Effects of additives on the results of improving peat soil: A case study at Mekong delta in Vietnam

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In Vietnam, peat soils are formed by lake-bog or alluvial-bog sediments, which are widely distributed in the Mekong Delta such as Dong Thap Muoi area, Kien Giang, Hau Giang provinces, and U Minh forest. In soil often contains a lot of organic matter, low pH, strong alkaline soil. This will affect the quality of reinforcing soft soil with cement. The results of this study on improving them with local cement showed that the reinforced soil samples had initially increased until 28 days of age and then decreased with curing time. Additives play an important role in soil improvement with cement. They can change the hydrological environment making the soil reinforced better. In this study, we used lime (CaO) and gypsum ($CaSO_4.2H_2O$) in combination with local cement to improve the peat soil mentioned above. The results show that, when adding a small amount of lime, 1, 2, 4, 6% or 1, 2, 3 % of gypsum compared to cement, the reduction in strength with curing time has been reversed. The optimal content of additives has been determined as lime 4% and gypsum 2%.

Keywords: Peat soil, additives, unconfined compressive strength, tensile strength, humic acid.

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1. Introduction

Organic clay is characterized by high natural moisture, high compressibility coefficient, permeability coefficient, and small shear strength. In the Mekong Delta, this type of soil is distributed quite popularly in Dong Thap Muoi, Tu Giac Long Xuyen, Kien Giang, Hau Giang, U Minh forest, etc., which is formed from upper Holocene sediments of alluvia - swamp origin $abQ2^32$ [1]. This type of soft soil has a high organic content, thus improving this type of soil with cement is inefficient. The results of the previous study showed that peat soil in the Mekong Delta is a weak soil type with strong alum (pH < 4.5), sulfate-contaminated salt. It was reported that the strength of cement-treated peat soil increased at an early age, but after curing time, the compressive strength of the sample decreased [2, 3].

Humic acid in organic soils has a great influence on the quality of reinforced soil, organic matter tends to reduce the pH to the extent that clay minerals cannot dissolve over time [4–6]. When the amount of humic acid increased from 0.5 to 3%, the compressive strength of soil samples decreased over time compared to samples containing 0% of humic acid [7]. $CaSO_4$ salt crystals act as an additive when improving organic mud containing humic acid, when reacting with $Ca\,(OH)_2$ they precipitate and clinging to the surface of clay particles [8], humic acid has a strong reaction to portlandite [9].

The results of previous studies [10–12] found that when applying a small amount of salt $CaCl_2$ or NaCl in the soil could reduce the effect of humic acid to order to increase the quality of reinforced soil. With a small amount of 0.5% $CaCl_2$ added to the soil containing 1.5% humic acid reinforced with 5% lime, the compressive strength is greater than that of 0.5% NaCl, and the compressive strength of this mixture increased with curing time [5].

Moreover, when adding lime to the soil, the ability to exchange Ca^{2+} and Na^{+} cations will be increased, promoting the solubility of clay minerals such as silicates and aluminates. As a result, the strength of organic clay will be increased. It was reported in previous studies that when soil containing more than 1% humic acid, the consolidation of clay will be significantly changed with the addition of lime, and it was found that a weak clay containing 14% organic, using 7% lime is appropriate [11, 13, 14]. For soils containing 12.8% organic soil reinforced with 10% lime, the sample strength increased only slightly compared to unreinforced soil [11].

From the above literature, it is accepted that the treatment of soil containing humic acid and organic matter with only cement is not appropriate. Because the strength of this treated mixture will decrease over time. Thus, to improve the quality of organic soil, it is necessary to use cement combined with lime to treat this soil. As the above discussion, this type of organic soil is very popular in the Mekong delta in Vietnam, thus, this type of soil needs to be improved with an appropriate method for further application.

However, to our best knowledge, there is no study on organic soil using cement in combination with lime and gypsum to improve the mechanical properties of this soil in the south of Vietnam. Thus, this is the first study that presented a solution to improve peat soil in the Mekong Delta (Vietnam) as a case study with cement combined with lime and gypsum and assess their role in soil improvement. Moreover, the results of this study will fill the gap in the literature on the study of cement-treated organic soil in combination with lime and gypsum.

2. Materials

2.1. Soil

2.1.1. The distribution characteristics of peat soil in Kien Giang province

Kien Giang is a province in the Mekong Delta region - southwest of Vietnam: the North borders the Kingdom of Cambodia; Ca Mau and Bac Lieu provinces in the south; Eastern and Southeast border An Giang province, Can Tho city and Hau Giang province; the West borders the Gulf of Thailand. The geographical map of the Mekong delta in this study is shown in Fig. 1. The topography of Kien Giang province includes plains, mountainous, and sea.

In the mainland, the terrain is relatively flat, lower from the Northeast to the Southwest. The delta has an elevation from 0.2 to 1.2 m, along with the tidal regime of the West

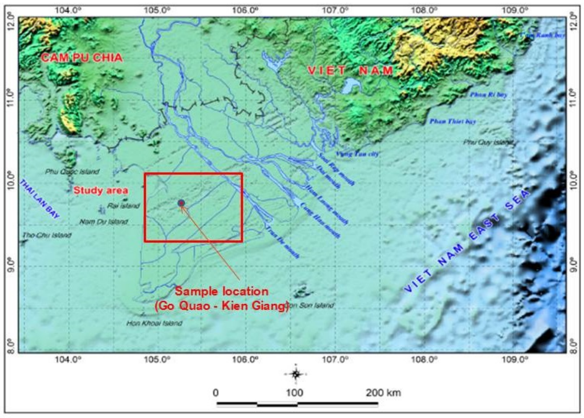

Fig. 1. The geographical map of the Mekong delta in this study.

Sea, which greatly influences the ability to drain water in the rainy season and is strongly affected by saline water, especially in the last months of the dry season. Due to the topographic characteristics, areas from Giang Thanh, Kien Luong, Rach Gia to Go Quao, Vinh Thuan, Cai Lon, and Cai Be are often flooded and the groundwater table rises.

These are areas where the flora develops and decomposes strongly creating organic sediments of alluvia-bog river origin abQ_2^{2-3} with the composition of organic clay mud, peat, organic content in soil varies from 20 $\sim$ 80%, the thickness of these soil layers is from 3m to more than 10m Fig. 2.

2.1.2. Physical and mechanical properties and chemical composition

Soil samples in this study were taken in their original state, at a depth of 2.5 m at locations from Rach Gia to Go Quao in Kien Giang Province and tested according to ASTM D 726321 and BS 1377 - 1990 standards to determine physical and mechanical properties such as humidity, volume weight, grain composition, etc. The mineral composition of the soil was determined by the method of X-ray diffraction on the device D8 – ADVANCE. The chemical composition of the soil was performed by spectroscopic analysis on the Plasma Emission Spectrometer – IRIS INTREPID.

The results cation exchange ability of soil is conducted according to D7503-18. Experimental results of Physico-chemical properties, mineral, chemical, and cation exchange tests are taken as an average and shown in Tables 1 to 4. The values of physical and mechanical properties of soil in this study are comparable with the result of previous studies [15, 16].

From the experimental results of the physical and mechanical properties, chemical and mineral composition

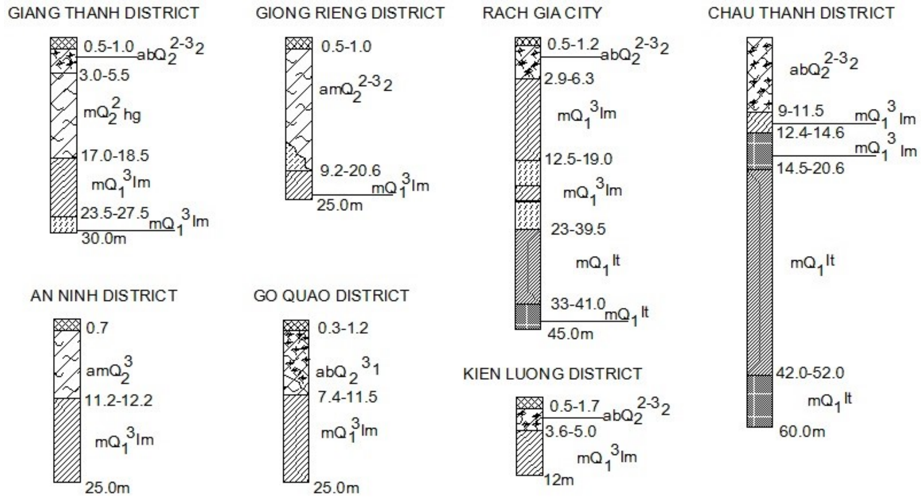

Fig. 2. Stratigraphy of soft soil distribution in Kien Giang province.

Table 1. Physical and mechanical properties of the studied soil.

Properties	Value	Standard	Properties	Value	Standard
Sand grain group (%)	36.5	D6913	Internal friction angle φ (degree)	$2^0 04'$	BS 17892-10
Dust grain group (%)	45.2	D7928-17	Cohesion unit (c, kPa)	1.47	BS 17892-10
Clay grain group (%)	18.3	D7928-17	Compressibility coefficient a_{1-2}	$16.49*10^{-3}$	D2435
Natural moisture (%)	285.0	D2216	Su (kPa)	10.10	D2573
Unit weight γ_w (kN/m^3)	11.3	D7263	Su' (kPa)	3.24	D2573
Bulk density γ (kN/m^3)	19	D854	Coefficient of permeability, k (cm/s)	1.28×10^{-5}	BS 17892-11
Liquid limit W_L (%)	235.8	D4318	SPT experiment, N_{30}	1	D1586
Plastic limit W_P (%)	171.6	D4318	-	-	-

Table 2. Mineral composition of soil.

Mineral composition(%)	Value	Mineral composition (%)	Value	Minerall composition (%)	Value
Montmorillonite	5	Quartz – SiO_2	23-25	Pyrite – FeS_2	5-7
Illite – $KAl_2\left[AlSi_3O_{10}\right](OH)_2$	13	Feldspar – $K_{0.5}Na_{0.5}AlSi_3O_8$	3-5	Pyrophyllite – $Al\left[Si_2O_5\right](OH)$	4
Kaolinite – $Al_2\left[Si_2O_5\right](OH)_4$	7	Goethite – $Fe_2O_3.H_2O$	14-16	Gypsum – $CaSO_4$	15
Clorit – $Mg_2Al_3\left[AlSi_3O_{10}\right](OH)_8$	5	Amphibole	≤0.1	Other minerals	Gipxit

Table 3. Chemical composition of soil.

Chemical composition	Value (%)	Chemical composition	Value (%)	Chemical composition	Value (%)	Chemical composition	Value (%)
SiO_2	27.87	FeO	0.15	K_2O	1.75	Loss on ignition (450^0C)	44.28
TiO_2	0.37	MnO	0.12	Na_2O	0.27	Loss on ignition (900^0C)	50.05
Al_2O_3	9.23	CaO	1,30	P_2O_5	0.11	-	-
Fe_2O_3	6.67	MgO	1,38	SO3	10.80	-	-

Table 4. Chemical composition of soil.

Parameter	Unit	Value	Parameter	Unit	Value	Parameter	Unit	Value
pH	mg/100g	2.1	Mg^{2+}	$m_{eq}/100g$	10.59	K^+	meq/100g	0.07
Total dissolved salt	mg/100g	292.5	Al^{3+}	mg/100g	1.30	CEC	mg/100g	5.42
Fe^{2+}	mg/100g	214.73	Cl^-	mg/100g	38.99	N	%	0.533
Fe^{3+}	mg/100g	19.52	SO_4^{2-}	mg/100g	397.2	Humus	%	26.56
Ca^{2+}	meq/100g	12.76	Na^+	$m_{eq}/100g$	0.68	Mn	mg/kg	621.2

show that: the studied soil is soft soil with high moisture content (285.0%), small density (11.3 kN/m^3), large compressibility coefficient (16.49*10^{-3}, kPa^{-1}), small bearing capacity, high organic content (26.56%).

The amount of SO_3 = 10.83% in the soil shows strong alum, containing pyrite, glycerite, and pyrophyllite, it contains a large organic content. Minerals such as montmorillonite, illite, chlorite, and feldspar are detrimental to soil improvement by cement because their crystal structure is grid-shaped, they are easily absorbed by water, thus they have strong swelling. pH = 2.1 proves that the soil environment is strongly acidic, according to the classification of the authors Bezruk. V.M, Motulev. Yu.L, Grot. A.L, Znamenxki. A.I, Ieruxalimyxkaya. MF [17] is based on the type of salt contaminated determined by the anion ratio of Cl^-/SO_4^{2-} = 38.99/397.2 = 0.1 indicating that the soil is in the form salt sulfate, based on the amount ofCl^- present in the soil, the soil is not saline-type Cl^- = 0.39‰. As a result, building construction projects on these types of soil without reinforcement will face many problems such as large settlements, instability of structures, etc.

2.2. Additives

It is known that to increase the strength of soft soil, two main methods are usually employed namely physical and chemical solutions. In particular, the physical solutions commonly used such as improving grain composition using mechanical loading with mechanical equipment such as roller compactors, vibrators, preloading, etc. While chemical solutions are used to supply additives such as cement, lime, fly ash, and bottom ash, etc. to reduce or eliminate detrimental physical properties. However, for the soil in the studied area, the use of the physical solutions is relatively difficult, thus, the authors chose chemical solutions by using chemical binders combined with additives. Based on the analysis of soil chemistry, it shows that this soil has a high organic content and low pH; when this soil is treated with cement, the strength increased initially at an early age, and then it decreased over time, thus it is necessary to combine the addition of additives. In this study, the authors used cement, gypsum, and lime to treat soft soil.

The main components of this mixture include silicate (SiO_2, calcium) with pozzolanic properties from clay. The pozzolanic reaction between clay minerals and portlandite is to bind to clay minerals to become harder in a given time [18]. In particular, cement acts as a binder, the lime powder works to create an alkaline environment that increases the cement hydration and pozzolanic reaction, and plaster works to quickly increase the strength of the soil [2] . Portland Cement Blended (PCB) is produced and consumed mainly in Mekong Delta, therefore in this study, we used some cement such as Tay Do PCB30, Tay Do PCB40, Kien Luong PCB40, and Ha Tien PCB40 to reinforce soft soil.

3. Research of improving Kien Giang's peat soil with cement and additives

3.1. Research results of soil improvement by cement

The physical and chemical properties of soil are determined according to ASTM and BS 1377 - 1990. A cement-treated soil mixture is produced with the undisturbed sample. In order to assess the impact of cement on the soil quality of reinforced peat soil, we chose the type of Portland Cement Blended as above to study. The chemical composition of these types of cement is shown in Table 5.

From Table 5, it can be seen that the content of oxides in 4types of cement: $SiO_2, TiO_2, Al_2O_3, Fe_2O_3$ oxides of TD30 cement are higher than those in TD40, KL40, and HT40 cement. The amount of CaO in KL40 cement is the largest (60.42%), while TD30 cement is the smallest (49.42) and PCB40 cement is over 50%; the total amount of alkaline oxide (Na_2O and K_2O) of TD30 cement is also greater than TD40, KL40 and Ha Tien PCB40 cement (HT40).

The mixtures of cement-treated clays with different cement contents of 250 kg/m^3, 300 kg/m^3, 350 kg/m^3, and 400 kg/m^3 were prepared and then cast into cylindrical specimens with a diameter of 50 mm, 100 mm high as shown in Fig. 3. The experimental results are the average of the results of 3 samples. The specimens were soaked in water for a curing period of 7, 14, 28, 56, 91, and 180 days of age, then the unconfined compression test was conducted to measure compressive strength. The unconfined compression test was conducted according to ASTM D2166 [19]. The compressive strength results of different mixtures

Table 5. Chemical composition of studied cement.

CementChemical composition (%)	Tay Do PCB30 (TD30)	Tay Do PCB40 (TD40)	Kien Luong PCB40 (KL40)	Ha Tien PCB40 (HT40)
SiO_2	25.41	21.71	16.97	23.77
TiO_2	0.66	0.46	0.26	0.52
Al_2O_3	6.20	5.27	4.70	5.83
Fe_2O_3	3.91	3.43	3.23	3.94
FeO	1.01	0.56	0.12	0.22
MnO	0.06	0.07	0.05	2.53
CaO	49.42	54.74	60.42	51.66
MgO	2.53	2.91	1.81	2.53
K_2O	1.25	1.23	0.89	0.88
Na_2O	1.24	0.79	0.26	1.04
P_2O_5	0.20	0.15	0.11	0.33
SO_3	1.93	2.25	1.40	2.25
Cr_2O_3	0.010	0.01	0.006	0.016
Fineness (m^2/g)	0.95	0.83	1.65	-
Loss (900^{o}C)	6.29	6.85	9.63	8.26

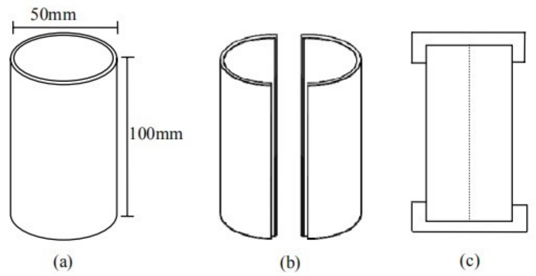

Fig. 3. The mould used for preparing specimens.

are shown in Table 6.

From Fig. 4, it can be seen that the compressive strength increases with an increase in the amount of cement. However, the increment is not significant. The specimens using TD40 cement have greater compressive strength than TD30 and KL40 cement. The maximum value is q_u = 271.3 kPa at 400 kg/m^3 content. Experimental results show that the chemical composition of cement has affected the quality of reinforced soil. The chemical composition test results in Table 5 show that the content of oxides SiO_2, TiO_2, Al_2O_3, FeO, K_2O, Na_2O, and P_2O_5 of cement TD40 is smaller than TD30 but higher than KL40 while the amount of CaO is the opposite.

Thus, the chemical composition of cement TD40 is mostly in the middle level compared to cement TD30 and KL40. In addition, the amount of CaO present in the cement can affect the strength formation of cement-reinforced peat soils. When a large amount of CaO (KL40 cement) will create a large alkaline environment (large pH), this reduces the strength compared to a sufficient amount of CaO in cement (TD40) will produce better strength because the hydration of cement is best when pH = 12.4.

For all cases, the compressive strength initially increased until 28 days, and then decreased with time. This phenomenon happened because the soil has a high organic content, small pH, acidic soil, strong alum environment, containing pyrite, pyrophyllite, and organic soil; thus, when mixed with cement, the decomposition process of organic compounds continue to occur, leading to a further reduction in the pH of the soil environment, which is detrimental to the hydration and pozzolanic reaction. In addition, it was reported that the decomposition of organic matter will destroy cement hydrated products, leading to a decrease in compressive strength [20].

The results of this study are consistent with the study of Yunus et al. [21] on the effects of humic acids and salt additives on the behaviour of lime-stabilized organic clay. Fig. 4 also shows that the sample strength decreased after 28 days of curing, but the decrease tended to be less at the age of 91 to 180 days than at 56 days. This is shown as the curve tends to flatten out. Thus, after 180 days, the sample strength may decrease but not significantly.

3.2. Results of peat soil treated by cement and additives

3.2.1. The result of compressive strength

To evaluate the effect of additives on the strength of reinforced soil, we prepared a peat soil sample (HC) only mixed with a cement content of 350 kg/m^3 and compared with soil samples mixed with the above cement content in combination with additives in different proportions.

The selected additives are: Gypsum Crystals ($CaSO_4.2H_2O$) with the proportions of 1%, 2% and 3% denoted as Ca1, Ca2, Ca3 and lime 1%; 2%; 3%; 4% and 6%, denoted as L1, L2, L3, L4 and L6. Cement selected as

Table 6. Experimental results of unconfined compressive strength of soil mixing cement samples with different content and days of age

No.	Content (kg/m^3)	Unconfined compressive strength (q_u, kPa) over time (days)					
		7	14	28	56	91	180
1	TD30 - 250	117.8	135.7	131.2	108.7	102.7	82.7
2	TD40 - 250	93.2	229.4	188.0	173.0	164.8	153.2
3	KL40 - 250	70.7	93.9	87.0	87.9	78.4	75.0
4	TD30 -300	122.6	164.7	184.1	144.1	127.4	126.4
5	TD40 - 300	154.9	267.4	236.2	152.5	148.3	101.6
6	KL40 - 300	174.3	208.3	202.9	138.6	116.7	107.6
7	TD30 -350	123.4	175.0	191.7	152.6	145.9	140.3
8	TD40-350	186.8	227.5	244.5	206.3	201.0	130.9
9	KL40-350	183.3	207.9	214.2	137.1	129.8	119.8
10	TD30-400	124.5	179.8	200.1	190.0	158.8	145.7
11	TD40-400	204.6	236.0	271.3	254.7	169.9	162.1
12	KL40-400	224.8	233.8	240.0	227.5	210.6	163.0

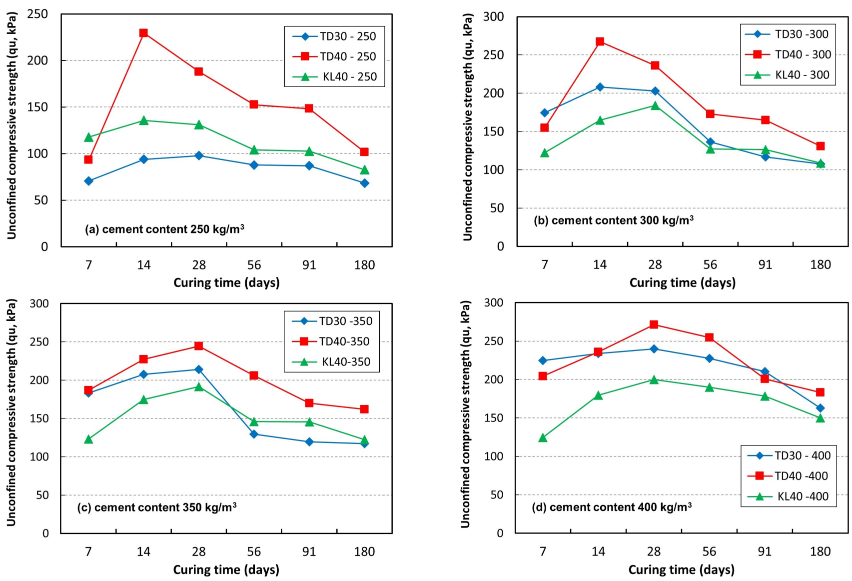

Fig. 4. Relationship diagram between unconfined compressive strength and curing time of soil.

Ha Tien Cement PCB40 is a quite popular cement in the Mekong Delta provinces. After mixing with additives, the samples are also cast and cured as described in section 3.1. Then, the unconfined compressive strength (q_u) of reinforced soil was determined using the unconfined compression test at different days of age. The result of compressive strength is shown in Table 7.

The relationship between the unconfined compressive strength qu (kPa) with a cement content of 350 kg$/m^3$, and additives such as gypsum ($CaSOO_4$) and lime (Fig. 5). From the figure, there is a decrease of compressive following time for the mixture without additives addition. In contrast, it was found that the addition of additives could provide an increment of compressive strength with time. From the figure, it can be also found that an optimal mixture can be obtained for the mixture with 2% of gypsum (HC350Ca2).

3.2.2. *The results of tensile strength*

The testing sample for determining the tensile strength of cement combined with additives is carried out in preparation and maintenance at the same time with the samples of unconfined compressive strength test, according to testing standard ASTM D1632 [22]. Experimental results to determine tensile strength are shown in Table 8.

The relationship between tensile strength R_k (kPa) of reinforced soil with a cement content of 350 kg$/m^3$ and additives (Fig. 6).

Table 7. Test results of unconfined compressive strength of reinforced soil with the cement content of 350 kg/m^3 and additives

No.	Content (kg/m^3)	Unconfined compressive strength (q_u, kPa) curing time (days)					
		7	14	28	56	91	180
1	HC350	64.7	66.0	69.5	64.9	51.8	49.0
2	HC350L1	111.9	128.2	134.3	143.2	148.1	153.4
3	HC350L2	117.0	124.0	155.5	155.9	174.6	210.8
4	HC350L4	134.9	139.8	148.6	186.3	200.1	218.7
5	HC350L6	44.3	64.3	80.5	96.1	103.0	113.8
6	HC350Ca1	70.2	114.9	116.7	119.6	133.6	140.7
7	HC350Ca2	103.0	117.6	119.3	136.7	224.7	254.1
8	HC350Ca3	144.7	146.1	150.0	151.8	162.4	212.0

Table 8. Test results of tensile strength of reinforced peat soil with a cement content of 350 kg/m^3 and additives

No.	Content (kg/m^3)	Tensile strength (R_k, kPa) curing time (days)					
		7	14	28	56	91	180
1	HC350	21.4	18.1	20.9	13.0	12.2	9.8
2	HC350L1	26.1	27.3	36.5	38.1	37.4	37.4
3	HC350L2	23.8	30.1	33.5	41.3	39.6	40.2
4	HC350L4	27.4	32.3	33.6	41.8	45.9	51.8
5	HC350L6	6.2	6.8	10.3	12.7	14.4	11.4
6	HC350Ca1	27.5	40.4	43.5	50.2	53.1	53.7
7	HC350Ca2	30.5	49.2	59.8	61.1	63.0	70.2
8	HC350Ca3	24.2	28.2	43.1	52.7	53.5	57.3

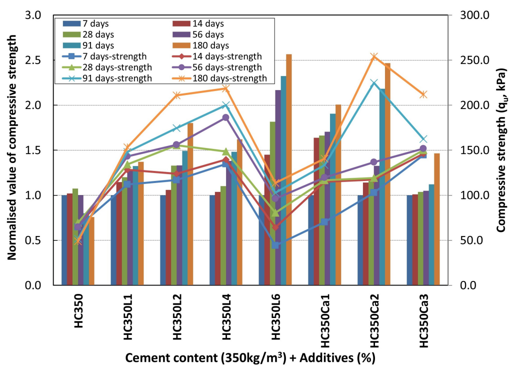

Fig. 5. Relationship between unconfined compressive strength of peat soil with a cement content of 350 kg/m^3 and additives curing time.

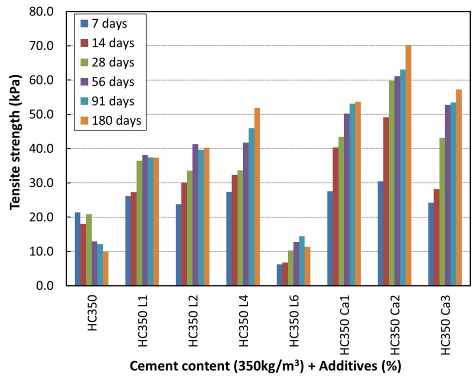

Fig. 6. Relationship between the tensile strength of peat soil with a cement content of 350 kg/m^3 and additives.

3.3. Discussion

From the experimental results of unconfined compressive strength and tensile strength of the reinforced soil samples show that the unconfined compressive strength and tensile strength of the samples with additives increased curing time because this physicochemical environment of the reinforced soil has changed. When adding lime (CaO) or gypsum ($CaSO_4.2H_2O$) to the mixture of soil cement, CaO will react with water to produce $Ca(OH)_2$ and $CaSO_4.2H_2O$ will react with divalent hydroxides to form $Ca(OH)_2$. Therefore, the acidic environment of the peat soil will change to an alkaline environment.

This is a favorable environment for cement hydration and the formation of ettringite. In addition, it increases the exchange capacity of Ca^{2+} cation in the hydration environment, which is convenient for the pozzolanic reaction that happens between portlandite cement and clay mineral, which enhances the development of the organic clay strength [10–12].

Based on the above result, it can be observed that the unconfined compressive and tensile strength with the optimal additive content are: 4% lime and gypsum ($CaSO_4$) 2% compared with the cement content. In which gypsum 2% gives greater strength than lime 4%. The soil samples with additives, after 28 days of curing time, all samples have greater unconfined compressive strength than soil samples without additives. Although the unconfined compressive strength of the sample is not high (only 254.1 kPa), the effectiveness compared to the soil without additives is quite large (5.18 times).

4. Conclusion

This study aims to extensively investigate the use of cement in combination with lime and gypsum to treat peat soil that contains organic matter and humic acid. According to the experimental results, the following conclusions can be drawn:

1. The strength of peat soil reinforced with cement increased from 7 to 28 days, after that the strength decreased with the curing time.

2. Additives play an important role in improving the physical and chemical environment to help stabilize cement soil curing time. In this study, adding lime and gypsum to peat soil mixed with cement created an alkaline environment to facilitate the cement hydration and pozzolanic reaction, resulting in the increase in compressive and tensile strength.

3. Research to improve peat soil with cement and additives shows that the optimal amount of additives to achieve maximum compressive strength with lime is 4% and 2% gypsum additives. With these additives, the sample intensity increased significantly compared to the sample of cement soil mixing without additives. The effectiveness of lime admixture at the optimum content (4%) increased from 2.08 to 4.46 times and gypsum (2%) from 1.59 to 5.18 times compared to the cement mixed soil without additives.

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