TEKNIKA: JURNAL SAINS DAN TEKNOLOGI

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The stabilization of clay soil using wood sawdust ash and its effect against unconfined compressive strength (UCS) value

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ARTICLE INFO

Article history:
Submitted 28 June 2023
Received 20 July 2023
Received in revised form 15 August 2023
Accepted 20 September 2023
Available online on 30 November 2023

Keywords:
Soil, stabilization, wood sawdust ash, UCT

Kata kunci:
Tanah, stabilisasi, abu gergaji kayu, UCT.

ABSTRACT

Soil is the basis for the construction of roads, buildings, dams, and embankments. Construction activities on roads cannot be separated from soil works on which the infrastructure was built. This study aims to improve (stabilize) clay soil by taking a location in Juhut Village, Pandeglang Regency using sawdust ash from meranti wood. The effect of the addition of sawdust ash was studied against the unconfined compressive strength value of the soil and its properties using several variations of the mixture. The mix variations used in this study use sawdust wood ash percentages of 0%, 5%, 10%, and 15%. The effect of the mixture on soil properties was investigated by tested the physical and mechanical properties through soil classification test, Atterberg limits tests, specific gravity tests, compaction tests, and unconfined compressive strength tests. The results of analysis and laboratory tests show that the soil can be classified as clay with moderate to high plasticity (OH) based on the USCS classification. The optimum value of unconfined compressive strength was obtained by adding variations of sawdust wood ash obtained at 15% variation of wood sawdust ash with 28 days of curing time of 3.790 kg/cm2. While the soil plasticity index value decreased from 22.8% to 7% with the addition of sawdust wood ash at a percentage of 15%. Therefore, it can be concluded that the addition of sawdust wood ash for soil stabilization could increase a good effect on soil strength.

ABSTRAK

Tanah merupakan dasar perletakan kontruksi jalan, bangunan, bendungan dan tanggul. Kegiatan konstruksi pada jalan tidak lepas dari pekerjaan tanah yang menjadi dasar berdirinya infrastruktur. Studi ini bertujuan untuk melakukan perbaikan (stabilisasi) pada tanah lempung dengan mengambil lokasi di Kampung Juhut, Kabupaten Pandeglang menggunakan abu limbah gergaji kayu dari jenis kayu meranti. Pengaruh penambahan abu gergaji kayu dilihat terhadap kekuatan tekan bebas tanah dan propertisnya dengan menggunakan beberapa variasi campuran. Variasi campuran yang digunakan dalam penelitian ini menggunakan persentase abu 0%, 5%, 10%, dan 15%. Pengaruh campuran terhadap propertis tanah dilihat dengan melakukan uji sifat fisik dan mekanis melalui uji klasifikasi tanah, batas-batas Atterberg, berat jenis, uji pemadatan dan uji kuat tekan bebas. Hasil Analisa dan pengujian menunjukkan bahwa sampel dapat diklasifikasikan sebagai tanah lempung dengan plastisitas sedang hingga tinggi (OH) berdasarkan klasifikasi USCS. Nilai optim,um kuat tekan bebas diperoleh pada penambahan variasi abu kayu diperoleh pada variasi 15% abu kayu dengan lama pemeraman 28 hari sebesar 3,790 kg/cm2. Sedangkan nilai indeks plastisitas tanah turun dari 22.8 % menjadi 7% dengan penambahan abu kayu pada persentase 15% abu kayu. Dengan demikian, dapat disimpulkan bahwa penambhan abu kayu untuk satabilisasi tanah memberikan pengaruh yang baik terhadap kekuatan tanah.

Available online at http://dx.doi.org/10.36055/tjst.v19i2.20849

1. Introduction

There are various kinds of soil properties and soil characteristics of each area where road construction was built. The soil must have good properties, good bearing capacity, safe against settlement and shrinkage so that roads and buildings are not damaged while in their service life periods. Clay soils have high shrinkage fluctuations due to increases and decreases in water content. This kind of soil is required special treatment to improve its strength by adding a stabilizing agent. The stabilizing agent used can be in the form of cement, lime, and other materials from existing natural resources to improve soil properties. Some of the soil properties that need to be considered are shear strength, volume change, degree of plasticity, degree of swelling potential, and shrinkage properties. One of the soil conditions that is often encountered is soil that has unfavorable properties such a very soft soil during the rainy season and very hard soil when the dry season arrives, as a characteristic of soil with high soil shrinkage. This will make the construction built on the soil unstable, so it is necessary to stabilize (strengthen) the soil first.

The soil samples used in this research were taken from Kp.Juhut, Karang Tanjung, Pandeglang Regency, Banten. At that location the soil used on the road is a type of soft clay soil. Some parts of the road were damaged, such as bumpy roads, slightly collapsed and potholes. This can be caused by excessive and uneven soil subsidence. Based on the DCP test results, the CBR value of the site is 3.01%, which is still less than the required 6% based on the 2017 Highways Regulation No 02/M/BM/2017. Figure 1 shows the road conditions in Kp Jukut Pandeglang.

Figure 1. Road condition at Kp. Jukut Pandeglang

This study aims to see the effect of adding a mixture of sawdust ash as a soil stabilizing agent on the value of the unconfined compressive strength of the soil and the physical properties of the soil. Several previous studies as a basis for research utilizing ash from natural ingredients such as wood, coconut shells and palm oil were carried out previously [1], [2], [3], [4], [5]. Soil stabilization using wood ash waste and its effect on unconfined compressive strength was previously carried out with the addition of sawdust ash with a mixture of 4%, 6% and 10% mixed with lime and cement and 0 days and 28 days treatments [1]. The research on soil stabilization with the addition of wood ash and lime with a mixture of 5%, 10% and 15% and treatments of 0 days, 7days, and 14 days was conducted previously [6]. The research on soil stabilization with the addition of sulfur and wood charcoal, was conducted using mixed variations of wood charcoal 0%, 2%, 4%, 6% and 10% [7], [8].

The results of research of soil stabilization based on the soil strength using wood ash mixed variations of 4%, 6% and 10% and 0 and 28 days of treatment showed that the clay soil at the Muara Fajar location, the plasticity index value changed from high plasticity clay to silt high plasticity. The maximum value of UCS and CBR occurs in a soil mixture of 90% cement + 10% lime. Treatment also affects the value of UCS and CBR. The highest UCS and CBR values were found in the 28-day (curing) sample [1].

The use of a mixture of wood ash and lime for soil stabilization with variations of wood ash mixtures of 5%, 10% and 15% and treatments of 0, 7 and 14 days. The results of this study showed that the UCS test with the addition of a combination of lime and wood ash showed positive results, able to cover the deficiencies that existed in wood ash and lime in terms of soil brittleness. From the results of the UCS test it increases with increasing curing time. However, the higher the mixture causes the soil brittleness to increase [6].

The effect of a mixture of sulfur and wood charcoal as a soil improvement material in Pejaten Village, Tabanan, Bali was studied previously. The soil was mixed with wood charcoal ash at percentage of 0.2%, 4%, 6%, and 10% and the addition of the percentage of sulfur 6%. The unconfined compressive strength (qu) of soil reaches a peak value at 3.8 kg/cm^2 at the percentage of 6% addition of sulfur and wood charcoal [7].

The research on soil stabilization using a mixture of bagasse ash, cement and fly ash was conducted with location at Central Kalimantan, Katingan district. The soil was mixed with variations of cement and fly ash content of 10% and 15% consecutively, while for bagasse ash using a mixture content of 5%, 10% and 15% by weight of the soil and curing time for 1 and 7 days. Those samples were testes for direct shear test and unconfined compressive strength test. The results of his research show that the longer the curing time the greater the increase in free compressive strength and direct shear strength. Curing for 7 days produces the highest percentage increase [9], [10].

2. Research Methodology

2.1. Research Procedure

In this study, the procedure began with collecting data from several references to library sources such as journals containing mixed materials to be used and the formulation of the problem of using wood ash on free compressive strength was obtained. Site survey and sampling with DCP test carried out at the location to obtain CBR value on site. The soil sample was collected into sacks as disturbed sample for laboratory testing. The soil properties was determined

through laboratory test such grain size analysis, specific gravity, water content liquid limit, plastic limit and plasticity index. Soil classification analysis was determined based on USCS system.

The wood sawdust waste then was collected from Craftsmen center in the Curug area in Tangerang Banten. The sawdust ash was obtained through burning process to get the remnants of this combustion. The sawdust ash will be used as an added material for soil stabilization process after it filtered to pass the filter no. 200. The soil sample was tested for compaction procedure test to determined optimum water content and maximum dry density of soil. The results is used as basis in the making soil sample with each variation admixture.

Soil stabilization was carried out by adding wood sawdust ash mixed with soil using various percentages of mixtures 0%, 5%, 10%, and 15%. The water content that used in the sample is optimum water content for each variation. Those samples then were cured with various curing time of 0 days, 7 days, 14 days and 28 days. The total number of samples that needed for Unconfined Compressive Test (UCT) in this study is about 48 samples. The results test was analyzed to describe the effect of sawdust ash admixtures to unconfined compressive strength and physical soil properties of soil for each variation.

2.2. Theoretical Basis

Soil is the supporting foundation of a building. Therefore, it is necessary to study the basic soil properties, such as their origin, grain size distribution, the ability to transmit water, compressibility, shear strength, load bearing capacity, and so on. Soils can be divided into three groups: coarse-grained soils (sand, gravel), fine-grained soils (silt, clay), and mixed soils [11].

Clay soil is the result of soil weathering due to chemical reactions producing a group arrangement of colloid-sized particles with grain diameters smaller than 0.002 mm, which are called clay minerals. Clay particles are shaped like sheets that have a special surface, so that clay has properties that are greatly influenced by surface forces [12].

2.3. Soil Stabilization

Soil stabilization is the mixing of soil with certain materials to improve physical and mechanical properties of the soil. The soil stabilization process includes mixing soil with other soils to obtain the desired gradation, or mixing soil with factory-made materials, so that the technical properties of the soil to be better. Soil stabilization can be divided into two, namely stabilization mechanical and stabilization with added materials [12].

2.4. Unconfined Compressive Strength

Unconfined compressive strength based on ASTM D 2166 is the magnitude of the axial force per unit area when the specimen collapses or when the strain reaches 20%. The workings of the unconfined compressive strength tool are hydraulically pushing the test object up so that the number on the compressive strength dial will go up, then the maximum value is multiplied by the calibration of the proving ring and divided by the cross-sectional area of the test object so that the value qu (free compressive strength) is obtained from the soil. Several laboratory tests to determine soil properties and soil shear strength using Indonesian national standard regulations [13], [14], [15], [16],[17], [18].

2.5. Sawdust Ash Waste

Wood sawdust ash is an industrial waste from sawmills which contains a lot of silica in it. The problem that arises from the processing industry is sawmill waste, which in fact is still piled up and some is simply thrown away. In the process of burning wood sawdust, there are inorganic materials that will be left behind. This remaining inorganic material is weighed and can be expressed as the remaining ash content. The amount of ash content in a wood is generally less than 1% of the weight of the dry wood. In the ash content of wood sawdust, there are two dominant contents. If the two chemical elements are mixed and hydrated, it will form a pozzolanic reaction called calcium silica cement where this pozzolan is useful as a substitute for cement in the soil later [1],[12], [19].

Table 1. Chemical contents of meranti wood ash

Chemical content	Content (%)
SiO_2	10.94
Al_2O_3	1.49
Fe_2O_3	2.50
K_2O	11.71
CaO	52.74
MgO	7.06
Na_2O	0.89

The reaction between silica (SiO2) and alumina (Al2O3) with lime (CaO) will produce pozzolanic mineral content. The formation of these chemical compounds can act as a binder which causes the soil to become hard and not easily brittle.

3. Analysis and Discussions

3.1. Soil Properties Test Results

The physical properties test and classification and type of soil was carried out using samples from soil source at Kp. Juhut, Karang Tanjung, Pandeglang Regency. The physical properties tests include water content test, grain size distribution test, specific gravity, analysis, Atterberg limit such soil liquid limit, soil and plastic limit test. Soil compaction test and unconfined compressive strength testing (UCT) was carried out based on the properties test. Table 2 shows the soil properties of original soil.

Table 2. The properties of original soil

Characteristics of Soil	Unit	
Water content	%	43,44
Specific Gravity		2,631
Passing No, 200 Filter	%	51,6
Liquid limit	%	64,5
Plastic limit	%	41,64
Plasticity Index	%	22,86
Compaction test		
Dry Density (γdry)	gr/cm^3	1,089
Optrimum water content (Wopt)	%	34,97

Based on Table 2, the water content of soil is 43.44%. This value is the average value of three samples of test objects. The specific gravity of the soil (Gs) value is 2.630. This value was obtained from the average value of two samples of soil test objects and is categorized as organic clay soil. As the soil is mixed with meranti wood ash with variation of 5%, 10% and 15%, the Gs value decreased to 2.604, 2.596 and 2.591. The soil liquid limit value of soil categorized as high plasticity soil because the average value soil plasticity index is larger than 50%. The plasticity index decreased as the percentage of sawdust ash material increased. The sawdust ash factor can absorb water so that the water content in the soil mixture has decreased as the curing time increased which caused of the decrease of liquid limit value. The plastic limit of original soil is 41.64%. The plastic limit value increased as the percentage of the adding sawdust wood ash increased. This can be due to the mixture of wood ash reacts with the soil causing the difference of the soil grains size and the bonds between the soil grains are not easily separated resulting in an increasing plastic limit value.

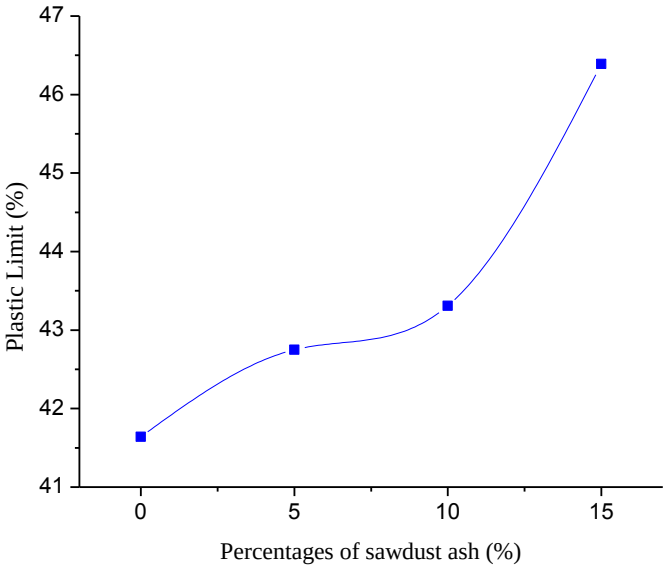

Figure 2. Plastic limit results for each variation of sawdust ash (Source: Authors analysis, 2023)

The original (natural) soil plasticity index (PI) is 22.86% where it categorized as high plasticity and cohesive clay. The PI value decreased as the percentage of mixture increased. The decrease in the plasticity index can be caused by the more admixtures in the soil tend to fill the soil pores, so the soil become denser and the expansiveness of soil decreases. Figure 3 shows the plasticity index value changes due to the increasing of percentage of sawdust ash. The complete results of PI value for each variation of wood sawdust ash are shown in Table 3 and Figure 3. It can be concluded that the addition of wood sawdust ash in soil can decrease the plasticity index significantly. This lowest PI value result is 7.31%, it can fulfill the requirements for soil subgrade which is PI value should less than 15% or the soil does not belong to the high plasticity (CH) soil group [20].

Tabel 3. Soil plasticity index (PI) value each variation

Percentage of sawdust ash (%)	PI
0%	22,86
5%	19,54
10%	17,39
15%	7,31

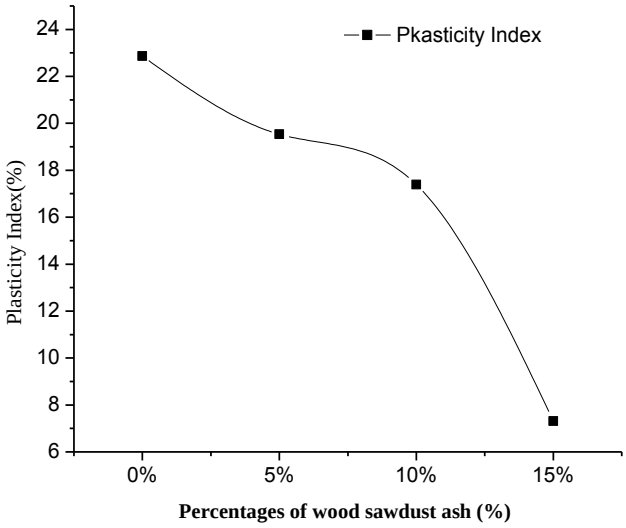

Figure 3. Plasticity index value by variation of sawdust ash

The value of soil bulk density is 1.90 gr/cm3 and a dry bulk density of 1.33 gr/cm3. The results of the soil grain size analysis test show that the soil is classified as a fine grain soil, where the number of soil grains on sieve No. 200 is more than 50%. The soil classification system according to the USCS (Unified Soil Classification System) give several results as follow:

1. Soil that passes filter No. 200 is 51.6%, the soil is included as fine-grained soil category.
2. A liquid limit value (LL) is 64.5%, is categorized as a soil that has high plasticity.
3. The plasticity index (PI) value is 22.36% which is included in the organic clay class with moderate to high plasticity.

The dry unit weight result from compaction test of original soil is 1.089 gram/cm3. Figure 4 shows the results of compaction tests for each variation. The value increased as the admixture content increase. In this case the added material would fill the pore voids in the soil which were previously filled with water and air in the original soil conditions, so the cementation process occurs between the soil and wood ash which causes the soil to become denser

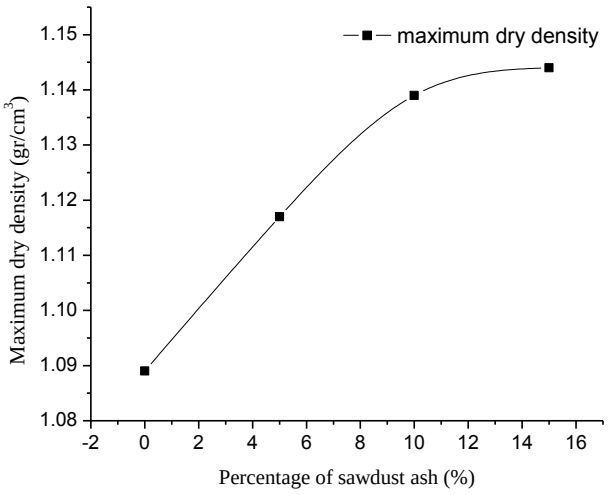

Figure 4. Dry density soil value by variation of sawdust ash

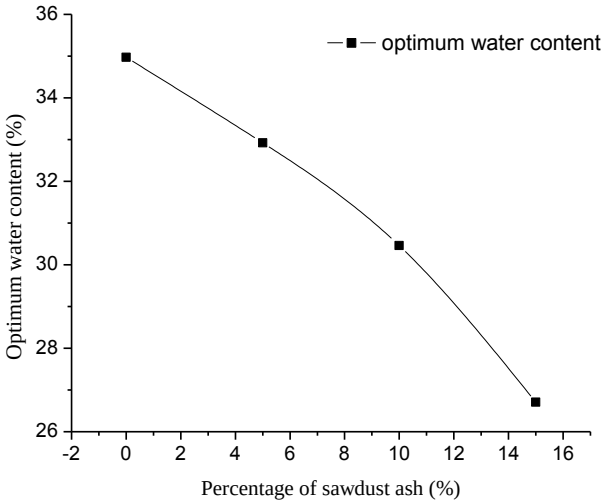

Figure 5. Optimum water content of soil by variation of sawdust ash

Figure 5 shows the values of optimum water content from compaction tests. The result of the optimum water content of the original soil is 34.97%. At percentage of sawdust ash 15% the optimum water content is 26.71%. The optimum water content value decreased as the percentage of admixture decreased, the greater the maximum dry density value and the less water content. This is due to decreased water absorption and decreased pore value due to an increase in the percentage of wood ash so that the percentage of solid particles that fill the soil volume increases.

3.2. Unconfined Compression Test Results

The results of the unconfined compressive strength test are shown in Figure 6 and Figure 7. The effect of variations and curing time factor to soil strength are shown that the addition of wood sawdust ash could increase the compressive strength (qu) value of the soil. At variations of percentages of sawdust ash of 15% the qu value got the higher value 3.79 kg/cm2 with curing time 28 days.

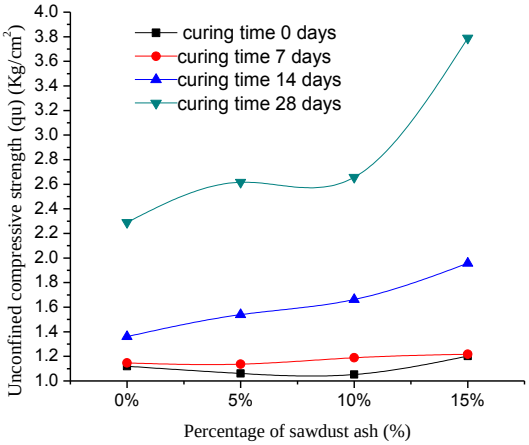

Figure 6. Unconfined compressive strength (qu) value by variation of wood sawdust ash

Figure 7 shows the maksimum value of unconfined compressive strength found in variations in the addition of 15% wood ash of 3.790 kg/cm2 with a curing time of 28 days. Meanwhile, in curing for less than 28 days with variations below 15%, the difference in value is only slightly, which indicates that the longer the curing time, the compressive strength will increase and be better.

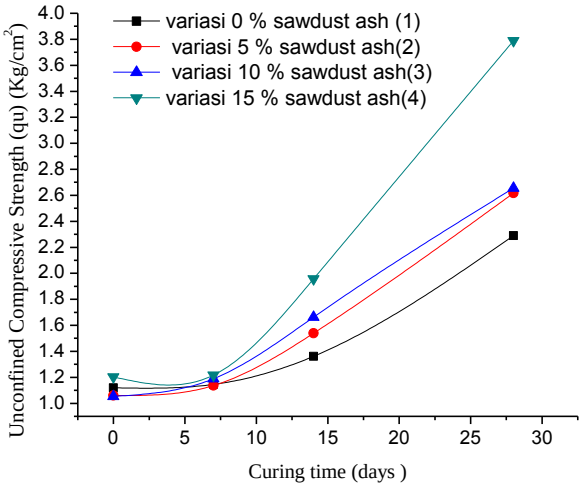

Figure 7. Unconfined compressive strength (qu) value by variation of curing time

The value of q_u of original soil is 1.119 kg/cm^2 which is categorized as stiff clay (1-2 kg/cm^2) based on Table 7. The variation of the addition of 15% wood ash with 28 days of curing the q_u value of the soil increased to 3.790 kg/cm2 categorized as very stiff clay (2-4 kg/cm2). Based on the results it can be concluded that the soil strength increased as using admixture with variations of adding 5%,10%, and 15 % of sawdust ash and curing time 7 days, 14 days, and 28 days. The changes of soil consistency from stiff clay category to very stiff clay category. The addition of wood ash in the stabilization process can increase the qu value and change the consistency of the soil category where this is also influenced by the optimum moisture content of each mixture variation on the free compressive strength value.

Table 4. Correlation of soil consistency and soil strength value

Consistency	UCT (kg/cm^2)
Very Soft	< 0.25
Soft	0.25 - 0.5
Medium	0.5 – 1
Stiff	1-2
Very Stiff	2-4
Hard	> 4

(Source: [19])

Based on Figure 8, it shows that the less value of water content the higher value of compression strength. The adding of material admixtures sawdust ash decreased the optimum water content. As the percentage of wood sawdust ash in soil increases, the dry unit weight value of the soil increases thereby reducing the optimum water content value. Those are caused by the decrease in water absorption and the decrease in void ratio due to an increasing the percentage of wood ash and compaction efforts. The more curing time the higher value of unconfined compression strength.

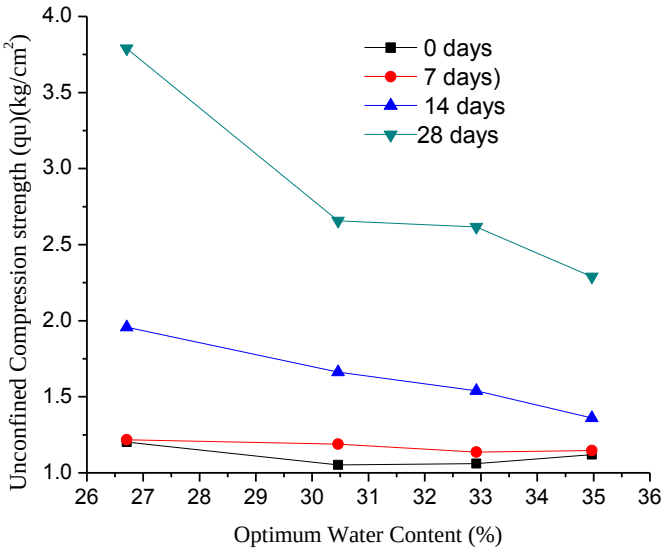

Figure 8. The unconfined compressive soil (qu) value by variation of optimum water content
(Source : Authors analysis, 2023)

3.3. Position The Results with Previous Research

Figure 9 and Figure 10 show the comparison between this study results with previous research results. In this study the optimum value of qu reached at 3,730 kg/cm^2 with a variation of sawdust ash of 15% and 28 days of curing time, while in Fatnanta's research has an optimum value of qu reached at 4,027 kg/cm^2 with a variation of wood ash 10% and 28 days of curing time. Zambika's research the optimum value of qu reached at 4.588 kg/cm^2 with a variation of wood ash 15% and 14 days of curing time. Wardana's research gives the optimum value of qu reached at 3,800 kg/cm^2 with variation of wood ash 6% without curing time. Based on those results, it can be concluded that the addition of wood ash in the soil stabilization process can improve and improve soil quality, especially the compressive strength value.

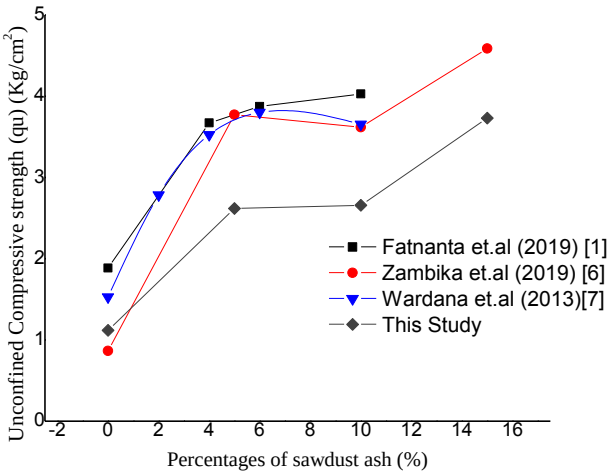

Figure 9. Position result of this study against previous research results of soil strength.

Figure 10 shows the comparison results of plasticity index in this study with the results of previous research. It shows that the data for each study has a significant difference in value. There is also a similarity, like the decreasing the PI value from original soil to PI value after soil stabilized by adding the admixtures wood ash. The difference in the decrease in the value of the plasticity index is influenced by differences in the type of wood and the chemical content of the wood ash used. For research using wood ash with the addition of several added materials such as cement and lime, the IP value decreased with a not too large difference in numbers. In this study using only wood ash as an additive experienced a significant decrease in IP value at the addition of 15% wood ash because the addition of ash made the soil harder and reduced the possibility of swelling and shrinkage of the soil that occurred and minimized water seepage.

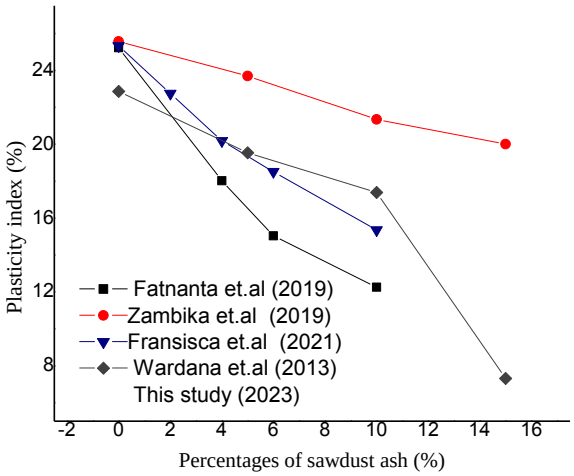

Figure10. Position result of this study against previous research results of soil plasticity index

4. Conclusions

Based on the results of this research with soil samples from Kp. Juhut, Karang Tanjung, Pandeglang Regency stabilized using wood sawdust ash as an added ingredient in the mixture, several conclusions were obtained as follows:

a. Based on the results of soil properties tests and the USCS soil classification system, it obtained that original soil has plasticity index value of 22.86% which is categorized as organic clay soil with high plasticity. The liquid limit value is 64.5% and CBR value is 3.01%, which is less than the standard

allowed for subgrade, so soil improvement is required at that location. In soil physical testing using a variety of wood ash mixtures, it was found that the liquid limit value and soil plasticity index decreased as the percentage of wood ash increased. While the plastic limit value increases with increasing.

b. Based on the unconfined compressive strength test, it can be concluded that the addition of wood ash can increase the compressive strength of the soil. The optimum value of unconfined compressive strength was obtained from the addition of 15% wood ash with a curing time of 28 days of 3.790 kg/cm2 which is classified as a very stiff consistency soil. The plasticity index value of 0% to 15% percentages of wood ash decreased from 22.86% to 7.31%. It can be concluded that the addition of wood sawdust ash in soil can increase the soil strength, so can fulfill the requirements for soil subgrade which is PI value should less than 15% or does not belong to the high plasticity (CH) soil group.

REFERENCES

[1] Fatnanta F., Faizal M. A., & Agus S. N. (2019). Efek Penambahan Abu Serbuk Kayu Pada Lempung Plastisitas Tinggi Yang Distabilisasi Dengan Kapur Dan Semen. *JOM FTEKNIK Universitas Riau,* 6 (2).

[2] Mina, E., Kusuma, I. R., & Wibowo, H. (2021). Pengaruh Penambahan Arang Tempurung Kelapa Sebagai Bahan Stabilisasi Tanah Dasar Terhadap Nilai Kuat Tekan Bebas (Studi Kasus di Jalan Raya Kubang Laban, Desa Trate, Kecamatan Kramatwatu, Kabupaten Serang, Banten. *Jurnal Fondasi,* 10(1).

[3] Kusuma R. I., Mina, E., & O.M. Bonar, Rudi. (2015). Stabilisasi Tanah Lempung Dengan Menggunakan Abu Sawit Terhadap Nilai Kuat Tekan Bebas (Studi Kasus Jalan Desa Cibeulah, Pandeglang). *Jurnal Fondasi,* 4(2).

[4] Triovaldi. (2020). *Stabilisasi Tanah Lempung Dengan Bahan Tambah Limbah Marmer Dan Bubuk Arang Kayu*. Universitas Tidar. Magelang

[5] Zamzam M. A., & Arif E. D. (2012). *Pengaruh Penambahan Abu Gergaji Kayu Sebagai Bahan Stabilisasi Subgrade Dari Tanah Lunak*.. Politeknik Negeri Bandung

[6] Zambika R., Fatnanta F., & Muhardi. (2019 Stabilisasi Tanah Menggunakan Abu Kayu Terhadap Tanah Lunak Bengkalis. *Jurnal Teknik Sipil Universitas Riau,* 4(1), 05-17.

[7] Wardana, I. G. N. (2013). Penggunaan Belerang Dan Arang Kayu Sebagai Bahan Perbaikan Tanah Lapis Dasar Konstruksi Jalan. *Jurnal Ilmiah Teknik Sipil Universitas Udayana,* 17(2).

[8] Sengeoris, M. & Wiqoyah, Q. (2016). *Pemanfaatan Bubuk Arang Kayu Sebagai Bahan Stabilisasi Terhadap Kuat Dukung Tanah Lempung Sukodono dengan Variasi Perawatan*. (Doctoral dissertation, Universitas Muhammadiyah Surakarta). Pp. 1-12.

[9] Oktaviana, S. F., Sarie Fatma, & Okrobianus, H. (2021). Stabilisasi Tanah Lempung Menggunakan Campuran Abu Ampas Tebu, Kuat Geser Dan Daya Dukung. *Jurnal Keilmuan Teknik Sipil Universitas Palangka Raya,* 4(1).

[10] Atina, R. (2014). Kajian Kuat Tekan Bebas Pada Tanah Lempung Yang Distabilisasi Dengan Abu Ampas Tebu Dan Semen. Universitas Sumatera Utara

[11] Verhoef, P. N. W. (1994). *Geologi Untuk Teknik Sipil*. PT. Erlangga. Jakarta.

[12] Hardiyatmo, H.C. (2012). *Mekanika Tanah I* (6th ed). Gadjah Mada Univercity Press: Yogyakarta

[13] Badan Standarisasi Nasional. (2008). SNI 1964-2008 *Cara Uji Berat Jenis Tanah*. Kementrian Pekerjaan Umum, Badan Penelitian dan Pengembangan PU

[14] Badan Standarisasi Nasional. (2008). SNI 1967-2008 *Cara Uji Penentuan Batas Cair Tanah*. Kementrian Pekerjaan Umum, Badan Penelitian dan Pengembangan PU

[15] Badan Standarisasi Nasional. (2008). SNI 1966-2008 *2008 Cara Uji Penentuan Batas Plastis dan Indeks Plastisitas Tanah.* Kementrian Pekerjaan Umum, Badan Penelitian dan Pengembangan PU

[16] Badan Standarisasi Nasional. (2008). SNI 1965-2008. *Cara Uji Penentuan Kadar Air Untuk Tanah dan Batuan*. Kementrian Pekerjaan Umum, Badan Penelitian dan Pengembangan PU

[17] Badan Standarisasi Nasional. (2012). SNI 3638-2012. *Uji Kuat Tekan Bebas Laboratorium.* Kementrian Pekerjaan Umum, Badan Penelitian dan Pengembangan PU

[18] Badan Standarisasi Nasional. (2008). SNI 1942-2008 *Cara Uji Pemadatan Tanah*. Kementrian Pekerjaan Umum, Badan Penelitian dan Pengembangan PU

[19] Das, B. M. (1985). *Mekanika Tanah* (*Prinsip – Prinsip Rekayasa Geoteknis)* Jilid I. Jakarta: Erlangga

[20] Soedarsono, D. U. (1993). *Konstruksi Jalan Raya (edisi keempat*). Jakarta: Yayasan Badan Penerbit Pekerjaan Umum.