# Proceedings of the 15th Japan-Korea-France-Canada Joint Seminar on Geoenvironmental Engineering

# Geo-Environmental Engineering 2016

June 2-3, 2016
Caen National University, Nantes, France

Organized by
University of Normandy, UniCaen, Caen, France
National Institute of Technology, Kagawa College, Japan
Kyoto University, Japan
Seoul National University, South Korea
University Grenoble Alpes, Grenoble, France
University of British Columbia, Vancouver, Canada

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GROUND IMPROVEMENT TECHNOLOGIES
GEOSYNTHETICS, GEO-ENVIRONMENTAL AND WATER ENGINEERING

# Investigation of polluted marine dredged sediment in North Sumatera Indonesia

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**Abstract:**
Disposal of large sediment from dredging activities will be intractable problem in Indonesia. The reuse of dredged sediment as a new material for the construction of foundation and base layers for roads is one of the solution. An effective method for reusing dredged waste materials as a new material in road construction is illustrated in this paper using Pozzolanic binders (Fly Ash and Silica Fume).
The main goal of this study is to describe the behavioural aspect of dredged sediment stabilized with Pozzolanic binders (Silica Fume and Fly Ash) as a binder for a use in road pavement work. The addition of Pozzolanic binders as a partial cement replacement is realized due to its engineering, economic and ecological benefits. The first step realized to identify the mechanical and chemical characteristics of the Pozzolanic binders and the dredged sediments. The second stage consists of identifying mechanical behaviour of dredged sediment with addition of different percentage of Pozzolanic binders. Finally, the chemical identification of dredged sediments with various percentage of binders (with or without Pozzolanic binders) were performed, compared and analysed. The results show that the addition of Pozzolanic binders in mixture improves mechanical characteristics and reduce the pollutants content.

**Keywords:**
Dredged sediments, Silica Fume, fly ash, unconfined compressive strength, Leaching Test.



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## 1. Introduction

Efficient and environmentally reutilization of dredged waste material in Indonesia calls for a multi disciplinary effort. That is why, the scientific, technological and economic information required to make an optimal choice among dredged waste because material disposal sites is now urgently needed in Indonesia. Available or attainable, there are many constraints on policy implementation needed to be design.

Information about the physical, chemical and biological processes that need to be considered in particular dredged waste material situation are linked together by means of predictive techniques. Various alternative existing treatment methods to reuse dredged sediments have been investigated in European country (BOUTOUIL, 1998). Thermal treatment, bio-remediation, solidification/stabilisation by hydraulic binders, washing, but due to high costs, several existing treatment methods are seldom used. The solidification/stabilisation of dredged sediment by hydraulic binders is one of the main alternatives. Previous studies concerning the potential use of dredged sediments as a material filler and in road construction was performed in the laboratory by several researchers (SILITONGA, 2010: KAMALI *et al.*, 2008). Since fly ash is by itself considered a waste, adding fly ash to treat contaminated dredged sediment would be a cost-effective method of disposing of it (SILITONGA *et al.*, 2009). It would provide economic benefits by reducing disposal costs and mitigating possible negative environmental effects, originating in either the fly ash or the solid waste, through proper engineering control, which is why in this study we tried to replace fly ash as alternative binders. It has been known that the addition of Silica fume, fly ash improve the geotechnical properties, due to the pozzolanic reaction and its role as a micro-filler, to achieve effectiveness of fly ash on soil stabilization work. Besides trying to find ways to reutilize dredged waste material (sediment) trying to make a more productive use of other waste such as fly ash would have considerable environmental benefits, reducing air and water pollution. A chemical, mineralogical and physical characterisation of this new material was performed.

## 2. Materials

This study was performed using the marine dredged sediments from Port of Belawan, North Sumatera Indonesia. Two types binders were used in this part of the main research: Fly Ash (FA) and Silica Fume (SF).

### 2.1. Site Description

The marine sediments used in this study were dredged from Port of Belawan, North Sumatera Indonesia (Fig. 1).

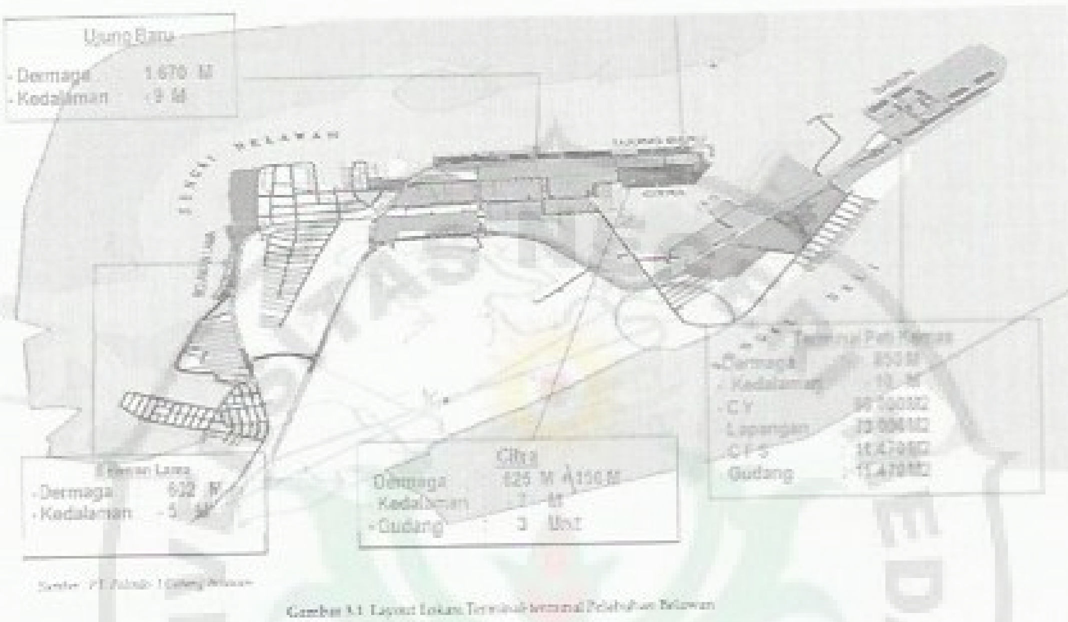


*Figure 1. Map of Port of Belawan.*

The location of ports of Belawan is very strategic. Access to the Malacca Strait linked by shipping channel along ± ± 13.5 km with a width of 100 m and a depth of 8.5 mwls to 10:00 mwls, while harbour pool depth is 6.0 to 11.5 mlws. Belawan Port is located 03° 47 ' North latitude and 98° 42 'East Longitude, in North side bordered by rivers Belawan, and Deli river in the South side.

The sediments used in this study were taken by TSHP (Trailing Suction Hopper Dredger). The dredged sediments were taken from six different locations (PoB A-1, PoB A-2, PoB A-3, PoB A-4, PoB A-5 and PoB A-6). The sediments are dredged from the sea-bed at about 22 m in depth.

## 2.2. Materials

### 2.2.1. *Particle size distribution*

*Dredged sediments*

Different methods have been used to describe the particle size distribution of powders of various types and sizes up to now. In this study, a laser diffractometer Beckman Coulter LS 1332 SW was used to determine the particle size distribution (PSD) of the dredged sediments. Another advantage of using Binders with fines particles such as Silica Fume and fly Ash, is its particles size distribution. It has been known that particles size distribution control the water demand and workability of the mixture.

*Table 1. Characteristic diameters of dredged sediment cement, fly ash and silica fume.*

| *Particle size* | *D10 (μm)* | *D50 (μm)* | *D90 (μm)* | *Clay (%)* | *Silts (%)* | *Sand (%)* |
|---|---|---|---|---|---|---|
| | | | | *< 2μm* | *2 – 63 μm* | *> 63 μm* |
| *Dredged sediment* | *168.3* | *46.1* | *3.922* | *3.96* | *61.81* | *34.23* |
| *Cement* | *730.1* | *34.24* | *0.61* | *13.97* | *56.02* | *30.01* |
| *Fly ash* | *66.65* | *14.15* | *3.07* | *8.11* | *80.14* | *11.72* |
| *Silica Fume* | *3.89* | *7.24* | *8.5* | *40.43* | *48.56* | *11.01* |

The previous study shown by JATURAPITAKKUL *et al* (1999) shown that calcium content, the size distribution and the shape of the particle of fly ash were the most important parameters provide the strength development rate of the mixture (JATURAPITAKKUL *et al.*, 1999). Study by BENICI *et al* (BENICI *et al*, 2007) showed that the specimen with a better fineness and a narrower particle size distribution had the highest compressive strength, sulphate resistance than the others specimens. Besides provides the strength development rate, the fineness particle size of the binders such as Silica Fume and Fly Ash (SILITONGA, 2010), a narrower particle size distribution could present a high compressive strength, sulphate resistance (JOSHI & LOTHIA, 1997). The influence of the finer particle size of fly ash produces more reactive pozzolanic reaction because smaller particle size of fly ash with a higher surface area and glassy phase content also improved the pozzolanic reaction.

As shown in Fig. 1, all binders utilized have different particle size distribution from the point of view of diameter particle most representative; Silica Fume (7.24 μm) has finest particles than other binders (Cement and Fly Ash). From this result, it can be expected that Silica Fume content will provide more strength in Mechanical test. The previous experiment by SILITONGA (SILITONGA, 2010) noticed that the compressive strength tends to reduce as the mean particle size increase for all curing ages. The reduce of the strength might be caused by coarse particles of binder tends to reduce the ability of packing effect of binder and disturbing pozzolanic reaction to enhance mechanical characteristics.

2.2.2. *Chemical properties*

<u>*Dredged sediments*</u>

The dredged sediments were taken from six different locations (PoB A-1, PoB A-2, PoB A-3, PoB A-4, PoB A-5 and PoB A-6). In order to identify the content of the pollutants in dredged sediments, Leaching Test was performed for sediments from all locations. The results in Table 2 show that from all locations sediments were taken, sample from PoB-5 003 is the most contaminated among others, according to its quantity of heavy metal contaminants, especially Zinc (Zn) and Copper (Cu).

*Table 2. Heavy metals in dredged sediments.*

| *Element* | *PoB-1* | *PoB-2* | *PoB-3* | *PoB-4* | *PoB-5* | *PoB-6* |
|---|---|---|---|---|---|---|
| *Nickel, Ni* | 0.09 | 0.17 | 0.04 | 0.11 | 0.05 | 0.05 |
| *Cadmium, Cd* | 1.85 | 0.86 | 0.29 | 1.96 | 1.68 | 2.07 |
| *Chromium, Cr* | 0.22 | 0.08 | 0.98 | 0.27 | 0.51 | 0.38 |
| *Copper, Cu* | 0.71 | 0.242 | 0.37 | 0.29 | 0.6 | 0.41 |
| *Lead, Pb* | 0.67 | 0.9 | 0.1 | 0.88 | 0.07 | 0.45 |
| *Zinc, Zn* | 24.6 | 19.2 | 35.0 | 32.8 | 41.1 | 29.5 |
| *Mercury, Hg* | 0.008 | 0.002 | 0.011 | 0.005 | 0.011 | 0.001 |
| *Arsenic, As**** | 0.19 | 0.08 | 0.38 | 0.095 | 0.08 | 0.24 |

<u>*Pozzolanic binders*</u>

As shown in Table 3, differences in chemical analysis between Silica Fume (SF) and Fly Ash (FA) can be seen that SF1 is characterized by a high content of $SiO_2$ (90-92%), this is one of the strong point of Silica Fume beside its finest particles if compared to FA. It is well known that high content of $SiO_2$ and its finest particles contribute the most important factor to improve mixture physical properties. (Compressive Strength, Tensile strength etc.). SILITONGA (2010)on his research noticed that one type Silica Fume which possess higher content of $SiO_2$, produces higher resistance on Unconfined Compressive Strength Test (SILITONGA, 2010).

*Table 3 Components of binders used.*

| *Parameter* | *Silica Fume* | *Fly Ash* |
|---|---|---|
| *Color* | Silver | Grey |
| *SiO2* | 90 - 92 | 47-55 |
| *Fe2O3* | 1.5 - 2 | 3-4.5 |
| *Al2O3* | 1 | 25-35 |
| *CaO* | 0.5 - 1 | 4.0-10 |
| *MgO* | 1 - 1.5 | 1 - 2.5 |
| *Na2O* | 0.5 - 1 | 0.2 - 0.8 |
| *K2O* | 1 - 1.5 | 0.5-1.0 |
| *C* | 0.5 - 1 | 1-1.5 |
| *Free CaO (%)* | < 1 | < 2 |
| *SO3 (%)* | < 1 | 0.1-0.5 |
| *Cl (%)* | < 0.2 | < 0.5 |
| *Surface specific ($m^2/g$)* | 18 - 25 | 0.8-1 |

On the other hand FA has more amount of CaO, which is very important to help pozzolanic reaction occurs. According to this result, we can expect that SF1 will be more reactive than FS2 as a pozzolanic binder.

## 3. Methods and results

### 3.1. Preparation

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, Silica Fume, 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 samples 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 NF EN 196-1 (NF, 1995) on a simple speed cross-head moving machine at a speed of 1 mm/s. The samples were pushed out from the mould directly after completion of the compaction and were stored in the curing room until testing at 7, 14, 28, 60, 90, 180 and 360 days.

### 3.2. Mix design

In order to determine the effect of pozzolanic binders on the mixtures performances, several compositions were realized. The different formulas in this experiment are given in Table 4.

*Table 4. Mixtures composition studied.*

| *Name* | *Symbol* | *FS1 (%)* | *FS2 (%)* | *Lime (%)* | *Cement (%)* |
|---|---|---|---|---|---|
| *Fly Ash* | *FA-2* | *5* | - | *2* | *2* |
| | *FA-2* | *10* | - | *2* | *2* |
| *Silica Fume* | *SF-1* | - | *3* | *2* | *2* |
| | *SF-2* | - | *6* | *2* | *2* |
| *Cement* | *CEM-1* | - | - | - | *4* |
| | *CEM 2* | - | - | - | *8* |

The goal of manufacturing SF2-2 and FA-2, was to compare the influence of pozzolanic binders if the amount increases two times. The amount of 4% of cement was the common amount that normally used in the road construction field, due to this reason, the sample CEM-1 was realized. CEM-1 and CEM-2 were realized to identify the behaviour of the mixtures without any pozzolanic binders.

### 3.3. Unconfined compressive strength (U.C.S)

In order to determine the effect of Binders used in this study, one of the most commonly parameter in road construction, Unconfined Compressive Strength (UCS) Test was realized. The result of UCS test was shown in Fig. 2.

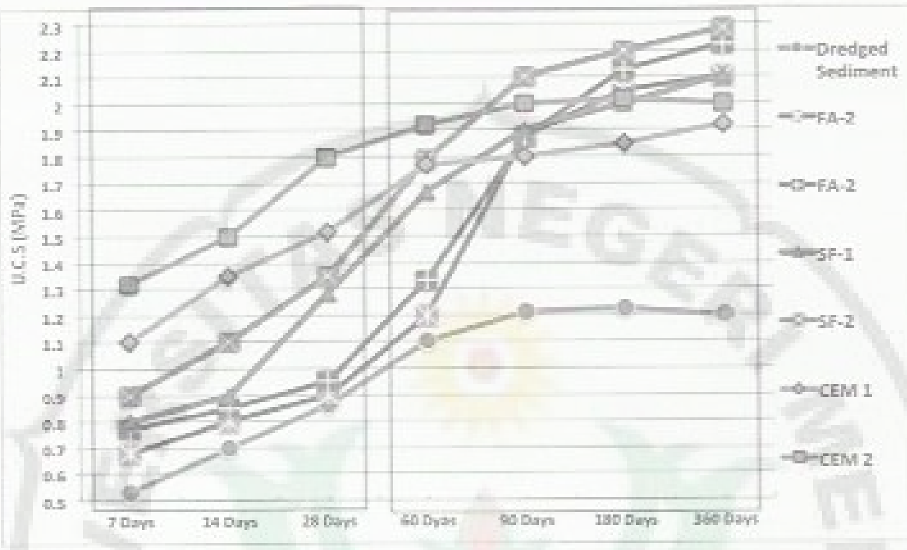


*Figure 2. Unconfined compressive strength test.*

All the mixtures were tested at age of 7, 14, 28, 60, 90, 180 and 360 days. As shown in figure 2, we divided all result to 2 different ages, a) early-medium age (7-28 days) and b)long term age. This method is realized to help to identify the improvement pattern of UCS. The hydration of Cement is well known contribute a rapid strength gain of the samples. This theory shown at UCS test result at early age (7-14 days). As shown in Fig.2 up until the curing age of 28 days, samples with high cement content (CEM-1 and CEM2) have a highest UCS values. At Long term (90-360 days) curing age sample with Cement content do not show any significant UCS values improvement.

Samples with Silica Fume content show an important increase values especially sample with 6% content of Silica Fume (SF-2). At this age (7 days) the effect of the finest particle size of silica Fume plays an important role to improve the UCS, help to generate heat, which accelerates the cementitious and pozzolanic reaction. Normally the hydration of Silica Fume start to contributes strength gain at 14 days curing ages.

On the other hand samples with Fly Ash content show any sign of important improvement UCS gain at early curing age. The pozzolanic reaction normally need to take a long time to contribute strength gain, in this test, Samples with Fly Ash content started to show an significant improvement UCS values at curing age of 90 days and continue show an significant increase of UCS values up to 360 days. This results show that the type of Fly Ash used in this study probably help lime to provides Ca(OH)2, required for the pozzolanic reaction to occurs, and produces C-A_H and C-S-H which are very important factor to the strength gain.

### 3.4. Leaching test

The dredged sediment was planning to land application. However, as the land applied dredged sediment is subjected to drying and oxidation, transformations in the chemical forms of heavy metals may affect their mobility and bioavailability, and phytotoxicity may be occurred by the dredged sediment land application. Therefore, it is necessary to assess the environmental risk of the dredged sediment before its land application

This Leaching Test was realized according to French standard NF X 31-210 (1998), refers to the solution containing the solubilized elements during the test, which are performed on the analytical characterization.

*Table 5. Reference values for dredged sediments.*

| *Inert waste* | *Non-hazardous waste* | *Hazardous waste* |
|---|---|---|
| 0,4 | 10 | 40 |
| 0,04 | 1 | 5 |
| 2 | 50 | 100 |
| 0,01 | 0,2 | 2 |
| 0,5 | 10 | 50 |
| 4 | 50 | 200 |
| 0,01 | 0,2 | 2 |
| 0,5 | 2 | 25 |

The leaching test is divided in three step according to the chemical environment applied in the test :a) The static leaching, we identify the leached elements in solution after presenting sample to the aqueous solution, b) semi dynamic leaching, where test applied with a regular renewal of the leaching solution, c) The dynamic leaching test in which the leaching solution is continuously renew. This leaching test is a simulation to identify the mixture reaction to aggressive chemical environment.

The decision of the European Council No. 2003/33 /EC has established reference values for the acceptance criteria in inert waste landfills, non-hazardous and hazardous. These values relate to the elements contained in the leachate and not in the raw material. The reference values were shown in table 5.

In this paper, only Leaching test result for Cadmium (Cd) was presented and analyzed. As shown in Fig. 3, Leaching Test for Dredged sediment categorize in Non-Hazardous Waste (1-5 mg/kg). As shown in Fig 3, the effect of binders utilized reduces the concentration of Cadmium. Although only sample with 6% of Silica Fume (SF-2) that show an significant reduce Cadmium concentration, After treatment with 6% of Silica Fume the concentration reduce from Category Non Hazardous Waste to Inert Waste. This concentration element reduction surely due to present of Silica Fume, Apparently even though the sample show a concentration diminution of Cd concentration but the amount of 3% SF was not enough to produce remarkable reduction of Cd concentration.

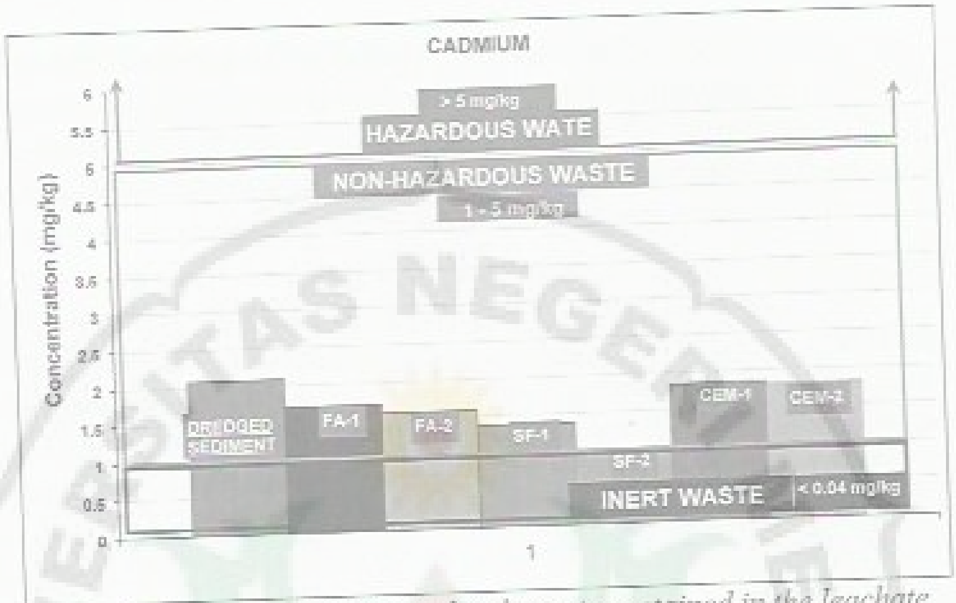


*Figure 3. Cadmium value relate to the elements contained in the leachate.*

Samples with Fly Ash content equally show a reduction on Cd concentration, although it is not as remarkable as Silica Fume, but we could see the effect of Fly Ash to reduce the Cd concentration. Probably because the samples were examined at 60 days of curing age, if the leaching test realized at 90, 180 or 360 days, there is possibilities the samples with Fly Ash will show a importance effect on reducing Heavy Metal element concentration. At long term curing age (>90 days) the pozzolanic reaction of Fly Ash already reacts completely. On the other hand, Sample with only Cement content show a minor reduction of Cd concentration compared to initial Cd concentration. The increase of percentage of Cement (from 4% to 8%) does not give remarkable reduction, from this result we can consider that Cement as a binder is not effective enough to reduce the heavy metal concentration.

## 4. Conclusion

The main goal of this experiment is to identify the effect of binders especially pozzolanic binder such as Fly Ash and Silica Fume on the strength behavior, its capacity to reduce the pollutants. The improvement in mechanical properties such as unconfined compressive strength values were investigated. Sediment-cement mixture, sediment-lime mixture and sediment-Silica Fume/ 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 Fly Ash was continuously increase up to 100 days, although the percentage of increase is not as higher as specimens treated with Silica Fume, 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 different various specimens, the sediment stabilized with Silica

Fume-lime-cement have the most potential values than the others to offer an alternative for stabilization of dredged sediments. From the leaching Test, the present of Silica Fume in mixture proved effective the reduce the amount of pollutant in dredged sediment, thus the dredged sediment could reuse as a new material. The Sample with Fly Ash content requires more time (>90 days) to maximally reacts and reduce the pollutants.

## 5. References


BOUTOUIL M., (1998). *Treatment of dredging muds by stabilization/ solidification with cement and additives).* Thesis, University of Le Havre, France, pp. 245.

COLIN D. (2012). *Valorisation de sédiments fin de dragage en technique routière.* Thesis, Université de Caen, France, 181p.

JATUTAPITAKKUL C., KIATTIKOMOL K., SONGPIRIYAKIJ S. (1999). *A study of strength activity index of ground coarse fly ash with Portland cement.* Science Asia 25, pp 223-229.

DUBOIS V, (2006). *Caractérisation physico mécanique et environnementale des sédiments marins.* Application en technique routière. Thesis, Ecole des Mines de Douai, France, pp 311.

ZENTAR R., DUBOIS V., ABRIAK N. E. (2008). *Mechanical behaviour and environmental impacts of a test road built with marine dredged sediments*, Resource, Conservation and Recycling, vol. 52, pp 947-954.

KAMALI S., BERNARD F., ABRIAK N., E., DEGRUGILLIERS P. (2008). *Marine dredged sediments materials resource for road construction*, Waste Management, vol. 28, 2008, pp 919-228.

SILITONGA E. (2010). *Valorisation des sédiments marins contaminés par solidification/ stabilisation à base de liants hydrauliques et de fumée de silice.* Thesis, Université de Caen, France, 160p.

SILITONGA E., LEVACHER D., MEZAZIGH S. (2009). *Effects of the use of fly ash as a binder on the mechanical behavior of treated dredged sediments*, Environmental Technology,vol 30.

SILITONGA E., LEVACHER. D., MEZAZIGH S. (2010) *Utilization of fly ash for stabilization of marine dredged sediments, 2010,* Revue Européenne de Génie Civil et Environnement, Volume 14 Issue 2, pages 253-265.

MEHTA P., K., (1985). *Influence of fly ash characteristics on the strength of Portland-Fly ash mixture*, Cement and Concrete Research, vol. 15, 1985, pp 669-674.

BINICI H., AKSOGAN O., CAGATAY I. H., TOKYAY M., EMSEN E. (2007). *The effect of particle size distribution on the properties of blended cements incorporating GGBFS and natural pozzolan*, Powder Technology, volume 177/2007, pp 140-147.

JOSHI R. C., LOHTIA R.P., *Fly ash in concrete, Production, properties, and uses*, Gordon and Breach Science Publisher, vol. 2, 1997, pp27-29.

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