Soil Reinforcement Using Coconut Shell Ash: A Case Study of Indian Soil

Shwetha Prasanna[1], Prasanna Kumar[2]
1. *Department of Civil Engineering, Don Bosco College of Engineering, Fatorda, Goa, India,*
2. *Department of Mathematics, Birla Institute of Technology and Science Pilani, K K Birla Goa campus, Zuarinagar, Goa, India*
Email:shwethaprasanna@gmail.com

Abstract: Soil stabilization can be achieved by increasing the density of the soil or by adding admixtures and then applying mechanical work to compact it, is a more economical solution for improving the performance of problematic soils, by enhancing their cementation, and reducing their sensitivity to moisture. Conventionally, cement, lime and fly ash have been used in stabilizing weak soils for construction purposes in order to provide a firm bases for all types of paved areas, to improve foundation conditions, and as a lining for trenches and staked earthwork. In order to make deficient soils useful and meet geotechnical engineering design requirements researchers have focused more on the use of potentially cost effective materials that are locally available from industrial and agricultural waste in order to improve the properties of deficient soils. The present work is aimed at assessing the impact of coconut shell ash on the stabilization of poor soil. For this sand and loamy sand textured soils were considered. This work mainly focused experimental study on the effect of coconut shell ash to increase strength of the soil. Different tests were conducted on soil with varying percentage of coconut shell ash. From the obtained results, it was observed that addition of 0.4% to 0.8% of coconut shell ash showed maximum improvement of dry density and optimum moisture content and also angle of internal friction and cohesion. Therefore coconut shell ash could be used as one of the best waste materials for soil reinforcement under the study area which falls under the district of South Goa in the Taluka of Salcete in India.
Keywords: coconut shell ash; compaction; shear strength; stabilization

1. Introduction

The volume of wastes generated in the world has increased over the years due to increase in population, socioeconomic activities and social development. These wastes come from agricultural, industrial, commercial as well as construction activities. One of the most attractive options of managing such wastes is to look into the possibility of waste minimization and re-use. Hence nowadays engineers have started using these wastes in sorting the problem of low stability in soil, thereby solving the issue of the growing waste and stability of the soil. Stabilization can increase the shear strength of a soil and/or control the shrink-swell properties of a soil, thus improving the load bearing capacity of a sub-grade to support pavements and foundations. Soil stabilization can be achieved by increasing the density of the soil or by adding admixtures and then applying mechanical work to compact it, is a more economical solution for improving the performance of problematic soils, by enhancing their cementation, and reducing their sensitivity to moisture. Soil stabilization methods help to preserve soils, water ways, unimproved roadways and much more. Conventionally, cement, lime and fly ash have been used in stabilizing weak soils for construction purposes like of road, building etc. in order to provide a firm bases for all types of paved areas, to improve foundation conditions, and as a lining for trenches and staked earthwork.

The over dependence on industrially manufactured soil improving additives (cement, lime etc.) have kept the cost of construction financially high. In addition large quantities of carbon dioxide are released during their production which leads to worsen global warming. In order to make deficient soils useful and meet geotechnical engineering design requirements researchers have focused more on the use of potentially cost effective materials that are locally available from industrial and agricultural waste in order to improve the properties of deficient soils. This research is aimed at assessing the impact of coconut shell ash on the stabilization of poor soil.

India is the third largest in Asia, having cultivation on an area of about 1.78 million hectares. Annual production is about 7562 million nuts with an average of 5295 nuts per hectare. The coconut industry in India accounts for over a quarter of the world's total coconut oil output and is set to grow further with the global increase in demand. However, it is also the main contributor to the nation's pollution problem as a solid waste in the form of shells, which involves an annual production of approximately 3.18 million tonnes. Coconut shell represents more than 60% of the domestic waste volume. Coconut shell, which presents serious disposal problems for local environment, is an abundantly available agricultural waste from local coconut industries. In developing countries where abundant agricultural and industrial wastes are discharged, these wastes can be used as potential material or replacement material in the construction industry. This will have the double advantage of reduction in the cost of construction material and also as a means of disposal of wastes.

In the modern history of soil stabilization, the concept and principle of soil reinforcement was first developed by Vidal (1969). He demonstrated that the introduction of reinforcing elements in a soil mass increases the shear resistance of the medium. Consequently, efforts for using fibrous materials, such as Natural fibers, Coconut (coir) fiber, Sisal, Palm fibers, Jute, Flax Barely straw, Bamboo and Cane as reinforcing elements were stated. The present study is mainly focused on coconut shell powder as a reinforcing element. The outer covering of fibrous material of a matured coconut, termed coconut husk, is the reject of coconut fruit. Rowell M et al. (2000) found fibers are normally 50–350 mm long and consist mainly of lignin, tannin, cellulose, pectin and other water soluble substances. However, due to its high lignin content, coir degradation takes place much more slowly than in other natural fibers. So, the fiber is also very long lasting, with infield service life of 4–10 years. The water absorption of that is about 130–180% and diameter is about 0.1–0.6 mm. Babu S and Vasudevan K. (2008), studied strength and stiffness response of coir fiber-reinforced tropical soil. They found coir retains much of its tensile strength when wet. It has low tenacity but the elongation is much higher. The degradation of coir depends on the medium of embedment, the climatic conditions and is found to retain 80% of its tensile strength after 6 months of embedment in clay. Coir geo-textiles are presently available with wide ranges of properties which can be economically utilized for temporary reinforcement purposes (Subaida A,et al. 2009). Chauhan S. et al. (2008), studied performance evaluation of silty sand subgrade reinforced with fly ash and fiber. Mainly, coir fiber shows better resilient response against synthetic fibers by higher coefficient of friction. For instance, findings show that coir fiber exhibits greater enhancements (47.50%) in resilient modulus or strength of the soil than the synthetic one (40.0%). Ayyar et al. and Viswanadham (1989), have reported about the efficacy of randomly distributed coir fibers in reducing the swelling tendency of the soil. Ravishankar and Raghavan (2004), confirmed that for coir-stabilized lateritic soils, the maximum dry density (MDD) of the soil decreases with addition of coir and the value of optimum moisture content (OMC) of the soil increases with an increase in percentage of coir. The compressive strength of the composite soil increases up to 1% of coir content and further increase in coir quantity results in the reduction of the values. The percentage of water absorption increases with an increase in the percentage of coir. Tensile strength of coir-reinforced soil (oven dry samples) increases with an increase in the percentage of coir. Khedari et al. (2005) introduced a new type of soil–cement block reinforced with coir fibers with low thermal conductivity. Black cotton soil treated with 4% lime and reinforced with coir fiber shows ductility behavior before and after failure. An optimum fiber content of 1% (by weight) with aspect ratio of 20 for fiber was recommended for strengthening the Black Cotton soil (Ramesh N et al. (2010). Ibrahim Adewuyi Oyediran and Oluwafemi Festus Fadamoro (2015) carried out a research on strength characteristics of genetically different rice and coconut husk ash compacted shales. 2 to 20 % by weight of both Rice Husk Ash (RHA) and Coconut Husk Ash (CHA) were separately added to Okitipupa (SW) and Enugu (SE) shales with the subsequent determination of Plasticity Index (PI), Maximum Dry Density (MDD), Optimum Moisture Content (OMC), Unconfined Compressive Strength (UCS) and California Bearing Ratio (CBR). They concluded that these materials can thus serve as suitable alternatives to modify and stabilize problematic shale and hence help to reduce construction costs, environmental hazards and ultimately bring about shales with improved geotechnical properties. One may also refer a detailed review article by Sayyed Mahdi Hejazi et al. (2012).

Research carried out on stabilization of sandy soils with coconut shell ash for soils from the coastal region of Goa, India is not available in the literature. This article is the first study in the region under consideration. It provides stabilization of soils, describing the vast literature in this field, and explains how the value of soil data can be increased by use of coconut shell ash. The main objectives of this study are to:

- To carry out physical test on soil without reinforcement.
- To carry out physical test on soil with reinforcement (coconut shell ash) in varying percentages.
- To analyze the specimen for Atterberg's limits, shear strength and compaction.
- To compare results of the test conducted on ordinary soil and soil with reinforcement.

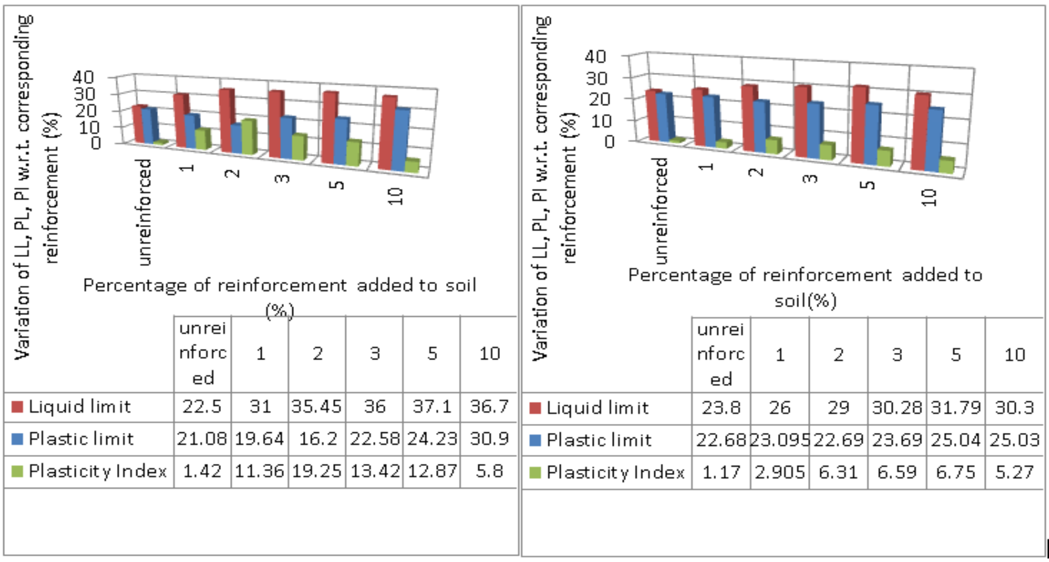
2. Materials and methodology

The soil samples used in this study were obtained as undistributed samples along the coast of the sea, and the little away from the sea in the city area. The study area falls under the district of South Goa in the Taluka of Salcete in India. The first sample was taken from Colva the second from Arlem falling in the above said region. The coordinates of Arlem are 15017’59.3’’ N and 73058’17.5’’ E, this sample was of sandy clay texture soil. The coordinates of Colva are 15016’55.9’’ N and 73057’19.0’’ E, this sample was of a sandy texture. The coconut shell wastes were collected from hotels and household wastes. In this project work, experimental study on the effect of coconut shell ash to increase the strength of the soil was studied. Different tests were conducted on soil sample with varying percentage of coconut shell ash. The samples were subjected to different laboratory tests, such as moisture content, specific gravity test, particle size distribution, Atterberg limits, bulk density, compaction and direct shear test.

3. Results and discussion

Atterberg's limit (Liquid limit and Plastic limit) test was performed on an unreinforced sample 1. The values of liquid limit (LL), plastic limit (PL) and plasticity index (PI) obtained were 22.5%, 21.08% and 1.42 respectively. At 1% application of reinforcement (coconut shell ash) on the soil sample, LL, PL and PI were 31%, 19.64% and 11.36 respectively. This shows that PL was decreased. LL was increased, as well as PI was increased considerably. At 2% reinforcement on the soil sample, LL, PL and PI were 35.45%, 16.20% and 19.25 respectively, Here LL is increased, but PL slightly reduced, PI increased considerably. At 3% reinforcement, LL, PL and PI were 36%, 22.58% and 13.42 respectively. Here LL increased, but PL is slightly increased, PI decreased slightly. At 5% reinforcement, LL, PL and PI were 37.1%, 24.23% and 12.87 respectively. At this percentage of coconut shell ash as reinforcement, the test obtained maximum values of LL and PI reduced gradually. At 10% reinforcement, LL, PL and PI were 36.7%, 30.09% and 5.8 respectively. Here decrease in PI and LL was constant. PL increased to achieve peak value. By comparing all the results, it could be conclude that, maximum plasticity index, liquid limit (approx.) was achieved at 2% and also maximum plastic limit was obtained at 10% coconut shell ash reinforcement.

For sample 2, LL was 23.8%, PL was 22.68% and PI was 1.17. At 1% application of coconut shell ash as reinforcement on the soil sample, LL, PL and PI were 26%, 23.095% and 2.905 respectively. This show both LL as well as PL was increased as well as PI was also increased. At 2% reinforcement on the soil sample, LL= 29%, PL= 22.69% and PI= 6.31. Here LL increased, but PL slightly reduced, PI increased considerably. At 3% reinforcement, LL= 30.28%, PL is 23.69% and PI= 6.59. In this case LL increased, PL slightly increased and PI increased slightly. At 5% reinforcement, LL= 31.79%, PL= 25.04% and PI= 6.75 At this percentage of coconut shell ash as reinforcement, the test obtained maximum values of LL, PL and PI. At 10% reinforcement, LL= 30.3%, Pl= 25.03% and PI= 5.27. There was no improvement in this case, all the three values decreased slightly. By comparing all the results, it can be conclude that, maximum plasticity index, liquid limit and also plastic limit is obtained at 5% coconut shell ash reinforcement.



	unreinforced	1	2	3	5	10
Liquid limit	22.5	31	35.45	36	37.1	36.7
Plastic limit	21.08	19.64	16.2	22.58	24.23	30.9
Plasticity Index	1.42	11.36	19.25	13.42	12.87	5.8

	unreinforced	1	2	3	5	10
Liquid limit	23.8	26	29	30.28	31.79	30.3
Plastic limit	22.68	23.095	22.69	23.69	25.04	25.03
Plasticity Index	1.17	2.905	6.31	6.59	6.75	5.27

Figure 1: Comparison of Atterberg limits with different percentages of coconut shell ash for sample 1 and 2

Next, compaction test results were analyzed on sample 1 and 2. The following results were observed for the sample 1, which is a gravel type soil. Optimum Moisture Content (OMC) was 22.2% and Maximum Dry Density (MDD) was 1.61 g/cm^3. After addition of coconut shell ash as reinforcement in various percentages the following changes were obtained. For 0.2% coconut shell ash, OMC and MDD were 20% and 1.69 g/cm^3. This shows that after addiction of 0.2 % ash there was a positive improvement in OMC and MDD, that is, OMC was reduced by 2.22% and MDD increased by 1.61 to 1.69 g/cm^3. Again after addition of another 0.2% that is a total of 4% ash, OMC and MDD were 17% and 1.64 g/cm^3 respectively. MDD did reduce slightly by 1.69 to 1.64

g/cm^3, but OMC reduced considerably by 3%. For 0.6% of coconut shell ash, MDD again increased by 1.7 g/cm^3, showing exceeding the highest MDD value obtained at 0.2% ash and also OMC reduced at 14% showing positive improvement. At 0.8% of coconut shell ash, the improvement was gradual, MDD slightly increased to 1.72 g/cm^3 and OMC reduced to 12.5% By comparing results obtained from all the graphs, it could be concluded that at 0.8% of coconut shell ash, maximum improvement of MDD and OMC for gravel type soil were achieved.

For sample 2, without coconut shell ash OMC and MDD values obtained were 17.64% and 1.66 g/cm^3. The soil was clayey sand. At 0.2%, OMC and MDD were 17.5% and 1.7 g/m^3. This shows that there was a slight improvement, MDD increased and OMC reduced. At 0.4% of coconut shell ash, OMC reduced from 17.5 to 14.5% and MDD increased exponentially from 1.7 to 1.8 g/cm^3. At 0.6%, OMC and MDD were 5% and 1.79 g/cm^3 respectively. There was increased in OMC and slight reduction in MDD. At 0.8%, again there was no improvement, OMC increased to 15.4% and MDD reduced to 1.693g/cm^3. At 1% of coconut shell ash OMC was 15.71% and MDD was 1.674 g/cm^3. From 0.4% to 0.8% the change was gradual but constant. Therefore by comparing the results from the graph it could be concluded that between 0.4% to 0.6%, maximum improvement of MDD and OMC were observed.

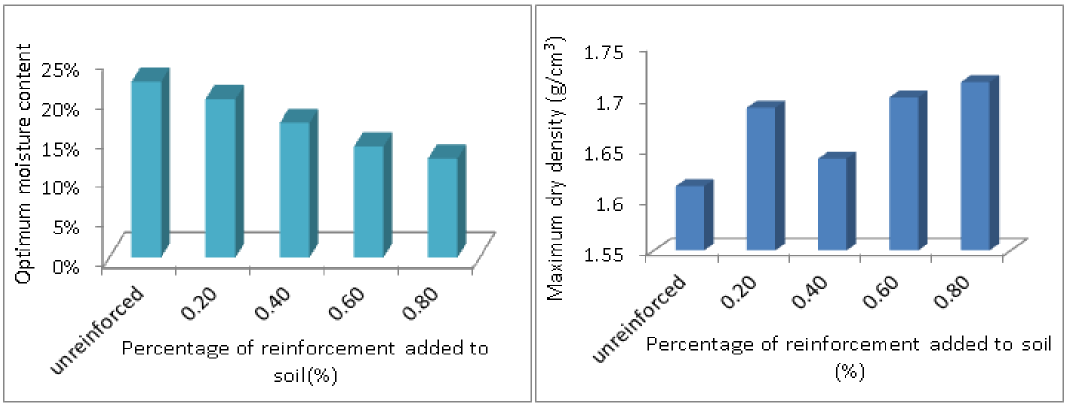


Figure 2: Comparison of OMC and MDD with different percentages of coconut shell ash for sample 1

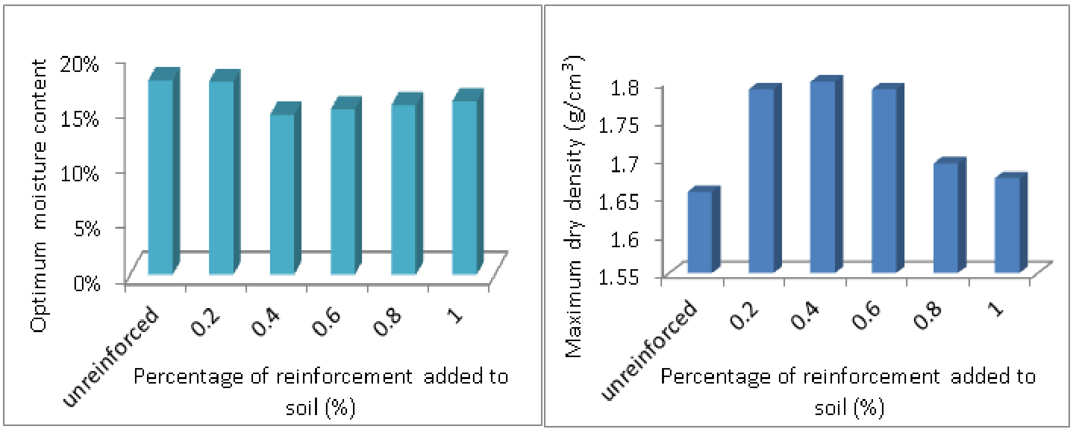


Figure 3: Comparison of OMC and MDD with different percentages of coconut shell ash for sample 2

Direct shear box test was conducted to determine the shear strength parameters of soil, which is cohesion(C) and angle of friction (Ø). First for sample 1, unreinforced test was conducted; coconut shell powder was not used. The following C=0.102 kg/cm^2 and Ø =8.83 ° values were obtained. Generally, higher the Ø and c values better is the shear strength of the soil and also the stability of the slope. Then soil was reinforced with coconut shell powder. After reinforcement with coconut shell powder, i.e., 0.2% of coconut shell powder the following C=0.164 kg/cm^2 and Ø =7.25 ° values were obtained. Cohesive value increased exponentially but the angle of internal friction reduced slightly. At 0.4%; C=0.194 kg/cm^2 and Ø =7.98 °. Here both C and Ø were increased. At 0.6% C=0.131 kg/cm^2 and Ø =10.69 °. Here cohesion value reduced invariably but the increase in angle of friction remained constant. At 0.8% C=0.1238 kg/cm^2 and Ø =9.609 °, here change was constant. At 1%, max angle of internal friction was achieved cohesion increased to 0.1835 kg/cm^2.

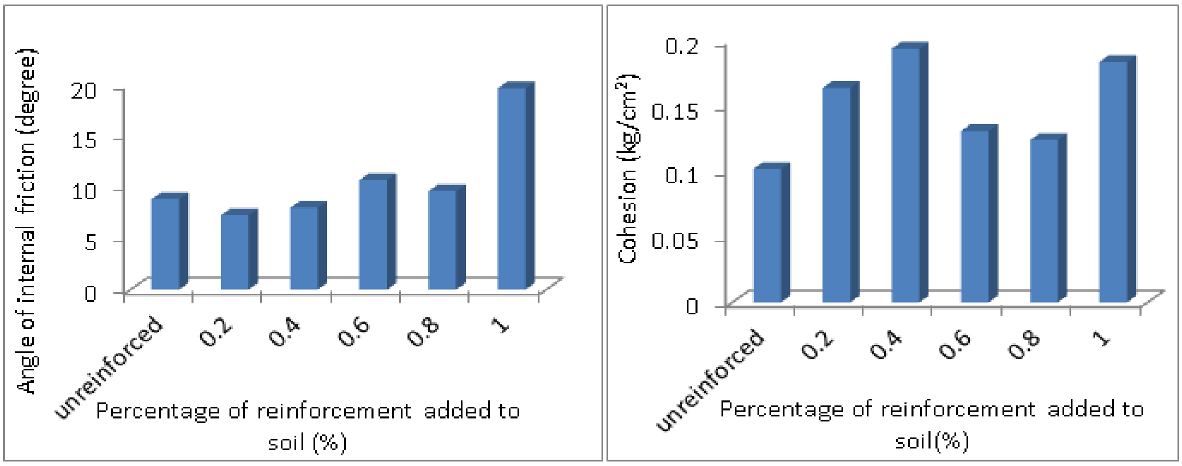


Figure 4: Comparison of friction and cohesion with different percentages of coconut shell powder for sample 1

For sample 2, Unreinforced soil without adding coconut shell powder, C=0.102 kg/cm^2 and Ø =8.83 ° When reinforced with coconut shell ash, at 0.2% of coconut shell powder C=0.122 kg/cm^2 and Ø =6.18 °, here cohesion value increased slightly but Ø value decreased. At 0.4%, C=0.138 kg/cm^2 and Ø =8.88 °, again cohesion increased and also Ø increased. At 0.6%, C=0.124 kg/cm^2 and Ø =12.47 °, here C values decreased slightly but Ø value improvement remained gradually constant. At 8%, C=0.072 kg/cm^2 and Ø =17.23 °, here C was reduced and value of Ø increased. At 1%, C=0.146 kg/cm^2 and Ø =19.41 ° here C and Ø both were increased.

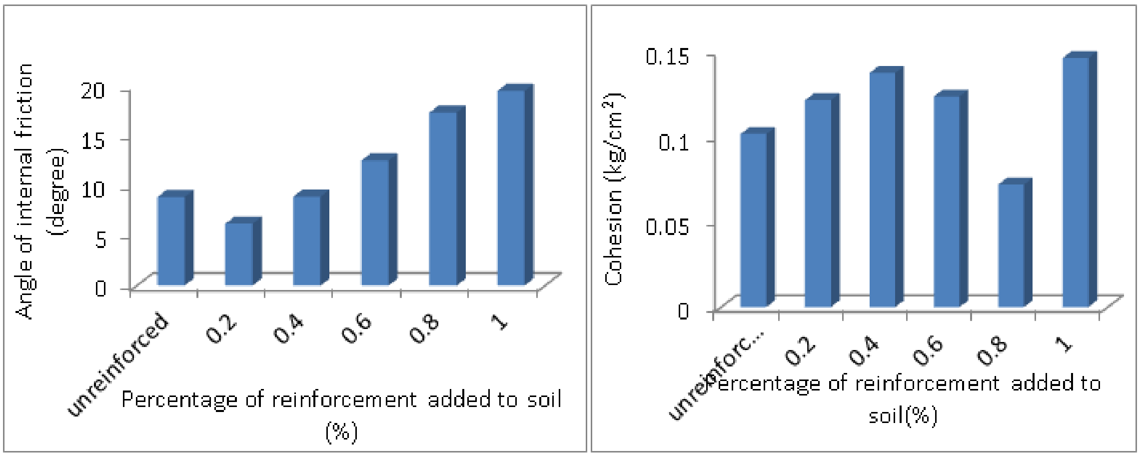


Figure 5: Comparison of friction and cohesion with different percentages of coconut shell powder for sample 2

Stabilizing soils with binders is now an extremely cost effective method of converting poor quality soil into a strong impermeable medium. This enables production of pavements, embankments, reinforced earth structures, railways, bulk fill applications, housing and industrial units in areas where they were not previously economically viable. Many years‘ experience has proved the effectiveness of this method. This, combined with rising costs of conventional civil engineering, has transformed soil stabilization into the most cost effective method of preparing sites for all construction projects. Coconut being naturally and largely available in a country like India, its waste left behind also is in large quantities. Utilization of coconut shell is minimal and unmanageable while its quantity increases annually and most of the coconut shell are disposed as waste in landfills causing environmental problems. Hence its use in processes like soil stabilization does not only reduce the waste but also solves problem of weak soils economically. The use of coconut shell powder (CSP) in the field of soil stabilization has not yet been properly exploited. Hence an experimental study on effect of CSP on strength of soil is made. It has different properties that make it suitable as soil stabilizer such as durability, high toughness, abrasion resistance etc. Coconut shell has long standing use and it is environmental friendly. Coconut shell ash being a pozzolanic material contains reactive silicates or alumino - silicates. Hence when reacts with water form compounds possessing cementitious properties. This main property enables its use in soil stabilization. On the basis of present experimental study, the following results were obtained: Specific gravity of soil sample obtained is**:** sample 1 is 2.31 and for sample 2 it is 2.34. Sieve test performed on the sample and it indicated that, for sample 1, Cu = 10, Cc = 0.9375(Gravel type soil). And for sample 2, Cu = 14.43, Cc = 2.5, (Sandy clay type soil). Moisture content of the sample 1 is 25.94% and sample 2 is 17.47%. Liquid limit obtained from graph corresponding to 25 blows for sample 1 is 22.5% and sample 2 is 23.8%. Plastic limit of sample 1 is 21.08% and sample 2 is 22.68% Optimum moisture content (OPM) and maximum dry density (MDD) obtained from soil compaction for soil sample 1 is OMC 22.22% and MDD 1.613 g/cm^3 and sample 2it is OMC 17.639% and MDD: 1.656 g/cm^3. Shear strength parameters-Cohesion (C) & angle of internal friction (Ø): for sample 1 is C: 0.1017 kg/cm^2 and Ø: 8.83 °and for sample 2, C: 0.1017 kg/cm^2 and Ø: 8.83 °.

4. Conclusion

By comparing all the results of Atterberg's limits for sample 1, it could be concluded that, maximum plasticity index, liquid limit (approx.) was achieved at 2% and also maximum plastic limit is obtained at 10% coconut shell ash reinforcement. For sample 2, it was observed that maximum plasticity index, liquid limit and also plastic limit are obtained at 5% coconut shell ash as reinforcement. Then regarding compaction for sample 1, by comparing results from all the graphs, it could be concluded that, at 0.8% ash achieved maximum improvement of MDD and OMC. For sample 2, it was observed from the results of graph that, 0.4% to 0.6% of coconut shell powder reached max improvement of MDD and OMC. From direct shear test results for sample 1, it could be concluded that angle of internal friction and cohesion is achieved at the range of 0.4 to 0.8%. For sample 2, by comparing the results from the graph it was observed that angle of internal friction and cohesion is achieved at 1% of reinforcement. Therefore it is once again proved that coconut shell ash could be used as one of the waste materials for soil reinforcement in the Goa region of India.

Acknowledgement
Authors thank Lekha Gangadharan, Allabaksh Devaleshwar, Aman Kumar, Akash Singh, Rochelle Colaco, and Warren Fernandes for their contribution during the experimental stage of this project work.

5. References

[1] Vidal H. The principle of reinforced earth. Highway Research Record, 1969, 282:1–16.
[2] Rowell M, Han S, Rowell S. Characterization and factors effecting fiber properties. Natural Polymers and Agrofibers Composites. 2000, 115–134.
[3] Babu S, Vasudevan K. Strength and stiffness response of coir fiber-reinforced tropical soil. Journal of Materials in *Civil Engineering*. ASCE, 2008, 20, 571–577.
[4] Subaida A, Chandrakaran E, Sankar N. Laboratory performance of unpaved roads reinforced with woven coir. Geotextile Geomembrane. 2009, 27, 204–210.
[5] Chauhan S, Mittal S, Mohanty B. Performance evaluation of silty sand subgrade reinforced with fly ash and fiber. Geotextile Geomembrane. 2008, 26, 429–435.
[6] Ayyar R, Krishnaswamy R, Viswanadham S. Geosynthetics for foundations on swelling clay. Int work on geotextile. Bangalore, India, 1989.
[7] Viswanadham S. Bearing capacity of geosynthetic reinforced foundation on a swelling clay master of technology dissertation. Madras (India), Indian Institute of Technology, 1989.
[8] Ravishankar U, Raghavan S. Coir stabilised lateritic soil for pavements. In: Indian Geotechnical Conference, Ahmedabad, India, 2004.
[9] Khedari J, Watsanasathaporn P, Hirunlabh J. Development of fiber-based soil–cement block with low with low thermal conductivity. Cement Concrete Composites. 2005, 27, 111–116.
[10] Ramesh N, Krishna V, Mamatha V. Compaction and strength behavior of lime coir fiber treated Black Cotton soil. Geomechnical Engineering. 2010, 2, 19–28.
[11] Ibrahim Adewuyi Oyediran and Oluwafemi Festus Fadamoro. Strength characteristics of genetically different rice and coconut husk ash compacted shales. International Journal of Geo-Engineering. 2015, 6, 2-14.
[12] Sayyed Mahdi Hejazi, Mohammad Sheikhzadeh, Sayyed Mahdi Abtahi, Ali Zadhoush. A simple review of soil reinforcement by using natural and synthetic fibers. Construction and Building Materials, 30, 2012, 100–116.