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Effects of Basalt Fiber and Coir Pith on Geotechnical Properties of Clayey Soil

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Abstract: ***Clay is a soft soil with low shear strength and high compressibility. These types of soils can be treated by stabilization. In this paper, the effects of basalt chopped fiber with coir pith on geotechnical properties of clayey soil in varying proportions are discussed. The utilisation of waste material and natural fibers helps to boost soil quality is beneficial, because they are inexpensive, accessible locally and ecological. Basalt fiber is a non - metal inorganic fiber which acts as a reinforcement for soil. It has excellent thermal, chemical, mechanical properties and environmental friendly material. The stabilizing effect of both the fibers on soil properties was observed. Addition of fibers improved the soil properties such as shear strength, and showed significant effects on cohesion, shrinkage characters. Also, it reduces desiccation and cracking.***

Keywords: Coir pith, Stabilization, basalt fiber

1. Introduction

Basalt fiber is a natural mineral fiber obtained from crushed basalt rocks. It is a non - metal inorganic fiber which acts as a reinforcement for soil.1 Kg of basalt reinforces is equal 9.6 Kg of the steel. It has better physicomechanical properties and can replace many costly and rare materials. When compared to other fibers like carbon fiber, sisal fiber and polypropylene fiber it has many unique physical advantageous properties and it is specifically environment friendly.

The pith material forming non - fibrous tissues of the coconut husk is generally referred to as coir pith and also coco - peat. It is a spongy material obtained during the process of extracting fiber from coconut husks. It is also a hydrophilic material and hence used as soil stabilizer. The spongy structure of coir pith facilitates retention of water. It absorbs over eight times its weight of water.

2. Literature Review

Ningyu et al. (2021) studied about red clay which is a soft soil with low shear strength and high compressibility. Through triaxial experiments, this work extensively explores the strength behaviour of red clay reinforced by basalt chopped fibre (BCF). During the experiments, BCF - reinforced specimens were compared to original red clay and specimens reinforced with polypropylene fibre (PPF) of various fibre concentrations and lengths. Scanning electron microscopy was used to investigate the variance in interior microstructure of specimens obtained from triaxial tests (SEM). The BCF has clear physical - chemical advantages over traditional reinforcing materials. The red clay reinforced by the BCF shows deformation hardening features on axial stress - strain curves. The main benefit of BCF on red clay is that it improves cohesiveness, although it only makes a minor contribution to the increase in internal friction angle. Xingfen et al. (2017) conducted the study of melting properties of basalt based on their mineral components. In this paper, the mineral components, initial liquid temperature, melting temperature, melting process, and melt homogeneity of andesite, andesitic basalt, tholeiite basalt, and alkali basalt are investigated. The results demonstrates that the basalts exhibit initial liquid temperatures and melting temperatures in the following descending order: andesite, andesitic basalt, tholeiite basalt, and alkali basalt. The basalts' initial liquid temperature and melting temperature rise as the quartz and plagioclase (anorthite and albite) content rises, but fall as the pyroxene (diopside and hypersthenes) content rises. The mineral components of basalt gradually melt during the melting process, and the ordered crystal structure is changed into an amorphous glass structure. To homogenise the basalt melt, the melting temperature or melting time must be increased throughout the melting process due to the high melting temperature and narrow temperature range of the melt reaction.

Hajar and Amin (2021) studied the Radioactive materials are widely used in mining, manufacturing, medicine, and agricultural processes. These materials produce hazardous waste, which should be properly disposed of. As a result, to prevent contamination of the surrounding environment, a sufficient radiation shielding barrier is required. Clay soil is a radiation shielding material that is often used to cap hazardous and radioactive landfills since it is effective and environmentally benign. In this study the effects of basalt fiber additive in four percentages, including 0.5, 1, 2, and 5 on the bentonite clay radiation shielding performance, were investigated using experimental and simulation methods. In addition, the permeability of the mixes is monitored to ensure that it remains within permissible limits, which is an important characteristic for radioactive waste disposal barriers. Energy - dispersive X - ray spectroscopy (EDX) and scanning electron microscopy were used to examine the material's chemical and microstructure (SEM). The HPGe spectrometer detector was used to determine the linear attenuation coefficient (μ), which represents the material radiation shielding performance. The addition of basalt fibre enhances shielding efficacy due to a larger linear attenuation coefficient with 2% of basalt fiber yielding the greatest values of 12.3 m−1, 10.14 m−1, and 8.5 m−1 obtained for

661.6 keV, 1173.2 keV, and 1332.5 keV energy levels respectively.

Jian et al. (2021) discussed about triaxial shear behavior of basalt fiber - reinforced loess based on digital Image. Unconsolidated - undrained (UU) triaxial shear tests were performed on loess samples using digital image technology at three fibre lengths (L) and four fibre contents (η). Results prove the improvement of the shear strength of loess by basalt fiber inclusion, which varies in inverted u - shaped pattern with fiber length or fiber content, with the maximum at η = 0.6%, L = 12 mm. Digital Image Technology was employed to analyze the damage characteristics and strain field of the surface of the sample at different loading time. From shear contraction to dilatancy, the volumetric strain of the reinforced sample reduces as the fibre content or length increases. A statistical damage constitutive model of fiber - reinforced loess was established with limited parameters calibrated. The rationality of the model was verified by comparisons of measured and calculated stress - strain data. Xiangfeng et al. (2019) conducted a series of triaxial tests was performed on a cemented sand improved by adding various contents of basalt fiber. SEM was used to investigate the binding and interfacial interaction between the fibre and the cemented sand matrix, as well as the failure model of the interfacial interaction at the sliding surface (SEM). The cohesiveness and residual cohesion increased and then reduced as the fibre content increased, and the brittleness index decreased, however the internal friction angle and residual internal friction angle showed no clear variation patterns.

Seyed et al. (2021) studied on the influence of freeze–thaw cycles on the mechanical behavior of cement - or lime - stabilized soils. However, only a few research have looked at the impact of freeze–thaw cycles on fiber - reinforced cement - stabilized soil. The main objective of this study is to determine the effects of polypropylene fiber (PPF) and basalt fiber (BF) content (0%, 0.5%, 1%, 2%, and 5%), cement content (0%, 3%, and 9%), number of freeze–thaw cycles (0, 2, 4, 8, and 10), and initial moisture content on the unconfined compressive strength (UCS) of clay soil. The study demonstrates that adding cement, PPF, or BF to soil results in a considerable increase in strength, with PPF - reinforced specimens having significantly higher strength than BF - reinforced specimens. The UCS values of specimens compacted at optimal moisture content (OMC) are nearly identical to those of specimens compacted at 0.8 OMC or 1.2 OMC. The strength of specimens rises when the cement content and cure period are increased. However, the axial strain at failure for cement - stabilized specimens decreased with increasing cement content or curing time. Furthermore, it is concluded that the increase in the UCS of combined PPF or BF with cement inclusion is more than that caused by each fiber without cement. A regression model is developed to predict the UCS in terms of four effective agents for each case of stabilization by BF or PPF. Results indicate a satisfactory performance of the model where the Pearson correlation coefficient above 0.95 for UCS prediction is obtained.

Deepak and Sitesh (2021) discussed on the design of the different pavement layers depends very much on the strength of the sub - grade soil they are to be laid over. The power of a subgrade is primarily measured in CBR (California Bearing Ratio). When the sub - grade is weaker, larger layers are required, whereas when the sub - grade is stronger, thinner layers of pavement are required. The utilisation of waste material and natural fibres to improve soil quality is advantageous since they are inexpensive, readily available, and environmentally friendly. In this study, the stabilising influence of Natural Fiber (coconut coir) on soil characteristics was observed. As a result, in this study, an attempt was made to assess the growth in subgrade intensity by adding Coir fibre in various layers. Different types of parent subgrade soil with coir fibre were tested in this CBR investigation. The total efficiency of coir fibre was shown to be greater in the laboratory investigation. The CBR value of the parent subgrade soil was also found to increase as the number of coir fiber layers increased. Leema et al. (2014) conducted laboratory investigation in the improvement of subgrade characteristics of expansive soil stabilised with coir waste Coir waste is a by - product of the coir production business, consisting of coir pith and coir fibre extracted from coconut husk during the extraction of coir fibre. This paper presents an investigation on the behavior of soft soil stabilized with varying percentages of coir pith (0 - 3%) and coir fibre (0 - 1%) by carrying out Standard Proctor, Static Triaxial test and California Bearing Ratio (CBR) tests. The test results showed that stabilization with coir waste had a significant effect on the compaction, Elastic modulus as well as CBR characteristics.

Yuan - shun et al. (2021) conducted an experimental study on the strength properties of fiber - reinforced clayey soil stabilized with lime or cement at lower content (5% by weight) cured for 28 days. On compacted untreated, lime - treated, and cement - treated clayey soil specimens reinforced with various materials, a series of consolidated undrained (CU) triaxial compression tests and unconfined compressive (UC) strength tests were undertaken. Polyester fiber content (i. e, 0%, 0.05%**,** 0.1%, 0.2% by weight) to evaluate the effect of fiber content on the strength behavior of tested soil. At a specific fibre percentage, the addition of lime or cement resulted in a considerable increase in strength and strength metrics, with cement having a stronger improvement impact than lime. The strain - softening curves for fiber - reinforced specimens treated with lime or cement were compared to the strain - hardening curves for fiber - reinforced specimens. For fibre and lime - treated specimens, residual strength is around 75% of peak strength, compared to a 50% decline in peak strength for fibre and cement - treated specimens. The specimen with higher fibre content has a stress and strain curve that is higher than the specimen with lower fibre content. The failure mode of fiber - reinforced plain soil was ductile, but the failure mode of lime or cement - treated specimens was brittle. When the polyester fibre content was increased from 0 to 0.2 percent, the values of undrained shear strength, unconfined compressive strength, cohesion, and internal friction angle rose in both plain and lime - treated soil. Peak values were observed in lime - treated soil sample when the fibre content was 0.1 percent.

Jayasree et al. (2015) studies on the shrinkage characteristics of coir waste mixed expansive soil by varying coir pith from

0 to 3 % and short coir fibre from 0 to 1 % by dry weight of soil. The results revealed that adding coir pith and short coir fibre to expansive soil efficiently reduces shrinkage. The volumetric shrinkage was obtained from shrinkage limit test and three dimensional shrinkage strain test. The three - dimensional shrinkage strain test was shown to be more reliable than the shrinkage limit test for calculating volumetric shrinkage. The study tries to exploit this demerit of coir waste by utilizing it to control the volume change behavior of expansive soils. The shrinkage characteristics were found to improve with both coir pith and short coir fibre addition to expansive marine clay soil. For short coir fibre, the degree of expansiveness, of Cochin marine clay changed from ‘‘Critical’’ to ‘‘Marginal’’. With coir waste treatment, the shrinkage limit increases, indicating that the soil is more resistant to volume change due to desiccation. The linear shrinkage strain reduction for treatment with coir pith and short coir fibre was by 46 % and 50 % respectively. Also, the volumetric shrinkage strains are reduced by 20 % with both the coir pith and short coir fibre. The vertical shrinkage strain is higher than that of diametrical shrinkage which indicates the structural anisotropy that simulates thE field condition. Jayasree et al. (2014) studied about coir waste which is a by product of the coir manufacturing industry. The work aims to study the use of coir waste to control the volume change behavior of marine. The effect of adding coir waste on volume change behaviour was studied using consolidation tests, swelling pressure tests, and three - dimensional (3D) shrinkage strain testing. Coir waste consists of pith along with some short fibers which were separated to study their independent effects on volume change behavior. Three - dimensional free swell tests were used to investigate the volumetric swelling of the best soil pith - fiber combination. Mixing of coir waste with expansive soil helps to mitigate the volume change behavior of expansive soil. Vivi et al. (2015) studied the effects of the mechanical properties of the coir fiber which reinforces soft marine clay were investigated by a series of laboratory tests regarding unconfined - compression, indirect tensile properties, and three point bending. Fiber content was found as the main factor that affected the strength of the soil specimens. The results indicated that for the unconfined compression test at the maximum dry density and optimum moisture content, compressive strength increased with fiber content up to 1%. A similar trend was also found in the tensile strength, flexural strength, and young’s modulus of the soil. The strength and ductility increased sharply until the threshold of 1.5% fiber content.

Narendar et al. (2014) studied on set of composites of same composition having chemically treated coir pith was also prepared. Mechanical properties of composites such as tensile strength, flexural strength, impact strength and hardness were evaluated. Though coir pith acts as a good reinforcement in epoxy resin, the incorporation of nylon fabric and the chemical treatment of coir pith were found to enhance the properties of the composites further. Chemical resistance and flame resistance of composite systems were also found to be improved with hybrid composites. Since water uptake and retentions property of coir pith is a major drawback when it comes to its application in composites, the ageing of composite panels in moist environment was investigated. The results suggested that the presence of nylon fabric and chemically treated pith can contribute to longer durability of the panels in moist conditions.

Qingxuan et al. (2020) conducted a fundamental investigation on the alkali resistance of basalt fiber and its textile in different alkaline solutions. C - glass fiber and AR - glass fiber are explored as references. The morphology, element and phase composition of fibers before and after etching in alkaline solution are studied via scanning electron microscopy (SEM), energy dispersive spectroscopy (EDS) and fourier transform infrared spectroscopy (FTIR), respectively. In addition, the tensile breaking force of the fiber mesh is determined. The results indicate that the alkali resistance of basalt fiber and its textile is much superior to that of C - glass, but slightly weaker than that of AR - glass. A typical structure of basalt fiber etched in NaOH solution is composed of fiber core, gel layer, deposition layer and crystalline compound, and the corrosion mechanism is a continuous and cyclic process characterized by the formation and subsequent exfoliation of corrosion shell. However, the typical structure of basalt fiber etched in cement solution is composed of fiber core, crystalline compound and the corrosion shell with a large amount of etch holes, and the corrosion mechanism is a damage accumulation process characterized by the formation, expansion and coalescence of the etch holes. It is also found that the dissolution behavior of basalt fiber in NaOH solution can be well evaluated by the dissolution kinetics based on zero - order model and contracting cylinder model.
Aravalli et al. (2018) analysed enhancement of index and engineering properties of expansive soil using chopped basalt fibers and silica fume, which included conduction of series of consistency tests along with unconfined compressive strength and california bearing ratio tests on untreated and treated soil for respective optimum moisture content and maximum dry density. The pronoumced combination includes, significant content of fibers considered is 0.15%, 0.25%, wherein the length of fiber is kept constant of 12mm along with 3% and 6% of silica fume. The test results illustrates tremondus improvement in the Atterberg’s limits, dry density and UCS of expansive soil. Amongst all the combinations considered for treatment, 0.25% basalt fiber+ 6% of silica fume contributed to enhance the strength of soil at maximum value. The combination of basalt fiber and silica fume induces mechanical as well as chemical strength of the expansive soil. The increment in the soil properties is due to the soil–column interaction characteristic of fiber and pozzolanic action of silica fume.

Dasaka and Sumesh (2011) in the present study, comprehensive experimental work has been conducted to investigate the effect of coir fiber on the stress–strain characteristics of a reconstituted cohesive soil. Laboratory model studies are conducted to study the effect of length and amount of fiber on the shear strength of soil. Tests were carried out using fiber contents varying in the range of 0%–2% by dry weight of the soil. The unconfined compressive strength of soil is significantly increased when coir fiber is added to it. The increase is directly proportional to the quantity of the fiber used. The peak compressive strength of the fiber - reinforced soil with 1.5% fiber content is more than twice that of the un - reinforced soil.

Jairaj et al. (2018) conducted study on compaction characteristics of black cotton soil (BC soil) admixed at different percentage of untreated and treated coir fibers were used with optimum lime content and without lime content. Alkali - treated and epoxy resin - coated and stone dust - sprinkled coir fibers have been comparatively assessed in terms of compaction characteristics and strength of fiber - reinforced BC soil. The present study indicated that the maximum dry density decreases with increase in percentage of coir fibers for both black cotton soils with and without optimum lime content. Marginal variation in maximum dry density (MDD) when fiber content is varied from 0 to 0.5% occurs and beyond 0.5% fiber content significant reduction in MDD occurs. Increasing fiber content increases the corresponding optimum moisture content (OMC) indicating addition of fiber increases water absorption by coir fibers causing an increase in OMC. However, the alkali treatment of coir fiber causes a significant reduction in water absorption leading to significant improvement in compaction characteristics and strength of BC soil.

Narenda and Priya (2013) conducted laboratory test to modify the morphology and chemical properties of pith to make it better filler in the processing of polymer composites. Coir pith was subjected to mercerization followed by different types of chemical treatment. The products were analyzed in detail using FTIR, XRD, optical microscope, AFM and SEM. The chemical treatment resulted in increased density, thermal stability and reduced water retention behavior.

Mahdi et al. (2021) investigated the influence of natural fibers as sustainable ones including basalt (BS) and bagasse (BG) as well as synthetic polyester (PET) fibers on the strength behavior of clayey soil. The effects of various fiber contents (0.5%, 1% and 2%) and lengths (2.5 mm, 5 mm and 7.5 mm) were experimentally evaluated. By conducting ITS and CBR tests, it was found that increasing fiber content and length had a significant influence on CBR and ITS values. Moreover, 2% of 7.5 mm - long fibers led to the largest values of CBR and ITS. The results of the triaxial compression test revealed that with the addition of BS fibers, the internal friction angle increased by about 100%, and with the addition of PET fibers, the cohesion increased by about 70%. Moreover, scanning electron microscope (SEM) analysis was employed to confirm the findings. The relationship between CBR and ITS values, obtained via statistical analysis and used for the optimum design of road pavement layers, demonstrated that these parameters had high correlation coefficients. The outcomes of multiple linear regression and sensitivity analysis also confirmed that the fiber content had a greater effect on CBR and ITS values than fiber length.

Abrahams (2008) demonstrates the potential for the use of sustainable biodegradable vegetable fibres over man - made polymeric materials in ground improvement. Built environment protection is important because construction represents a major contribution to climate change, resource depletion and pollution at a global level. Global strategy for more sustainable construction is a significant step towards a more successful, socially and environmental friendly atmosphere making a strong contribution to the better quality of life signaled by sustainable development strategy. The brightest sustainable strategy in ground engineering is the consideration of substituting the use of biodegradable materials as substitute to the non - biodegradable (man - made materials) in a situation where there is requirement for short - term ground improvement. The most important properties of biodegradable geotextiles such as vegetable fibres for soil reinforcement are their high initial tensile strength. Widespread use of biodegradable fabrics in ground engineering has not happened due to the limited service life of these fabrics and availability of chemical fibres, which are superior to vegetable fibres.

Vivek and R. K. Dutta (2021) presents the bearing ratio behavior of sand overlying clay with two woven and two non - woven treated coir geotextiles at the interface. The chemicals such as *p* - aminophenol, sodium periodate and sodium hydroxide were used to treat the coir geotextiles. The results indicated that the unsoaked/soaked bearing ratio of the sand overlying clay with woven coir geotextiles at the interface decreased after the chemical treatment whereas the trend was reverse in case non - woven geotextiles. The unsoaked bearing ratio of the sand overlying clay with the treated/untreated woven and non - woven coir geotextiles at the interface was higher than the soaked bearing ratio. The C: O ratio both for the woven and the non - woven coir geotextiles increased after the chemical treatment. The emissions of Si increased for the woven coir geotextiles whereas it decreased for the non - woven coir geotextiles after the chemical treatment. The chemical treatment results in the modification of the surface of both the untreated woven and non - woven coir geotextiles.

Sivakumar and Sandeep (2010) conducted an analytical model for the analysis of fiberreinforced soil in the framework of modified cam clay model is presented. The analytical model is verified using experimental results from the standard undrained triaxial tests with pore water pressure measurements. Tests have been conducted on clayey soil specimens reinforced with randomly oriented discrete coir fibers with different percentages of fiber contents. Numerical simulations of triaxial compression tests on fiber - reinforced clay specimens were also performed. Results are presented in the form of stress vs. strain curves for plain soil as well as fiber - reinforced soil for various fiber contents based on the model developed. The results demonstrate the applicability of proposed analytical model in predicting the stress strain response of fiber - reinforced soils.

Yilmaz (2015) investigate the effects of discrete polypropylene fibers and Class C fly ash on the stress–strain and shear strength behavior of clayey soil. Two types of fiber (fibrillated polypropylene fiber and multifilament polypropylene fiber) in two different lengths (6.0 mm and 19.0 mm) and two fiber dosages (i. e.0.5% and 1.0% by dry weight of soil) were considered. At first, compaction characteristics of the untreated soil and seven different fly ash–soil mixtures (2.5%, 5.0%, 7.5%, 10.0%, 15.0%, 20.0%, and 30.0% by dry weight of soil) were evaluated at standard compaction energy. Considering compaction characteristics, unconfined compression tests of untreated soil and five different fly ash–soil mixtures (5.0%, 10.0%, 15.0%, 20.0%, and 30.0% by dryweight of soil) were carried out after 1 - , 7

- , 14 - , 28 - and 90 - day curing periods. According to the obtained test results, untreated soil and two different fly ash–soil mixtures (i. e.10.0, and 30.0% by dry weight of soil) were mixed with fibrillated polypropylene fiber and multifilament polypropylene fiber in two different lengths and in two different fiber dosages, separately. A total of 17 different fiber–fly ash–soil mixtures were composed, and their unconfined compression testswere carried out after 28 - day curing period. According to unconfined compression test results, 6 different fiber–fly ash–soil mixtureswere selected for UU triaxial tests at the end of 28 - day curing period. The obtained test results indicated that the effect of fly ash content on the stress– strain behavior is superior to the effect of fibers. The post - peak strength behavior is strongly affected by fiber type, length and dosage. The magnitude of the effect increases as the fly ash content increases. Inclusion of fiber alone without fly ash decreases unconfined compressive strength (UCS) of the compacted fiber–clay mixtures. On the other hand, when combined with fly ash, fiber inclusion increases UCS depending on fiber type, length and dosage. Moreover, for both fiber types and fiber lengths, the higher the dosage of fiber, the higher the UCS is. The increase in UCS becomes as much as 218% for 30% fly ash content and 1.0% 19 mmlong fibrillated polypropylene fiber.

3. Conclusion

Basalt fiber is a non - metal inorganic fiber which acts as a reinforcement for soil. It has excellent thermal, chemical, mechanical properties and environmental friendly material. Coir pith is renewable product, also act as a soil stabilizer with fiber is abundant, non - toxic in nature, low density and high degree of water retaining capacity. Finding the optimum percentage of both materials and combining them together make it more economical and vital in soil stabilization. Effective utilization of coir pith as a soil conditioner paved the way for economic utilization of the potential valuable waste product into an environmental friendly product, thus solving disposal problem faced by coir industry.

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