Solidification of dredged sediments using hydraulic and geopolymer binders

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RÉSUMÉ. *Les opérations de dragage des sédiments sont nécessaires pour maintenir de bonnes conditions de navigabilité des ports et les voies navigables. La valorisation de ces sédiments est une alternative à l'immersion en mer et au stockage à terre. La stabilisation des sédiments fins nécessite la plupart du temps un traitement préalable, souvent par ajout de liants hydrauliques (chaux, ciment). Parmi les voies potentielles où les sédiments pourraient être valorisés, les filières matériau de remblai et de couche de forme routière sont les plus intéressantes du point de vue économique, environnementale et technique. La stabilisation des sédiments nécessite l'utilisation des liants hydrauliques comme le ciment et la chaux. L'utilisation intensive de ces liants, a un impact considérable sur l'environnement (émissions de CO_2, la consommation d'énergie et de matières premières). Les géopolymères sont des liants alternatifs pour le ciment ordinaire. Dans la présente étude, les sédiments et les liants utilisés ont été caractérisés avant d'être mélangés. Après avoir mélangé les sédiments avec 5 à 15% de liants, ceux-ci ont été compactés dans des éprouvettes cylindriques puis testés à l'aide de l'essai d'aptitude au traitement. Les résultats ont montré que l'ajout de sable est nécessaire pour valoriser un sédiment très organique.*

ABSTRACT. *Dredging operations are necessary to maintain the navigability of harbors and waterways. The recovery process of dredged sediments is an alternative to the disposal at sea and to ashore storage. Among the potential recovery methods, fill materials and road construction are the most interesting from economic, environmental and technical point of views. The stabilisation of sediments requires the use of hydraulic binders like cement and lime. The extensive use of these binders in civil engineering resulted in significant impact on the environment due to CO_2 emissions, energy and raw materials consumption. Geopolymers are alternative binders for ordinary Portland cement. In the present study, dredged sediments and the used binders were characterized before being mixed and compacted. The binders were investigated using Vicat apparatus for its consistency, initial setting and final setting and its compressive resistance were compared as well. The thermal microcalorimetry was used to determine its chemical activity. After mixing sediments with 5 to 15 % of binders, these were compacted in cylindrical specimens then tested against aptitude for treatment test. Results showed that the addition of sand is mandatory for highly organic sediments recovery.*

MOTS-CLÉS : *sédiments de dragage, valorisation routière, géopolymère, aptitude au traitement, analyse thermogravimétrique*
KEY WORDS: *dredged sediments, road recovery, geopolymer, aptitude for treatment, thermogravimetric analysis*

1. Introduction: Issue of sediments management

Sediment refers to the conglomerate of materials, organic and inorganic, that can be carried away by water stream or wind. Man-made structures (*e.g. dams, harbors, bridges)* hinder/disturb the natural transition of sediments, which reduces the navigable depth of harbors and waterways. Thus, to maintain the navigability, dredging operations become necessary. In France, 26.89 Million of tons of sediments were dredged in 2013 [CET 13], which is the origin of ashore sediment's management issue. Sediments polluted with heavy metals and organic pollutants cannot be disposed in the sea due to stringent environmental regulations. Therefore, the recovery process (valorization) of dredged sediments became an alternative to the disposal at sea and to ashore storage. There are several recovery methods in civil engineering, such as substitution in concrete, cement, bricks. However, from technical, environmental and economic point of views, earthworks recovery is the most interesting.

1.1. The need for alternative binders?

Knowing that the geotechnical properties of sediments are not adapted for road construction, a solidification/stabilization process is mandatory. It requires a process of solidification-stabilization (S/S), a well-known treatment approach of fine grained soils by cement and lime admixtures. The very high demand on ordinary cement worldwide, presents an important environmental footprint due to raw materials consumption and energy for production, add also due to CO_2 emissions. Geopolymer cement is an alternative binder that showed high mechanical performance for lower environmental impact than ordinary cement.

1.2. Objectives

In the present study, three binders are characterized, to be used for sediments treatment afterwards. These binders are: OPC, and two geopolymer binders. These are characterized using *Vicat* apparatus for normal consistency, initial setting and final settings. The thermal microcalorimetry was used as well to determine its chemical activity. The compressive mechanical resistance, after 28 days curing period, of these binders were compared as well. The identified binders were then mixed with sediments to be used in road subgrade construction. The test of aptitude for treatment was performed to investigate the feasibility of treatment using the different binders.

2. Methods

2.1. Properties of raw sediments

The characterisation of raw sediments is a mandatory step for the recovery process. [MOG 18] modelled the resistance of treated sediments as function of raw sediments properties and added percentages of different binders/additives. In case of earthworks recovery method, [MOG 18] identified two properties of sediments that affect highly it's mechanical resistance upon treatment, these are the organic matter content (OM) and the index of plasticity (IP). These properties should be investigated using the adapted methods.

The organic matter percentage by mass was estimated using three methods: 1) calcination at high 450 °C (according to XP P 94-047), 2) calcination at high 550 °C (according to NF EN 12879) and 3) calcination at low temperature using hydrogen peroxide. [ROB 27] presented a method for OM destruction using hydrogen peroxide solution (H_2O_2), and thus it became widely used for soil texture analysis. H_2O_2 is an oxidizing agent that digests organic C (carbon). The calcination at 450 °C or higher volatize clay-linked water. In addition, higher temperature is needed for complete OM destruction. That is why the method of hydrogen peroxide was chosen.

The index of plasticity IP defines the water content range in which the soil remains flexible and deformable, while maintaining a certain shear strength. Limit of liquidity can be determined using the *Casagrande cup* method and cone penetration test. In case of montmorillonitic soil, [CHA 00] recommended the *Casagrande* cup method. The limit of plasticity was determined using roll test. Moreover, a thermogravimetric test permitted to identify some organic and in-organic materials in the used sediment.

2.2. Binders

Three binders were used in this study: ordinary Portland cement (OPC), and two geopolymers binders. Since 1978, Joseph Davidovits introduced the term 'geopolymer' (mineral polymer) to describe a family of mineral binders, consisted of aluminolisilicte materials activated using chemical solution (i.e. alkali silicate solution) [DAV 82]. Aluminosilicate raw materials, *e.g. Fly ash, slag*, dissolute when mixed with highly alkaline activator(s), *e.g. sodium or potassium hydroxide*, which leads to the liberation of aluminates and silicates necessary to for geopolymerisation process afterwards. Three parameters were identified using Vicat apparatus:

the normal consistency, initial and final setting according to EN 196-3. Afterwards, its mechanical resistance was compared. The thermal microcalorimetry test was also used to investigate its thermal activity.

2.3. Aptitude for treatment test

The aim of this test is to verify, that the combination of a material with hydraulic binder(s), ensures an acceptable mechanical behavior. It consists of accelerating the phenomena of hydraulic setting produced in a sample, by emerging the specimens is water controlled at 40 °C, then measuring the potential swelling of specimens and its diametric compression resistance after one week according to [NF 99]. From left to right, Figure 1 shows a specimen after fabrication, a specimen to be tested for diametric compression resistance and finally a specimen for swelling measurement. According to [NF 99], swelling should be less than 10% and the minimum diametric compression resistance should be of 0.2 MPa.

3. Results and discussion

Sediments OM content was found to be 13.2 % using H_2O_2 method, and of IP 32 %. These properties show that the sediment is highly organic and highly sensitive to water, which makes the valorization more difficult. Figure 1 shows that the tested sediment consists of several OM components, such as humus and lignin. Moreover, the peak at 650 °C shows the presence of calcium carbonate. Clay-linked water volatize between 80 °C and 850 °C.

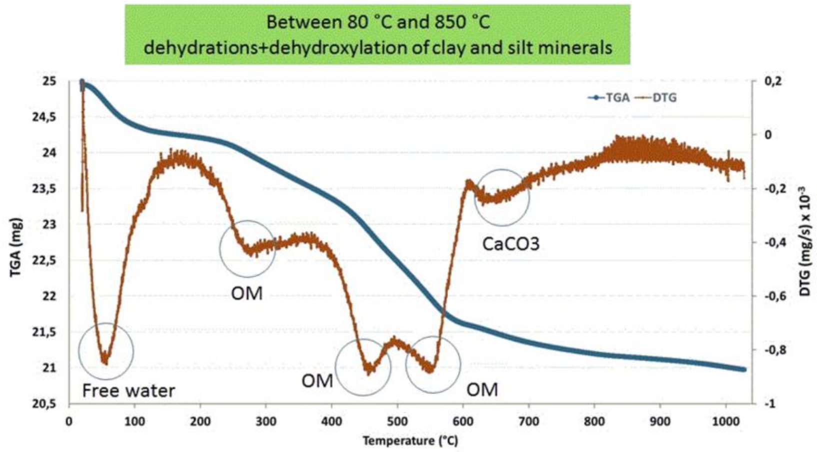


Figure 1. *Thermogravimetric test on raw sediments*

The composition of three tested binders is given in Table 1. These were identified from literature, and the dosage of the activation solution and water were fixed according to consistency test. Results in Table 1 show that the initial and final setting of geopolymer 1 and 2 are faster than that of OPC, and that of geopolymer 2 faster than that of 1. This result is due to the high activity of ground blast furnace slag. The thermal microcalorimetry test shows that the activity of geopolymer 2 (GP2) is superior to that of geopolymer 1 (GP1), which is also superior to the activity of OPC. These findings confirm the initial and final setting results.

Table 1. *Composition of used binders*

	OPC	**Geopolymer 1**	**Geopolymer 2**
Composition	100 % CEM II 32.5	Ground blast furnace slag + Class F fly ash + alkali-silicate solution	Ground blast furnace slag + alkali-silicate solution
Normal consistency Solution/dry matter	0.25	0.37	0.42
Initial setting (minutes)	120	54	37
Final setting (minutes)	245	121	92
Compressive resistance (MPa)	62.8	49.1	105.8

Sediments were treated using 5 % to 15 % of hydraulic binder (lime and cement), geopolymer 1 or geopolymer 2, then fabricated by static compaction (Figure 3.a). specimens were then covered using a geotextile for swelling measurement (Figure 3.b) or covered by plastic and aluminum films to be isolated from moisture and light during curing (Figure 3.c). Figure 4 shows that the produced swelling destroyed the sample, which is the case for all tested mixtures. Diametric compression resistance of all tested mixtures was found below the threshold (0.1 MPa). The high OM content hindered the hardening of the three tested binders.

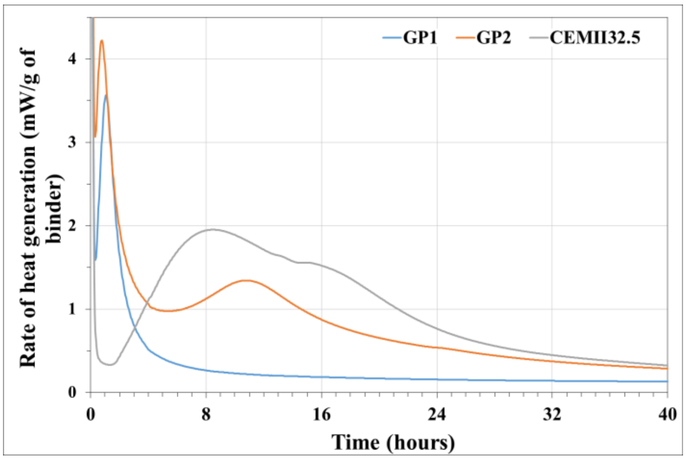
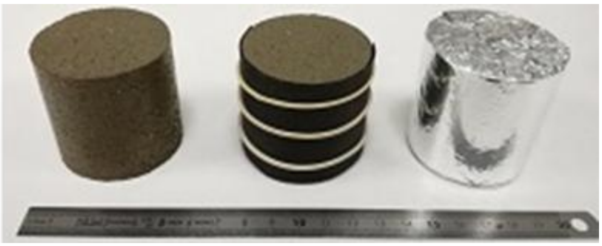


Figure 2. *Thermal microcalorimetry on tested binders*

This result was validated by the tests, which showed the absence of hydrates peaks, that validates that the high OM content prevents hydration/geopolymerisation reactions. Complete results will be presented at the oral presentation.



(a) **(b)** **(c)**

Figure 3. *a) fabricated specimen by static compaction, b) specimen prepared for swelling measurement, c) specimen prepared for diametric compression test*

Figure 4. *Swelling after 7 days curing period*

4. Perspectives

To recover a highly organic sediment using any binder, dredged sand should be added to improve the granular skeleton of mixtures and to dilute the organic fraction as well. That is the perspective of the present study. Further investigations are also necessary to understand the effect(s) of each binder at the scale of the microstructure such as: Isothermal microcalorimetry, XRD, Thermogravimetry and mercury porosimetry.

5. References

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