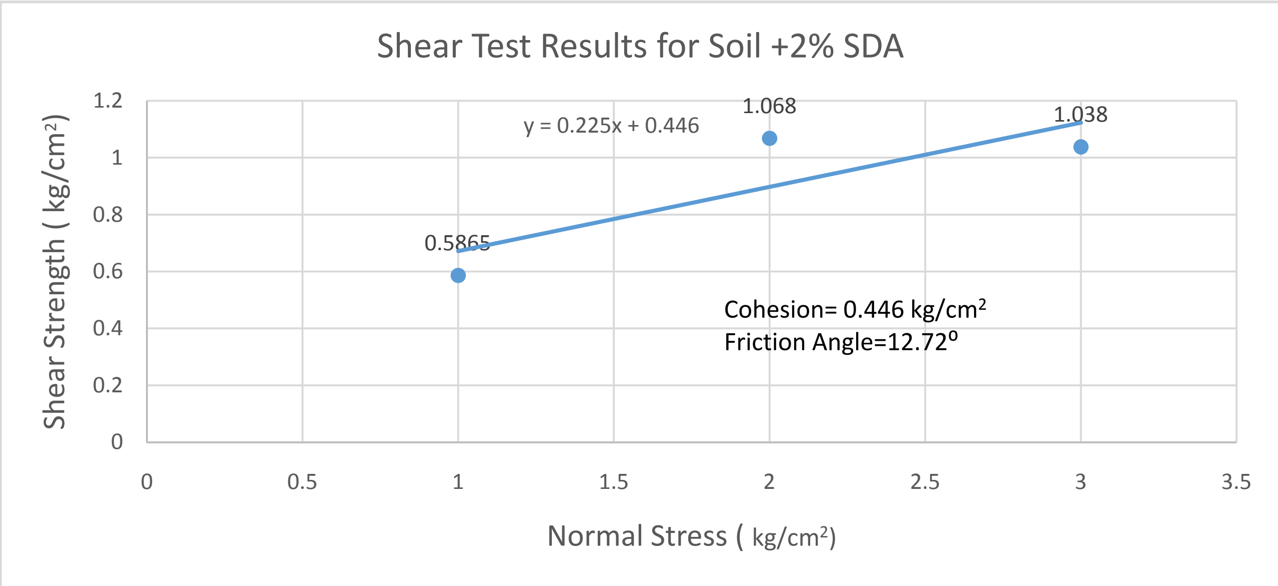


**Figure (3): With 2% addition of SDA, the soil sample shows the optimum value of cohesion of 0.446kg/cm$^2$**

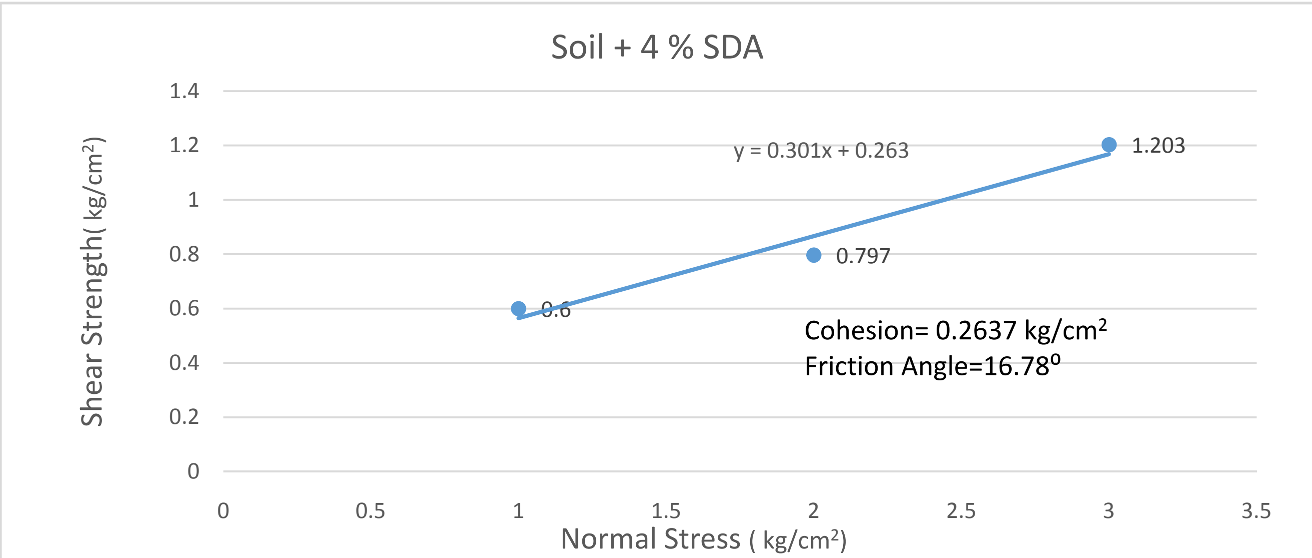


**Figure (4): 4% addition of sawdust ash into the soil increases the shearing friction angle**

Permeability results show that the water-retention rate of soil decreases by the addition of SDA. Because of its fine powdered compact structure, SDA has less void ratio. Water first gets adsorbed on the layer of SDA and then slowly penetrates into micro-voids present in it. Thus, the soil's imperviousness prevents water seepage to the concrete foundations which can render it vulnerable to cracks. On the basis of test results, engineers should use soil stabilized with sawdust ash in locations prone to water-logging and where water table is at a higher level than normal.

**Direct Shear Test**

This test was conducted by applying the load on a disturbed soil specimen placed in shear box. The control sample had 0% sawdust ash content, while the corresponding samples had sawdust ash content varying in proportions of 2%, 4%, 10% and 12%. The proving ring constant and area of soil sample amounted to 0.425 and 28.26cm$^2$, respectively. Shear stress was found out by using the formula; shear stress = proving ring constant* proving gauge reading/ area of soil sample. The least count of proving ring gauge was 0.01mm and 0.01*5mm for deflection gauge. The soil samples were weighed using a balance before the test. Results were carefully plotted in a graph.

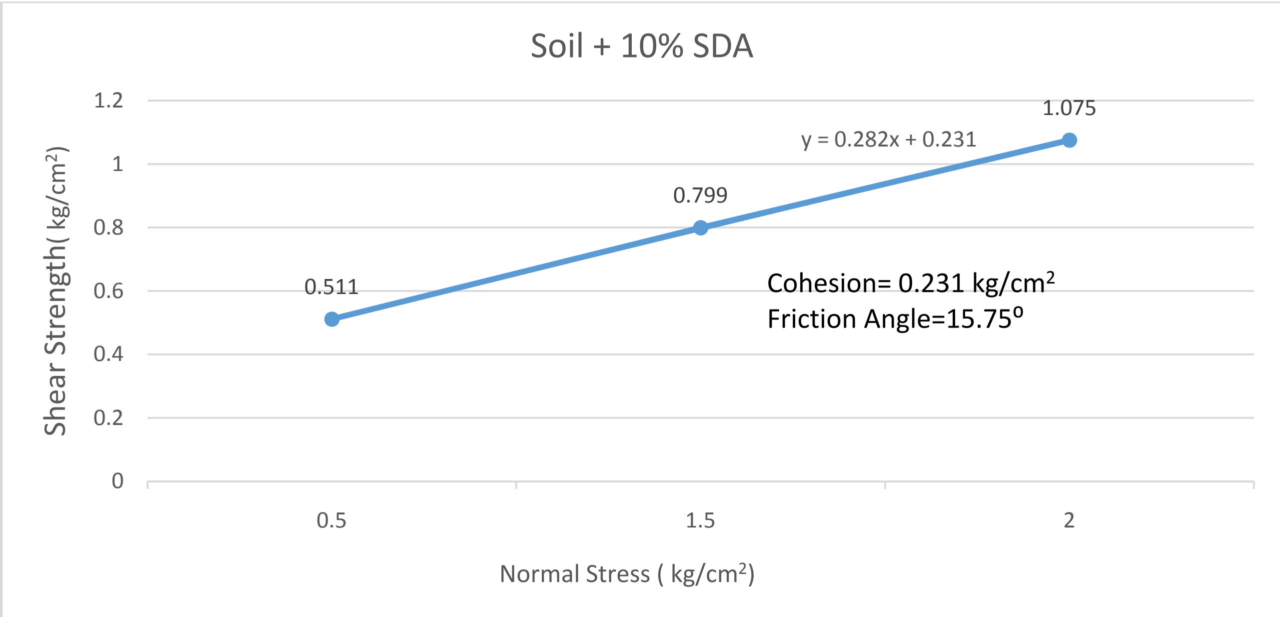


**Figure (5): Results for soil with 10% sawdust ash**

Results show that the control sample has an internal friction angle of 18.7$^0$ and a cohesion of 0.2653 kg/cm$^2$ (Figure 2*)*. The cohesion parameter increases abruptly to a maximum value of 0.446 kg/cm$^2$ with the addition of 2% sawdust ash (Figure 3*)*. This may be attributed to the effect of sawdust ash particles which as a result of mixing with the soil might have absorbed a little amount of moisture and utilized its fineness for adhering to the soil grains. With further addition of sawdust ash into the soil, the friction angle value increases to reach the maximum value of 22.84$^0$ with the addition of 12% sawdust ash into the soil mixture (Figure 6). Although the specimens were prepared one hour before the test, it can be stated that due to the quick pozzolanic reaction of sawdust ash and CaOH present in the soil (Laxmikant, 2011), it contributed effectively to the shear strength increase. It should be noted that additional quantity of fly ash acts as unbounded silt particles, with neither appreciable friction nor cohesion, causing decrease in strength (Bell, 1996; Kate, 2005). The friction of the soil grains in 4% sawdust ash soil mixture (Figure 4) is greater than in the 10% sawdust ash soil (Figure 5) mixture. This may be due to the presence of fine particles of sawdust ash in the 10% sawdust ash mixture and the absence of large-sized particles. Results indicate that there was a 22.14% increase of friction angle with the addition of 12% sawdust ash and a 68.1% increase in cohesion parameter with the addition of 2% sawdust ash as compared to the virgin soil. Further, there was a gradual increase of 3.4% in cohesion of soil with 4% sawdust ash addition compared to soil with 10% SDA. Sawdust ash consists of fine white spherical particles which have little affinity for water but make a good bond with the soil grains. This property helps them cling to the surface of soil grains, whether large or small in size, to increase the soil's cohesion which in turn helps in increasing the shear strength of the soil. This shear strength is an important factor for soil stability and its magnitude reduces the chances of failure of soil on which civil engineering structures are constructed.

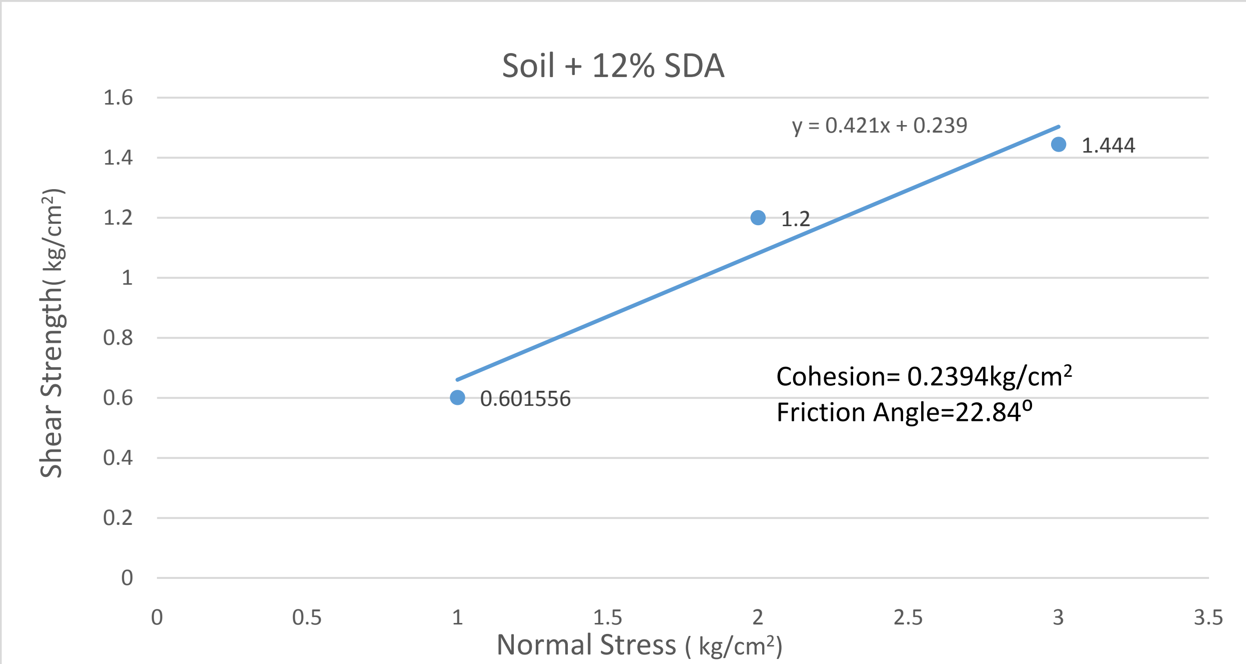


**Figure (6): The soil sample with 12% sawdust ash has the greatest friction angle among all of the other specimens**

Shear strength parameters are enhanced with the addition of sawdust ash as the results indicate. When compared to virgin soil with no SDA, soil with SDA addition performs better under effective normal stresses caused by loadings and fails at higher values of stress than virgin soil. However, it is important to note here that the test conducted did not take into account pore water pressure making the results undrained. So, approximate results should be expected.

**Shrinkage Limit**

Shrinkage limit test was conducted in accordance with ASTM D-427. The weight of soil sample (control test) and soil sample with SDA (12%) was measured in a shrinkage dish. After oven drying the sample, the weight was measured again and the weight of mercury displaced by oven- dried sample was determined. Using the dry density value of mercury (13.6g/cm$^3$), the volume of dry soil sample was determined. Finally, the shrinkage limit was found out for both samples.

Mean shrinkage limit of control sample = 29.15 %.

Mean shrinkage limit of SDA sample = 38 %.

As is clear from the test result, the shrinkage capacity of the soil is enhanced with the addition of SDA. This reduces the ability of the soil to expand under certain circumstances which might prove hazardous to the constructed foundations. Soil tends to expand, especially due to freeze-thaw process which causes swelling of grains. Such shrinkage can cause instability or even assist in shear failure.

**Compaction Behavior**

In order to test the compaction properties of soil with SDA, standard proctor compaction test was conducted on virgin soil and on soil with 12% SDA. The mould of 10cm diameter with a height of 11.46cm was filled with the soil sample and compacted in three layers by giving 25 blows with the help of a rammer of 3.99kg mass at a height of fall of 30cm. The compactive effort energy per unit volume was 6.236kg-cm/cm$^3$. Samples were taken each time to determine the moisture content of soil sample, while moisture content was varied from its initial water content to 2%, 10%, 18% and 24%. The corresponding dry density and moisture content were plotted in a graph (Figure 7).

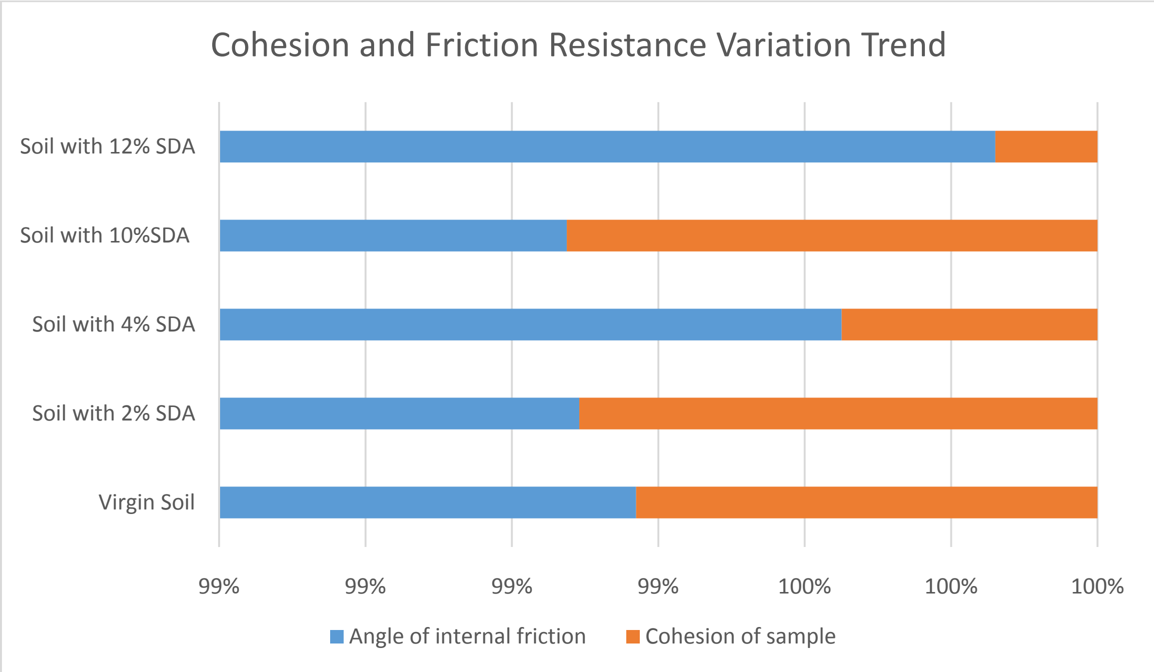


**Chart (1): It is clear that soil's friction parameter considerably increased with sawdust ash addition. Though the cohesion of sample decreased implying the change to coarse behavior of the soil, the cohesion is greater for the soil with 10% sawdust ash. 10% SDA addition may be declared as the optimum quantity as it gives the optimum quantity of both cohesion and friction angle. However, if we consider the friction angle as an important parameter, soil with 12% SDA proves efficient in this regard**

Maximum dry density increased from 0.010414kg/cm$^3$ to 0.011290kg/cm$^3$ with the addition of 12% SDA into the soil. The dry density of both soil samples increases linearly but slowly till it reaches the moisture content of 18.74%. Afterwards, its behavior is non-linear. The 7.8% increase in its compaction behavior is due to the addition of ash which compacts the soil grains by filling in the spaces between the soil particles. The empty voids that exist in the soil particles' contact area are now occupied by fine ash particles. They tend to block the easy flow of water as well as permit the '*denseness'* of soil. Hence, the soil's compactive attributes are improved. In field, less compaction energy will be needed to suit the requirements of engineers as soil has already an increased compactive quality.

**Chemical Interaction between Soil and Ash**

In order to evaluate chemical interaction and effect on soil by the addition of SDA as admixture , soil's pH and presence of nutrients were checked before and after the application. Interestingly , the pH increased from

5.2 to 6.2 .Therefore , SDA enhanced the soil's pH and nutrient status. Increase in soil's alkalinity indicates an increasing content of basic cations including calcium and potassium (Awodun, 2007). Also, the elevated pH of soil treated with SDA could have resulted from the immobilization of ammonium from the decomposing organic matter (Obi and Ekiperigin, 2001). Further , it was also observed that soil aggregate size distribution was more uniform than in the control sample. Although insignificantly, soil's aggregation was positively affected by SDA application. SDA with time significantly increased the supply of exchangeable bases when incorporated into the soil which was responsible for high pH. After the application of SDA, the soil gave highest value of exchangeable Mg and increased available P, Ca and Mg relative to the control. The nitrogen level decreased from 0.42% to 0.35%. Potassium Level was also significantly reduced.

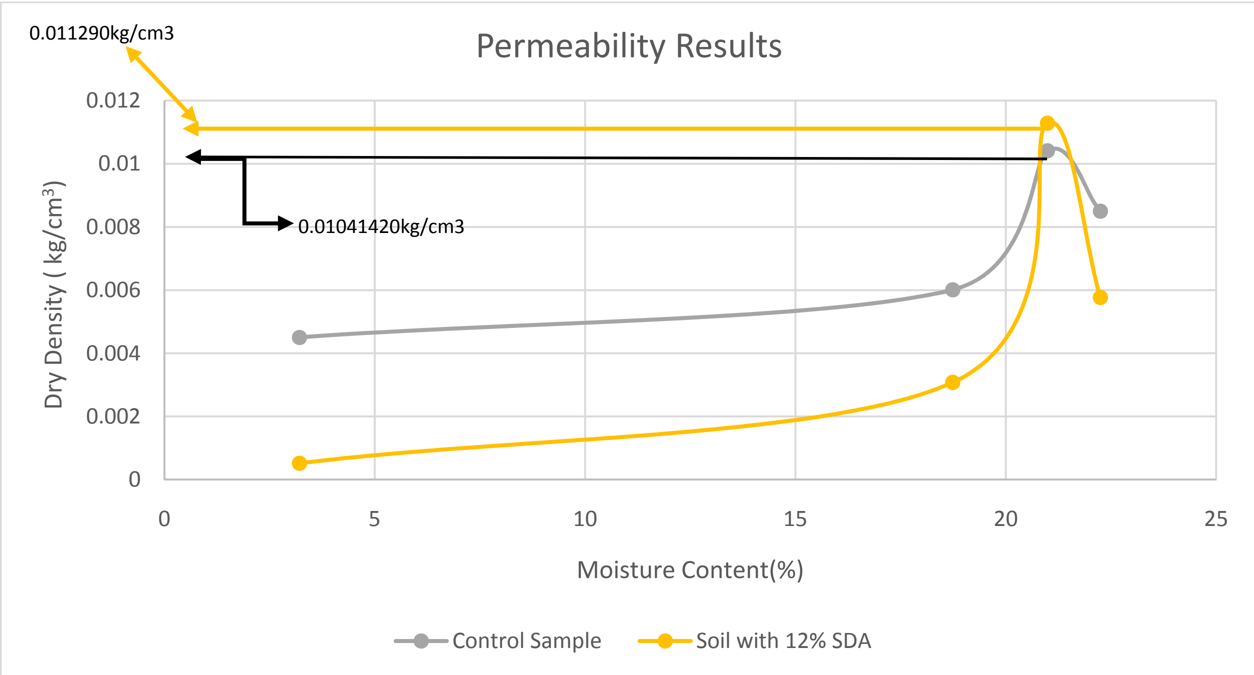


**Figure (7): Compaction curves for soil samples**

**Table 2. Variation of liquid limits with addition of SDA**

| SDA Content | Liquid Limit |
|---|---|
| 0% | 19.4% |
| 2% | 18.5% |
| 6% | 12.1% |
| 10% | 10.3% |
| 12% | 6.9% |

**Effect of SDA Content on Plasticity Index**

The effect of SDA on plasticity index of soil was investigated. The liquid limit decreased considerably from 19.6% to 6.9% as shown in Table 2. The plasticity index decreased from 9.4% to almost non-plastic. This is attributed to reduced affinity of water of sawdust ash which makes the soil become less plastic.

## CONCLUSIONS

Based on the results, the following conclusions can be drawn:

- The optimum reduction in soil permeability occurs when 12% sawdust ash is added to the soil.

- The strength parameters are improved by increasing the quantity of sawdust ash in the soil.
- Although the effect of sawdust ash content on shrinkage limit of soil was not tested, one of the samples with 12% sawdust ash addition showed a shrinkage value of 38% as compared to its initial value of 29.15%. The shrinkage limit increased with the addition of SDA into the soil. Since the shrinkage limit is an indication of expansiveness of the soil, it is concluded that addition of SDA reduces the expansion of soil. Also, it is less likely going to develop cracks if used for embankments.
- Compaction tests showed that dry density of the compacted soil with SDA was enhanced. Such a compact soil will be beneficial for the construction of foundations on it, since it will have a high bearing capacity and more capability to withstand the static load while decreasing the rate of settlement.

Further addition of SDA is not desirable, since the shrinkage limit exceeds values suitable for dam construction.

Sawdust ash had, in sum, positive impacts on the properties of soil. Thus, a soil with proper quantity of SDA is recommended for use in geotechnical works. It is a known fact that many buildings have failed due to shear failure in the past. This and the SDA disposal problem can be avoided to a great extent and more stable structures can be guaranteed in future.

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