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# Effect of temperature and heating time variation on characteristics of fibrous peat soils

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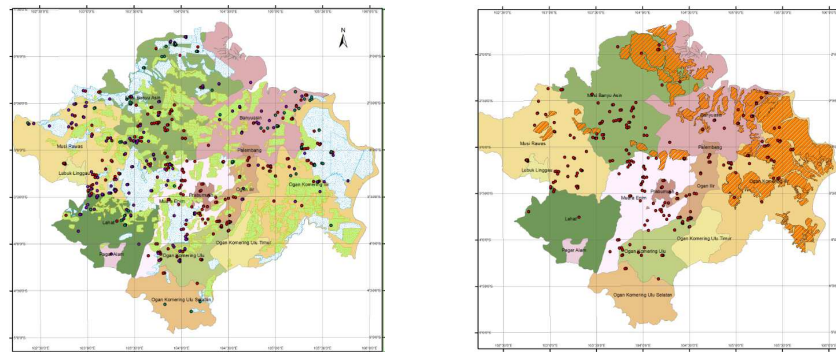
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**Abstract.** Peat soil is a soil that has a large organic content and high moisture content. During the dry season, on the island of Sumatra, especially South Sumatra, the earth's atmospheric temperature has increased, causing frequent cases of forest fires on peatlands. Both those caused by humans and the sun's heat. Increasing the atmospheric temperature of the earth and fires on peatlands will have an impact on the characteristics of peat soils. To find out the changes in peat soil, in this research using temperature variations (30°C, 50°C, 80°C, 100°C, 120°C, 150°C) and heating time variations (6 hours, 12 hours, 24 hours, 36 hours and 48 hours). The locations for peat soil sample: KTM Telang Mulya Sari, Dusun I Banyu Urip, and Dusun III Banyu Urip. The optimum value of the remaining water content ( $\omega_{opt}$ ) is 93.65 % of the location of the peat soil KTM Telang Mulya Sari. These results were obtained at a temperature of 30°C and a heating time for 6 hours. Then for testing the unconfined compressive strength for peat soil without heating obtained the most optimum  $c_u$  value of 0.285 kg/cm<sup>2</sup> in the soil of Dusun I Banyu Urip. As for the testing of unconfined compressive strength test with heating, the highest  $c_u$  value was also found in the peat soil test specimen in Dusun III Banyu Urip which was heated with a temperature of 150°C and a heating time of 48 hours which was equal to 0.93 kg/cm<sup>2</sup>.

## 1. Introduction

Sumatra Island has a large peatland area, which is around 7.3-9.7 hectares. Sumatra Island has a quarter of the total peatland in the tropics. Total peat soil deposit in Banyuasin regency, South Sumatera Province was about 200.000 hectares [1]. The increasing number of human population and activities. Hence the earth's atmospheric temperature is also increasing due to global warming. Due to the increase in earth's atmospheric temperature, especially on the island of Sumatra in the dry season causes frequent cases of forest and peat land fires. Both those caused by humans and the sun's heat. On peatlands, fires are usually caused by the condition of the peat soil when the dry season becomes very dry and for peat soils which contain lots of plant fibers in it will cause the soil to become flammable. Increasing atmospheric temperature of the earth and fires on peatlands will have an impact on peat soil. Figure 1 describes the location of the spread of fires on peatlands in South Sumatra Province [2].





**Figure 1.** Distribution of hotspots on peatland in South Sumatra Province [2]

Heating will cause changes in the characteristics of the soil in the area. Such as: reduced amount of water content, increase in ash levels, reduced organic content, and so forth. This will certainly affect the quality of the land. Heating of peat soil is expected to affect the water content and the shear strength of peat soil. The amount of temperature and the length of time from heating that occurs in various places varies according to the conditions of the location of the land. From the description above, a research will be conducted on the effect of changes in temperature and heating time on the water content and shear strength of peat soil in the Banyuasin Regency, South Sumatra Province. [3] study about the shear strength parameter for peat soil sample.

Temperature is a measure of the heat or cold of an air. Changes in air temperature are caused by a combination of working air, differences in the speed of cooling, and heating of an area and the amount of water and the surface of the earth. In Indonesia, the unit of degree used to measure temperature is expressed in units of Celsius ( $^{\circ}\text{C}$ ). Peat soils are known for their flammability because peat soils have a high organic content [4]. [5] classifies fire rates into the three forms, namely: (1) Low fire severity is a fire condition with low soil heating. some of the remaining woody waste is burned or charred. black ground surface. Soil minerals do not change. And the surface temperature at 1 cm  $< 50^{\circ}\text{C}$ . (2) Moderate fire severity is a fire condition where the soil heating is moderate. The mineral layer beneath it does not appear to change. The remaining ash of the burning color is bright. Burning wood waste. and the soil surface temperature with a depth of 1 cm reaches  $100\text{--}200^{\circ}\text{C}$ . And (3) High fire severity where fire conditions have high soil heating. Charcoal layer can widen with a depth of 10 cm or more, pieces of wood burn out, soil texture on the surface changes, and the soil temperature is 1 cm  $> 250^{\circ}\text{C}$ .

Indonesia, which is a tropical region, has an average atmospheric temperature of  $28\text{--}33^{\circ}\text{C}$ . In the dry season, atmospheric temperature can increase to  $37^{\circ}\text{C}$ . This can cause peatlands which contain high organic content to become flammable. The water content and the shear strength of the soil have an inversely related relationship. Lower temperature on the ground, the amount of water content will increase then the shear strength will decrease, and vice versa if the higher the temperature on the ground the amount of water content will decrease and the value of shear strength will increase.

## 2. Materials and Method

In this research, laboratory testing had been used for the method. All the laboratory testing were used ASTM standard [6, 7, 8, 9, 10]. The location of laboratory test is in the Soil Mechanics laboratory, Civil Engineering Department, Faculty of Engineering, Sriwijaya University, Indonesia. The methodology in this research divided into: peat soil sampling, preparation material and sample, survey, water content testing, and unconfined compressive strength testing [6].

### 2.1. The collection and preparation of peat soil samples

Samples of peat soil were taken in the Tanjung Lago Subdistrict area, Banyuasin Regency, South Sumatra Province. There are three locations for peat soil sample including: KTM Telang Mulya Sari. Dusun I Banyu Urip, and Dusun III Banyu Urip. Samples taken in this research were disturbed soil

samples and undisturbed soil. Undisturbed peat soil samples had been used for testing physical and chemical properties.

## 2.2. Soil properties test

The soil properties (physical and chemical properties) test were carried out in the laboratory as follows: water content ( $\omega$ , %) ASTM D 2216-98, Ash Content (AC) ASTM D-2974, Organic Content (OC) ASTM D-2974, Fiber content (FC) ASTM D-4427, Specific Gravity (Gs) ASTM D-854, and acidity (pH) [7,8,10].

## 2.3. Sample Test

The temperature were used in this research: 30°C, 50°C, 80°C, 100°C, 120°C, and 150°C. Whereas for heating time were: 6 hours, 12 hours, 24 hours, 36 hours, and 48 hours. [12,13] states that the temperature for air content in organic soils is in the range of 35-90°C. The heat temperature used by the [14] study was 100-400 °C. [15] had been used range of room temperature to 140°C. The sample in the [16] research was kaolin, which used heating with a temperature of 200-800 °C with an increase of 200 °C. [17] also uses a temperature of 5 °C, 20 °C, and 40 °C in the research and a normal stress range of 5-80 kPa. The field temperatures ranging from 5-35 °C were used by [18]. Expansive soil properties were also heated in a temperature range until 140 °C [19].

The test sample was made by compaction of the soil, namely by testing ASTM D 698-00 Standard Soil Compaction [9]. Standard soil compaction testing is needed to determine the optimum water content ( $\omega_{opt}$ ) on peat soil. After that proceed with the manufacture of test sample. The test sample was divided into two, namely peat soil without heating and peat soil with the heating process. The total number of peat soil test sample for water content testing and unconfined compressive strength testing in each location (KTM Telang, Dusun I, Dusun III) is shown in Table 1.

**Table 1.** Number of test sample

Temperature (°C)	Water Content Test					Unconfined Compressive Strength Test				
	Heating Time (hour)					Heating Time (hour)				
	6	12	24	36	48	6	12	24	36	48
30	6	6	6	6	6	6	6	6	6	6
50	6	6	6	6	6	6	6	6	6	6
80	6	6	6	6	6	6	6	6	6	6
100	6	6	6	6	6	6	6	6	6	6
120	6	6	6	6	6	6	6	6	6	6
150	6	6	6	6	6	6	6	6	6	6

Peat soil without heating is a sample of soil that has been compacted and than test with unconfined compressive strength. Whereas for peat soil with heating process, the soil after compacting and test with unconfined compressive strength was then put into an oven using the temperature and heating time determined in this research. The next stage is testing the water content and unconfined compressive strength. Testing unconfined compressive strength using ASTM D 2166-00 standard [6].

## 3. Results and Discussions

### 3.1. Fibrous peat soil properties

Table 2 describes the results of physical and chemical properties of peat soils [1]. The peat soil used in this research was taken in three different locations, namely KTM Telang Mulya Sari, Dusun I Banyu Urip Tanjung Lago, and Dusun III Banyu Urip Tanjung Lago, Banyuasin Regency, South Sumatera Province. Based on the data in Table 2, it can be seen that the classification of the peat soil. Peat soils

from three locations have the same soil classification. According to Mac Farlane (1969), peat soil classification is included in the fibrous peat soil because the fiber content contained in peat soil is more than 20 %. Based on Von Post (1992), peat soil classification was included in the H<sub>4</sub> scale because the peat soil is slightly decomposed, dark color, and when squeezed in the hand there is no part of the soil coming out from between the fingers. Furthermore, based on ASTM D-4427-92 (2002) of fiber content values, peat soil is included in the fibric peat type because the soil fiber content is more than 67 %. Based on ASTM D-4427-92 (2002), according to soil pH, peat soil is highly acidic because the soil has a pH of less than 4.5. As well as from ash content values (ASTM D4427-84), peat soil is classified as high ash peat.

**Table 2.** Soil properties of peat soil

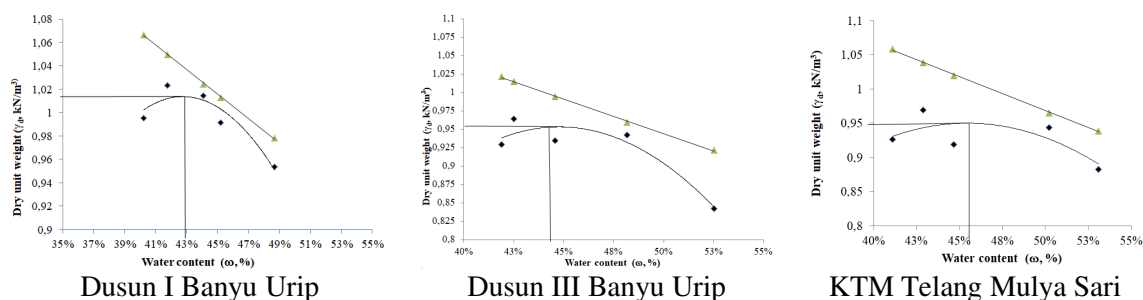
No.	Parameter	Results		
		KTM Telang	Dusun I	Dusun III
1.	Water Content ( $\omega$ , %)	259.790	236.523	294.300
2.	Specific Gravity (Gs)	1.873	1.869	1.799
3.	Acidity (pH)	3.700	3.200	3.160
4.	Organic Content (OC, %)	80.990	77.690	77.400
5.	Ash Content (AC, %)	19.010	22.310	22.610
6.	Fiber Content (FC, %)	74.001	76.659	70.450
7.	Void Ratio (e)	3.351	3.445	3.092
8.	Wet Unit Weight ( $\gamma_b$ , kN/m <sup>3</sup> )	15.488	14.149	17.335
9.	Dry Unit Weight ( $\gamma_d$ , kN/m <sup>3</sup> )	4.305	4.205	4.396

### 3.2. Standard soil compaction testing results

The results of standard compaction testing obtained optimum water content ( $\omega_{opt}$ , %) of fibrous peat soil. Graphs of standard compaction testing for Telang Mulya Sari KTM, Dusun I Banyu Urip, and Dusun III Banyu Urip can be seen in Figure 2. From Figure 2, the optimum water content data for fibrous peat soil KTM Telang Mulya Sari, Dusun I Banyu Urip, and Dusun III Banyu Urip respectively were as follows: 46 %, 43 %, and 45 %. The results of [14] research explain that the optimum water content decreases with increasing dry density.

### 3.3. Test results of soil weight and water content

The weight of the soil is the weight of the soil per unit volume. The weight of the soil will only depend on each grain of the soil. the amount of soil particles present and the amount of water present in the cavity. The weight of the soil can change with the change of water content from the soil mass. The smaller the water content the smaller the weight of a soil. Testing of water content was carried out to determine how much water content was lost and the water content still stored in peat soil was fibrous based on heating temperature and heating time.

**Figure 2.** Results of Standard Soil Compaction Testing

Test results based on heating temperature variations and heating time variations from 3 locations were shown in Figure 3, Table 3, Table 4, and Table 5. After heating, the dry content weight for the three largest peat soil was in the sample specimens with a temperature of 30 °C and a warm-up time of 6 hours. The largest dry weight value ( $\gamma_d$ , gr/cm<sup>3</sup>) for KTM Telang Mulya Sari fibrous peat soil is 1.48. For Dusun I Banyu Urip fibrous peat soil is 1.41 and Dusun III Banyu Urip fibrous peat soil is 1.44. From these tables, it can be concluded that the greater the heating temperature of a fibrous peat soil so the smaller the weight value of the water content and the weight value of the dry content is also smaller due to the high temperature heating of the water lost due to evaporation large and cause much water in the water content to be small so that water content of the pat soil becomes reduces.

Based on the table, it can also be seen that the largest water content remaining for the peat soil of KTM Telang in Mulya Sari was found in the sample with a heating temperature of 30°C and a heating time of 6 hours. The biggest water content lost is 93.65 %. For the peat soil of the Dusun I Banyu Urip, the highest water content lost at 30°C with a heating time of 6 hours was 93.21 %. As well as the largest Dusun I Banyu Urip fibrous peat soil in the sample with a heating temperature of 30°C and a heating time of 6 hours that is equal to 93.51 %. Of the three fibrous peat soil in testing, the same results were obtained. So, the value of the remaining water content is the largest in the sample with a heating temperature of 30°C and a heating time for 6 hours. It because the higher the temperature and the longer the heating time had been used, then the greater the evaporation that occurs and the more water is lost. [13] recommended the test water content with temperature 105-110°C or 105±5°C, mass of wet sample is 50 gram, and drying in 24 hours.

**Table 3.** Test results based on heating temperature on fibrous peat soil at KTM Telang

Temperatur (°C)	Dry Unit Weight ( $\gamma_d$ , gr/cm <sup>3</sup> )					Lost of Water Content (%)				
	Heating Time (hour)					Heating Time (hour)				
	6	12	24	36	48	6	12	24	36	48
30	1.48	1.46	1.45	1.43	1.41	93.65	87.63	82.01	77.41	72.93
50	1.44	1.41	1.38	1.36	1.34	69.87	65.30	61.77	58.97	54.36
80	1.34	1.31	1.28	1.25	1.23	56.17	53.55	50.40	47.79	45.52
100	1.23	1.22	1.21	1.19	1.17	48.19	46.75	44.35	42.99	40.92
120	1.20	1.17	1.16	1.14	1.12	42.15	40.52	38.51	37.44	35.96
150	1.15	1.13	1.12	1.10	1.10	37.97	36.97	36.09	35.51	35.02

### 3.4. Unconfined compressive strength testing result

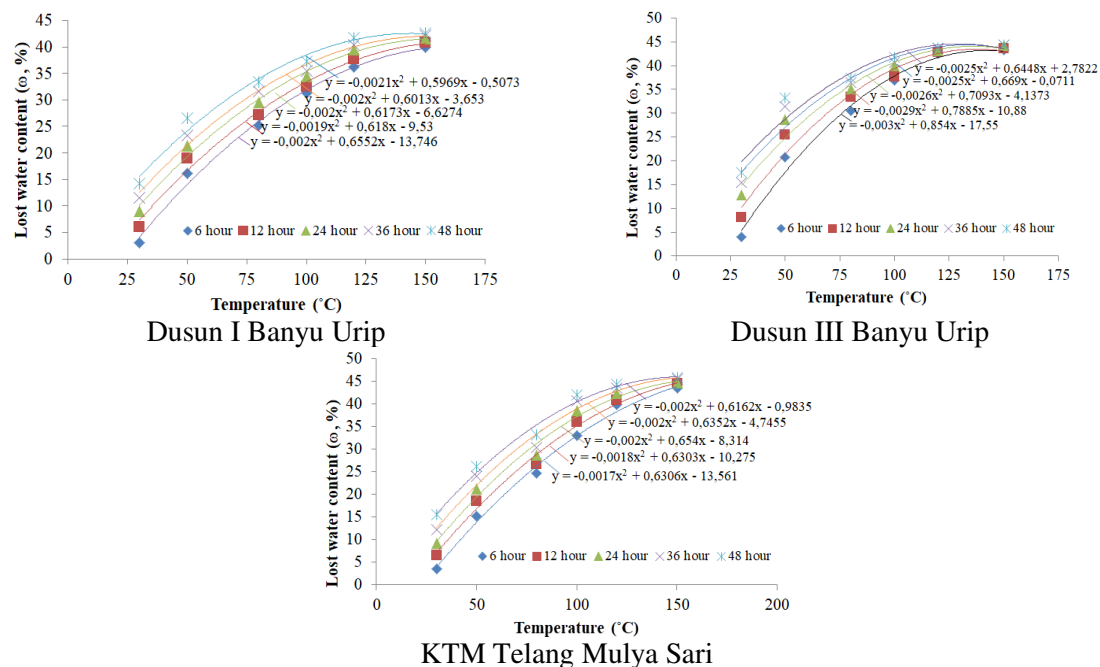
Shear strength of ibrous peat soil is further tested using a unconfined compressive strength equipment. Results obtained from unconfined compressive strength testing without heating and with heating from 3 locations can be seen in Figure 4. Based on Figure 4, the value of  $q_u$  without heating for KTM Telang Mulya Sari peat is 0.51 kg/cm<sup>2</sup>, for peat soil Dusun I Banyu Urip is 0.51 kg/cm<sup>2</sup>, and fibrous peat soil of Dusun III Banyu Urip is 0.51 kg/cm<sup>2</sup>. Then from the value of  $q_u$  from peat soil without heat above the value of  $c_u$  for each peat soil is 0.29 kg/cm<sup>2</sup> (KTM Telang Desa Mulya Sari), 0.26 kg/cm<sup>2</sup> (Dusun I Banyu Urip), and 0.25 kg/cm<sup>2</sup> (Dusun III Banyu Urip). Figure 5 describes the graph of the relationship between  $c_u$  value and temperature based on heating time.

**Table 4.** Test results based on heating temperature on fibrous peat soil at Dusun I Banyu Urip

Temperature (°C)	Dry Unit Weight ( $\gamma_d$ , gr/cm <sup>3</sup> )					Lost of Water Content (%)				
	Heating Time (hour)					Heating Time (hour)				
	6	12	24	36	48	6	12	24	36	48
30	1.41	1.39	1.38	1.37	1.37	93.21	86.77	80.75	75.84	71.04
50	1.38	1.35	1.34	1.30	1.28	67.76	62.88	59.10	56.11	51.17
80	1.30	1.27	1.24	1.21	1.19	53.12	50.31	46.94	44.15	41.71
100	1.25	1.22	1.19	1.15	1.13	44.57	43.03	40.47	39.01	36.80
120	1.15	1.12	1.09	1.07	1.05	38.12	36.37	34.22	33.08	31.49
150	1.08	1.07	1.06	1.05	1.04	33.65	32.58	31.63	31.01	30.48

**Table 5.** Test results based on heating temperature on fibrous peat soil at Dusun III Banyu Urip

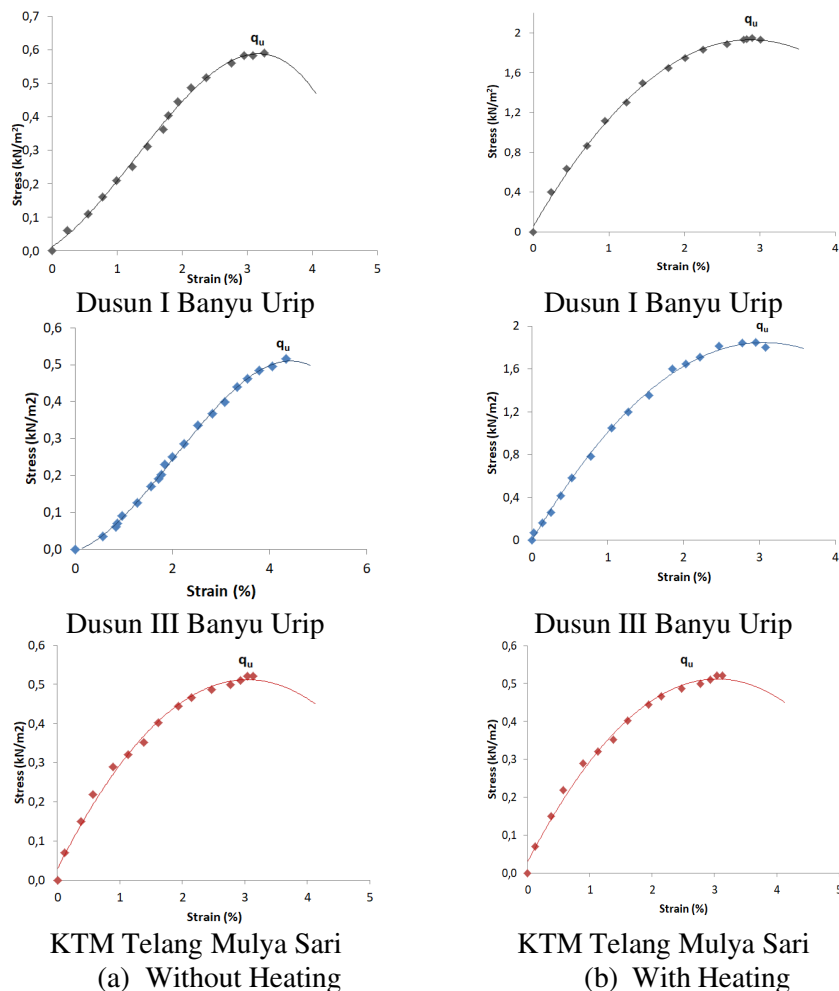
Temperature (°C)	Dry Unit Weight ( $\gamma_d$ ,					Lost of Water Content (%)				
	Heating Time (hour)					Heating Time (hour)				
	6	12	24	36	48	6	12	24	36	48
30	1.44	1.42	1.41	1.40	1.39	93.51	87.36	81.61	76.91	72.33
50	1.40	1.39	1.38	1.36	1.34	69.20	64.53	60.92	58.06	53.34
80	1.31	1.28	1.25	1.25	1.23	55.20	52.52	49.30	46.63	44.30
100	1.26	1.24	1.23	1.21	1.18	47.03	45.56	43.11	41.72	39.61
120	1.25	1.22	1.16	1.15	1.13	40.87	39.20	37.15	36.05	34.53
150	1.15	1.13	1.10	1.10	1.09	36.59	35.57	34.67	34.08	33.57

**Figure 3.** Graph of the relationship between temperature and water content lost with heating time

For unconfined compressive strength test with heating, the test uses a remolded soil sample which has been molded with a unconfined compressive strength mold. Then put in the oven first for the heating process. The optimum  $q_u$  value obtained from the three peat soils is a sample with a high temperature of 150°C with 48 hours of heating time. Fibrous peat soil for KTM Telang Desa Mulya

Sari, the  $q_u$  value is  $1.775 \text{ kg/cm}^2$  and the value of  $c_u$  is  $0.89 \text{ kg/cm}^2$ . Peat soils in Dusun I Banyu Urip, the  $q_u$  value is  $1.86 \text{ kg/cm}^2$  and the value of  $c_u$  is  $0.93 \text{ kg/cm}^2$ . Then for Dusun III Banyu Urip got  $q_u$  value of  $1.825 \text{ kg/cm}^2$  and  $c_u$  value equal to  $0.91 \text{ kg/cm}^2$ . Based on previous research data [1], shear strength parameter for undisturbed sample are: KTM Telang Desa Mulya Sari, the cohesion ( $c$ ) value is  $0.75 \text{ kg/cm}^2$ , Dusun I Banyu Urip, the cohesion ( $c$ ) value is  $0.70 \text{ kg/cm}^2$ , and Dusun III Banyu Urip, the cohesion ( $c$ ) value is  $0.76 \text{ kg/cm}^2$ . If this data compared with fibrous peat in heat treatment, the shear strength of the soil has increased. But, this result is smaller compared to [4], for reconstituted peat ( $c = 2.1 \text{ kg/cm}^2$ ) and undisturbed peat ( $c = 1.0 \text{ kg/cm}^2$ ).

Based on the three peat soils used, peat Dusun I Banyu Urip is the highest shear soil. This is because peat soil I Banyu Urip is peat soil with the smallest optimum moisture content between the three soils. Whereas from the two soil conditions tested, ie unheated soil and heat soil, it is known that after being given heating on fibrous peat soil. Then  $q_u$  and  $c_u$  values become increasing. This happens because the water content of the compressed soil is evaporated, causing soil conditions to become hardened and able to withstand greater loads. Compared with the results from [16] showed that kaolin-peat soil heated to  $400^\circ\text{C}$ , the shear strength also increases.



**Figure 4.** Graph test results of unconfined compressive strength of fibrous peat soil



**Table 6.** Value of  $q_u$  dan  $c_u$  from unconfined compressive strength testing at KTM Telang

Temperature (°C)	$q_u$ (kg/cm <sup>2</sup> )					$c_u$ (kg/cm <sup>2</sup> )				
	Heating Time (hour)					Heating Time (hour)				
	6	12	24	36	48	6	12	24	36	48
30	0.580	0.650	0.750	0.785	0.835	0.290	0.325	0.375	0.392	0.417
50	0.680	0.825	0.870	0.960	1.000	0.340	0.412	0.435	0.480	0.500
80	0.890	0.960	1.005	1.080	1.110	0.445	0.480	0.502	0.540	0.555
100	1.010	1.105	1.200	1.345	1.410	0.505	0.552	0.600	0.672	0.705
120	1.405	1.401	1.500	1.570	1.755	0.702	0.705	0.750	0.785	0.877
150	1.525	1.565	1.710	1.735	1.775	0.7625	0.7825	0.855	0.867	0.887

**Table 7.** Value of  $q_u$  dan  $c_u$  from unconfined compressive strength testing at Dusun I Banyu Urip

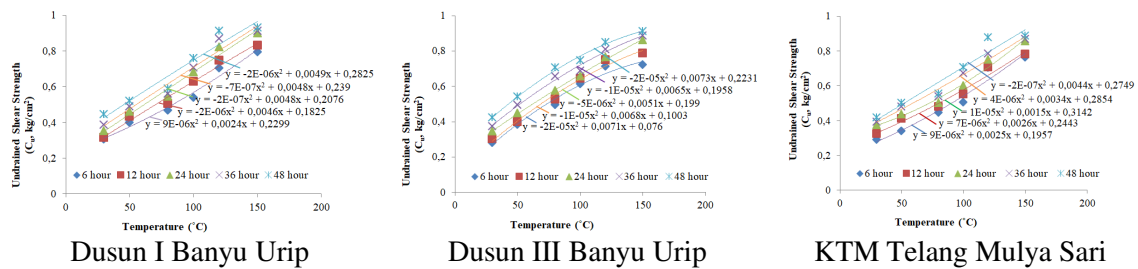
Temperature (°C)	$q_u$ (kg/cm <sup>2</sup> )					$c_u$ (kg/cm <sup>2</sup> )				
	Heating Time (hour)					Heating Time (hour)				
	6	12	24	36	48	6	12	24	36	48
30	0.610	0.630	0.705	0.775	0.890	0.305	0.315	0.352	0.387	0.445
50	0.795	0.865	0.920	0.980	1.040	0.397	0.432	0.400	0.490	0.520
80	0.935	1.010	1.090	1.120	1.180	0.467	0.505	0.545	0.560	0.590
100	1.080	1.260	1.365	1.415	1.520	0.540	0.63	0.682	0.707	0.760
120	1.405	1.495	1.645	1.735	1.825	0.702	0.747	0.822	0.867	0.912
150	1.590	1.660	1.800	1.825	1.860	0.795	0.830	0.900	0.912	0.930

**Table 8.** Value of  $q_u$  dan  $c_u$  from unconfined compressive strength testing at Dusun III Banyu Urip

Temperature (°C)	$q_u$ (kg/cm <sup>2</sup> )					$c_u$ (kg/cm <sup>2</sup> )				
	Heating Time (hour)					Heating Time (hour)				
	6	12	24	36	48	6	12	24	36	48
30	0.565	0.605	0.695	0.750	0.845	0.282	0.302	0.347	0.375	0.422
50	0.770	0.800	0.900	0.990	1.085	0.385	0.400	0.450	0.495	0.542
80	0.99	1.050	1.150	1.315	1.410	0.495	0.525	0.575	0.657	0.705
100	1.225	1.290	1.315	1.375	1.495	0.612	0.645	0.657	0.687	0.747
120	1.425	1.500	1.530	1.615	1.700	0.712	0.75	0.765	0.807	0.850
150	1.445	1.575	1.725	1.775	1.825	0.722	0.787	0.862	0.887	0.912

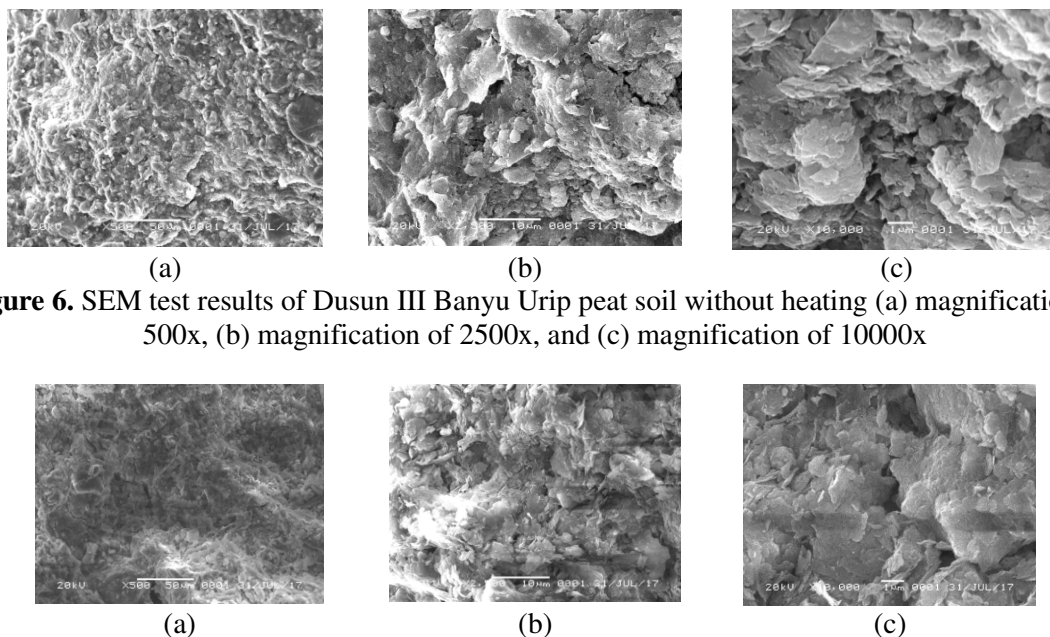
### 3.5. Results of SEM-EDX test

SEM-EDX testing was only carried out on Dusun III Banyu Urip peat soil test sample. Tests are carried out on fibrous peat soil that has been compacted without heating and by heating. The results of SEM testing carried out on peat soil without heating and peat soil with heating can be seen in Figure 6 and Figure 7. From Figure 6 and Figure 7 it can be seen the difference, where the soil conditions at the time before heating contain elements that fill the cavities soil. As for the heated soil it appears that some of the contents of these elements are reduced so that the cavities between the soil look more tenuous. This is because the soil which originally contained elements and filled the cavities of the soil after being heated by these elements was reduced. The results of this study are the same as those of [19]. [19] shows the results that heating temperature carried out on expansive soil affects the behaviour of the soil such as physical and structural changes. And also the heating effect of 100 °C, particle density from the soil changes.

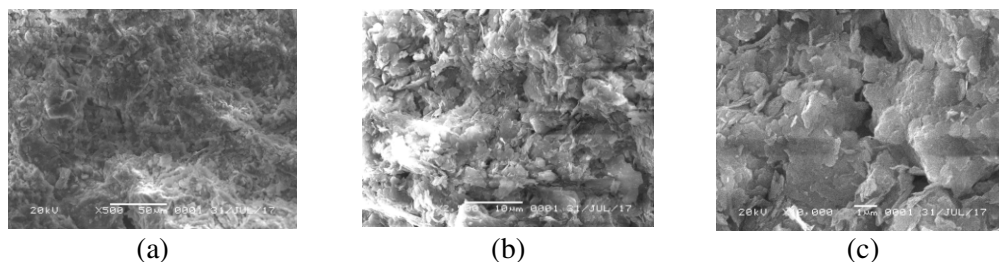


**Figure 5.** Graph of the relationship between  $c_u$  value and temperature on heating time

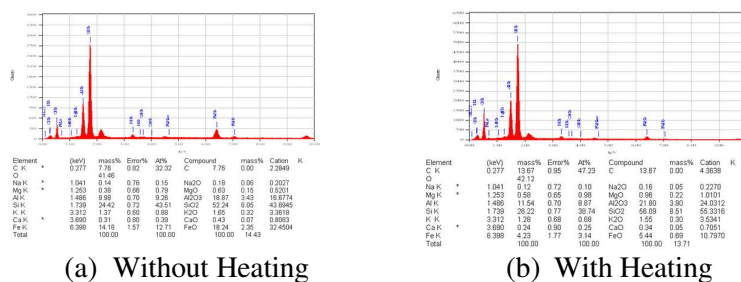
Mineral content contained in fibrous peat soil is obtained from EDX testing. The results of this EDX test can be seen in Figure 8. Based on Figure 8, it is known that both peat soils, either pre-heated or heated have chemical elements in the form of C (carbon), O (oxygen), Na (sodium), Mg (magnesium), Al (aluminum), Si (silicon), K (potassium), Ca (calcium), and Fe (ferrum/iron). The difference between the two lands above lies in the number of elements contained. For example, the content of element C in the soil that has not undergone a heating process is as much as 7.76 % while after the soil has undergone a heating process, the amount of element C contained in the soil increases to 13.67 %.



**Figure 6.** SEM test results of Dusun III Banyu Urip peat soil without heating (a) magnification of 500x, (b) magnification of 2500x, and (c) magnification of 10000x



**Figure 7.** SEM test results of Banyu Urip Dusun III peat soil by heating (a) magnification of 500x, (b) magnification of 2500x, and (c) magnification of 10000x



**Figure 8.** Graphic of elements contained in peat soil of Dusun III Banyu Urip

#### 4. Conclusion

Based on the analysis of the results and discussion of each specimen. The conclusion can be drawn as follows: The most optimum remaining water content of fibrous peat soil is located at KTM Telang Mulya Sari with a temperature of 30°C and a heating time of 6 hours is 93.65 %. Testing of unconfined compressive strength for soil without heating obtained the most optimum  $c_u$  value of 0.285 kg/cm<sup>2</sup> in the fibrous peat soil of Dusun I Banyu Urip. While for testing the unconfined compressive strength of the soil that was heatingd, the highest  $c_u$  value was also found in the fibrous peat soil test of Dusun III Banyu Urip which was heated with a temperature of 150°C and a heating time of 48 hours, which was 0.93 kg/cm<sup>2</sup>. Based on the results of SEM-EDX, it can be seen that the soil conditions at the time before heating contain elements that fill the soil cavities. One of them is the element of Fe in the amount of 14.18 %. Then for heated soil, some of the contents of these elements are reduced so that the cavity of the soil is more empty seen from the elemental content of Fe which is reduced to 4.23 %. Changes in the elemental content of Fe affect the shear strength of peat soil. This can be seen from the increased of  $c_u$  value.

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