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Experimental Investigation on the Properties of Borneo Soft Soil Stabilized with Industrial Waste

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Abstract. This research aims to investigate the physical and mechanical properties of soft soil stabilized using industrial wastes, namely fly ash and rice husk ash. For this purpose, 6 (six) variations in the composition of fly ash (F), lime (L), and rice husk ash (R) were prepared. The variations in sample composition are SFLR1 (F: 15%, L: 2.5%, R: 5%), SFLR2 (F: 20%, L: 2.5%, R: 5%), SFLR3 (F: 25%, L: 2.5%, R: 5%), SFLR4 (F: 15%, L: 5%, R: 10%), SFLR5(F :20%, L: 5%, R: 10%) and SFLR6 (F: 25%, L: 5%, R: 10%). Meanwhile, soft soil was obtained from Banjarmasin City in South Borneo. The sample's physical properties were analyzed using the Atterberg limit test. Moreover, the California Bearing Ratio (CBR) and direct share tests are conducted to assess the sample's mechanical properties. The research results can provide confidence that fly ash, lime, and rice husk ash have the potential to improve the physical and mechanical properties of Borneo soft soil. The results of the Atterberg limit test show that industrial wastes can lower the liquid limit and increase the plastic limit; thus, the soil plasticity index decreases. As for the CBR test results, the untreated soft soil bearing ratio value of 1.4% can be increased to 2.6% after being treated with industrial wastes. In addition, using industrial wastes also decreases the swelling of the soil. Moreover, it can be seen that greater use of fly ash can improve the mechanical properties of the soft soil. However, increasing the composition of lime and rice husk ash can reduce the mechanical properties of the soft soil. Based on the experimental results, it is proposed to use SFLR3 as soil stabilization mixtures.

Keywords: Soil Stabilization, CBR, Industrial Wastes, Borneo Soft Soil

Introduction

Many researchers have discovered that industrial wastes can be used in the construction industry, such as in making mortar, concrete, and even as a soil stabilization material [1]–[4]. Industrial wastes that are often used as construction material include fly ash, rice husk ash, stone dust, and blast furnace slag [5]–[8]. South Borneo has enormous potential for utilizing industrial wastes, primarily fly ash and rice husk ash. This is because Borneo has many coal-fired power plants and is one of Indonesia's most prominent rice production areas.

In 2023, Borneo's coal demand is estimated to be approximately 9 million tons [9]. As stated by Anggara et al., 5% of the Coal burned will become fly ash and bottom ash (FABA) [10]. Thus, at least 450 thousand tons of FABA will be produced. This number is not comparable to the use of FABA waste, which accounts for only about 5%-10% [11]. Meanwhile, as the largest rice-producing region, South Borneo produces 1.15 million tons of grain from the rice-cultivated area along 289.84 thousand hectares [12]. After the grain is milled, 677 thousand tons of rice will be produced. The remainder is in the form of rice husk, which is not optimally utilized [13]. When rice husk is incinerated, approximately 15% becomes rice husk ash [14].

An example of using fly ash is to use it as a concrete mixture [6], [15]–[17]. Fly ash can also be used as a soft soil stabilization material [18]–[22]. The use of fly ash in soft soil has excellent potential, where adding fly ash as a stabilizing material has been proven to improve soft soil's physical and mechanical properties [23]–[28]. Furthermore, based on previous research, it is known that fly ash can increase the California Bearing Ratio (CBR) value of soft soil [29], [30]. Using 15% fly ash can increase the CBR value of soft soil to reach the required minimum CBR value of 6%, based on the Indonesian road pavement design manual [31]. However, compared with soil stabilization using fly ash and cement, the results in increasing the CBR value are still inadequate. Utilizing 20% fly ash and 10% cement can significantly increase the CBR value of soft soil. However, the use of cement increases the cost of soil stabilization.

Alternatively, lime and rice husk ash are commonly combined with fly ash as soil stabilizers [32]–[37]. Based on several studies, the use of 2%-5% lime and 15%-25% fly ash can provide an optimal increase in CBR values [33], [34], [38]. As for the use of lime with rice husk ash, the proportion of lime ranges from 4%-10%, and the proportion of rice husk ash ranges from 10%-25% [4], [19], [32], [35], [36], [39]. Meanwhile, mixing the three materials (lime, fly ash, and rice husk ash) as soil stabilizers is still rarely conducted.

With abundant sources of industrial waste in South Borneo (fly ash and rice husk ash), it certainly has the potential to be used as a soil stabilization material. South Borneo has soft soil areas with characteristics of low strength, large deformation, high water content, and low permeability. This condition will prolong the soil consolidation time and make the soil unsuitable for construction. Based on this background, research on the stabilization of soft soil using industrial wastes, in this case a mixture of fly ash, rice husk ash, and lime, is necessary to be carried out. In addition, it is hoped that this research can provide solutions for handling industrial waste and support sustainable and environmentally friendly development.

1. Materials and Methods

1.1. Materials

For the purpose of this study, soft soil was extracted at a depth of 1 m from the campus of Universitas Lambung Mangkurat in Banjarmasin City, South Borneo. Whilst fly ash was collected from South Borneo coal-fired power plants (PLTU) Asam-Asam. The rice husk ash was obtained from farmers around Banjarmasin, and lime was purchased from shops in Banjarmasin. The chemical composition of fly ash can be seen in Table 1, and Table 2 shows the fly ash classification used in this study. In addition, Table 3 illustrates the Physical properties of soft soil. Furthermore, Figure 1 displays the material used in this experiment.

SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	Na_2O	K_2O	MnO_2
40.92%	10.08%	23.51%	12.86%	8.97%	0.82%	0.26%	0.74%	0.49%

Table 1. Chemical composition of fly ash

Source: [40]

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Sample	$SiO_2 + Al_2O_3 + Fe_2O_3$	SiO_2	SO_3	Class
Fly Ash	74.51%	40.92%	0.82%	Class C

Table 2. Classification of coal ash from PLTU Asam-Asam

No	Parameters	Value
1	Water Content	52,62%
2	Specific Gravity	2,58
3	Liquid Limit (LL)	52,53%
4	Plastic Limit (PL)	42,00%
5	Plasticity Index (PI)	10,53%
6	Sand Content	13,61%
7	Silt and Clay Content	34,44%
8	Fraction < 0,002 mm	51,95%

Table 3. Physical properties of soft soil

(a) (b) (c) (d)

Figure 1. Material a) soft soil, b) fly ash, c) rice husk ash, d) lime

1.2. Methods

Atterberg Limit tests were carried out based on ASTM D4318 to determine the physical properties of all samples [41]. In addition, Specific Gravity tests according to ASTM D854 and Particle-Size Analysis based on ASTM D422 were conducted on untreated soft soil (SS) [42], [43]. As for assessing the mechanical properties of the samples, Laboratory California Bearing Ratio (CBR) tests were undertaken based on ASTM D1883 and Direct Share test according to ASTM D3080 [44], [45]. In addition, CBR tests were divided into 2 (two) types: Unsoaked CBR test and Soaked CBR Test. The Unsoaked CBR tests were applied to samples with air-curing at 3 and 7 days. In addition, the Soaked CBR tests were applied to samples with air-curing at 7 days, followed by 4 days of water-curing. Besides measuring the bearing capacity, soaked CBR tests were also carried out to determine the expansivity of samples [44]. The composition of the stabilizer used is presented in Table 4.

No	Samples	Stabilizing Agent		
		Fly Ash (%)	Lime (%)	Rice Husk Ash (%)
1	SS (untreated sample)	0%	0%	0%
2	SFLR1	15%	2.5%	5%
3	SFLR2	20%	2.5%	5%
4	SFLR3	25%	2.5%	5%
5	SFLR4	15%	5%	10%
6	SFLR5	20%	5%	10%
7	SFLR6	25%	5%	10%

Table 4. The mixture proportions of the stabilizing agent

2. Results and Discussions

2.1. Soil Characteristic

2.1.1. Soft soil characteristic

Based on the classification according to the Unified Soil Classification System (USCS), the soft soil used can be categorized as inorganic silt (MH) or organic clay (OH) with medium to high plasticity, due to the LL value is more than 50% (Table 3). Furthermore, soft soil's Specific Gravity (Gs) value indicates that it can be categorized as organic clay soil [46]. Thus, the soft soil in this study could be classified as organic clay (OH) with medium to high plasticity. Furthermore, based on the AASHTO system, with an LL value > 41 and a PI of 10.53% ≤ LL-30 (22.53%), it can be categorized as Group A-7-5.

2.1.2. Stabilized soil characteristic

The results of the Atterberg limit test for stabilized soft soil are displayed in Table 5. Adding fly ash, lime, and rice husk ash can reduce the LL value. Especially for samples with a percentage of 2.5% lime and 5% rice husk ash (SFLR1, SFLR2, and SFLR3), it can be seen that the LL value is <50%. Based on the USCS system, the soft soil classification of SFLR1, SFLR2, and SFLR3, previously organic clay (OH), changed to organic clay (OL) with low plasticity. Meanwhile, samples SFLR4, SFLR5, and SFLR6 are still classified as organic clay (OH). In addition, there was an increase in the PL value of samples SFLR2, SFLR3, and SFLR6. Moreover, PI values were decreased in samples SFLR2, SFLR3, SFLR5, and SFLR6. A

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lower PI value can reduce the expansive (swelling) potential of the soil and improve the mechanical properties of the soil [47]–[51].

These results show the industrial waste effect to improve the soft soil's physical properties. Increasing the percentage of fly ash can improve the physical properties of the soft soil. However, increasing the percentage of lime and rice husk ash did not significantly improve the physical properties of the soft soil. In general, SFLR3 sample composition provided the most significant improvement in soil physical properties.

No	Samples	Atterberg Limit		
		Liquid Limit (LL)	Plastic Limit (PL)	Plasticity Index (PI)
1	SFLR1	44.55%	27.17%	17.38%
2	SFLR2	48.31%	42.27%	6.04%
3	SFLR3	44.05%	43.72%	0.32%
4	SFLR4	51.20%	35.42%	15.78%
5	SFLR5	50.25%	40.87%	9.38%
6	SFLR6	52.02%	49.88%	2.14%

Table 5. Atterberg Limit Test Results

2.2. Compaction Test Results

The compaction test on the original soil was carried out by referring to the standards from ASTM D698-07[52]. The soft soil compaction curve is shown in Figure 2. The test results found that the optimum moisture content (OMC) value was 16.23%. The maximum dry weight is 1.56 gr/cm^3 (15.30 kN/m^3). Furthermore, the OMC values obtained are used to mix the stabilizer composition of SFLR1 to SFLR6.

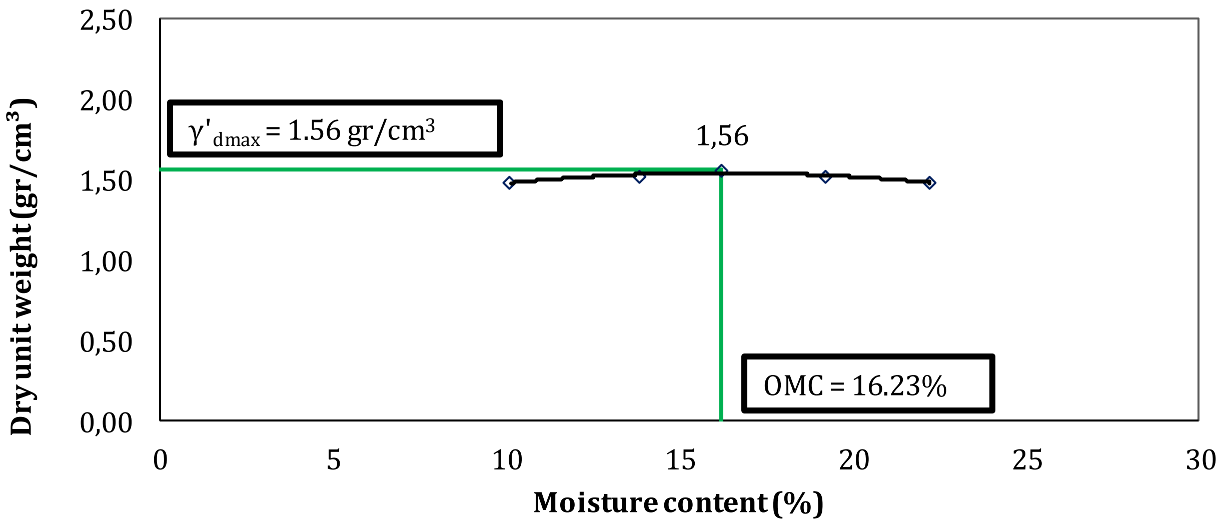

Figure 2. Compaction curve graph

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2.3. Unsoaked CBR Test Results

The results of the unsoaked CBR tests for 3 (three) days of air-curing can be seen in Figure 3. Moreover, the test results for 7 (seven) days of air-curing can be seen in Figure 4. As for the untreated soft soil samples (SS), the CBR test is carried out without sample curing. The CBR value of the SS sample is 1.4%.

From Figure 3 and Figure 4, it can be seen that the CBR values increase as the curing time increases. These results follow research from Soehardi [53] and Zulnasari et al. [51]. Furthermore, it was seen that there was a decrease in the CBR values with the addition of lime and rice husk ash percentage. These findings add more confidence to the results on the physical properties that have been described previously. Based on these results, it can also be concluded that the recommended variation is SFLR3.

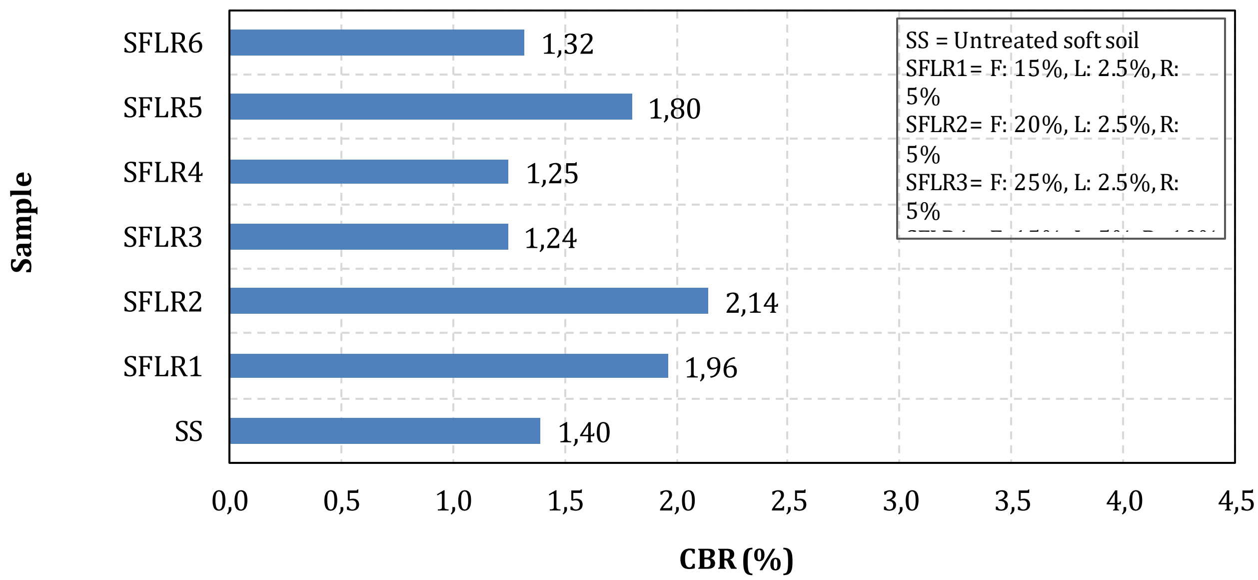

Figure 3. CBR test results for the 3-day samples

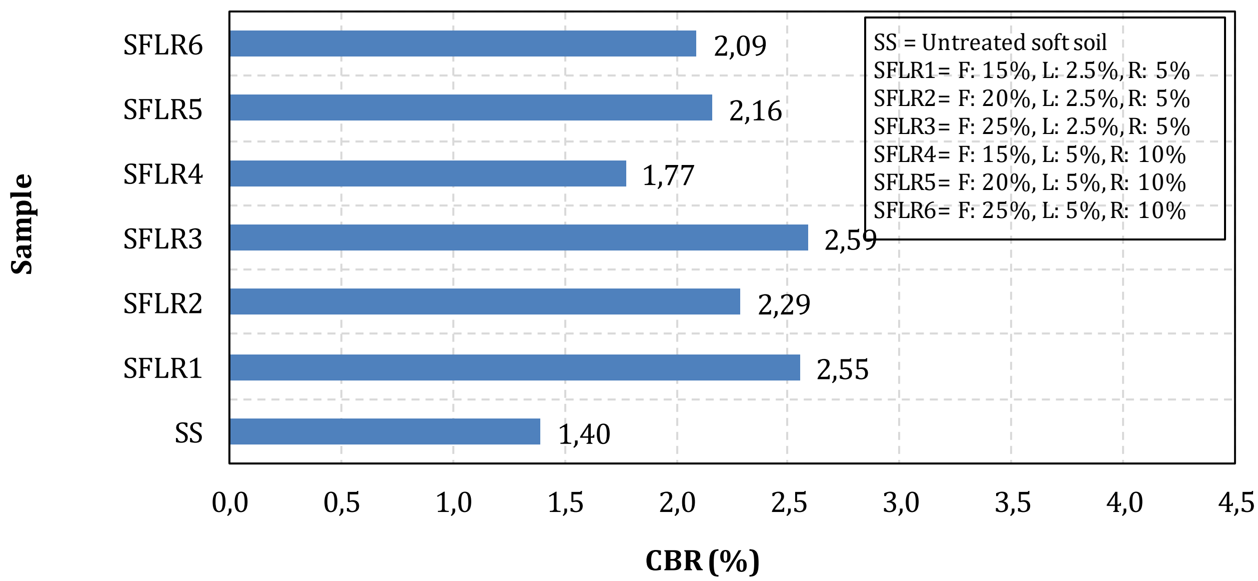

Figure 4. CBR test results for the 7-day samples

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2.4. Direct Share Test Results

The cohesion value (c) from the direct share test results of untreated soil (SS) and treated soil can be seen in Figure 5. In addition, the friction angle (ϕ) from the test results can be seen in

Figure 6. In general, the test results strengthen the results of the previous analysis, where the SFLR3 variation is the most optimal mixture combination. However, a slightly different pattern can be seen from the research results. It is noted that increasing the presentation of lime and rice husk ash does not affect soil cohesion values. The direct share test shows that the increase in cohesion value is based only on the amount of fly ash. The greater the ratio of fly ash, the soil cohesion will increase.

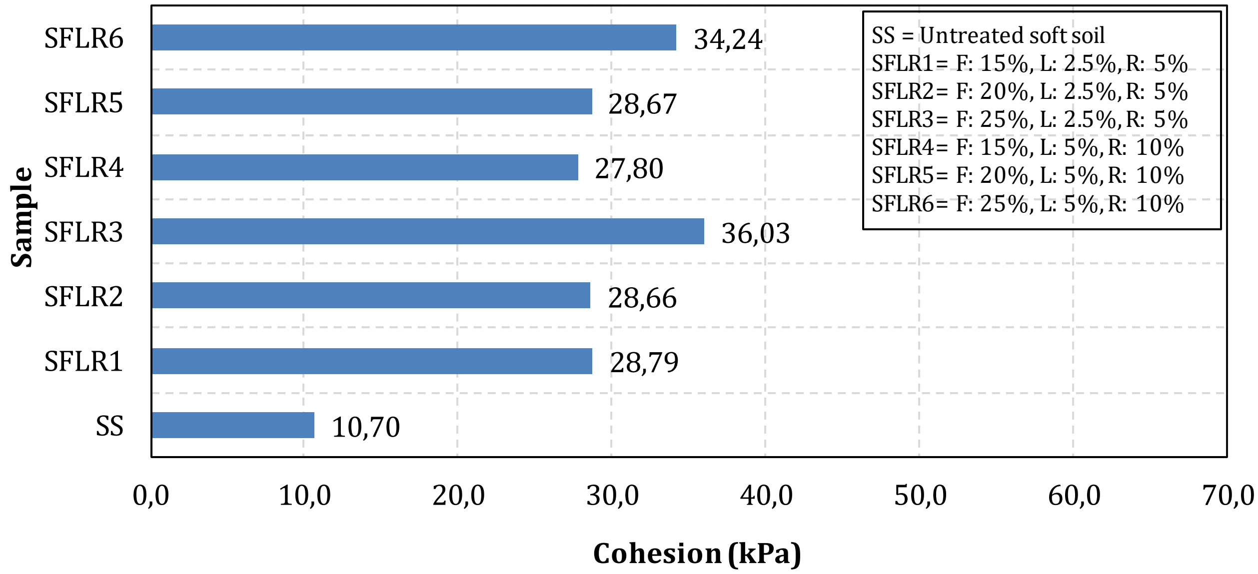

Figure 5. The Cohesion value of samples

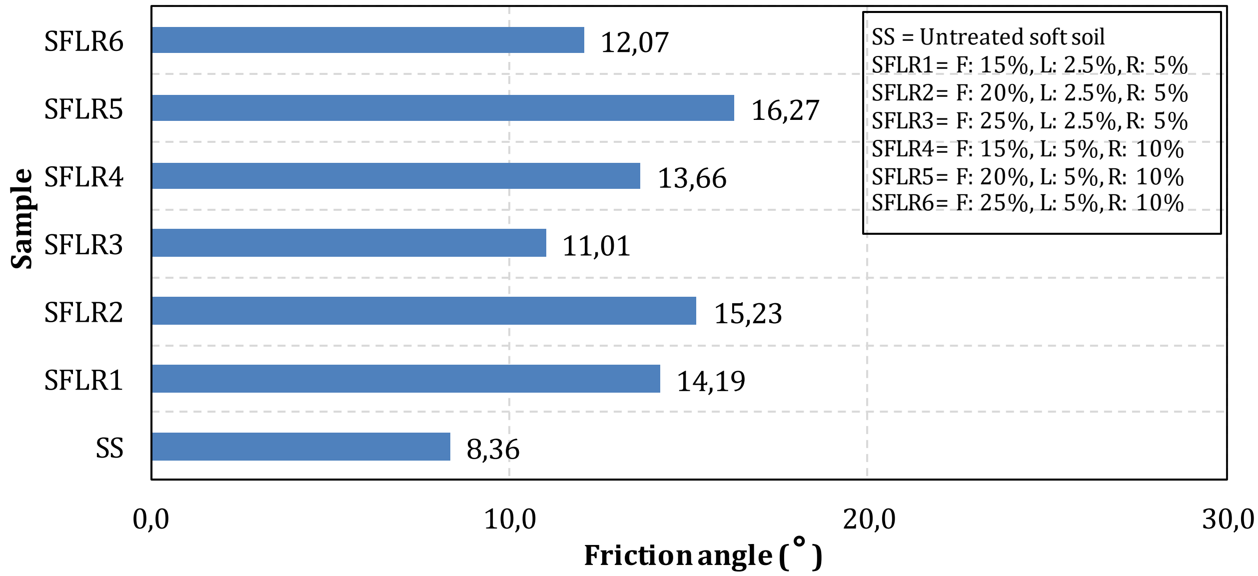

Figure 6. The friction angle of samples

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2.5. Soaked CBR Test Results

Besides conducting the Unsoaked CBR test, this research also carried out the Soaked CBR test. For this purpose, the samples were first air-curing for 7 (seven) days and then submerged in water for 4 (four) days. Air-curing for 7 (seven) days is intended to allow the chemical reaction to occur between the stabilizing material and the soil. As stated by Simatupang et al. [54], in the presence of water, fly ash can form cementitious and pozzolanic gels in the form of calcium silicate hydrate (CSH) and calcium aluminate hydrate (CAH), which then bind soil particles. This reaction can increase the strength and stiffness of the soil. However, pozzolanic materials such as fly ash and rice husk ash react slowly, so that the chemical reaction will take time. Figure 7 presents the CBR test results of soaked samples.

The results of the Soaked CBR tests show that the CBR value has decreased compared to the unsoaked CBR value. This finding is in accordance with the research results of Horpibulsuk et al. [55]. When the soil is submerged, it will absorb water over time. This absorption will increase the swelling pressure of the soil. Therefore, soaked soil's bearing ratio value will be smaller than unsoaked soil's.

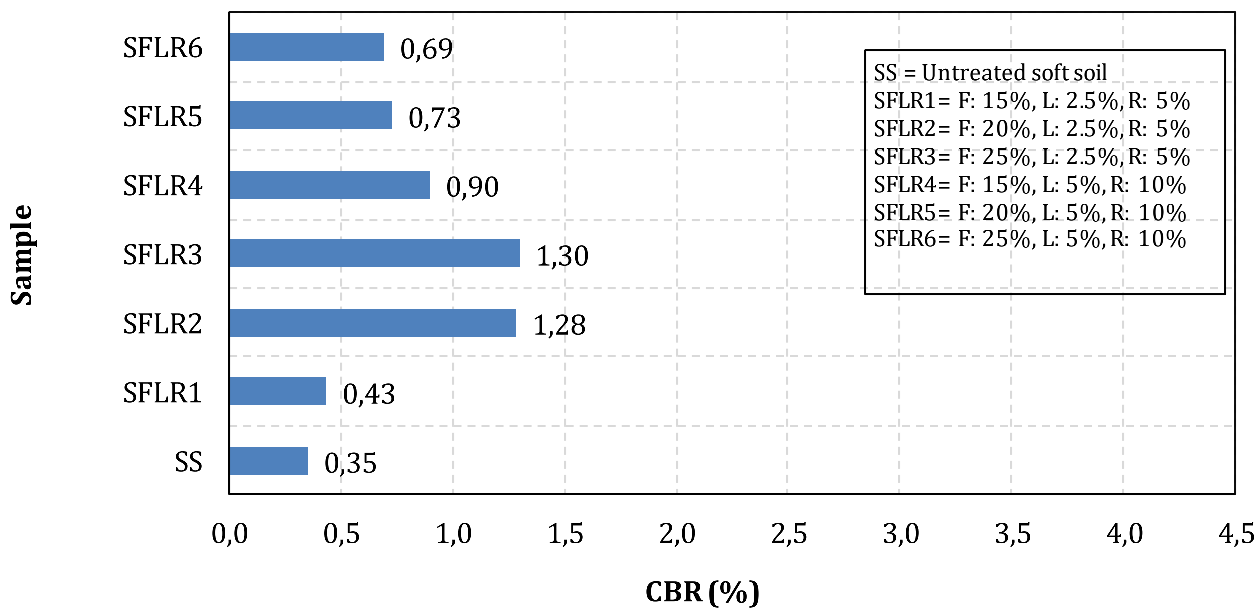

Figure 7. Soaked CBR test results

2.6. Swelling Test Results

The Soaked CBR test provides not only bearing ratio values but also swelling values of the sample. As can be seen in Figure 8, the swelling value for untreated soil was quite significant, namely around 12%. As for samples with additional fly ash, lime, and rice husk ash, the soil's swelling only increased up to 8%. These findings prove that industrial waste and lime can inhibit soil swelling. Therefore, soil stabilization with this material has been proven to provide good results for increasing the CBR value and the ability to resist soil swelling. Furthermore, for samples containing SFLR2, SFLR3, and SFLR6 variations, the soil's ability to resist swelling was visible immediately after being submerged. This phenomenon could be explained due to the physical cementation mechanisms of fly ash [56]. In addition, it can be concluded that a higher amount of fly ash positively reduces the possibility of volumetric expansion of plastic soils. Especially for the SFLR3 sample, the swelling value is only around 1%.

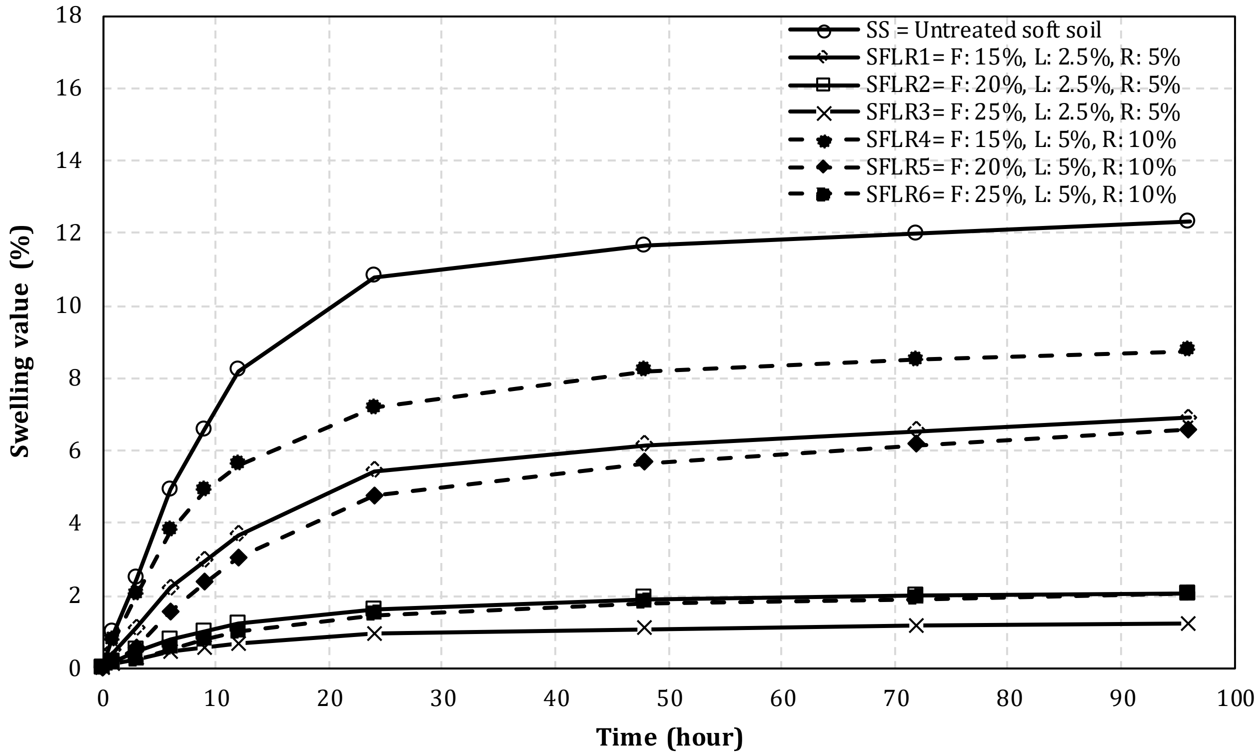

Figure 8. Swelling value versus time

3. Conclusions

The purpose of this research is to determine the effect of industrial waste, fly ash, and rice husk, combined with lime on the soft soil's physical and mechanical properties. In addition, this latest research also aims to recommend the optimum combination of stabilizing agent mixtures. The important points that can be drawn as conclusions in this research are:

1. The results of physical properties testing show that fly ash, lime, and rice husk ash can reduce the liquid limit and increase the plastic limit of the soil. Thus, the soil plasticity index decreases. Thus, these three materials can be used to improve the physical properties of soft soil.
2. CBR test results show that the soil bearing ratio value has increased by up to 85% from the untreated soft soil bearing ratio value of 1.4% increased up to 2.6% for the treated soft soil. These results show that fly ash, lime, and rice husk ash can improve the mechanical properties of soft soil.
3. The direct share test results showed that increasing the fly ash presentation could increase the soil cohesion value. These results also add confidence to the potential of industrial waste as a stabilizing agent.
4. Regarding soil swelling, industrial waste proved able to reduce the volumetric expansion of soft soil submerged in water, especially for SFLR3 sample.

5. Based on the experimental results of this research, the mixture composition proposed is SFLR3 variation with a composition of 25% fly ash, 2.5% lime, and 5% rice husk ash.

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