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Effect of Coal Combustion Waste on Cement-Treated Clay

Soewignjo A. Nugroho [1*], S. P. Retno Wardani [2], A. S. Muntohar [3], Syawal Satibi [1]

[1] *Department of Civil Engineering, Faculty of Engineering, Universitas Riau, Pekanbaru, Indonesia.*

[2] *Department of Civil Engineering, Faculty of Engineering, Diponegoro University, Semarang, Indonesia.*

[3] *Department of Civil Engineering, Engineering Faculty, Universitas Muhammadiyah Yogyakarta, Yogyakarta, Indonesia.*

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Abstract

High plasticity clay is soil with poor material characteristics; one of them is the large shrinkage condition due to its high plasticity. Therefore, it is necessary to improve the soil using cement and coal-combustion waste (CCW). The purpose of this research is to determine the effect of mixture addition on the CBR value of the specimen on stabilization. Variations of 6%, 9%, 12%, and 15% of CCW and cement content vary by 3% and 5%. Based on the test results, there is an increment in the CBR bearing capacity, which was initially 0.80% to 18.75% to 42.90% by adding cement and CCW between 6% and 15%, respectively, after 7 days of curing. This increment is the largest of all variations in the CBR test. The percentage of increment in CBR value is quite large, i.e., a multiple of 200. This proves that the mixture is able to work effectively in increasing the bearing capacity of the soil. Based on microscopic testing of CBR samples, it is obtained that the higher the levels of Bottom Ash Fly Ash (BAFA) and cement, the rougher and paler the samples became as the structure changed. And vice versa, the lower CCW content and cement content made the sample structure become smoother and brighter in color, closer to the original color of natural clay.

Keywords: Bottom Ash; Fly Ash; Cement; High Plasticity Clay; Stabilization.

1. Introduction

Coal Combustion Waste (CCW) is a type of additional material (additive) obtained from coal residue or waste material from burning coals. The main difference between bottom ash and fly ash (BAFA) is the amount of compound elements such as calcium, silica, aluminum, and iron. According to data released by the Ministry of Energy and Mineral Resources in 2019, national coal production was 548 million tons, and the amount of coal production in 2018 resulted in BAFA waste reaching 5% to 6% of total production, or 27 million tons to 37.4 million tons. Several companies in Riau Province, both national and private companies, use coal as their main fuel, including PT IKPP, PT RAPP, and PLTU Tenayan. Nainggolan & Muhardi [1] and Indriyati et al. [2] studied the chemical composition of fly ash (FA) and bottom ash (BA) from PT IKPP, with the findings as displayed in Table 1.

The CBR value has a direct proportional relationship to the degree of density. When the CBR value is greater, it tends to have higher soil density. The similarity of their density degree demonstrates the relationship between CBR in the field and CBR in the lab. In order to obtain them, use Equations 1 and 2, and Table 2 shows the qualitative value of the density degree.

$$CBR_{lab} = \frac{P_{(0.1'/0.2')}}{P_{standard}} \times 100\% \tag{1}$$

* Corresponding author: nugroho.sa@eng.unri.ac.id

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$$CBR_{field} = D_r \times CBR_{lab} = \frac{\gamma_{dry}}{MDD} CBR_{lab} \quad (2)$$

Table 1. Chemical content of PT IKPP coal combustion waste

No.	Compound Chemistry	ASTM C-618		BAFA PT IKPP	
		F	C	FA	BA
1	Silica Oxide (SiO_2)	>70	>50	45.58	58.79
2	Alumina Oxide (Al_2O_3)			37.53	20.33
3	Iron Oxide (Fe_2O_3)			11.17	9.78
4	Sulfur Trioxide (SO_3)	5	5		
5	Calcium Oxide (CaO)	<10	>10	1.74	3.17
6	LOI			0.56	
7	Water Content (%)	3	3	0.70	3.06
8	Heat loss	6	6		
9	Specific Gravity			2.43	2.54*
10	unit weight (gr/cm^3)			1.17	1.70

* Enters the 1.90-2.60 range according to Kim's research [3]

Table 2. Degree of Density [4]

No.	Degree of Density (Dr, %)	Description
1	0 - 15	Very loose
2	16 - 50	Free
3	51 - 70	Currently
4	71 - 85	Congested
5	86 - 100	Very solid

The use of fly ash and/or bottom ash has been carried out by Zulnasari et al. [5]; Nugroho et al. [6]; Galvín et al. [7]; Pokharel & Siddiqua [8], which increased the shear strength of the soil. The increment of CBR value due to the addition of Fly Ash (FA) and Bottom Ash (BA) was also proven by Lembasi et al. [9], Nugroho et al. [10], and Putra et al. [11]. Using coal waste as additives is usually combined with conventional pozzolanic materials such as cement [12-15] and lime [16-19]. Previous research results concluded that the optimum cement content is in the range of 2%–7%, and the lime content is 5%–12%. Using fly ash or bottom ash up to 30% can still increase the shear resistance and bearing capacity of the soil. Using coal ash together (BAFA), which is also still in the range of 10%–30%. The compaction of samples for shear strength and bearing capacity testing is all around and at the water content at the Optimum Moisture Content (OMC). Stabilization of high-plasticity clay with cement and BAFA with high water content and moisture content at a liquid limit of over 50% is still rare. This research was carried out on high-plasticity clay stabilized with cement at 50% water content. This research aims to utilize CCW as a stabilizing additive for high-plasticity clay soil (CH) with cement. The main goal of the study is to find out how CCW waste mixed with cement affects the soil's ability to hold weight or loads. This will be done by checking the amount of bottom ash and fly ash at a 2:1 ratio at different curing times (unsoaked CBR).

2. Methods

2.1. Equipment and Materials

The equipment used in this research is obtained from the Soil and Rock Mechanics Laboratory, Civil Engineering Department, Riau University, including physical and mechanical properties testing equipment (CBR lab equipment). The Microscope 1000x Digital Microscope test equipment was used to see the bonds between clay, cement, and BAFA at the weakest plane (fracture method) and certain cut planes. High-plasticity (CH) clay was taken from Muara Fajar Village, Rumbai District, Pekanbaru-Riau. Fly ash and bottom ash were obtained from burning coal from PT Indah Kiat Semen (PT IKPP) Perawang Regency and PCC (Portland Composite Cement) produced by PT Semen Padang.

2.2. Test Types and Sample Variations

The addition of coal combustion waste affects both physical and mechanical properties (soil properties and shear strength) as well as bearing capacity. Some observations were carried out on how the CBR value changed as bottom ash

(BA), fly ash (FA), and bottom ash-fly ash (BAFA) were added. The original soil and the original soil mixed with cement and BAFA were also observed. The mixture composition is the dry weight ratio of the original soil, cement, and CCW. The process of creating CBR test samples involves adding water at a rate of 50% of the mixture's total weight. The sample was mixed properly and then compacted in a CBR mold according to Standard Proctor testing. The CBR test samples were stabilized with cement at levels of 3% and 5%, and coal combustion waste (CCW) was added. The CCW levels were 6%, 9%, 12%, and 15%. BAFA waste consists of bottom ash and fly ash in a ratio of 2 to 1. Variations and codes for mixtures of high-plasticity clay (CH), cement, and BAFA are summarized in Table 3.

Table 3. CBR Test Sample Mix Code

Mixed Variations	Code	Cement	Combusting Coal (CC)		
			BA*	FA**	BAFA***
Nature clay (CH)	C	-	-	-	-
CH+3% C+6% CCW	C3-Coal6	3	6	6	6
CH+3% C+9% CCW	C3-Coal9	3	9	9	9
CH+3% C+12% CCW	C3-Coal12	3	12	12	12
CH+3% C+15% CCW	C3-Coal15	3	15	15	15
CH+5% C+6% CCW	C5-Coal6	5	6	6	6
CH+5% C+9% CCW	C5-Coal9	5	9	9	9
CH+5% C+12% CCW	C5-Coal12	5	12	12	12
CH+5% C+15% CCW	C5-Coal15	5	15	15	15

* Var-1: High Plasticity Clay + Cement + Bottom Ash; **Var-2: High Plasticity Clay + Cement +Fly Ash; ***Var-3: High Plasticity Clay + Cement+ BAFA (Bottom Ash + Fly Ash).

The reason for choosing a water mixture content of 50% was because it was the same water content as the liquid limit value of low plasticity and high plasticity clay on the Atterberg Limit chart. Samples were tested after curing for 7 days to analyze changes in water content during curing against the CBR value for conditions without soaking (Figure 1).

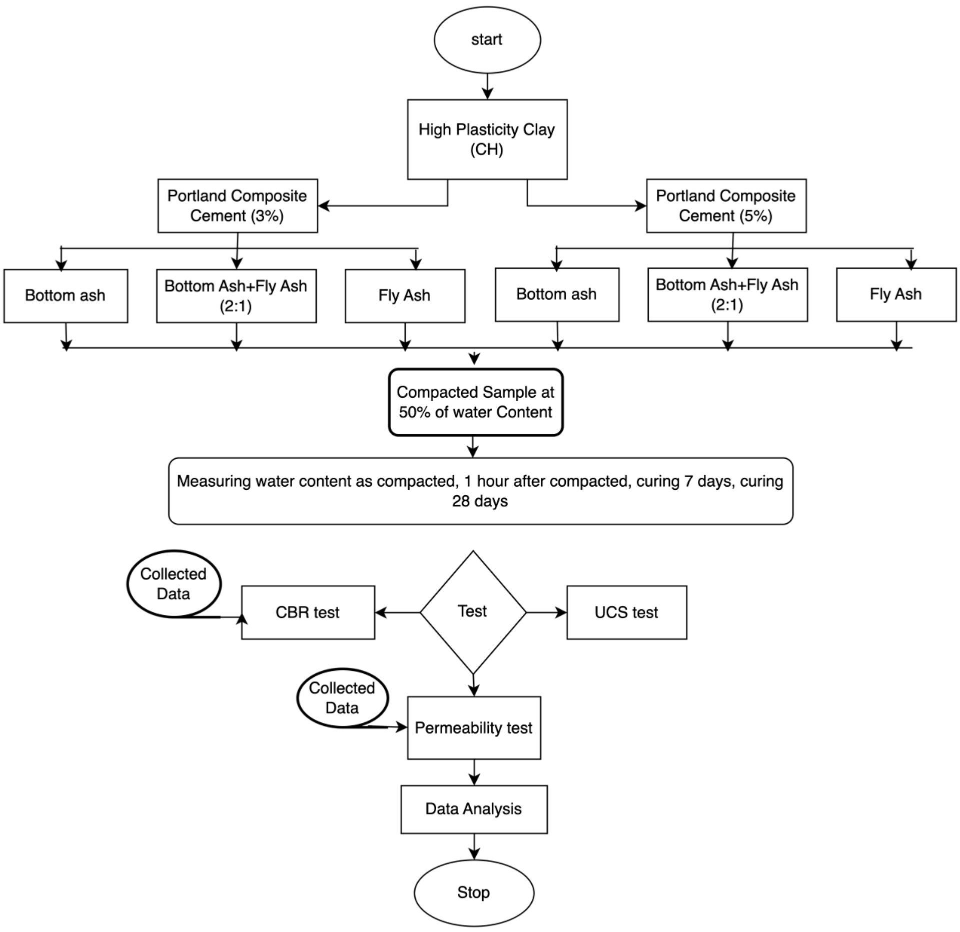


Figure 1. Flowchart of Test

3. Results

3.1. Original Soil Properties Test

The result of the Specific Gravity (Gs) test on the subgrade gave the magnitude of 2.61. By using Proctor Laboratory standard test, it was obtained that Optimum Moisture Content (OMC) was 32.25% and Maximum Dry Density (MDD) was 13.82 kN/m^3. Water levels for laboratory CBR testing are set above the OMC value, which was 50%. The original concentration at the time of sampling in the field was 46.24%.

3.2. CBR Test Results

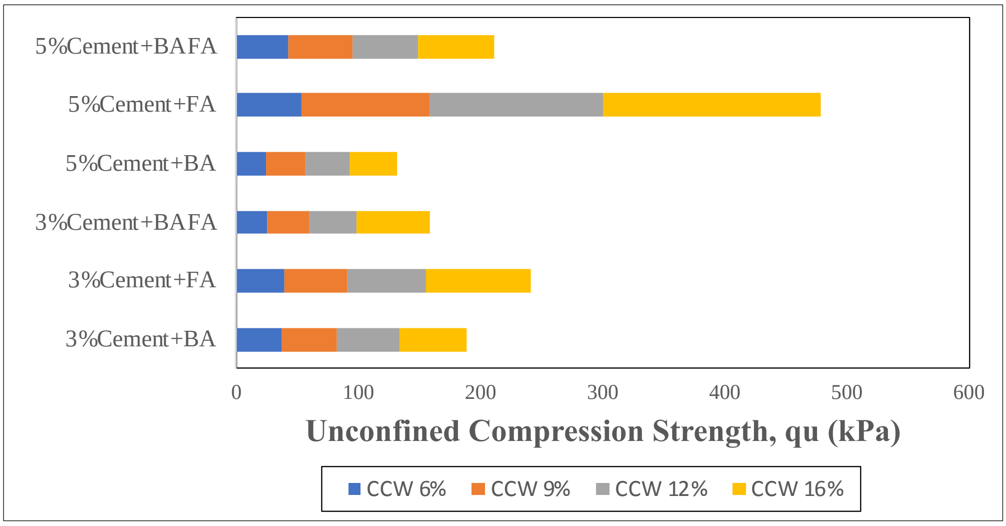
The data obtained from this research came from tests carried out in the laboratory, which were then presented systematically and clearly so that analysis can be carried out. The data obtained, consecutively CBR value (%) and water content (%), is shown in Table 4.

Table 4. Measurement of Moisture Content and CBR value

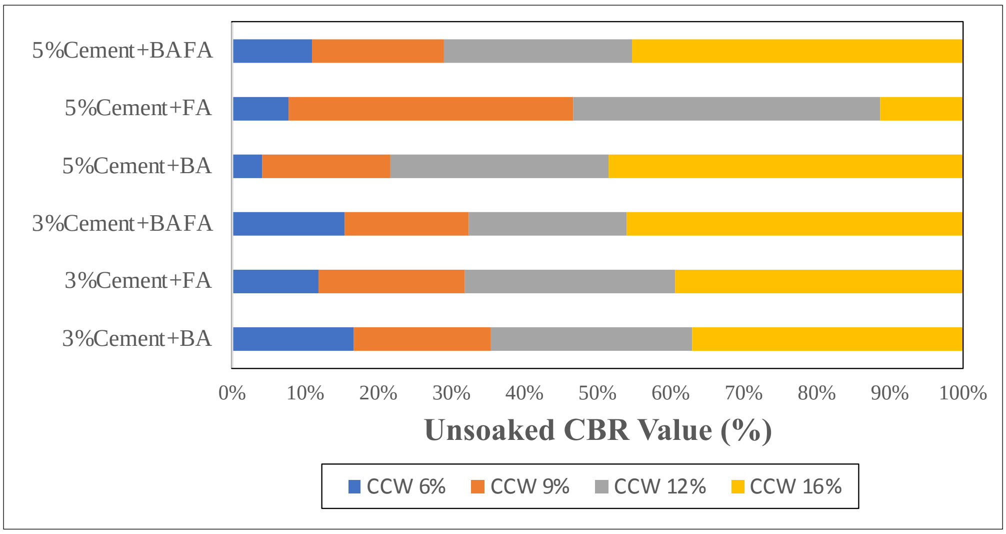
Mixed Variation Code	Unconfining Compression Strength. qu (kPa)						Curing 7 days CBR unsoaked (%)		
	Bottom ash		Fly Ash		BAFA				
	non	7 days	non	7 days	non	7 days	BA	FA	BAFA
CH (origin clay)	22.00						0.80		
CH-C3-CCW6	31.55	36.80	31.65	38.90	23.65	25.85	2.45	3.40	2.15
CH-C3-CCW9	36.60	45.95	41.40	52.45	28.30	34.45	2.80	5.75	2.35
CH-C3-CC12	46.55	51.10	55.30	64.35	38.60	38.90	4.05	8.30	3.00
CH-C3-CCW15	38.30	54.70	71.65	85.55	52.50	59.95	5.50	11.35	6.40
CH-C5-CCW6	19.80	24.70	40.85	53.80	31.06	42.65	3.35	7.20	4.50
CH-C5-CCW9	22.60	32.10	46.20	104.70	34.35	52.40	13.90	36.80	7.50
CH-C5-CCW12	23.15	36.45	56.15	140.65	38.76	54.20	23.90	39.55	10.65
CH-C5-CCW15	23.40	38.70	76.00	178.55	56.20	62.10	38.65	42.90	18.75

Notes: BA=var-1, FA=var-2, BAFA=var-3.

At the same cement content (Table 4), adding BAFA immediately after mixing required water to react with the clay and cement. The higher the BAFA content, it will require more water. This also happens during the seven-day curing process. The higher the BAFA content is, will make greater water loss. At 3% of cement content, fly ash reacted better than bottom ash, so the bonding of cement and clay was stronger, hence created the highest CBR value. The CBR values of variant-1 (BA) and variant-3 (BAFA) mixtures are relatively the same; possibly the fraction of bottom ash is dominant in BAFA. During the formation of bonds between clay, cement, and coal, it requires only a small amount of water, so during bond formation stage, the moisture content decreases slightly. Conversely, with the addition of cement content to 5%, there is a very high increment, especially in samples with BA and/or FA of more than 6%. At the right composition, cement and CCW are proven to improve the bearing capacity of high-plasticity clays. The laboratory CBR test results and UCS are displayed in diagram form for each variation of 3% cement and 5% cement, which can be seen in Figure 2.



(a) Unconfined Compression Strength vs Cement and CCW



(b) CBR value vs Cement and CCW

Figure 2. CBR and qu Value

The results also explained that the sample variation with a cement content of 3% has a lower magnitude compared to the sample variation with 5% cement. The Ministry of Public Works and Public Housing (PUPR, 2017) states that the minimum value for CBR subgrade is 6%. Referring to PUPR standards, stabilization with 3% cement and 16% BAFA will meet the requirements. Meanwhile, stabilization with 5% cement, the addition of more than 6% BAFA meets PUPR standards.

3.3. Relationship between Water Content and Strength

Tables 5 to 7 summarize the changes in water content from the start of mixing, compression, and right after compressing, as well as after splashing. The hydration/heat that occurs as a result of the reaction between cement, soil, and CCW requires water. Water loss due to hydration processes, compared directly with the addition of cement and CCW.

Table 5. Moisture Content drop of Bottom Ash along mix, compacted, and curing (Varian-1)

Variation	Code	Mixture	As Compacted	Non Curing	Curing	
					7 days	28 days
Nature clay (CH)	C	50.00	50.00	50.00	-	-
CH+3% C+6% CCW	C3-BA6	50.00	46.00	45.19	44.54	44.31
CH+3% C+9% CCW	C3-BA9	50.00	43.50	41.14	40.47	40.37
CH+3% C+12% CCW	C3-BA12	50.00	42.20	42.06	39.40	39.24
CH+3% C+15% CCW	C3-BA15	50.00	41.00	40.06	39.73	36.63
CH+5% C+6% CCW	C5-BA6	50.00	45.00	45.00	43.61	43.59
CH+5% C+9% CCW	C5-BA9	50.00	42.50	42.50	40.78	37.89
CH+5% C+12% CCW	C5-BA12	50.00	41.25	39.50	39.45	39.41
CH+5% C+15% CCW	C5-BA15	50.00	40.00	39.81	39.85	35.51

Table 6. Moisture Content value of Fly Ash during mixing, compaction, and curing (Varian-2)

Variation	Code	Mixture	As Compacted	Non Curing	Curing	
					7 days	28 days
Nature clay (CH)	C	50.00	50.00	50.00	-	-
CH+3% C+6% CCW	C3-FA6	50.00	46.00	43.70	43.59	42.55
CH+3% C+9% CCW	C3-FA9	50.00	45.65	42.61	41.58	40.85
CH+3% C+12% CCW	C3-FA12	50.00	43.15	40.54	40.37	39.37
CH+3% C+15% CCW	C3-FA15	50.00	41.00	39.23	37.81	37.54
CH+5% C+6% CCW	C5-FA6	50.00	45.98	45.42	45.00	44.57
CH+5% C+9% CCW	C5-FA9	50.00	43.63	43.53	42.50	41.38
CH+5% C+12% CCW	C5-FA12	50.00	41.42	41.40	39.52	39.40
CH+5% C+15% CCW	C5-FA15	50.00	40.48	40.00	39.07	38.78

Table 7. Moisture Content value of FABA during mixing, compaction, and curing (Varian-3)

Variation	Code	Mixture	As Compacted	Non Curing	Curing	
					7 Days	28 Days
Nature clay (CH)	C	50.00	50.00	50.00	-	-
CH+3% C+6% CCW	C3-BAFA6	50.00	43.90	43.70	43.59	42.55
CH+3% C+9% CCW	C3-BAFA9	50.00	42.81	42.61	41.58	40.85
CH+3% C+12% CCW	C3-BAFA12	50.00	40.57	40.37	39.37	40.54
CH+3% C+15% CCW	C3-BAFA15	50.00	39.23	37.81	37.64	37.54
CH+5% C+6% CCW	C5-BAFA6	50.00	45.99	45.98	45.52	44.57
CH+5% C+9% CCW	C5-BAFA9	50.00	43.63	43.53	41.48	41.38
CH+5% C+12% CCW	C5-BAFA12	50.00	41.42	41.40	39.72	39.52
CH+5% C+15% CCW	C5-BAFA15	50.00	40.48	39.07	38.88	38.78

At the samples with the addition of bottom ash, more water is required when reacting with soil and bottom ash in the mixture (Table 5). Table 6 presents the decrease in water levels during the preparation process until the sampling period. The loss of water during the curing process with the addition of fly ash is higher compared to the addiction of bottom ash. On the addition of BAFA, the level of water also decreased during the hydration process between the sludge, cement, and BAFA. The decreases are comparable to the additional BAFAs. The rate of the greatest reduction in the water content, occurs when the process of compression takes place. High plasticity slate properties that absorb water and rapid cement hydration created rapid water loss. The relationship between water content (%) and CBR value (%) in this study is at inverse proportion between as the water content increased and the CBR value decreased, as seen in Figures 3 and 4.

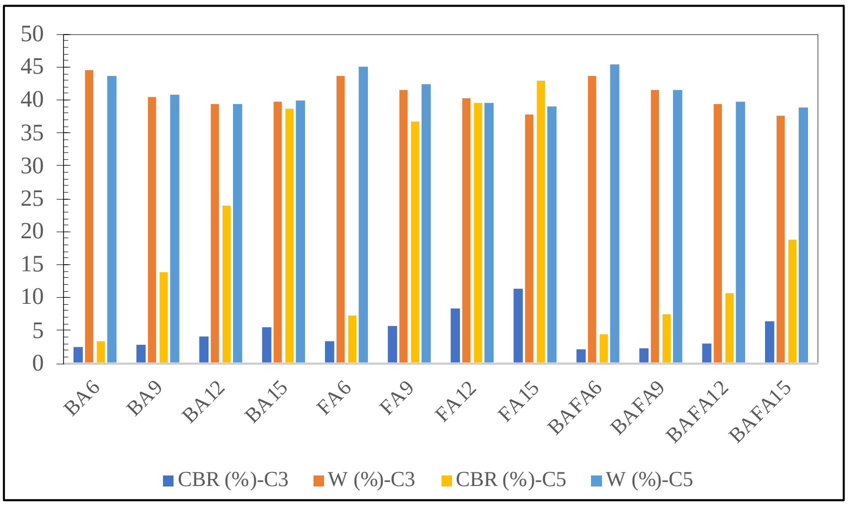


Figure 3. Relationship between CBR Value and Water Content

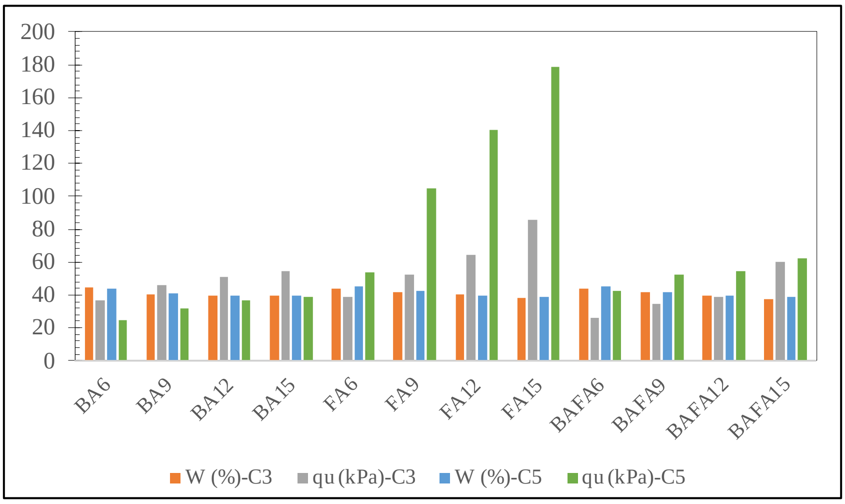


Figure 4. Relationship between qu Value and other parameter values (Water content, Cement content)

Based on Figure 3, it is clear that as the water content increases, the CBR value decreases, and vice versa. Figure 4 explains that with the range of BAFA 9 to 15, gives the best qu results.

3.4. Percentage CBR Value Increase

The overall value obtained has a different percentage increase in the value of the CBR value. In the case of all of these samples being cured for the same period of time, namely 7 days, the percentage of increase in CBR value is influenced by the amount of BAFA content and cement content. A recapitulation of the percentage increase in CBR values can be seen in Figure 5.

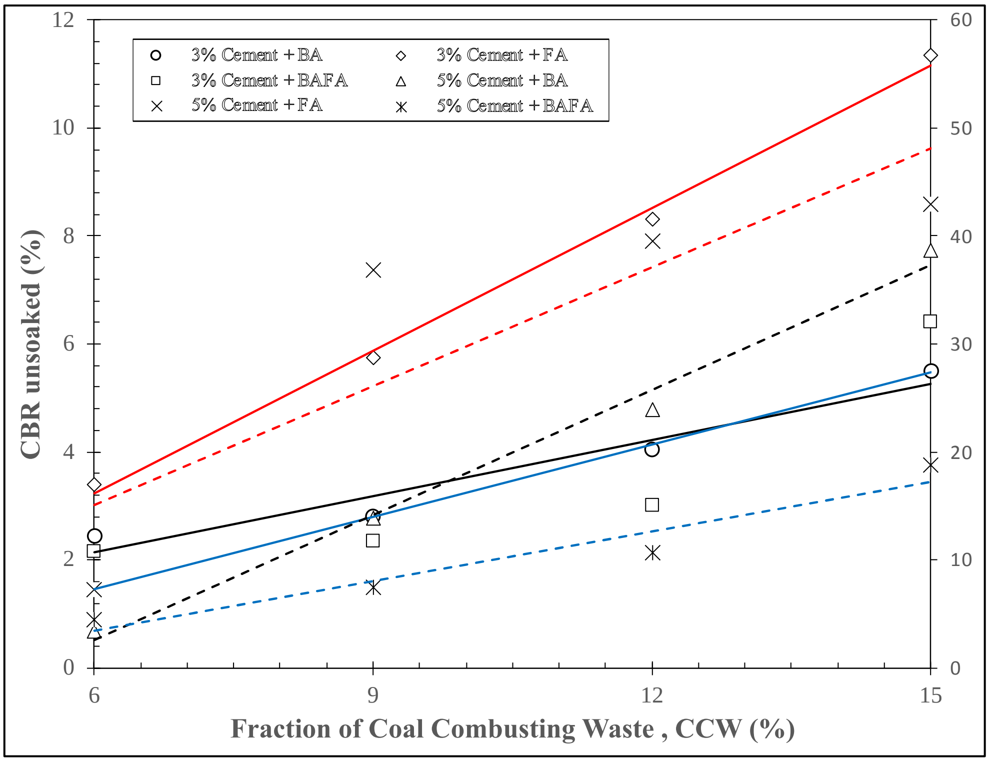
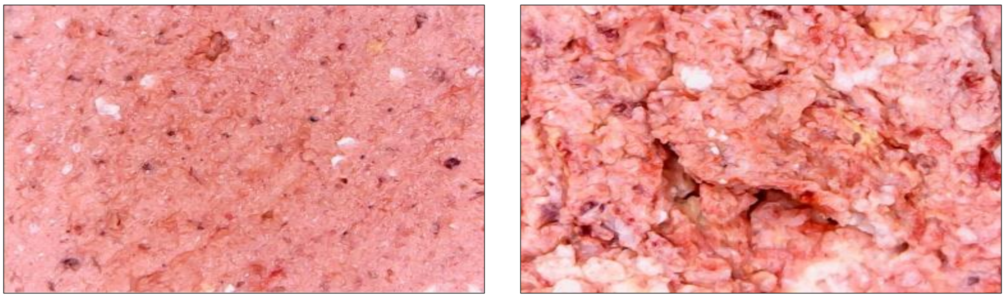


Figure 5. Percentage Increase in Mixed CBR value

Figure 5 explains the percentage increase in BAFA values between variations of 3% cement and 5% cement. The largest percentage increase in 3% cement occurred at BAFA levels of 12% to 16%, and this characteristic also occurred in the 5% cement variation, where the largest percentage occurred at BAFA levels of 12% to 15%.

3.5. Microscopic Results of Original and Mixed Soil

The results of this test are images that explain the structure and color changes. The results of this increase are directly related to the results of the original soil CBR and mixed CBR tests [20]. All image samples obtained are related to several parameter values that influence each other, such as the effect of adding BAFA content, cement content, and curing. [21]. The following is a discussion of the results of microscopic testing images of the inside of the sample using the fracture and slice method on the original soil taken, as seen in Figure 6 (i.e. BAFA).



(a) Slice Method (b) Fracture Method

Figure 6. Microscopic Testing of Non-cured Original Soil Samples

The CBR value of the original soil, which is 0.78% without curing, is a comparison for seeing changes in the microscopic image of the sample mixed with BAFA and cement. The slice method has the characteristics of lots of clay granules and a pink and bright color, similar to original color of clay, and looks paler when BAFA and cement are added. It can also be seen in Figure 7 that the soil grains look tight and stick together but have few pore cavities on the surface. The fault method explains the existence of a fault line, indicating that the line is a weak plane (shear) of the sample taken when the fault was carried out.

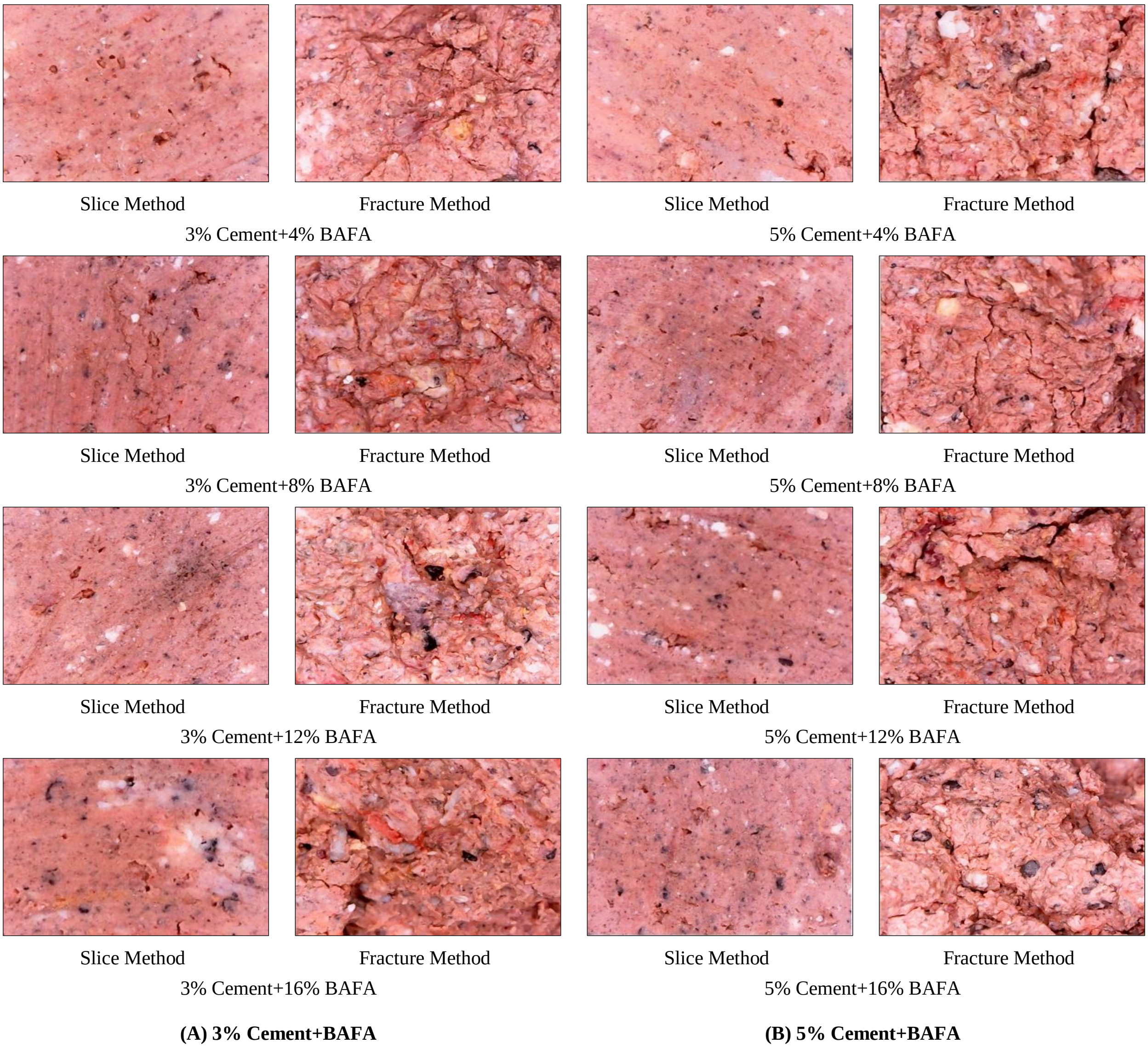


Figure 7. Enlarged image (microscopic) of soil with cement and BAFA

Table 8. Hydraulic Conductivity value all variations

Variation of samples	Coal Content (%)				Hydraulic Conductivity		
	Var-3		Var-2	Var-1	BAFA	BA	FA
	BA	FA	FA	BA	($\times 10^{-11}$ m/s)		
CH (origin clay)	-	-	-	-	610		
CH-C3-CCW6	4	2	6	6	343	140	300
CH-C3-CCW9	6	3	9	9	310	160	350
CH-C3-CCW12	8	4	12	12	265	172	400
CH-C3-CCW15	10	5	15	15	235	195	545
CH-C5-CCW6	4	2	6	6	14400	260	625
CH-C5-CCW9	6	3	9	9	6165	2510	3200
CH-C5-CCW12	8	4	12	12	2315	3450	4670
CH-C5-CCW15	10	5	15	15	1695	3995	5400

4. Conclusion

Based on the test results, there was an increase in the CBR value, which initially was only 0.78% for variation A, to 18% for the sample variation A-S5-B16-C7. This increase is the largest of all variations in the CBR mixture samples. The percentage increase in CBR values is quite large, with magnitude of 2288.48%; this proves that the mixture is able to work effectively to increase the bearing capacity of the soil. Based on CBR and UCS microscope sample testing, it can be seen that the higher the levels of BAFA and cement, the more the sample structure changes, and the rougher and paler it looks. Likewise, the lowest BAFA content and the lowest cement content make the sample structure smoother and lighter color, closer to the original color of the original soil sample.

5. Declarations

5.1. Author Contributions

Conceptualization, S.A.N., A.S.M., S.P.R.W., and S.S.; methodology, S.A.N.; software, S.A.N.; validation, S.A.N., S.P.R.W., and A.S.M.; formal analysis, S.A.N.; investigation, S.A.N.; resources, S.A.N.; data curation, S.A.N.; writing—original draft preparation, S.A.N.; writing—review and editing, S.A.N.; visualization, S.A.N.; supervision, S.P.R.W.; project administration, S.A.N.; funding acquisition, S.A.N. All authors have read and agreed to the published version of the manuscript.

5.2. Data Availability Statement

The data presented in this study are available in the article.

5.3. Funding

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5.5. Conflicts of Interest

The authors declare no conflict of interest.

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