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7

<u>BENEFICIAL USE IN OTHER FIELDS</u>

<u>SEDIMENTS TRANSPORT</u>

<u>SPECIAL SESSION</u>

...uence of fly ash addition on the mechanical properties of treated dredged material.

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...uction

...se of many waste products as construction engineering material is of major concern to ... due to their applications for different objectives. For this reason, search on the use of ... products will help to solve many environmental problems, and create new useful findings in ... of engineering. Usually, it has been known that the addition of fly ash improves the ...ical properties, due to the pozzolanic reaction and its role as a micro-filler. As fly ash ..., empty space in the matrix structure of stabilized material will be filled by the hydration ... However the main problem is this hydration reaction depends on curing period. Several ...ers, reported that material stabilized with fly ash needs a longer curing period than ...nal binders, which bring a slow development of strength at early ages, especially when a ... amount of fly ash is used. To achieve effectiveness of fly ash on soil stabilization work, some ... added a small amount of lime [1]. This research showed that the resilient modulus of a ... of class F fly ash and lime is higher and plastic deformation is lower than that of class F fly ... Another example of addition of lime in soil-fly ash mixture is the highway sublayers ...on project in Lousiana, where bases were stabilized with lime and class C fly ash mixture ... compare their strength gain, the cement mixture was made. The overall unconfined ...ive strength (U.C.S) for sublayers stabilized with lime-class C fly ash mixture was 30% ... than that of the soil-cement [2]. Making a more productive use of fly ash would have ...able environmental benefits, reducing air and water pollution. Increased use as a partial ... or lime replacement would also represent savings in energy because fly ash has been called ...energy- based material.

... properties.

...dy was performed using the following materials. Sediments were dredged from Port of ...bourg, France. Two types of fly ash (FA) were used in this part of the main research: named ... (SD) and Soproline (SP). These two FA were produced respectively from different ... coal and limestone feed coals from fluidized-bed power plant.

... size. Different methods have been used to describe the particle size distribution of powders ... types and sizes up to now. In this study, a laser diffractometer Coulter LS2000 was used ...ine the particle size distribution (PSD) of the dredged sediment and the fly ashes. As ... in *Fig.1*, Sodeline and Soproline have different particle size distribution From the point of ... diameter particle most representative, Sodeline has particles almost 2 times bigger than ..., regardless of the small different of percentage (see *Table 1*). The two fly ashes and ... sediment studied in these experiments has an important quantity of silt fraction size .... Usually, fineness increases the early compressive strength of the specimen. Hanifi *et al* ... claimed that the specimen with a better fineness and a narrower particle size distribution had the highest compressive strength, sulfate resistance than the others specimens. This theory clarified with the work of Joshi and Lohtia [4] that proved the influence of the finer particle size of fly ash produce more reactive pozzolanic reaction.

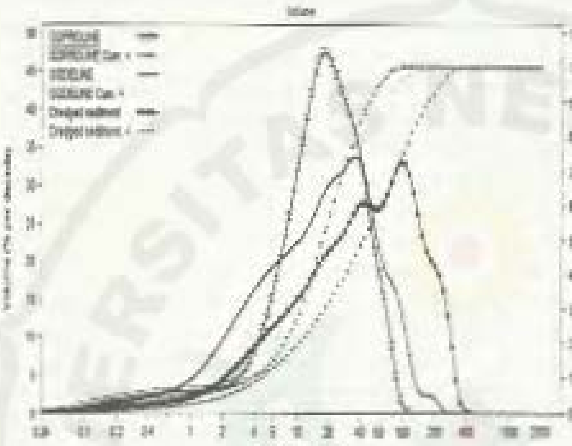

Fig.1 Particle size distribution of dredged sediment and 2 types of fly ashes

Particle size	Dredged sediment	Fly ash (Sodeline)	Fly ash (Soproline)
D_{90} (µm)	172.4	60.23	48.17
D_{50} (µm)	42.12	17.58	17.68
D_{10} (µm)	4.517	2.17	3.79
D_{max} (µm)	96.49	34.59	18
Clay < 2µm	4.52%	10.15%	7.58%
Silts 2 - 63 µm	56.60%	79.30%	90.87%
Sand > 63 µm	38.88%	10.47%	1.79%

Table1. Characteristics diameters and fraction of dredged sediment and fly ashes

A previous work [5] showed that the crystalline to amorphous ratio in coal combustion ratio residues varies with the particle size, where as the crystallinity of cenospheres increased as the particle size decreased. The coal combustion residues with coarser size show less and wider range of hardeness, while the fine size has the better and narrow range of hardeness. Others researchers claimed the contrary of this theory, Antiohos *et al* [6], [7] have proved that the coarser fraction of fly ashes, contain more amorphous silica than the fines ones, as it is already known that amorphous silica is actually the main factor of pozzolanic reaction to improve the strength of the stabilized soil.

Chemical composition. *Table 2* provides the chemical analysis of the two fly ashes. The differences in chemical analysis between Sodeline and Soproline can influence the mechanical properties of the sediment stabilized. It can be seen that the free lime contents of Soproline largely higher than Sodeline. On the other hand Sodeline has higher silica content.

Oxide (%)	SiO_2	Fe_2O_3	Al_2O_3	MgO	MnO_2	Na_20	K_20	SO_3	$_{total}CaO$	$_{free}CaO$
Sodeline	47.36	7.09	21.63	3.22	0.62	0.46	4.75	4.02	8.52	0.98
Soproline	28.38	1.91	11.70	1.87	0.03	0.13	17.21	17.11	36.31	13.35

Table2. Chemical analysis of Soproline and Sodeline

According to Ranganath *et al* [8] for lime-fly ash treated soil, the influence soluble silica in strength is more pronounced than the effect of fineness at later ages. ASTM C-618-98 [9] stated that to achieve high quality of pozzolans, the total amount of SiO_2, Fe_2O_3, and Al_2O_3 should be similar or greater than 70%, Sodeline (76.08%) fully comply to this standard specification, and for Soproline the amount is only equal to 33.99%.

Methods and Results

Preparation of the samples. The dredged sediment, oven-dried for 5 days at 60°C was pulverized to 2mm sieve size, it was initially mixed with determined quantities of fly ash, lime and cement as a binder, in a dry state and subsequently mixed with water by a mechanical mixer with a speed of 150 rd/min for a period of approximately 8 minutes. After mixing the specimens were prepared with the static compaction method, at the optimum moisture content and maximum density determined by Proctor test. Cylindrical specimens (ø = 40mm, h = 80mm) were used for unconfined compressive strength testing. The compressive strength is determined using a 10 kN capacity automatic compression machine according to EN 196-1 [10] on a simple speed cross-head moving machine at a speed of 1 mm/s. The specimens were pushed out from the mold directly after completion of the compaction and were stored in the curing room until testing at 7, 14, 28, 60 and 90 days. The specimens have been examined for their resistance in different extreme temperatures and for the effect of water immersions, they were also cured as the other specimens for 7 and 28 days and then they were subjected to 20 cycles consisting of 17 hours at -10°C followed by 7 hours at 10°C (freeze-thaw test) and it is the same for the specimens examined for the effect of water immersion (wet-dry test) were subjected to 10 cycles consisting of 24 hours cured at 60°C followed by 24 hours immersed into water containers stored in the curing room. The different chosen compositions in this study are given in *Table 3*. The goal of manufacturing of binder CEM 1 and Lime 1, was to compare the reaction and strength gained to the combining FA-L-C treated samples.

		F.A I (Sodeline)(%)	F.A II (Soproline) (%)	Lime (%)	Cement (%)
FA-L-C	SD 1	5	-	2	1
	SD 2	10	-	2	1
	SD 3	15	-	2	1
	SD4	20	-	2	1
	SD 5	30	-	2	1
	SP 1	30	30	2	1
Lime	Lime 1	-	-	6	-
Cement	CEM 1	-	-	-	6

Table3. Different compositions of binders

Compaction test. Soil compaction is a process of re-arranging and condensing particles by mixing water with the soil particles and adding external energy to soil. Hence, soil can reach the most dense condition with the help of wetting and re-arranging particles by water molecules and compaction energy. The used compaction procedures for the present study are the Standard Proctor methods. This method is used to determine the moisture content at which maximum bulk density occurs, which also known as the optimum moisture content w_{opt}. To determine the influence of binder addition on decreasing the density of solid particles, *ρs*, solid particle density tests on dredged sediment in the natural state and with various binder additions were conducted. The standard Proctor test experiments were firstly conducted on the dredged sediment without using any binder addition as control for the others specimens. The next step was carried out with the binder-matrix ingredients. The void ratio of soil depends upon the shape of the grains, the uniformity of grain size, and the uniformity of grain size and the conditions of the sedimentation. The addition of binder changes the porosity and void ratio within the range of void ratio of fly ash and soils. At maximum, the void ratio and porosity are free from moisture. At the bulk density under compaction, the void ratio of the sediment and the porosity are minimum. So one can say, due to the lower specific gravity of the binder (fly-ash, cement, and lime) than that of the dredged sediment, the maxim dry density decreased and with the increasing of fly-ash contents meanwhile the optimum moist content increased with increasing fly-ash content. As displayed in *Fig.2* the maximum dry un weight, γ_{dmax}, for untreated sediment is between 1.16g/cm^3 and optimum moisture content w_{opt} = 27%. When different amounts of binders were added to sediment, the maximum dry unit weig were decreased between 1.15 and 1.08 g/cm^3, and optimum moisture content w_{opt} increase, vari between 28 and 32%. From this test results we can notice that the use of binder especially for fl ash and lime, as a soil stabilizer had an important impact on the compaction of dredged sedimen It should be noted that the high optimum moisture content maybe difficult and costly to achie during dry season. *in contrario* during wet season the high water demand of fly ash will facilita compaction.

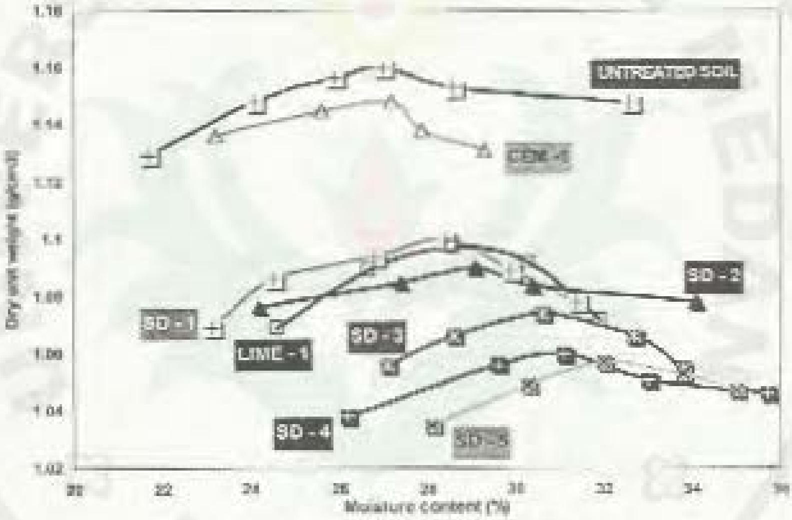

Fig.2 Standard compaction test for dredged sediment

PH measurement. When a significant quantity of lime is added to a soil, the pH of soil-lim mixtures is elevated to approximately 12.4, which is the pH of saturated limewater. This is substantial pH increase from natural soils. The solubility of silica and alumina greatly increase a elevated pH levels (12 – 13), which can lead to an increase in pozzolanic reactions. Eades and Grim [11] suggested that the pH causes silica from the clay minerals to dissolve and in combination wi Ca++, to form calcium silicate. This reaction will continue as long as $Ca(OH)_2$ exists in the soil and there is available silica. As shown in *Fig.3* shows the effect of binders contents on the pH of the specimens, we can observe that the role of addition of FA increase the pH, more the amount of FA added in the mixture, higher the pH values obtained. We can concluded also that the amount of 1% (10.91) and 2%(11.86) lime were insufficient to increase the pH of the specimens, but with addition of 5% FA and 1% cement, the amount of 2% lime obtained sufficient pH values to allow the dissolution of silica and alumina from the FA and from the sediment treated and preserve the additional strength.

Fig.3 Effect of binder contents on the pH evolution

On the other hand for the sample treated with cement, the pH values obtained (10,73) is not higher enough to dissolve silica and alumina from in the clay fraction from the sediment treated, this is might be the reason why the evolution of strength in mixture treated with cement was not increase like the other samples with pH equal or more than 12. There are different pH values between sample treated with Sodeline and Soproline, this different might be due to the CaO content. As we can see previously, Soproline has almost 3,5 times more CaO content(35,31%) than Sodeline (9,52%). It has been known that CaO content in the binder plays important role in pozzolanic activity, when the specimens mixed with water, $Ca(OH)_2$ in the blend hydrolyses first and the solution reaches a high pH values, [Eq.(1)]

$$Ca(OH)_2 \rightarrow Ca^{2+} + 2OH^- \qquad (1)$$

Under the attack of OH- in such high pH solution, leads to an increasing of the concentration of OH^- ions, and as a result of a high pH environment, a mineralogical breakdown take place in the matrix and silicate or aluminosilicate network formers (from the sediment and fly ash) are also depolymerised and dissolve into solution, and produce two primary cementing agents C-S-H and C-A-H which have important roles on improving of the mechanical properties of the specimens

Unconfined compressive strength (U.C.S). Based in previous studies and geotechnical engineering literature [12], the stabilization of soil by using fly ash significantly changes and improves the mechanical properties of soil such as U.C.S, durability, compressibility and permeability. The U.C.S of soil is considerably one of the most important designing parameters used for pavement design highway construction that is why in this study we focused on the U.C.S properties. As shown in *Fig.4*, the gain in the U.C.S with respect to the curing period for dredged sediments with 5, 10, 15, 20, and 30of fly ash contents. It was observed that as the percentage of fly ash was used for the stabilization process increased, the value of the UCS also improves. From *Fig.4* we can observe that, beyond 14 days curing period, all the early strength values of the specimens stabilized with FA-L-C (except for SD-5) and the specimen with lime content (LIME-1), are slightly less than specimen mixed with cement (CEM-1)

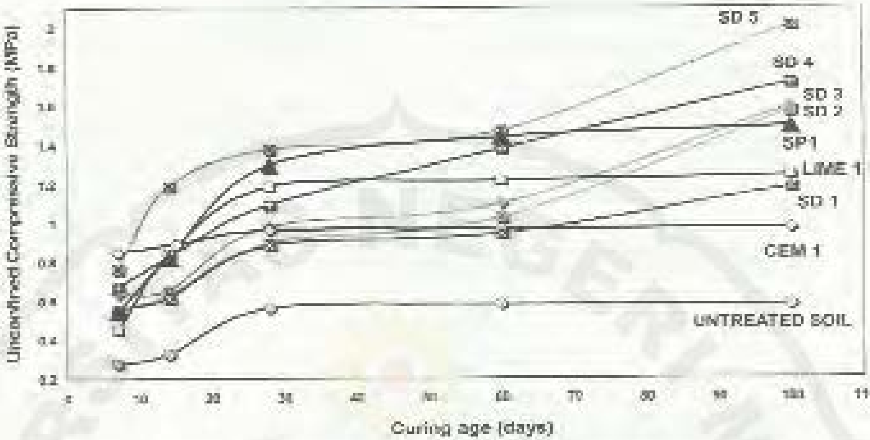

Fig.4. U.C.S development of solidified samples at different curing ages

It may be due to the specimens stabilized with F.A.L.C and with lime, need more time to react to achieve their maximum pozzolanic reaction, as already explained previously. On one hand, the hydration of cement that provides its own pozzolans and therefore requires only a supply of water which directly started as the water introduces in to the mixture. But on the other hand the development of ultimate cured strength for F.A.L.C treated sediment and lime-treated sediment are gradual and continuous for several years, as we can observe in *Fig. 4*. The strength development for sediment treated with these two types of binders, after 28 days of curing period, lime treated sediment (LIME1) and all the F.A.L.C treated sediments from 15% to 30% (SD3, SD4, SD5) of FA content reached strength higher that cement treated specimen. This strength development continues up to 100 days curing period, although for lime treated sediment (LIME1) the strength variation from 60 days to 100 days curing period not very high (2.3%), but this gap strength variability shows that the development of strength in lime treated sediment still continues, but its value depends on the characteristic of the sediment treated, because we can assume that the weak strength variation can be attributed to the quantity of the silica and alumina present in the dredged sediments. This clearly indicates after 60 days curing period, the role of fly ash start becomes more important to provide silica and alumina in stabilization matrix to enhance the strength of the specimen, as long as the pH of the specimen keep stable at 12 (or more).

Cyclic wetting-drying test. The finding from the previous studies shows the influence of cyclic wetting and drying (W-D) always related to the swelling behavior potential of the specimen treated. Several researchers have studied the influence of cyclic wetting and drying on the swelling behavior of expansive soil [13], [14]. From their works we can conclude that the swelling potential significantly increase after the first cycle when the stabilized soil is allowed to dehydrate to its shrinkage limit or maybe below. For the case of addition of fly ash, the researchers found out that with the addition of fly ash in the soil treated generally reduces the swelling potential of the expansive soil [15], [16]. As for soil stabilized by lime, the swelling potential has increased when the wetting and drying cycle was applied to the specimens [17]. In this study we tried to focus on the influence of cyclic wetting and drying on its durability point of view. This method was proposed by Stegemann and Cote [18]. As we explained before, the specimens for this test were divided by two different days of curing, the first specimen series was cured for 7 days at 20°C and after the wet-dry cycles were applied for 20cycles. For the second type of specimen series was cured for 28 days at 20°C before the W-D cycles were applied. The results of the test were reported in *Fig.5* and *Fig.6*.

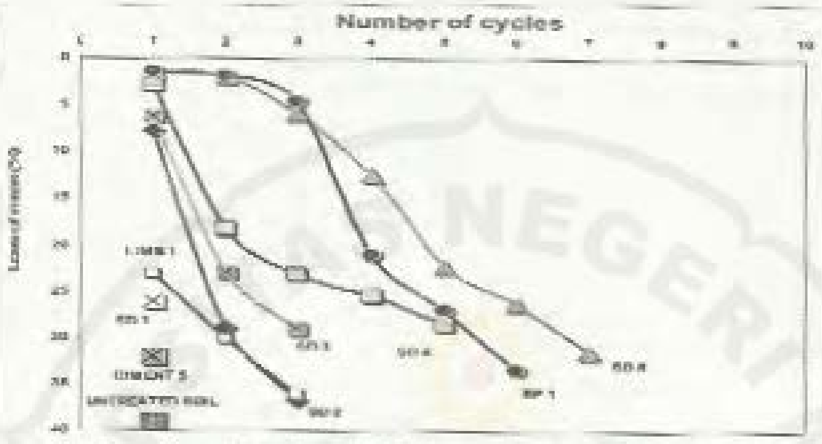

Fig 5 Loss of mass of specimens with 7 days normal cured + 20 days W-D cycles

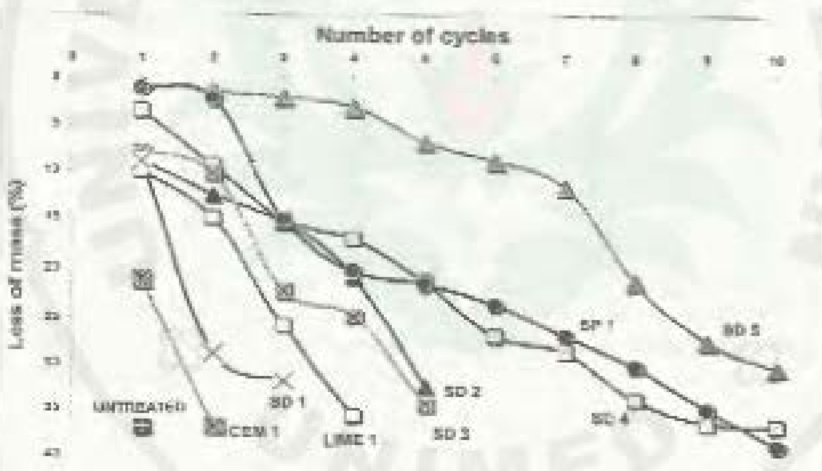

Fig.6 Loss of mass of specimens with 28 days normal cured + 20 days W-D cycles

Fig.5 shows that for the specimens cured at 7 days before subjected to W-D cycles, there is any single specimen which could resists until the end of cycles of the W-D test. Untreated sediment and specimen treated with cement (CEM1) and FA-L-C treated with 5% of FA (SD1) immediately were dispersed on its structure due to wetted condition for the first cycles. Although none of the specimen that can survive from the 10 cycles of W-D cycles, the results show that the resistance in water immersion for the specimens slightly increase according to the addition of fly ash, because for 7 days cured, as was spoken in U.C.S test results, the reaction pozzolanic in these specimens was still not react maximally. As shown in Fig.5, the most resistant specimen to the W-D test (at 7th cycle) was the specimen with the highest FA content (SD1), and the number of cycles obtained slightly decrease as the FA content decrease. And for the specimen treated with Soproline (SP1), it shows that though SP1 has 30% FA content, but its strength behaviour in this W-D test was slightly similar with specimens treated with 20% Sodeline content, (SD4). This is probably due to the mineralogical composition of Soproline, as we observed previously on U.C.S test. For the specimens with 28 days normal cured before submitting to W-D test, as shown in Fig. 6, all the specimens resisted on more number of cycles than specimens for 7 days cured, even two samples of FA (Sodeline) with 20% (SD4), 30%(SD5) and one sample of FA (Soproline) 30% (SP1) were successfully passed all the 10 cycles of W-D test.

Freeze and thaw test. Generally, there are two types of damage deterioration of treated sample structures by cyclic freeze-thaw (F-T). First type is the surface scaling, which is the loss of paste from the surface of the specimens, this loss of paste can result in loosening of coarse aggregate and gradual reduction in strength of treated sample structure. The second type is the internal crack growth in the paste of sample, can result crumbling and deterioration of the sample structure. The F-T test are normally applied on concrete application. The damage produced from this F-T test might be caused by the freezing pressures within the specimen results in a local redistribution of moisture during freezing and it is followed by the absorption of moisture from outside the concrete or internal redistribution of moisture during the thawing process. In this study we focused to observe the evolution of the U.C.S values between freeze-thawed specimen and control (under normal curing condition). The F-T test were applied with testing procedures according to NFP 98-234-1 [19]. The results of F-T test were reported in Fig 7 and Fig 8.

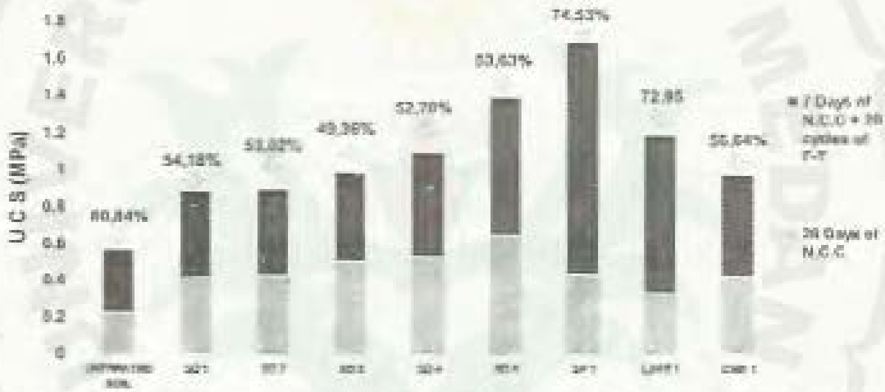

Fig.7. The influence of F-T test on evolution of U.C.S values for specimen after 7 days Normal Curing Condition

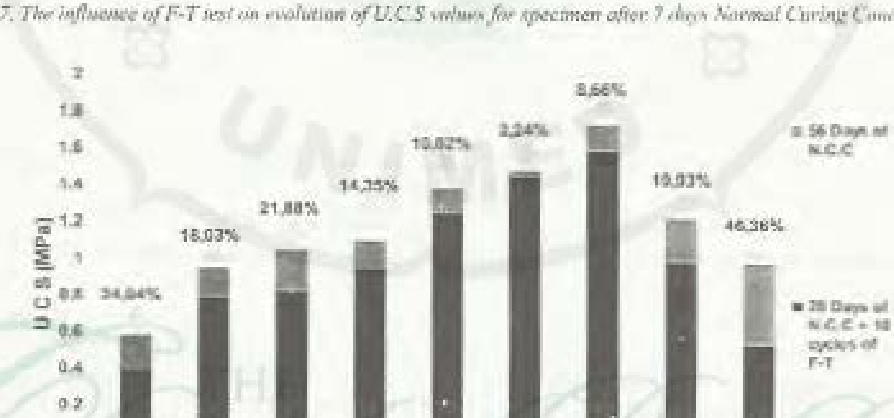

Fig8. The influence of F-T test on evolution of U.C.S values for specimen after 28 days Normal Curing Condition

From *Fig.7* we can see that the influence on the decrease on the UCS values after the W-T test which is largely significant for all samples. Considering the case of specimens treated with FA-L-C., as was explained before, 7 days of normal curing it is not enough for pozzolans material to achieve their maximum pozzolanic reaction. But although this argument was given, we can see the different decrease percentages strength values between different contents of the FA, which explained the influence of the FA considered important as the filler in the particles matrix of the specimens. For after normal 28 days of curing (Fig 8), which gave more time for the hydration of lime/ cement and followed by the pozzolanic reaction took place as explained in evolution of strength on UCS values, and accommodated the structure of the specimens more solid. Hence the damage deterioration of the specimens produced by F-T cycles did not influence as much as it did on specimens cured at 7 days curing ages. We can conclude that higher the FA content in the mixture, lower the influence of the F-T test affected. We can prove this conclusion by observing the results for F-T test reported in Fig 8, the decrease of the UCS values after F-T test for untreated sediment was largely higher than the treated specimens. The lowest decrease for UCS values after F-T test obtained (2.24%) by the specimen treated by FA-L-C with the highest (30%) FA content. As for specimen treated with cement and lime (LIME 1), even the influence of the F-T test did not effect as minimum as the specimens treated by FA-L-C, but the increase on the UCS strength values from the first F-T test (with 7 days normal curing condition) to second F-T test (28 days normal curing condition) 0.32 MPa to 0.97 MPa respectively was better than the specimen treated by cement (CEM 1) with U.C.S values from 0.42MPa to 0.52 MPa respectively..

Conclusions

The objectives of these experiments were to identify the effect of fly ash on the strength behavior and its strength durability on the extreme conditions. The improvement in mechanical properties such as optimum moisture content, pH values and unconfined compressive strength values were investigated. Sediment-cement mixture, sediment-lime mixture and sediment-fly ash-lime-cement mixture were prepared and compacted at the optimum water content. Unconfined compressive strength tests were then performed on these mixtures in normal conditions and in extreme condition. The UCS value gained by specimen treated with lime was continuously increase up to 100 days, although the percentage of increase is not as higher as specimens treated with FA-L-C, for the specimens treated by cement, the increase of UCS value strength almost stop after 60 days. The research has shown that, from the comparison of these three various specimens, the sediment stabilized by fly ash-lime-cement have the most potential values than the others to offer an alternative for stabilization of dredged sediments.

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