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Enhancing Geotechnical Properties of Contaminated Sediment of by Using Fly Ash and Hydraulic Binders

Ernesto Silitonga

Universitas Negeri Medan, Faculty of Engineering, Jalan Willem Iskandar Pasar V, Medan 3199, Indonesia

Abstract: ***The contaminated sediment in this study is a waste material from annual dredging work in industrial harbor. This waste due to its heavy metal content need a special treatment. The reuse of this contaminated sediment as a substitute material in roadwork is one of one of the solutions proposed. In order to meet the requisite in roadwork, a fly ash is used as a binder with an intention to enhance the geotechnical properties of contaminated sediment. Beside that, the main goal of this study is to maximize the utilization of waste by applying a waste stabilization with a waste material. To identify the physical properties of sediment, various engineering test is performed. TCLP (toxicity characteristic leaching procedure)test find out that the sediment categorized as non-hazardous waste. The geotechnical tests performed and concluded that without any binder, the performance of untreated sediment could not passed the requirement needed in roadwork. The effect of fly ash shows an important effect on increase of the strength (unconfined compressive and tensile strength), Due to its Pozzolanic reaction that takes more time to reacts, the addition strength performs at a long-term curing age. The wet and dry test confirmed that fly ash addition is needed in order to increase the sensitivity to water. The test result confirmed that, with the present of fly ash in the admixture, the reuse of the sediment is allowed as a substitute material in the sub base course in road pavement work.***

Keywords: fly ash, contaminated sediment, geotechnical properties, and road pavement work

1. Introduction

Port authorities have been facing the problem of waste material of dredging work since years. Since the European regulation prohibit disposing the waste material in to the sea. According to regulation, the material after dredging work directly consider as a waste, and assumed endanger to environ and human. Colin stated that the rejection the waste sediment in to the sea could enlarge the contamination to the surrounding environment [1]. Several methods have been realized in order to solve this waste material problem. Hamburg Port authority proposed project called METHA (mechanical treatment and dewatering of Harbor Sediment)[2].This method concentrates on dewatering and treatment of sediment and produce a new and clean material. According to previous study [3], the heavy metal content in the sediment is depending on the grain size of the sediments. The finer the particle size distribution and the higher organic material content in the sediment, the higher will be the contamination content. METHA is focus on the dewatering and the separation of the particle, that believed can reduce the heavy metal content. Beside METHA, another method is realized by stored the waste sediment in the disposal site. The sediment is stored in the special designed area to accommodate hazardous waste, with the intention of preventing the spread the pollution in to the surrounding environment. This method is suitable for the small port level, contrary for the large industrial port with high volume waste sediment, due to its high cost, this method becomes non profitable. Stabilization with chemical binders is one of the most popular methods to encounter this problem. The principal goal of this stabilization method is to enhance the geotechnical properties of the waste sediment so that can be used as a replacement material. According to previous study, road construction is the sector that consumed the most percentage of the waste material. Previous studies [4][5]already tried various type of binder to stabilize this particular waste material. The waste sediment from dredging work is well known as for its high heavy metal content. Besides could endanger the environment. The organic material and especially the heavy metal could block/ obstruct the hydration of cement and lime[6]. Wang et alin his research find out that stabilization only with hydraulic binders such as cement and lime could not satisfy the requirement needed in road construction[7].Due to its high organic material content, its effect the hydration of cement and lime and automatically disturb the strength gained. Especially at long term curing age, the sample stabilize with cement/ lime could not meet the specific demand on road construction.Several studies already realized using other potential binder such as silica fume [8][9]. Silica fume is known as a binder that capable to improve the engineering properties. Several studies used Silica fume in concrete; to produce a high performance concrete with high strength value [10]. or to reuse recycled material [11]. Silitonga stabilized marine sediment contaminated from Port en Bessin in Basse Normandie, with heavy metal and other pollutant. The marine sediment used is a waste of dredging project from industrial port in France. The experiment result confirmed that the difference of the strength evolution (unconfined compressive test) is very significant between sample with only cement content and sample mixed with silica fume [12]. The evolution of strength for sample with cement is almost constant at 90 days of curing age. Contrary with sample mixed with Silica fume, show an increase of strength since teenage of curing age (7 days) and still the increase strength still significant until 180 days of curing age [13].This study confirmed the need of alternative binders to enhance the engineering properties of waste sediment to meet the requirements needed as replacement material in road construction work.

2. Material Utilized

Material studied in research is contaminated waste sediment residual from dredging project along Cherbourg Industrial Port. This port can be classified as a Medium Port according to its industrial activates. In order to represent the original condition of contaminated sediment, the samples are taken from 4 different locations. These locations are CRBG1, CRBG2, CRBG3 and CRBG4 (see Figure 1). The sampling locations are predicted as a location that contains most contaminated sediments. An area of disposal site is prepared with distance 2 km from the Port of Cherbourg. This special design area is realized to prevent the pollution spread during the test. After being placed in the area, the next step is started, the dewatering process, this process is realized in order to reduce the high water content of waste sediment. The sediment will be treated with optimum water content that determined with Proctor test. The hydraulic binder used in this study is the type that commonly used in soil stabilization work. The Pozzolanic binder utilized in this is fly ash is waste produced from local mining. This fly ash used is coarser than normal fly ash that used in industrial work.

Figure 1: Sampling Location in Port of Cherbourg.

The Fly ash used is divided into three types, which produced from two different places. The mineralogical characteristics of fly ash will not be discussed in this paper.

2.1. Initial Characteristics

2.1.1. Particle size distribution

According to previous studies, waste sediment result from dredging work composed of fines particle. Due to its fine particle size distribution, the classical method of sieving is not an option anymore.

Table 1: Particle size distribution of waste sediment of Port of Cherbourg

Parameters	*CBG1*	*CBG2*	*CBG3*	*CBG4*	*CBG5*	*CBG6*
D10 (µm)	9.2	12.1	9	10.1	8.5	11.2
D50 (µm)	9.1	8.9	11.2	8	7.6	9.6
D90 (µm)	62	53.9	51.4	47.8	60.9	55.3
<2 µm (%)	2.2	2.6	6.1	4.0	3.0	1.90
2 - 63 µm (%)	82.4	78	76	68%	77	79.80
> 63 µm (%)	15.4	19,4	17.2	28%	18.9	18,4

In this study a laser granulometry Diffractometry is used to determine the particle size distribution of material used in this study. As told before the samples are taken from six different locations. The particle size for waste sediment from dredging work is presented in Table 1. The particle size distribution of waste sediment taken from six different locations shows a uniform pattern. This reveals the homogeneity of the waste sediment. As shown in Table 1, the particle size distribution of sediment is majority in range of 2 - 63 µm. Silitonga[12]stabilizes a dredged sediment of Port en Bessin with particle size 2 - 63 µm, Behmanesh[14] stabilizes dredged sediment of Port Le havre and the particle size distribution of Port de Le Havreis between 2 - 63 µm, the test results show that the majority of particle size distribution of waste dredged is between 2 - 63 µm, from all this result, we can concluded that the particle size distribution of waste sediment from dredging work is between 2 - 63 µm.

Table 2: Particle size distribution of fly ashes

Parameters	*FA1*	*FA2*	*FA3*
D10 (µm)	23	17	12
D50 (µm)	21	30	17
D90 (µm)	38.7	48	30
<2 µm (%)	18.2	17	24
2 - 63 µm (%)	70	75	72.7%
> 63 µm (%)	11.8	8	3.3

The fly ash utilized in this study is waste of local coal mining in France. There are three types of fly ashes; each type has different characteristics (physical and chemical). Table 2 shows the particle size distribution of each fly ash. As shown in table 2, we can conclude that fly ash type 3 has finer particle with finer size. The majority of fly ash type (FS_3) is 30µm (D90), this is the finest majority particle size between three types fly ashes used. Previous study [15] stated that the reactivity of fly ash depends on its fine particle size. The samples mixed with fly ash with finer particle size show a higher unconfined compressive strength than the other. The increase of strength for long term curing ages (90-180 days) is more important than sample stabilized with fly ash with coarser particle size. This result demonstrate that the Pozzolanic reaction of fly ash with finer particle size occurs and reacts very well and provides the additional strength after 90 days.

2.1.2. Leaching test

Leaching test is realized in goal to identify the chemical characteristics of waste sediment, this study focused on determine the heavy metal content of waste sediment from dredging work. According to Decision of Council of European Union concerning the dredged material [16] stated that all material that dredged considered as a hazardous waste material and should be dispose in special designed, that can protect the environment from the disperse of pollutant from waste material. After stabilization process then the waste material should be examined to identify the heavy metal content, if the heavy metal content classified as inert waste (according to Decision of Council of European Union) then the waste material can be reused as new material and considered safe for the human and environment.

Table 3: Heavy metal content of waste material from dredging work

Micropollutant	CBG1	CBG2	CBG3	CBG4	CBG5	CBG6
As (mg/kg)	1.2	1.8	3	2.9	2.7	3.8
Cd (mg/kg)	2.1	1.3	3.8	2.5	2	3.3
Cr (mg/kg)	50.6	61.2	69	45.8	52	70
Cu (mg/kg)	0.38	0.31	0.9	0.47	0.48	0.71
Hg (mg/kg)	0.12	0.28	0.39	0.27	0.17	0.3
Pb(mg/kg)	7.3	11	27.4	8.9	22.1	21
Ni (mg/kg)	4	7.2	26.3	5.9	23	18
Zn (mg/kg)	52	84	74	62	62	81

The previous studies[17], [18]find out that heavy metal content and organic content has an important impact on gaining the strength during the stabilization process. Especially heavy metal can importantly disturb the hydration of cementor lime. High content of heavy metal can affect the strength gained of sample stabilized with hydraulic binders.

Table 4: Level of pollution according to Decision of Council of European Union [12]

Micropollutant	*Inert waste*	*Non-Hazardous waste*	*Hazardous waste*
As (mg/kg)	0.5	2	25
Cd (mg/kg)	0.04	1	5
Cr (mg/kg)	2	50	100
Cu (mg/kg)	0.01	0.2	2
Hg (mg/kg)	0.01	0.2	2
Pb(mg/kg)	0.5	10	50
Ni (mg/kg)	0.4	10	40
Zn (mg/kg)	4	50	200

Table 3 provides the result of leaching test and from this table we can see that almost all the sample has a level of micro pollutant of heavy metal classified in non-hazardous waste (according to France regulation, see table 4). This result confirms that after the dredging work, the waste sediment should be disposed and stabilized to reduce the level of micro pollutant first. This study only discusses the effect that made by the fly ash (as Pozzolanic binder) to the physical performance. The chemical effect will not be discussed in this rapport.From the result in table 3, we can see that there is a different level of heavy metal content depends where waste sediment is taken. The waste sediment taken from location CBG3, CBG5 and CBG 6 has higher pollution level of heavy metal than others. Contrary to this result, CBG1 shows a lowest for all the micro pollutants of heavy metal content. This result can be explained by the activities around sampling location. From figure 1 we can see that the activities around location of CBG3, CBG5 and CBG6 is more active than others, these locationsare where the ships drop anchor, and do all the maintenance activities such as cleaning, repairing and painting. All the waste of maintenance activities is throw in to the sea, this is the reason why in these areas the heavy metal content is higher than others areas.

3. Methods

After being dredged, the waste sediment disposed in special area, designed with impermeable geo membrane layers to protect the environment from the pollutions found in waste sediment. The initial water content of the waste sediment after dredging process is very high; it is impossible to start the treatment with such high water content. That is the reason why the dewatering process must be realized. The dewatering process is done with the help of the sun. The timeline of the stabilization project should be planned correctly, to maximize the result of the dewatering process. After the water content reduce to the level needed, the admixture realized with mixing step and with the composition presented in table 5. The water content determined with help of proctor test. The sample is produced with diameter of 4 cm and 8 cm high. The samples are prepared depend on the need and stored in the normal room temperature.

3.1 Admixture designed composition

The composition admixture designed according to the test needs and goals. The composition should present the effect of the different type of binders and the effect of the volume of the binders. The various compositions of the binders are presented in table 5. All the samples are mixed with additional of 5% of sand (from total weight)

Table 5: Particle size distribution of waste sediment of Port of Cherbourg

Name	*Cement (%)*	*Lime (%)*	*FA1 (%)*	*FA2 (%)*	*FA3 (%)*
WS	x	x	x	x	x
7FA1	5	5	7	x	x
14FA1	5	5	14	x	x
7FA2	5	5	x	7	x
14FA2	5	5	x	14	x
7FA3	5	5	x	x	7
14FA3	5	5	x	x	14
CMT1	5	5	x	x	x
CMT2	10	5	x	x	x

The sample without any binders (WS) is realized to identify the initial engineering performance of waste sediment (at ideal water content). The percentage of fly ash in the mixture divided in two; 7% and 14%, this percentage is realized to determine the effect of different percentage of fly in its performances. The production of sample with only cement content is to identify the effect of cement and sample with 10% of cement is realized if the percentage of 5% of cement is not important enough to stabilize the waste sediment with high heavy metal content.

4. Analysis and Result

The tests realized is to identify the capabilities of stabilized waste sediment to achieve the requirement needed in road construction work. All the test performed in this chapter are the normal test effectuated in road construction work, because the waste sediment will be used as a replacement material in road pavement work.

4.1. Unconfined compressive strength

Unconfined compressive strength is one of the most effectuated tests in civil engineering test. The minimum value of unconfined compressive strength for parking area is 1 MPa at curing age of 28 days. The table 2 presents the result of unconfined compressive strength (UCS) with waste sediment taken from CBG 6. The sample taken from CBG 6 has the highest percentage of micro pollutant (heavy metal) compared to other locations. As shown in table 2, we can conclude that sample of waste sediment without any binders (WS) even until 180 days of curing ages; the unconfined compressive strength value is less than 1MPa. It means even at curing ages of 180 days, the waste sediment without stabilizer binder could not be used as a material, not even as a replacement material for parking area [19] [20]

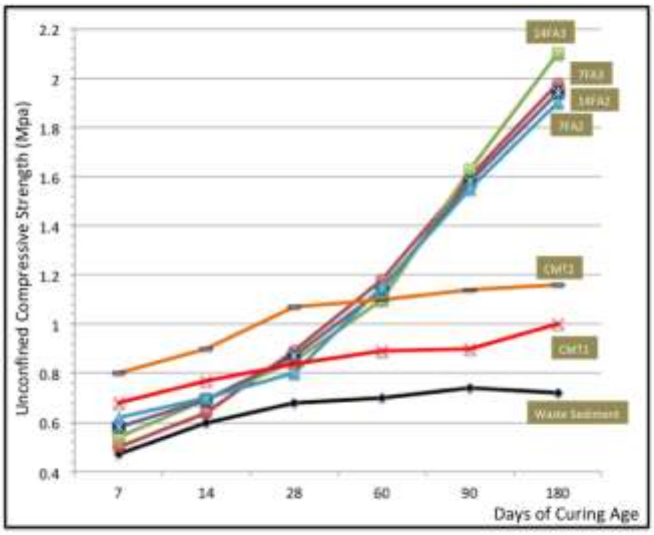

Figure 2: UCS result for al the samples

The samples with only cement content show the best UCS value from 7 days to 28 days of curing ages. This is clearly due to the quick hydration of cement of resulting the solidity of the sample. As shown in table 2, the increase of cement content, from 5% (CMT1) to 10% (CMT2) is affecting the increase the UCS value. The evolution value between sample with 5% cement (CMT1) and sample with 10% (CMT2) shows a significant different of value of UCS, this difference can be noticed since 7 days up to 180 days of curing ages. This confirmed that the present of cement addition clearly affect the strength of the mixture. 5% to 7% is the normal percentage of cement that normally used in soil stabilization. From the result we can confirmed that for contaminated soil (with strong percentage of heavy metal content), 5% of cement is insufficient. 10% of cement is an ideal percentage for contaminated soil but unfortunately it still needs an alternative binder to increase the strength for long term curing age. The effect of fly ash Pozzolanic binder on the mixture can be observed in figure 2. The evolution of UCS value of samples mixed with fly ashstart to show a significant increase since period of 28 days of curing ages. At 7 to 14 days only hydration of cement and the role of fly ash as corrector granulometric that provide strength. Pozzolanic binder normally need time to reacts and produces C-SH and C-A-H [19], [21]. Previous study done Wang that stabilized marine sediment with other type of Pozzolanic binder (fly ash) stated that, the effect of Silica fume in providing additional strength start to show an significant increase after period of 28 days of curing ages[22]. The sample with 14% of fly ash content shows a highest UCS value (2.16 MPa) at 180 days of curing age, this value is two times the UCS value of sample with 5% of cement at the same curing age. This result shows us the significant increase of UCS value because the addition of fly ash. The effect of addition different type of fly ash can be observed from figure 2 where the fly ash type 3 with 14% of fly ash type 3 (14FA3) from period of 14 days to 180 days of curing age always show a highest UCS value. The sample with 7% of fly ash type 3 (7FA3) shows higher UCS value (at 180 days) than sample with 7% of fly ash type 2 (7FA2), even slightly higher than samplewith 14% of fly ash type 2 (14FA2). The result clearly confirmed that fly ash type 3 is more reactive than fly ash type 2; more reactive means provides more strength. This result confirmed the theory from particle size distribution test. Table 2 presents the particle size distribution of fly ash type 3 is finer than fly ash type 1 and type 2. According to previous study [23] the reactivity of fly ash depends on its mineral content and its particle size.

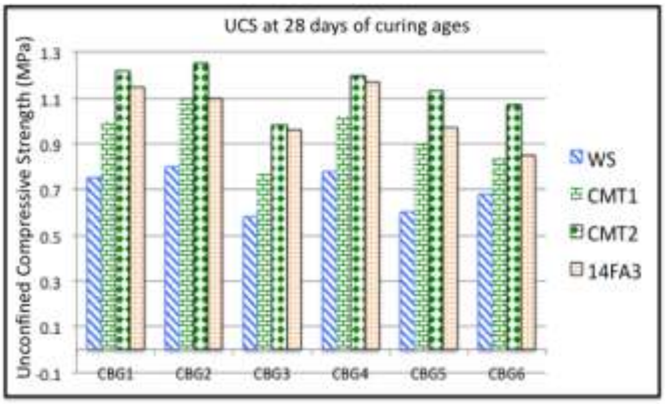

Figure 3: UCS result at 28 days of curing ages

The percentage of heavy metal content in the sediment affects the strength evolution of the admixtures. Because the presents of the pollutants can block and disturb the chemical reaction of binder hydraulic to provides strength. Figure 3 presents the UCS result with different waste sediments content. As shown in figure 1, the waste sediment is taken from 6 different locations. Table 3 shows the micro pollutants content of heavy metal, from this table we can conclude that CBG6, CBG5 and CB3 is the location where the micro pollutant content is higher than other locations. This is because CBG6, CBG5 and CBG3 us the location where the ships parked and where the activities are more important than other locations. For the samples without any binders content (WS), we can observe that the sample with highest micro pollutants (CBG6, CBG5 and CBG3) show the lowest UCS value. Sample with only cement content CMT1 (5% of cement) show that the sample with sediment taken from CBG6 and CBG5 and especially CBG3 provide the lowest UCS value. The result confirmed the present the micro pollutant of heavy metal could disturb the strength gained process, by blocking the hydration of cement or lime. The samples with 10% of cement (CMT2) show less significant difference between sample with highest heavy metal content (BGC5, BCG6 and BCG3) and others. The samples with fly ash content show the same tendency, all the samples with high heavy metal content provides the lowest UCS value. This result again confirmed the negative effect of micro pollutant of heavy metal on gaining the strength.

4.2. Wet and Dry Test.

Test wet and dry is realized to determine the sensitivity of the sample to water. To prevent the dispersion of the pollutant in to the environment around; the bonding between the sediment particles should be excellent. The micro pollutants carried away to the outside environment by water, this could be happens if the water can penetrates in to microstructures of the samples [24].The test is performed by effectuating 10 cycles of test. The test is realized using the samples of 60 days of curing age. The test started by dry test, where the sample subjected to a drying condition at temperature of 27C for 24 hours of period of time. The wet condition is performed by drowning the sample it to the water for 24 hours of period of time. After the sample subjected to 10 cycles of wet and dry condition, the samples will be tested with Unconfined compressive strength and the result will be compared to the UCS value of normal sample with 60 days of curing ages. The result of this test is shown is figure 4

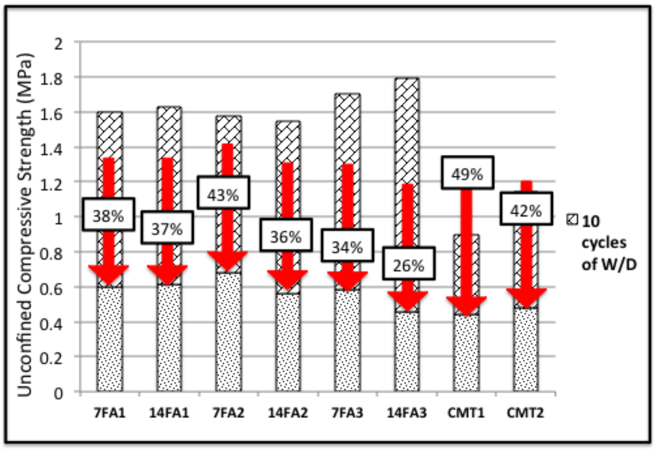

Figure 4: Wet and dry test result.

The UCS value of the samples after being subjected to wet and dry test, show a significant degradation if compared to the normal sample at 60 days of curing age. The samples with cement content only show a biggest reduction UCS value, for sample with 5% of cement (CMT1) show 49% of reduction after subjected to wet and dry test and 42% of reduction for sample with 10% of cement (CMT2). Samples with fly content established less reduction of UCS value after the test. Sample with 14% of fly ash type 3 (14FA3) shows the lowest reduction then follow with sample with the same type of fly ash (type 2). The sample with 7% of fly ash type 2 (7FA2) shows the biggest reduction (43%) after subjected to the wet and dry test. This result confirmed that the fly ash addition not only affect on providing UCS strength but also increase the sensitivityof water. According to this result, for the sample with only cement content, the bonding between particles can be penetrated by water and destruct the structure particles. Samples with fly ash content has stronger bond between particles. Due to its finer particle size, the particle fly ash can penetrate and fill the empty space between particles so there are no more available places for water to slip. This effect of granulometric correction is very significant and happens for teen curing age (7-14 days).After the pozzolanic reaction occurs (at 28-180 days) and strengthen the bonding between the particles.These factors are the main reason of high resistance of water present. The type of percentage of fly ash plays an important role either to increase the ability of waster resistance. This can be verified from the wet and dry test, where the fly ash type 3 shows lowest UCS value reduction after the wet and dry test. The sample with 7% of fly ash type 3 (7FA3) establish lower reduction UCS value compared to the sample with 14%. As shown in table 3, where the fly ash type 3 (FA3) own a finest particle size distribution. The finerthe particle size more reactive the fly ash reacts.

4.3. Gel degel Test.

The main goal of realization this gel degel test is to identify the ability of treated sample to extreme condition (temperature). The gel degel test is realize in two cycles; first cycle is thaw condition where the sample subjected in to the temperature of 35° C for 24 hours, then follow by Freeze condition at -20°C for 24 hours. Visually,

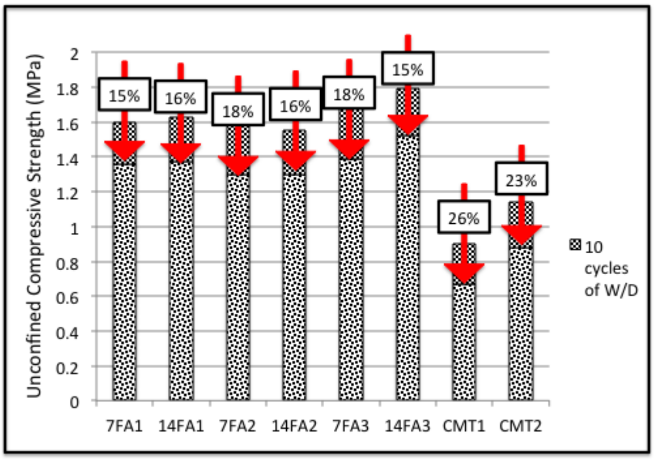

Figure 5: Gel degel test result.

The sample subjected to this gel degel test is sample with period of curing age of 60 days. The result is displaying the result of gel degel test. The sample after subjected to the test show damage deterioration during the process, the surface scaling, which is the loss of paste from the surface of the sample, this result automatically result in loosening of coarse aggregate. From figure 5 we can observe that the sample with cement content only display the reduction of UCS value. The sample with only 5% of cement shows a reduction of 26% of UCS value compared with normal. Sample with 5% of cement (CMT1) decreases it UCS value to 26% and 23% UCS value reduction for sample with 10% of cement. This two sample is the first and second lowest UCS value reduction.

If compared to other samples. The samples with different type of fly ash show a significant reduction UCS value. This result confirmed the positive affect of fly ash addition on strengthen the bond between sediment particle. The samples with fly ash content increase ability on the extreme temperature changes. When the gel cycle started, the sample subjected to high temperature (-20°C), if the empty space between the particle will be fulfilled with freezing water andcan generate internal crack on the microstructure. When the degel cycle started, the freezing water will be thawed and the internal crack evolve. This internal crack generates losing strength after the gel degel cycles. Due to its role as corrector granulometric, the fly ashes particles fulfill the empty space in between particles. If the empty space can be fulfilled, and there is no place for water to take placed. This automatically reduces the possibility to growth an internal crack[25] We can noticed from table 5 that the different UCS value reduction (after subjected to gel degel test) between fly ash type 1 (FS1) type (FS2) and type 3 (FS3) does not show any significant difference. Contrary to this result, the percentage of fly ash (7%-14%) is more dominant to make a different on ability of extreme temperature than the type of fly ash utilized.

5. Conclusion

The main objective of this research is to improve the geotechnical properties of contaminated sediment from dredging work to be reused as new material in road construction. In order to identify the possibilities of this waste sediment reused, it must meet the requirements needed in road construction. The majority particle size distribution of waste sediment is between 2 - 63 µm. The majority particle size of fly ash used is in the same range with sediment (between 2 - 63 µm). The leaching test stated that percentage of micro pollutant (heavy metal) content in the waste sediment classified as a non hazardous waste (according to France regulation).The Unconfined compressive strength (UCS) test stated that at teen curing age (7-12) sample with only cement content reached the best UCS value. At long term curing age, the effect of fly ash addition started to show its role, the sample with fly ash content, especially sample with 14% of fly ash possess the highest UCS value. The result of wet and dry test shows that addition of fly ash is promoting the strength of sensitivity to the water. The difference between sample with and without fly ash of strength on sensitivity to water is very significant. The different type of fly ash also shows an important difference on reduction of UCS value. the gel-degel test shows the similar pattern, the fly ash addition produces higher strength on extreme temperature, except the difference type of fly ash doesn't show any significant decrease of UCS value, contrary the percentage of fly ash is more dominant on providing the strength on extreme temperature. The result concludes that the addition of fly ash clearly improve the geotechnical of contaminated sediment.

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