Enhancement of Engineering Properties of Clayey Soil by the Addition of Silica Fume and Nylon Fiber

Owais Gani [1], Anoop Sharma [2]

[1]*PG student, Dept. of Civil Engineering, Sri Sai College of Engineering& Technology, Badhani, Punjab, India*
[2]*Assistant Professor, Dept. of Civil Engineering, Sri Sai College Of Engineering& Technology, Badhani, Punjab, India*
anoopsharma777r@gmail.com
waniowais233@gmail.com

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Abstract - Civil engineers still face difficulties while building on soft soils in the present world, even despite the quick development of infrastructure projects and improvements in construction technology. The reason for their limited bearing capacity is that they show a significant volumetric change when they come into contact with water. The problem of shear strength in soft clay can be addressed by a variety of stabilization techniques. In this experiment, the optimal moisture content and strength parameters for achieving the maximum dry density of the clay soil were determined by adding varying amounts of nylon fiber and silica fume. The Unconfined Compressive Strength (UCS) and California Bearing Ratio (CBR) tests have been used to evaluate the strength of natural clay and clay modified with silica fume (10%, 15%, 20%) and Nylon Fiber (3.0%, 4.0%, 5.0%) separately, as well as the combination of all the materials, by varying the amount of Nylon Fiber for each amount of silica fume. The optimal moisture level and maximum dry density were ascertained using a standard proctor test and a small compaction apparatus. The maximum dry density decreases as the silica fume content rises, while the maximum dry density rises as the nylon fiber content rises, according the test results. The clay sample's maximum strength, when considering the strength parameter, is achieved by adding 3.0% nylon fiber and 15% silica fume.

***Key Words*:** Compaction test, CBR, UCS, Silica Fume, Nylon Fiber

1. INTRODUCTION

The highest unconsolidated portion of the earth that is naturally occurring in the universe is called soil. It is created when rocks break down in the presence of naturally occurring elements like heat, wind, rain, and snow. It is the least expensive building material and widely accessible. Due of its extremely varied composition and features, it is a challenging material. The location and geography of the soil affect its properties. The characteristics of the soil should align with the specifications of an engineering structure's design for safer construction. In this work, the geotechnical engineer is crucial in determining whether or not the soil satisfies the structural criteria. Building engineering structures on unstable ground carries a significant risk. These soils show settlements, low shear strength and high compressibility.

Very often the available soil is not suitable for construction purposes. Strength, permeability and stability on slopes are the main aspects of soil that we have to deal with. For studying the engineering behaviour of soil, we have to deal with the stability of underground structures, retaining structures, foundations, slopes, earth dams and pavement construction.

Due to the variable behaviour of soil, we encounter following problems:

- As the relationship between stress and strain is not linear, hence we cannot apply the elasticity theory.
- Factors such as drainage, pressure, moisture conditions greatly influence the strength and behavior of soil, so while dealing with soil these factors need to be considered.
- Due to the change in characteristics of soil fromone place to another, test results also vary.
- We cannot easily interpret the results of tests conducted on the soil.
- Proper inspection of soil is also difficult as most of it is underground; so proper exploration need to be done.
- As soil is a particulate material, its properties change as the particles shift their position.
- Due to indifferent behavior of soil, same construction method cannot be adopted at all locations.

2. Literature Review

Megha S. Mahaladkar et al., (2022) the main objective of this study is to investigate the effect of index properties of clayey soils when blended with silica fume and basalt fiber. A series of laboratory experiments have been conducted on samples with 0%, 5%, 10%, 15% and 20% of Silica fume and 0.05%, 0.1%, 0.15% and 0.2% of Basalt fiber by weight of dry soil. The test results showed a significant change in consistency limits of samples containing Silica fume and basalt fiber. The investigation showed that the Silica fume is a valuable material to modify the index properties of black cotton soil to make them suitable for different construction activities. The addition of basalt fiber gives a very good compressive strength to the BC soil as compared to silica fume.

Ahanaf Tahmid et al., (2022) the effects of coconut fiber and nylon fiber on unconfined compressive strength and compaction value were investigated in this article. The soil samples were created by measuring their Maximum Dry Density (MDD) and Optimum Moisture Content (OMC), as well as varying percentages of coconut fibers and nylon fibers by dry weight of soil. The current study discovered compaction and unconfined compressive strength values by employing 0.5%, 1.0%, and 1.5% coconut fiber for 30 mm length, respectively. This study found
that the proportion of coconut fiber raised the unconfined compressive strength value substantially. 1.5% coconut fiber resulted in the highest compressive strength rating compared to the other ratios.

Mohamed A. Sakr et al., (2020) In this study, the effect of using micro silica fume to stabilize the soil was investigated through a laboratory study. Test results showed that, the micro silica fume can considerably decrease the free swell index value by 69% at 25% micro silica fume content. Also, the swelling pressure is reduced from 410 kN/m2 to nearly 330 kN/m2 and 302 kN/m2 at micro silica fume content of 5% and 25%, respectively. This demonstrates the effectiveness of the proposed addition in the expansive soils improvement. This improvement technique can be used in different civil engineering construction projects including slope stabilization and road embankments.

Soundara B et al., (2019) In this experimental study, the strength parameters and optimum moisture content for achieving maximum dry density of the clay soil have been studied with the inclusion of sisal fibers and silica fumes in varying proportions. Unconfined compression strength (UCS) test has been conducted to investigate the strength of natural clay and clay modified with silica fume (5%, 10%, 15%) and sisal fibres (0.25%, 0.5%, 0.75%) separately and combination of all the materials by varying the proportion of sisal fibre for each proportion of silica fume. The optimum moisture content and maximum dry density were derived from standard proctor test performed with miniature compaction apparatus.The test results indicated that increase in silica fume content decreases the maximum dry density from 1.81g/cc to 1.613 g/cc similarly there is a decrease in maximum dry density from 1.81g/cc to 1.61g/cc when sisal fibre content is increased. The optimum moisture content shows slight variation when there is addition of sisal fibres and silica fume and was found to be around 16.67 %.

Kawther et al., (2018) studied the Remediation of Clayey Soil Using Silica Fume. Different percentage of silica fume added with soil sample are 0, 3, 5 and 7%. Tests like Specific gravity, compaction characteristics, swell and swell pressure, CBR and compressive strength tests had been conducted on the prepared and modified soils. Results clarified that by increasing silica fume content leads to decrease the plasticity index and liquid limit while causes an increase in plastic limit and optimum water contents . The maximum dry unit weight values also decreases. The compressive shear strength, California Bearing Ratio (CBR), swell and swell pressure is also improved by using silica fume .

Bharathan et al., (2017) studied the effect of silica fume and cement on clayey soil . The fixed ratio of cement 10% added by varying the percentage of silica fume from 5% to 20% at an interval of 5% with clayey soil. The results showed that the increase in silica fume upto 15% increases both unconfined compressive strength and California bearing ratio. Further increase of the silica fume will reduce both UCS and CBR value.

Saxena et al., (2017) studied the effect of marble dust powder and fine sand on properties of Expansive soil. The clay soil was mixed with marble dust powder and sand from 30% to 50% and 20% to 40% respectively at an interval of 10%. From the analysis of test results it was found that , liquid limit plasticity index , optimum moisture content , permeability and cohesion decreased and plastic limit, shrinkage limit, maximum dry density, California bearing ratio and angle of internal friction increased with an increase in marble powder content. From the economic analysis , it was found that marble powder upto 20% is optimum for sand mixed with clayey soil.

Patel et al., (2017) studied the use of waste marble powder to improve the characterstics of black cotton soil. The proportion of marble powder used was 20% to 60% . The test results showed a significant change in consistency limits of sample containing marble dust powder. The liquid limit would decrease from 31.3% to 23.5%. The plasticity index decreased from 11.57% to 4.35%. The CBR test value increased from 10.36 to 27.19. From this laboratory investigation it was concluded that the waste material like marble powder generated from stone industries has a potential to modify the characteristics of expansive clay soil.

Sreekumar et al.,(2017) studied the effect of marble dust powder on soil stabilization. Marble dust is added in varying percentages (3,6,9,12,15%) along with curing periods of (3,7,14) days to the soil sample. Basic properties of soil like Atterberg limits, compaction characteristics and strength characteristics were determined. On addition of marble dust, unconfined compressive strength increases from 99.2 kN/m2 to 286.5 kN/m2 for 14 day curing period. The California Bearing ratio (CBR) of soil increased from 5.19% for the virgin soil sample to 8.83% for 9% marble dust addition for 0 day curing period. Further addition of marble dust reduces the CBR value.

Trivedi et al., (2016) studied Impact of Micro Silica Fume on Engineering Properties of Expansive Soil. Laboratory tests were conducted on soil samples with increment in 5% proportion from 0%, to 15% of Silica Fume by weight of dry soil. LL increased by 17% from 50% to 67% and Plasticity Index increased by 7% from 24% to 31%. There was an increase in Shrinkage limit, decrease specific gravity and differential free swell from 10.44% to 13.01%, 2.69% to 2.59%and 48.46% to 9%

respectively indicating a fall in swelling characteristics of soil. It was thus recommended for use in stabilization of soils.

Abdelzaher et al., (2016) studied on Stabilization of Subgrade Pavement Layer Using Lime, Silica Fume and Nano Silica. The tried percentages of lime were 2, 4, 6 and 8% and 5, 10 and 15% for SF, while 1, 2 and 3% used for NS. Various tests conducted were modified proctor test, Atterberg limits test, free swelling (FS%) test, (UCS) and (CBR) test. At last, direct shear (DS) test was carried out on the optimum mixes from the previous test. The results indicated that the (OMC) increased, while the (MDD) dramatically decreased for all used additives and plasticity index (P.I) decreased. The FS% decreased, and the maximum reduction in FS% was occurred at the two combinations (8% L + 15% SF) and (8%L+3%NS). The UCS increased by adding both SF and NS activated by lime to the test soil , and the optimum percentages of the two combinations were occurred at 6%L+10%SF and 6%L+3%NS for traditional and nanomaterials additives respectively.The maximum value of CBR occurred at 8% L + 10% SF, while DS results indicated that adding 6L+10SF and 6L+3NS, the soil parameters (cohesion and internal friction angle) have been improved.

Tiwari et al. (2016) They studied the stabilization of black cotton soil using fly ash and nylon fibre. In their study, they used different combinations of fly ash as 10%,20%, 30% & 40%. 20% was their optimum value. After which they calculated the optimum value of nylon fibre from various values as0.25%, 0.50%, 0.75%, 1%, 1.5%. From which 0.75% nylon fibre comes to be the optimum. The CBR value of soil+20% fly ash+0.75% fibre was maximum of all other readings. And the MDD was also maximum of this mix proportion.

Chayan et al., (2014) studied Influence of Micro Silica Fume on Sub Grade Characteristics of Expansive Soil. Number of laboratory tests were conducted and it was proven that the material is good agent of stabilization of expansive soils for sub-grade modification. Tests like Standard compaction test, MDD, OMC were carried out. Micro silica fume was increased at 5% each. The test was thus done in proportion of 5%, 10%, 15%, 20% and 25% respectively. It was noticed that 10% was optimum percent for soaked CBR which was same with unsoaked CBR as they both witnessed an increased.

Negi et al., (2013) Effect of Silica Fume on Index Properties of Black Cotton Soil. The main objective of this study was to investigate the effect of the index properties of clayey soils when blended with Silica Fume. A series of laboratory experiments have been conducted on samples with 0%, 5%, 10%,15% and 20% of Silica Fume by weight of dry soil. The test results showed a significant change in consistency limits of samples containing Silica fume. The Liquid limit would increased by 54% to 57% and Plastic limit would decreased by 27.07% to 26.29% with increasing Silica fume contents from 5% to 20% . Their Plasticity Index would increase from 26.93% to 30.71% and shrinkage limit would increase from 7.55% to 12.70%, respectively, when subjected to a SF blend of 5% to 20%. Also the Differential Free Swell decreased from 25% to 7% showing appreciable decrease in swelling behaviour. The investigation showed that the Silica fume is a valuable material to modify the index properties of black cotton soil to make them suitable for different construction activities.

Phanikumara et al. (2013) This paper presents the swell-consolidation characteristics of remoulded expansive clay specimens reinforced with randomly distributed nylon fibre.In the case of nylon fibre, the length of the fibre (l) was varied at 15 mm and 20 mm. As the diameter of the fibres was 1mm, the aspect ratio of the fibres used was equal to 15 and 20, respectively. The fibre content (fc) used in the testing programme was

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varied at 0%, 0.05%, 0.1%, 0.15%, 0.2%, 0.25% and 0.3% by the dry weight of the soil. Their result shows that the swell potential (S%) and the vertical swelling pressure also decreased with an increasing fibre content (fc) for a given fibre length. & thesecondary compression decreased with an increasing length of fibre. The value of the secondary consolidation coefficient (Cα) for fibre-reinforced specimens was less than that for the unreinforced specimen.

3. Materials

3.1 SOIL

Source of soil

As per IS classification of soil, the soil used is low compressibility Clay. The soil properties are given in the table as under:

Table no. 1 Properties of soil used in the study

S.No.	Properties	Result
1.	Liquid limit (%)	31
2.	Plastic limit (%)	18
3.	Plasticity Index (%)	13
4.	Specific Gravity	2.62
5.	Maximum Dry Density (KN/m³)	17.8
6.	Optimum Moisture Content (%)	12.55
7.	Soil Classification	CL (Low Compressibility Clay)
8.	CBR (%) (soaked)	2.1
9.	CBR (%) (Unsoaked)	3.7
10.	UCS ($kN/m^{2)}$	212

3.2 SILICA FUME

Source of SILICA FUME

The silica fume used in this study for stabilizing clayey soil was procured from Mahalaxmi Chemicals Enterprises, Delhi. The density of silica fume is 2.0–2.5 mg/m3, and its bulk density is 0.3–0.5 mg/m3. Silica fume consists primarily of amorphous (non-crystalline) silicon dioxide and it is produced in electric furnace. The raw materials are quartz, coal and woodchips. The ash that results from this process is collected and sold as silica fume.

Table 2: The properties of silica fume are given below;

S.No	Parameters	Mass (%)
01.	Silica as SiO_2,	85-95%
03.	Lime as CaO	0.8-2%
04.	Magnesia as MgO	1-2%
05.	Alumina as Al_2O_3	1-3%
06.	Iron Oxide as Fe_2O_3	0.5-1%
07.	Density , kg/m^3	$600kg/m^3$

3.3 NYLON FIBER

Source of Nylon Fiber

Nylon fiber that is used in this project is known as Gujcon-CRF and is manufactured by Gujarat state fertilizers and chemicals limited which was collected from their warehouse in New Delhi. The physical property of this Nylon Fiber is shown in table.

Table 3:- Physical Properties of Nylon fiber

S.No.	Property	Value
1.	Density	1.14gm/cc
2.	Melting point	215
3.	Length(L)	20mm
4.	Specific gravity	0.90
5.	Diameter(D)	0.50mm
6.	Aspect ratio(L/D)	40

4. EXPERIMENTAL RESULTS

4.1 STANDARD PROCTOR TEST

Table no. 4: MDD and OMC for soil– Silica Fume - Nylon fiber mix

Sr. No.	Proportion Soil : Silica fume: Nylon fiber	MDD (kN/m^3)	OMC (%)
1.	100:00:00	17.80	12.55
2.	83:15:02	17.40	13.20
3.	82.5:15:2.5	17.10	13.50
4.	82:15:03	16.60	13.80

Fig:-1 Variations b/w MDD and OMC of Silica Fume - Nylon fiber & soil with different proportions

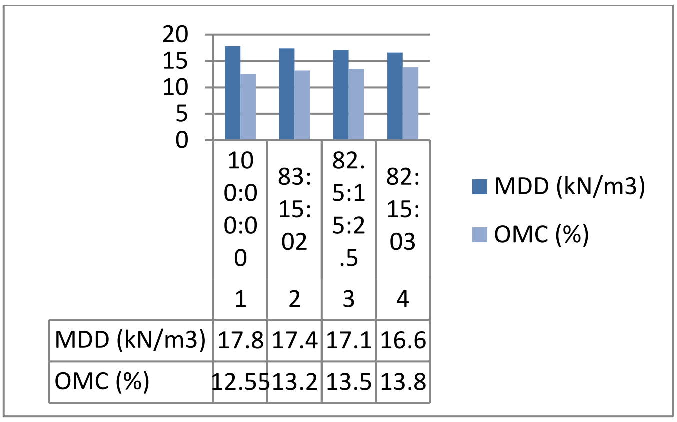


Table 5: Results of UCS of Silica Fume and Nylon fiber Mix with Soil with 7 days curing period

Sr. No.	Proportion Soil : Silica fume: Nylon fiber	Curing Period (Days)	UCS (kN/m^2)
1.	100:00:00	7	212
2.	83:15:02	7	340
3.	82.5:15:2.5	7	430
4.	82:15:03	7	540

Fig:-2 Variations b/w UCS Values of Clayey soil, Silica Fume and Nylon fiber with different proportions with 7 days curing period

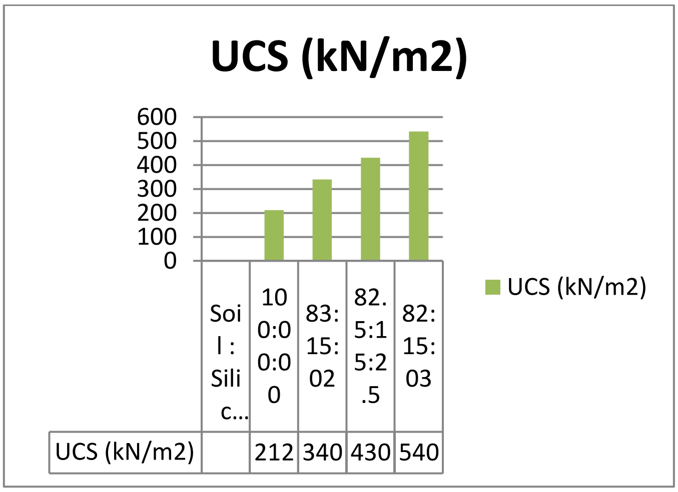


Table 6: Results of UCS of Silica Fume and Nylon fiber Mix with Soil with 14 days curing period

Sr. No.	Proportion Soil : Silica fume: Nylon fiber	Curing Period (Days)	UCS (kN/m^2)
1.	100:00:00	14	230
2.	83:15:02	14	390
3.	82.5:15:2.5	14	470
4.	82:15:03	14	560

Fig:-3 Variations b/w UCS Values of Clayey soil, Silica Fume and Nylon fiber with different proportions with 14 days curing period

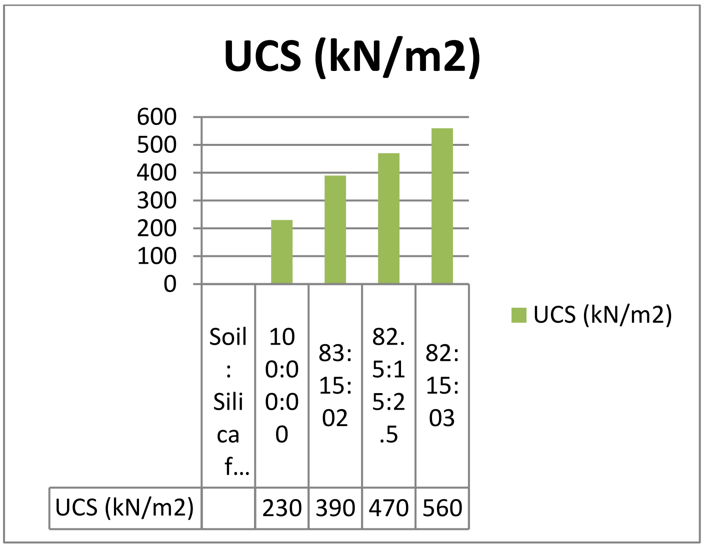
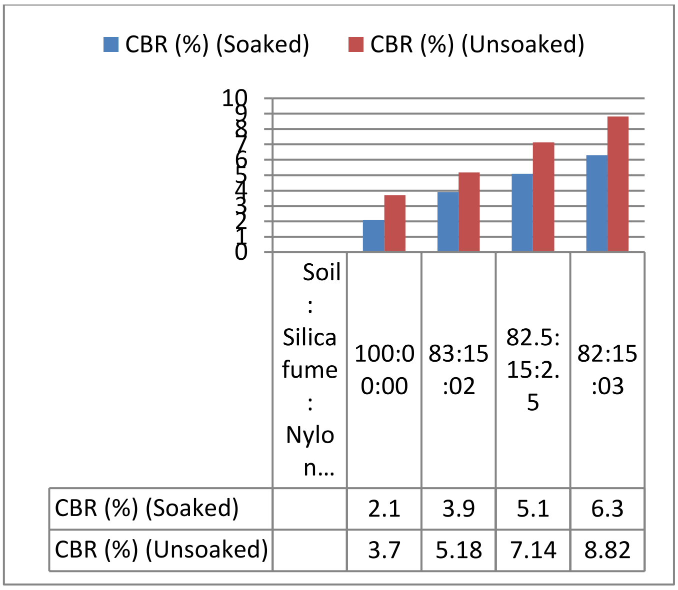


Table 7: Results of CBR of Silica Fume and Nylon fiber Mix with Soil

Sr. No.	Proportion Soil : Silica fume: Nylon fiber	CBR (%) (Soaked)	CBR (%) (Unsoaked)
1.	100:00:00	2.10	3.70
2.	83:15:02	3.9	5.18
3.	82.5:15:2.5	5.1	7.14
4.	82:15:03	6.3	8.82

Fig:-4 Variations b/w CBR Values of Clayey soil, Silica Fume and Nylon fiber with different proportions



5. DISCUSSIONS

5.1 STANDARD PROCTOR TEST:

- There is an also increase of OMC from 12.55 to 13.80% and decrease of MDD from 17.80 to 16.60% when the percentages of Nylon Fiber vary from 02, 2.5 and 3% and Silica fume is fixed at 15%.
- With Silica fume kept constant at 15% MDD increases with an addition of Nylon Fibre content in soil and Silica fume mix. The reason behind such behaviour is silica fume is lighter in weight and it has high water absorption properties because of the presence of silica oxide and hence OMC increases with the increase of silica fume content.

5.2 CBR TEST:

- The increase in CBR value from 2.10 to 6.3 when Silica Fume is fixed at 15% and Nylon Fiber added at different ratios i.e. 02, 2.5, 03.
- The CBR value of soil is 2.10 and it increases to 3 times with addition of Silica Fume 15% and Nylon Fiber 03% when observed in soaked conditions.
- This enhancement in CBR may be because of the gradual formation of hydration compounds in the soil due to the reaction between the stabilizers and the essentials particle present in the soil.

5.3 UCS TEST:

- The UCS value of soil also improves considerably with expansion of Nylon Fiber 3.0% and Silica Fume 15% with 7 days curing period. The value increases from 212kN/m² to 540kN/m² with addition of Nylon Fiber and Silica Fume.
- The UCS value of soil also improves considerably with expansion of Nylon Fiber 3.0% and Silica Fume 15% with 7 days curing period. The value increases from 230kN/m² to 560kN/m² with addition of Nylon Fiber and Silica Fume.

6. CONCLUSIONS

Following conclusions can be inferred on the basis of the experiments performed:

1. The silica fume changes compaction parameters of clayey soil. The maximum dry unit weight decreases with the increase of the silica fume content, while optimum moisture content increases with increasing silica fume content.
2. The addition of the fixed quantity of silica fume 15% with changing the content of Nylon Fiber (2%, 2.5% and 3.0%) increases the value of optimum moisture content and decrease the value of maximum dry density.
3. The C.B.R value increases with increase of Nylon Fiber along with fixed quantity of silica fume. It increased from 2.10% to 6.3% when in soaked condition.
4. Unconfined compressive strength increases with increase of quantity of Nylon Fiber and with fixed quantity of silica fume.
5. The UCS value increases with increase of Nylon Fiber along with fixed quantity of silica fume with 7 and 14 days curing period. The value increased from 212kN/m² to 540kN/m² for 7 days curing period and 230kN/m² to 560kN/m² for 14 days curing period.
6. The optimum value of Nylon Fiber and silica fume required for soil stabilization is 3.0% and 15% by weight of soil respectively.
7. Hence, the addition of Nylon Fiber and silica fume makes the soil mixes durable, economical and effective for soil stabilization process.

References

- Mrs. Megha S. Mahaladkar, Mrs. Megha Mayuri B G., "Comparison of Soil stability using Silica fume and Basalt fiber on Black cotton soil". International Research Journal of Engineering and Technology (IRJET) Volume: 09 Issue: 07 | July 2022.
- Ahanaf Tahmid, Md. Jahidur Rahman., "Soil Stabilization by Using Coconut Fiber and Nylon Fiber". Journal of Geotechnical Studies, Researchgate, Volume-7, Issue-3 (September-December, 2022)
- Mohamed A. Sakr, Wasiem R. Azzam., "Improvement of Expansive Soil by Using Micro Silica Fume". Journal of Engineering Research (ERJ), VOL 2, 2020. Researchgate.
- Soundara B, Prakash S, Sadham Hussain R J., "Performance Evaluation of Clay Soil By The Addition Of Silica Fume And Sisal Fibre". International Research Journal of Engineering and

Technology (IRJET) Volume: 06 Issue: 03 | July 2019.

- Kawther Y. AL-Soudany., "Improvement of Expansive Soil By Using Silica Fume". Kufa Journal of Engineering Vol. 9, No. 1, January 2018, PP. 222-239 Received 15 May 2017, accepted 13 June 2017, Researchgate.
- Vishal Rana and Prof. Vinod Kumar Sonthwal, "Improving the Engineering Properties of Soil Using Sisal Fibre with Rice Husk Ash," International Journal for Research in Applied Science & Engineering Technology (IJRASET), ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.538, Volume 10 Issue V May 2022.
- Ahmed Khan, Mohd Fahiem Tahir and Er. Tripti Goyal, "Study on engineering properties of soil using bagasse ash and sisal fiber shazad", International Research Journal of Engineering and Technology (IRJET), Volume: 06 Issue: 03 | Mar 2019.
- Sandyarani, Dr.Vageesha S Mathada and Sharanakumar. "Stabilization of black cotton soil by using Sisal fiber", International Research Journal of Engineering and Technology (IRJET), Volume: 05 Issue: 08 | Aug 2018.
- Adarsh Minhas, Veena Uma Devi (2016), *soil stabilization of alluvial soil by using marble powder*, International Journal of Civil Engineering and Technology (IJCIET) Vol. 7, Issue pp. 87–92, Article ID: IJCIET ISSN: 0976-6316.
- Kumar, S., Dutta, R. K., & Mohanty, B. "Potential of bentonite-lime-mix modified with phosphogypsum and reinforced with sisal fibers", Periodica Polytechnica Civil Engineering, 59(2), pp. 143-154, 2015.
- Ayyappan, S., Hemalatha, M.K. and Sundaram M., "Investigation of Engineering Behavior of Soil, Polypropylene Fibers and Fly Ash-Mixtures for Road Construction", International Journal of Environmental Science and Development, 1(2), pp.171, 2010.
- Aigbodion, V. S., S. B. Hassan, T. Ause, and G. B. Nyior. "Potential utilization of solid waste (Sugarcane Bagasse Ash)." Journal of minerals and materials characterization and engineering 9(01), pp. 67, 2010.
- Amu, O.O., Ogunniyi, S.A. and Oladeji, O.O., 2011. Geotechnical properties of lateritic soil stabilized with sugarcane straw ash. American journal of scientific and industrial research, 2(2), pp.323-331.
- Saravanan, R., Thomas, R.S. and Joseph, M., "A Study on Soil Stabilization of Clay Soil using Fly Ash. "International Journal Research. Civil Enggineering Architecture Design, 1, pp.33-37, 2013.
- Kawade, U. R., V. R. Rathi, and Vaishali D. Girge. "Effect of Use of Sugarcane Bagasse Ash on Strength of Concrete." International Journal of Innovative Research in Science, Engineering and Technology 2(7), pp. 2997-3000, 2013.
- Wubshet M. Sugarcane Bagasse Ash as a sub-grade soil stabilizing material. Addis Ababa Institute of Technology. 2013.
- Kharade, A.S., Suryavanshi, V.V., Gujar, B.S. and Deshmukh, R.R., "Waste Product Sugarcane Bagasse Ash from Sugar Industry can be Used as Stabilizing Material for Expansive Soils". International Journal of Research in Engineering and Technology, 3(3), pp.506-512, 2014.
- Jiesheng, Liu, Zhang, Juan, and Xia Lin. "Deformation and Strength Characteristics of

Sisal Fibrous Soil." EJGE, 19, 2014.

- Das, Arindam, and Sabyasachi Roy. "Effect of Expansive Soil on Foundation and its Remedies." In National Conference on Emerging Technology and Applied Sciences (NCETAS) 15th-16th Feb, pp. 92-95. 2014.
- Butt, Wajid Ali, B. A. Mir, and J. N. Jha. "Strength Behavior of Clayey Soil Reinforced with Human hair as a Natural Fiber", Geotechnical and Geological Engineering, 34(1), pp. 411-417, 2016.
- Abhijit, S. and Aruna, T. "Effect of Ground Granulated Blast Furnace Slag (GGBS) and Sisal Fibers on Black Cotton Soil", International Journal of Innovative Research in Science, Engineering and Technology, 4(7), pp. 5409-5417, 2015.
- Alhassan, Musa, and Alhaji Mohammed Mustapha. "Improvement of Deficient Soils in Nigeria using Sugarcane Bagasse Ash- A Review", In Proceeding of 17th International Conference on Civil and Building Engineering, Dubai, pp.1040-1049, 2015.
- Akshaya Kumar Sabat and Radhikesh P. Nanda, *"Effect of marble dust on strength and durability of Rice husk ash stabilised expansive soil"*, International Journal Of Civil And Structural Engineering, Volume 1, No 4, 2011, 939-948.
- Altug saygili (2015) *Use of Waste Marble Dust for Stabilization of Clayey Soil*' ISSN 1392–1320 materials science (Medziagotyra).
- Asskar Janalizadeh Choobbasti , Saman Soleimani Kutanaei (2017) *Microstructure characteristics of cement-stabilized sandy soil using nanosilica*, Journal of Rock Mechanics and Geotechnical Engineering.
- Baser O (2009), "*Stabilization of Expansive Soils Using Waste Marble Dust",* Master of Science Thesis, Submitted to Civil Engineering Department, Middle East, Technical University.
- Chhaya Negi, R.K. Yadav, A.K. Singhai (2013) *Effect of Silica Fume on Index Properties of Black Cotton Soil* International Journal of Scientific & Engineering Research, Volume 4, Issue 8, ISSN 2229-5518.
- Parte Shyam Singh and Yadav (2014*) Effect Of Marble Dust On Index Properties Of Black Cotton Soil* IJERST Vol. 3, ISSN 2319-5991.
- R.P. Arora, N.K. Ameta, Kapil K. Samar And K.L. Samdani (2014) *Improvement of engineering characteristics of locally available soil mass by use of marble dust* ISSN-2230-9284 .
- R.Bharathan, A.Giridharan, P.Saranya (2017) *Soil Stabilization Using Silica Fume and Cement* SSRG International Journal of Civil Engineering – (ICCREST'17) - Special Issue- ISSN: 2348 – 8352.
- Sreekumar. V.Babu, Mary Rebekah Sharmila (2017) *Soil Stabilisation Using Marble Dust* International Journal Of Civil Engineering And Technology (IJCIET) Vol. 8 Pp. 1706-1713, Article Id: Ijciet_08_04_192 ISSN : 0976-6316.
- Singh, R.B. and Khanna, P. (1999). *Studies on a reinforced system for utilization of thermal power plant waste fly ash, fly ash disposal and deposition*: Beyond 2000 AD, Narosa Publishing House, New Delhi (INDIA).
- Sachin N. Bhavsar and Ankit J. Patel,(2014) "*Behavior of Black Cotton Soil after Stabilization with Marble Powder",* International Journal of Science and Research (IJSR). Volume 3, Issue 11 (November2014) pg 200-206 and Volume 3 Issue 12 (December 2014) pg 769-772.