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Strength Characteristics of Sandy Soil Reinforced with Kenaf Fiber and Natural Rubber Latex

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The construction industry continuously seeks sustainable and cost-effective alternatives for soil improvement to address the growing environmental concerns associated with cement-based stabilization methods. Sandy soils present significant challenges in construction due to their low cohesion, high permeability and prone to erosion and liquefaction. This study investigates the strength behaviour of reinforced sandy soil with kenaf fiber and bonded using natural rubber latex (NRL). An experimental program of 15 samples was conducted to evaluate the physical and mechanical properties of poorly graded sand samples treated with varying percentages of kenaf fiber and NRL. Physical properties tests included particle size distribution, Atterberg limits and specific gravity determination. Strength properties were determined through direct shear box tests while compaction characteristics were evaluated using standard Proctor compaction tests. The results demonstrated that the used of kenaf fiber as sustainable reinforcement and natural rubber latex stabilization agent significantly enhances the soil's shear strength parameters. The optimum percentage of the soil mixture identified to be 1.0% kenaf fiber combined with 10% natural rubber latex achieved a cohesion of 16.03 kPa and friction angle of 22.80° representing improvements of 68.4% and 9.5% respectively compared to untreated sandy soil. The compaction properties showed that maximum dry density decreased from 1.74 g/cm^3 to 1.59 g/cm^3 while the optimum moisture content decrease from 15.72% to 15.50% for the best combination of soil mixture. The strength enhancement of soil cause from these two mechanisms: NRL provide interparticle bonding by coating soil particles and filling void spaces while randomly distributed kenaf fibers provide tensile reinforcement for soil. The findings demonstrate that kenaf fibers and natural rubber latex effectively improve the strength properties of sandy soils which offer a sustainable alternative to cement-based stabilization methods.

Keywords:
Soil stabilization; natural rubber latex; kenaf fiber; shear strength; sandy soils

1. Introduction

The global construction industry faces mounting pressure to develop sustainable and environmentally responsible solutions for geotechnical engineering challenges, particularly in the realm of soil improvement for weak or problematic soils. With infrastructure development

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accelerating worldwide and the construction sector accounting for significant carbon emissions, the need for eco-friendly alternatives to conventional soil stabilization methods has become increasingly urgent. Soil improvement represents a fundamental challenge in geotechnical engineering especially when dealing with problematic or weak soils that are unable to sustain the environmental stresses or support structural loads. Soil stabilisation has been widely used to modify the geotechnical properties of soils which improving the soil performance, strength, and durability for a various construction application [1] . Chemical additives such as Portland cement and lime which can be considered traditional methods of soil stabilization can increase soil strength and reduce the compressibility through cementation and pozzolanic reactions. However, the cement industry poses serious environmental concerns due to it contribute to the global carbon dioxide emissions for more than 8% with approximately 60% coming from process-related activities and 40% from energy consumption [2] . Researchers and practitioners are starting to explore alternative stabilizing materials that are both environmentally friendly and technically efficient due to the growing awareness regarding sustainable development goals and to reduce greenhouse gas emissions. Soil stabilization usually involves modifying the soil matrix by chemically or mechanically which change the properties of soil particles by cementation, ion exchange or particle rearrangement. In contrast, soil reinforcement incorporates discrete components to the soil mass which improve soil shear or tensile resistance without alter the basic properties of the soil [3] .

According to the Unified Soil Classification System, sandy soil can be ranging from 0.075 to 4.75 millimeters in diameter which this type of soil was one of the most common geomaterial types found in geotechnical engineering practice. The properties of sandy soil include high permeability, loose structure, low cohesion and high porosity can cause the serious engineering issues in terms of stability and load-bearing capacity [4] . Research has demonstrated that based on USCS and AASHTO, sandy soils that are categorized as poorly graded sands usually have specific gravity between 2.55 and 2.65 and natural moisture contents between 2 and 16 percent which depend on environmental condition and groundwater levels **Error! Reference source not found.**. The relative density of sandy soils which corresponds to the ratio of the actual decrease in void volume to the maximum possible decrease in void volume which shows the point which the sand can be further densified beyond its natural state. This will become major effect on the engineering behavior of sandy soils. Sandy soils pose challenges in geotechnical application because of its tendency to lose particle-to-particle friction over time, susceptibility to erosion and potential for liquefaction during seismic events. The absence of cohesion in pure sandy soils requires the addition of chemical stabilizing agent or reinforcing material to improve its properties for application such as pavement foundations, earth structures and building foundations. The lack of cohesiveness in sandy soils has been addressed by recent research through variability of improvement techniques to improved tensile resistance and crack preventing capabilities by use the addition of clay fraction to create cohesive bonding, chemical stabilization with cement, lime or other binders and reinforcement with natural or synthetic fiber [5] .

Kenaf (Hibiscus cannabinus L.) was a warm season annual fiber crop which belonged to Malvaceae family that have been cultivated by people for thousand years for produce fiber. Kenaf fiber require less water and fewer pesticides to grow due to its exceptional adaptability to different types of soil types and climatic conditions making it an environmentally friendly compared to other fiber crop. The global cultivation footprint of kenaf spans over twenty nations, with predominant production concentrated in India, Bangladesh, China, Thailand, and Malaysia, underscoring its broad utility and acceptance in tropical and subtropical regions [7] . Kenaf bast fiber are biochemically composed of cellulose (56 -64%), hemicellulose (21 – 35%), and lignin (8 – 14%) which it contributes to high mechanical strength and dimensional stability [8] . The application of kenaf fiber in geotechnical engineering has attracted a lot of attention in recent years because of their exceptional mechanical properties, quick production and natural biodegradability. According to research, kenaf fiber can improve the shear strength parameters of the soil which function similarly to plant and tree roots in natural soil stabilization when distributed it randomly within the soil matrix **Error! Reference source not found.**. Additionally, kenaf fiber-based composites have shown biodegradability in soil within ten to sixty days compared to synthetic geosynthetics which reducing long term environmental impacts [10] . Research on fiber-reinforced soils has consistently demonstrated that the addition of discrete fibers increases the peak shear strength, residual strength, and energy absorption capacity of soils, with improvements directly related to fiber content, length, and distribution uniformity **Error! Reference source not found.**.

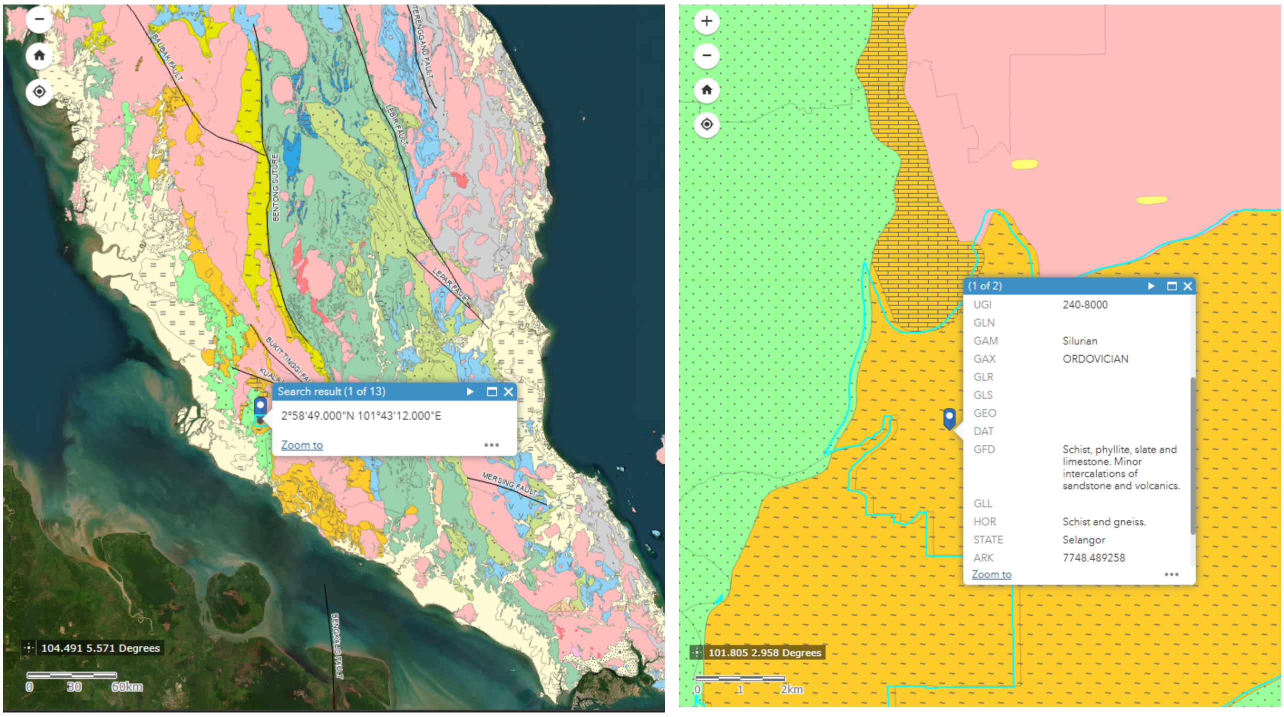
Natural rubber latex (NRL) was a renewable and sustainable resource that was extracted from the Hevea brasiliensis tree by a tapping process which collects the milky fluid from the bark. The rubber particle which was a colloidal emulsion made of cis-1,4-polyisoprene that were suspended in an aqueous serum contain the organic and mineral compounds. The commercial natural rubber latex can be characterized by its elasticity, water resistance and electrical insulation properties. This unique properties of NRL make it suitable for advanced applications such as soil stabilization. Recent research has introduced NRL as a sustainable polymeric additive by offering an environmentally friendly substitute for conventional synthetic additives and may lower the cement consumption in soil stabilization which may improve the mechanical performance of soil-cement-mixtures [2] . Natural rubber latex improves the soil properties by forming thin polymeric films that will fill the void space within the soil matrix and coat the soil particle. The latex particles disperse throughout the soil mixture when NRL was mixed with soil and water which it will coagulate to form continuous elastic films that bind the soil particles together after the compaction and curing. This process will enhance the soil properties in term of improved ductility, reduced porosity, increased resistance to crack propagation and improved interparticle bonding. The addition of NRL has been shown to change the soil behavior from brittle to ductile which particularly useful for pavement base and subbase applications where resistance to fatigue and cyclic loading was important. Researchers found that mechanical strength improvements in pavement bases using NRL [12] , while subsequent studies highlighted its specific role in enhancing long-term durability **Error! Reference source not found.**. Research have shown that NRL treatment can improve the compressive strength, flexural strength and durability of cement-stabilized soils where the optimal rubber-to-cement ratios between 10 to 20 percent by weight of cement or mixing water. Furthermore, NRL treatment in soil have demonstrated to be effective in reducing the potential for liquefaction in sandy soils when the sand grain was binding together to prevent development of excess pore pressures during seismic loading **Error! Reference source not found.**. The environmental benefits of NRL treatment include its biodegradability, non-toxicity and carbon-neutral production cycle that was proved by the field studies that NRL treatment does not damage vegetation or seed germination in treated areas [15] .

Despite extensive research on individual applications of natural fibers or polymers in soil stabilization, limited studies have investigated the synergistic effects of combining kenaf fiber with natural rubber latex for sandy soil improvement. This research gap is significant because the complementary mechanisms of fiber reinforcement and polymeric stabilization could address multiple failure modes simultaneously. Furthermore, most existing studies focus on fine-grained soils, leaving sandy soils have been neglected in the literature despite their prevalence in construction sites worldwide. The significance of this research lies in its potential to provide sustainable, cost-effective solutions for sandy soil improvement while reducing environmental impact compared to conventional cement-based methods. This research aims to identify optimal dosages that maximize strength enhancement while maintaining practical constructability for geotechnical applications. Therefore, the objective of this study is to investigate the strength properties of sandy soil mixed with natural rubber latex and kenaf fiber, specifically evaluating the effects of various combinations on shear strength parameters, compaction characteristics, and overall engineering performance.

2. Methodology

2.1 Sample Preparation

Soil sampling was conducted at a site in Hospital Pengajar Universiti Putra Malaysia (HPUPM), Persiaran Mardi – UPM, Serdang, Selangor (2°58'49"N, 101°43'12"E). This area contains schist with minor of limestone and phyllite shown in Figure 1 (a) and (b).



(a) (b)

Fig. 1. a) Geological map of Hospital Pengajar Universiti Putra Malaysia (HPUPM), Persiaran Mardi – UPM, Serdang, Selangor (2°58'49"N, 101°43'12"E), b) the geological details of studied area (source: Geological of Peninsular Malaysia - MyGEMS, 2025).

Kenaf fiber was obtained from Lembaga Kenaf and Tembakau Negara (LKTN). The fiber was cut to certain length which were 30 mm to 50 mm for all test specimens. Alkaline treatment of kenaf fiber was done using sodium hydroxide (NaOH) where it is to improve the physical and chemical properties of fiber. The treated fibers were manually mixed with the soils in a random manner. Natural rubber latex was procured from a commercial supplier which is Getahindus (M) Sdn Bhd with specifications indicated in Table 1. The latex was stored in airtight containers at ambient temperature to prevent coagulation.

Table 1
Properties of Natural Rubber Latex (NRL)

Parameter	Unit	Value
Total solids content	%	61.62

Dry rubber content	%	60
Alkalinity	%	0.74
Mechanical stability time	Sec	1360
Coagulum content	ppm	19
KOH number	-	0.44
pH	-	10.44
Viscosity, B/F 2/60 at 26°C	cP	78

The geotechnical properties of the soil sample were tested at Universiti Putra Malaysia (UPM). The soil mixture with the specific percentage is demonstrated in Table 2. The variations of kenaf fiber and NRL, individually mixed into the soil, were prepared at 5%, 10% and 15%. Then, the mixtures of soil with kenaf fiber and NRL were tested at the specific percentages listed in Table 2.

Table 2
Percentage of soil-kenaf-Natural Rubber Latex (NRL) mixture

Symbols	Mixture Percentage
S	Natural soil
S0.5KF	Soil+0.5% Kenaf fiber
S1.0KF	Soil+1.0% Kenaf fiber
S1.5KF	Soil+1.5% Kenaf fiber
S5NRL	Soil+5% Natural Rubber Latex
S10NRL	Soil+10% Natural Rubber Latex
S15NRL	Soil+15% Natural Rubber Latex
S0.5KF5NRL	Soil+0.5% Kenaf fiber+ 5% Natural Rubber Latex
S0.5KF10NRL	Soil+0.5% Kenaf fiber+ 10% Natural Rubber Latex
S0.5KF15NRL	Soil+0.5% Kenaf fiber+ 15% Natural Rubber Latex
S1.0KF5NRL	Soil+1.0% Kenaf fiber+ 5% Natural Rubber Latex
S1.0KF10NRL	Soil+1.0% Kenaf fiber+ 10% Natural Rubber Latex
S1.0KF15NRL	Soil+1.0% Kenaf fiber+ 15% Natural Rubber Latex
S1.5KF5NRL	Soil+1.5% Kenaf fiber+ 5% Natural Rubber Latex
S1.5KF10NRL	Soil+1.5% Kenaf fiber+ 10% Natural Rubber Latex
S1.5KF15NRL	Soil+1.5% Kenaf fiber+ 15% Natural Rubber Latex

2.2 Physical Properties Test

Particle size distribution analysis was conducted using sieve analysis according to ASTM D6913/ D6913M-17). The soil sample was passed through a set of sieves using Endecotts EFL 2000 Sieve Shaker machine. The retained then will be calculated to obtain the grading curves for characterize the soil texture. The Atterberg limits of soil sample were evaluated according to ASTM D4318-17 for characterize plasticity characteristics and classify the soil behaviour. This test was conducted using the Casagrande apparatus. The specific gravity was conducted using the pycnometer method which follow the standard ASTM D854-14. This test was done to determine the density of the soil and phase relationships of soils including the void ratio and degree of saturation.

2.3 Compaction Tests

The compaction characteristics of soil specimen were conducted using the Standard Proctor test (ASTM D698) by compacting soil samples at various moisture contents to obtain the optimum moisture content (OMC) and maximum dry density (MDD).

2.4 Direct Shear Box Test

The shear strength parameters of untreated and treated soil specimens were determined using direct shear apparatus which were Soil Direct Shear Testing Machine Model DS5A. The test was conducted in accordance with ASTM D3080 where three different normal stress of 100kPa, 200kPa and 300kPa were applied to determine the cohesion and internal friction angle of soil specimen.

3. Results

3.1 Physical Properties Analysis

Table 3 shown summary of the physical properties of soil samples which include particle size distribution, specific gravity, Atterberg limits and linear shrinkage determination.

Table 3
Physical properties of soil samples

Soil Parameters	Unit	Values
Grain Size Distribution		
- Gravel	%	10.42
- Sand	%	82.97
- Fines (Silt;Clay)	%	6.61
Plastic Limit, PL	%	28.06
Liquid Limit, LL	%	39.67
Plasticity Index, PI	%	11.61
Linear Shrinkage	%	3.57
Specific Gravity	-	2.67

According to Figure 2, sand-sized particles consist of 82.97% of the total soil followed by the gravel content of 10.42% and fines material (silt and clay) content of 6.61%. The particle size distribution analysis showed that the soil used in these studies was classified as poorly graded sand (SP) based on Unified Soil Classification System (USCS). The gradation characteristics were further evaluated through the Coefficient of Uniformity (Cu) and Coefficient of curvature (Cc) was 10.00 and 0.45 respectively. According to USCS criteria for clean sands with less than 5% fines materials, a soil is classified as well-graded sand (SW) if Cu is greater than 6 and Cc is between 1 and 3. Based on Cu and Cc obtained, although the coefficient of uniformity of 10.00 exceeds the minimum requirement of 6, the coefficient of curvature of 0.45 falls below the lower limit of 1 which fail to satisfy both criteria resulting in this type of soil be classified as poorly graded sand (SP).

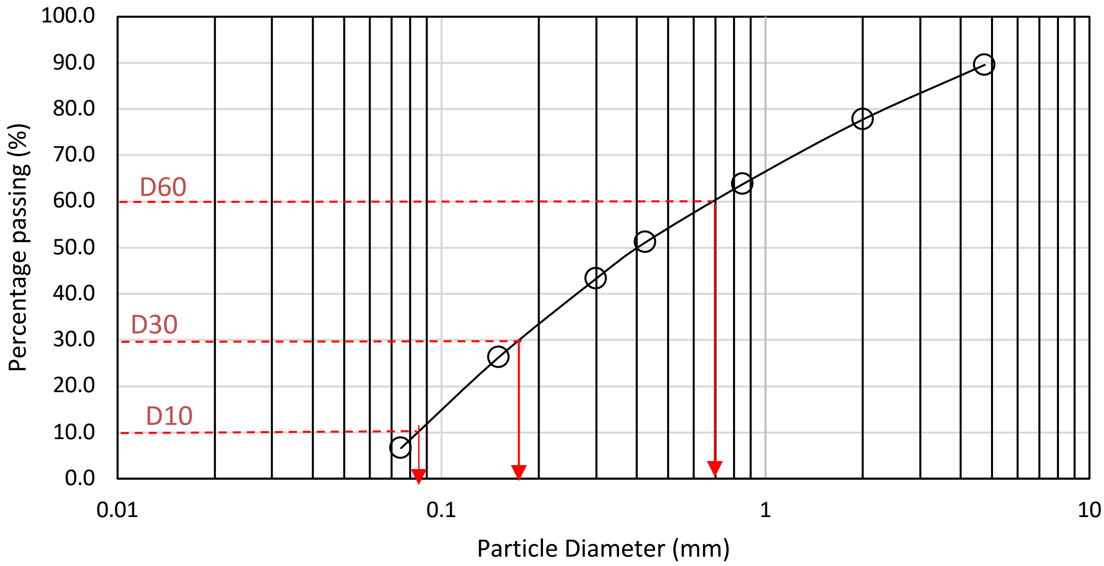


Fig. 2. Particle size distribution curve of soil sample

The Atterberg limits produced the value of plasticity index of 11.61% with a liquid limit of 39.67% and a plastic limit of 28.06%. These values lead to the classification of silt of low plasticity (ML) or organic silts (OL) when plotted on the Casagrande plasticity chart for fine fraction shown in Figure 3. Thus, the soil sample can be classified as SP-SM which was poorly graded sand with silt due to it consist of small fraction of silty fines. The linear shrinkage value of 3.57% indicated low to medium volume change potential of soil which the soil will undergo minimal dimensional changes during drying cycles. In addition, the specific gravity of soil solids was found to be 2.67 which is within the range of natural sands (2.65 to 2.70).

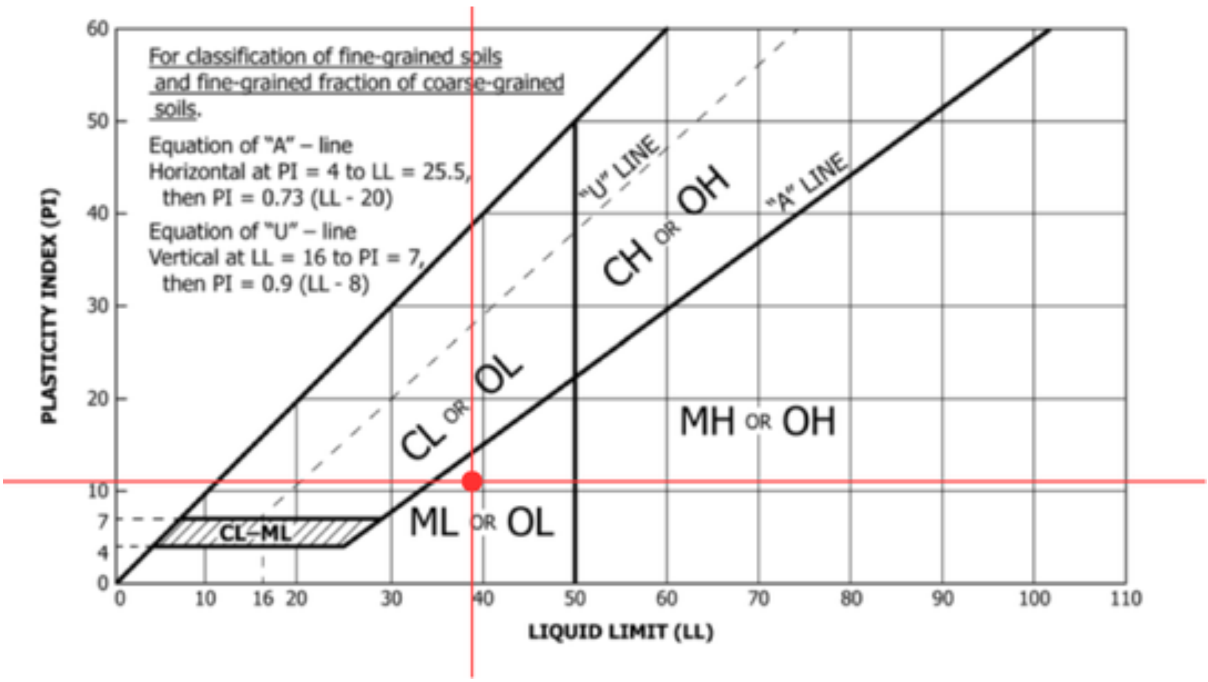


Fig. 3. Plasticity index chart

3.2 Compaction Properties Analysis

Figure 4 and Figure 5 shown the result obtained from the standard Proctor compaction test for untreated soil and soil mixture with kenaf fiber and NRL. The untreated soil achieved a maximum dry density of 1.74 g/cm^3 at an optimal moisture content of 15.72%. The addition of kenaf fiber alone at contents of 0.5%, 1.0%, and 1.5% resulted in maximum dry densities of 1.68 g/cm^{3,} 1.66 g/cm^3, and 1.64 g/cm^3 at optimum moisture contents of 15.83%, 17.95%, and 18.64%, respectively. These reduction in maximum dry density indicated that the lower specific gravity of organic fiber material compared to mineral soil particles and the tendency of fiber to create a larger void space within the compacted matrix by connecting between soil particles. The increases in optimum moisture content indicated that additional water is required to lubricate the soil-fiber mixture and allow adequate compaction around fiber. These alterations in compaction properties were aligned with the findings where the additions of discrete fibers typically reduce maximum dry density while increasing the optimum moisture content [16] .

The incorporation of natural rubber latex had more pronounced effects on compaction characteristics compared to fiber addition alone. At NRL contents of 5%, 10% and 15%, maximum dry density was shown to decrease to 1.67 g/cm^3, 1.60 g/cm^3, 1.55 g/cm^3, respectively, while the optimum moisture contents increased to 15.65%, 14.93% and 13.62% respectively. This value demonstrated that the latex addition show trend with the highest NRL content of 15% produce less reduction in maximum dry density and reduce the optimum moisture content below the control sample. This behavior can be explained to the liquid form of latex facilitating better particle rearrangement and the formation of polymeric films that fill voids that partially counteract the effect of density reduction effect. The optimum moisture content does not increase equally with NRL content addition and can decrease at higher dosages was due to the water already present in the natural rubber latex which approximately 40% by volume contribute to the mixing water.

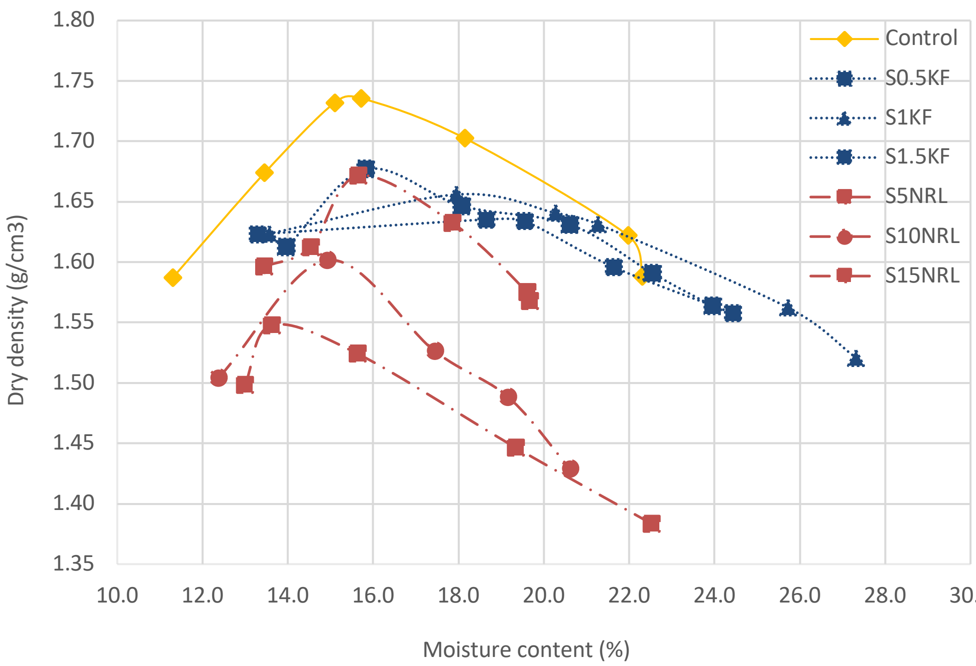


Fig. 4. Compaction curves for sandy soil treated with kenaf fiber and natural rubber latex

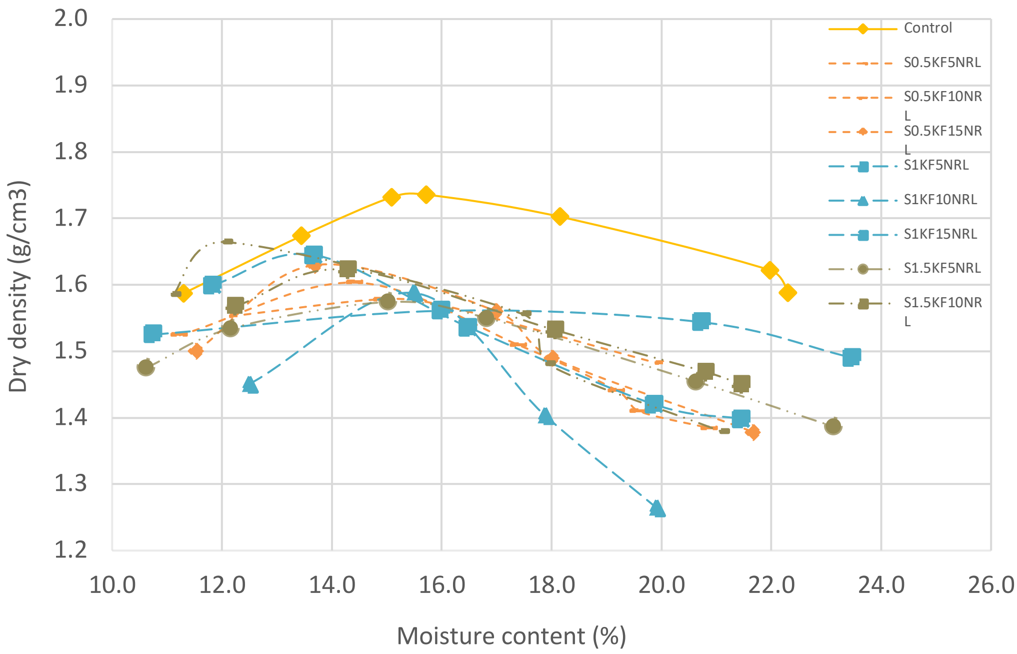


Fig. 5. Compaction curves for sandy soil treated with various percentage of kenaf fiber and natural rubber latex

The optimum moisture content and maximum dry density of soil mixture with kenaf fiber and NRL was shown in Figure 6 and Figure 7. The compaction behavior of the combined kenaf fiber and natural rubber latex treatments indicated the opposing effects of both additives. The percentage combination of 0.5% kenaf fiber with 5%, 10%, and 15% NRL yielded maximum dry density of 1.58 g/cm^3, 1.60 g/cm^3, and 1.63 g/cm^3 at optimum moisture content of 14.77%, 14.43% and 13.69% respectively. The combination of 1.0% kenaf fiber combined with NRL at the same contents produced maximum dry density of 1.56 g/cm^3, 1.59 g/cm^3, and 1.64 g/cm^3 at optimum moisture contents of 16.00%, 15.50%, and 13.67% respectively. At the kenaf fiber content of 1.5% combined with NRL of 5%, 10% and 15% achieved the maximum dry density of 1.57 g/cm^3, 1.59 g/cm^3, and 1.66 g/cm^3 at optimum moisture contents of 15.03%, 14.29%, and 12.05% respectively. The trend indicated that higher natural rubber latex contents can partially compensate for the densification issues introduced by kenaf fiber addition in soil mixture where the combination of 1.5% kenaf fiber and 15% NRL achieving a maximum dry density closest to the control sample at optimum moisture content of 12.05%. This finding has important implications for field construction as it suggests that proper composition of kenaf-latex treatments can maintain the reasonable compaction characteristics while provide the strength improvements.

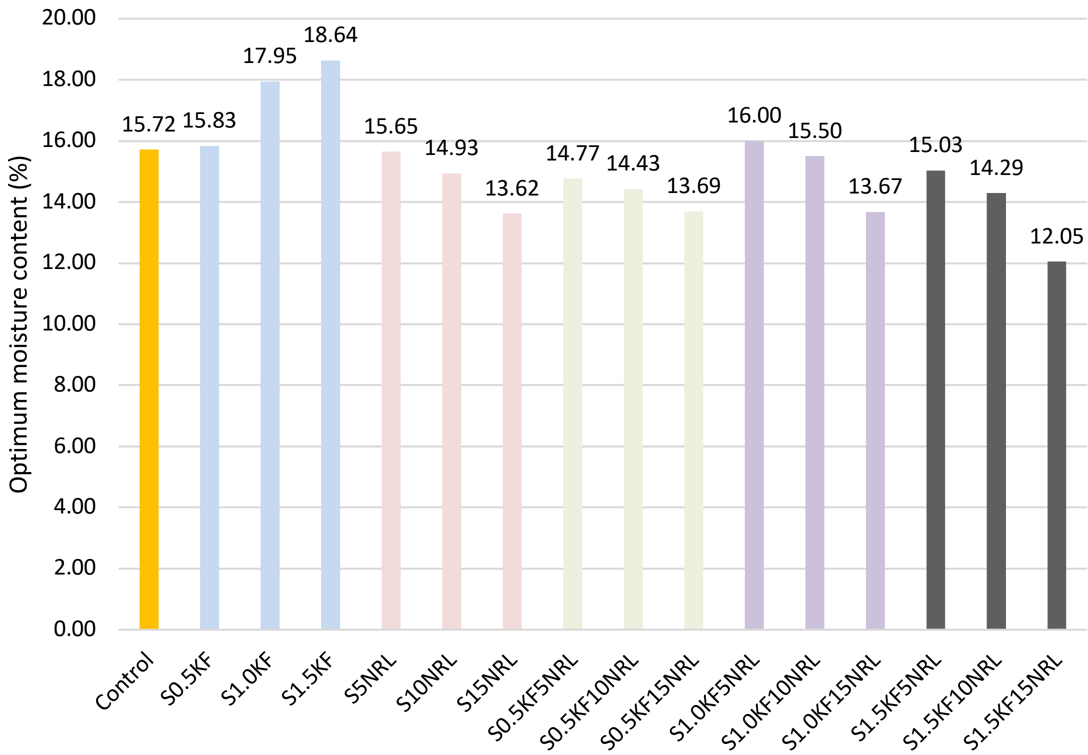


Fig. 6. Optimum moisture content of soil mixture varied by percentage

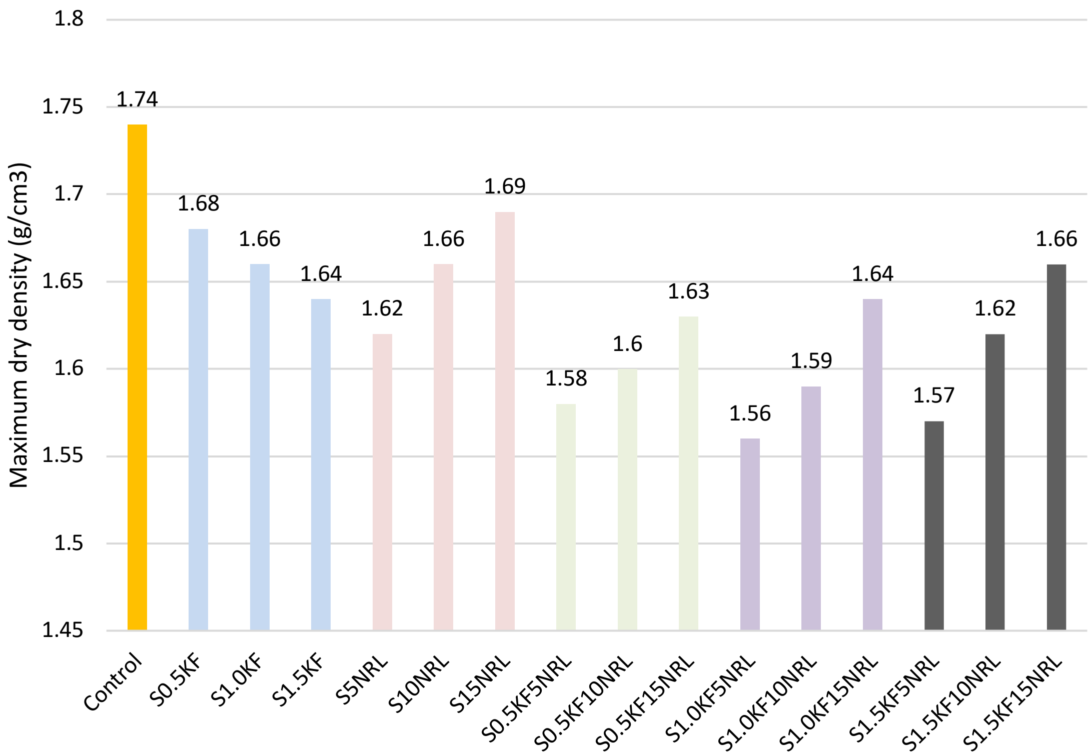


Fig. 7. Maximum dry density values of soil mixture varied by percentage

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3.2 Strength Behaviour

There was a significant and progressive improvement in shear strength parameters such as cohesion and internal friction angle with the addition of kenaf fiber and natural rubber latex to the sandy soil as shown in Figure 8 and Figure 9. The control specimen (untreated soil specimen) indicated the cohesion value of 9.52 kPa and internal friction angle value of 20.83^o which provide the baseline shear strength values for typical poorly graded sand with a small fine fraction.

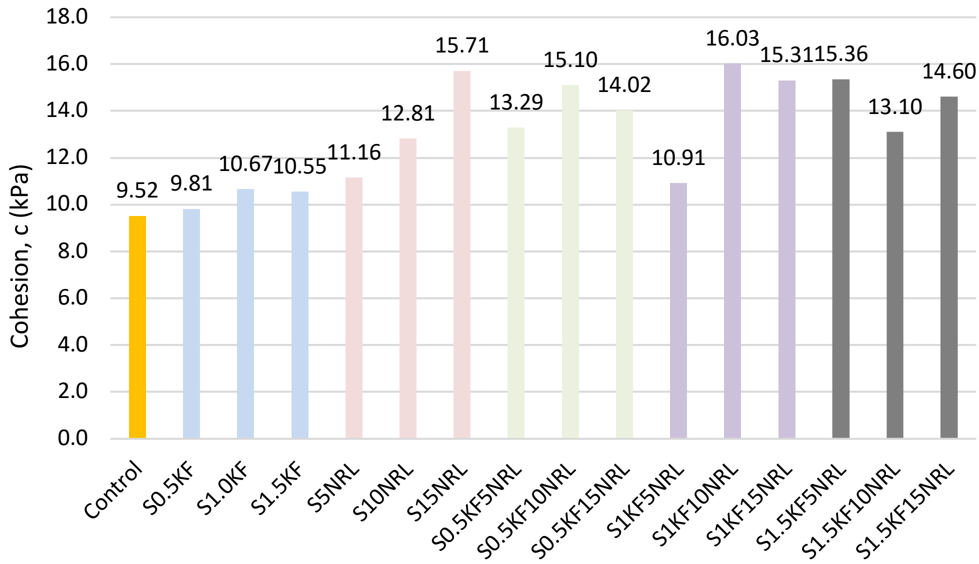

Fig. 8. The bar chart of variation cohesion value of soil mixtures varied by percentage

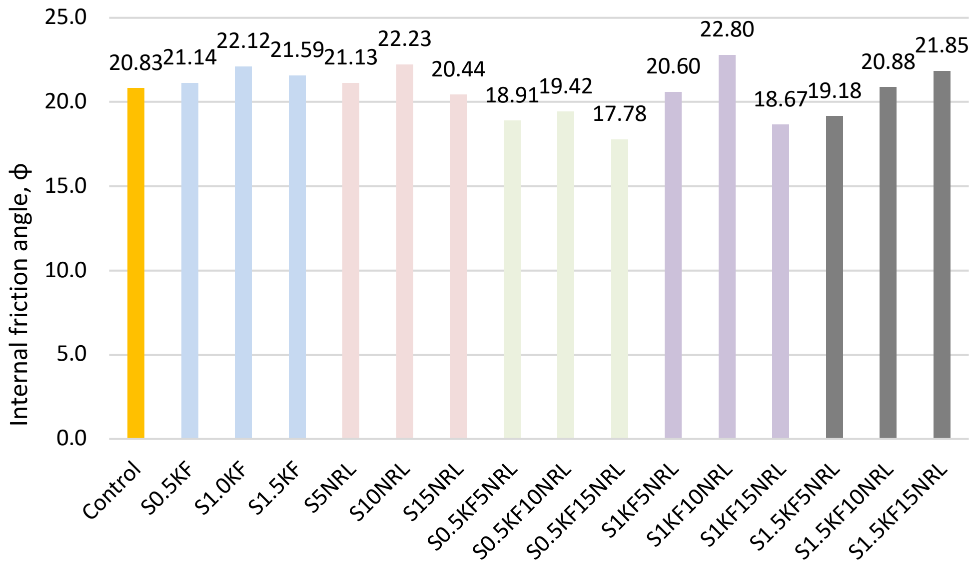

Fig. 9. Internal friction angle values of variation soil mixtures varied by percentage

The addition of kenaf fiber alone as soil reinforcement materials at contents of 0.5%, 1.0% and 1.5% by dry weight of soil caused the cohesion value to increase gradually to 9.81, 10.67, and 10.55 kPa respectively. This value showed the improvement of 3%, 12.1% and 10.8% over the untreated soil. Meanwhile the internal friction angles increase to 21.14°, 22.12°, 21.59°, respectively which show the improvements of 1.5%, 6.2%, and 3.6%. These results indicated that randomly distributed kenaf fiber provide the improved cohesion through tensile resistance that mobilized across potential failure planes and mechanical interlocking with soil particles **Error! Reference source not found.**. The optimal fiber content for maximum strength gain was found to be at 1.0% which after this percentage it might slightly decrease due to fiber clustering that create weak zones and prevent uniform stress distribution.

The synergistic effects of combined treatment using kenaf fiber and natural rubber latex that can outperform the results of treating the additive alone. The cohesion values for 0.5% kenaf fiber combined with 5%, 10% and 15% natural rubber latex were 13.29, 15.10, and 14.02 kPa respectively, while the internal friction angles values were 18.91°, 19.42°, and 17.78°.

Furthermore, the combination of 1.0% kenaf fiber with NRL at 5%, 10% and 15% yielded the cohesion values of 10.91, 16.03, and 15.31 kPa with internal friction angles of 20.60°, 22.80° and 18.67°, respectively. At 1.5% kenaf fiber combined with 5%, 10% and 15% NRL, cohesion values were 15.36, 13.10 and 14.60 kPa were obtained with internal friction angles of 19.18°, 20.88° and 21.85° respectively. The optimal percentage of combination was found to be 1.0% kenaf fiber with 10% natural rubber latex with the value of cohesion and internal friction angles 16.03 kPa and 22.80° respectively, represent highest internal friction angle among all tested combinations. These findings showed that the tensile fiber prevent from excessive deformation of the soil-latex mixture while the ductile latex matrix can improve the load transfer to the fiber which result in an optimized reinforced-stabilized system. However, excessive percentages of both fiber and additives can lead to reduction performance of soil mixture which likely due to poor compaction, fiber clustering or excessive plasticity that can reduce frictional resistance.

4. Conclusions

These studies investigated the combined kenaf fiber and natural rubber latex treatment significantly enhances the strength properties of poorly graded sandy soil through mechanisms which changes in physical and compaction characteristics of soil mixture. The untreated sandy soil with lower cohesion values that produces the typical deficiencies of cohesionless materials. 1.0% Kenaf fiber and 15% natural rubber latex treatments achieved cohesion improvements of 12.1% and 65.0% respectively while the optimum combined treatment of 1.0% kenaf fiber with 10% natural rubber latex produced superior synergistic effects that achieve cohesion improvements of 68.4% and 9.5% respectively. Compaction properties remained practical with maximum dry density of 1.59 g/cm^3 at optimum moisture content of 15.50%. These values showed the mechanisms of tensile reinforcement from kenaf fiber while natural rubber latex coating the soil particles and filling voids to establish interparticle bonding. The mechanisms that overcome the density reduction to achieve improvement in shear resistance. The compaction behavior demonstrated that natural rubber latex facilitates better density than fiber alone and reduce required moisture content at higher percentage due to water content in the natural rubber latex itself, while kenaf fiber addition increases optimum moisture content to 17.95% for proper soil-kenaf fiber distribution. Future research should focus on long-term durability assessment, standardized mix design procedures, and field demonstration projects to validate these laboratory findings for practical implementation in geotechnical engineering applications.

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