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Influence of granulometric corrector on the properties of the sediments treated with hydraulic binders

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Abstract:
In this experimental study, beneficial use of dredging sediments is considered using sands to modify particle size distribution. Two different sands, crushed and smooth, were added to the fine non-contaminated sediment before cement-based treatment. Results show that after 28 days in normal cure, unconfined compressive strength was improved up to 40% after adding crushed sand. No significant difference was noted between the two sands relating to tensile strength. Scanning electronic microscopy and grain size analysis show a development in the microstructure of the treated sediment and allow better understanding of the layout of the new matrix.

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1. Introduction

Since the 80's, the traditional practices of management of the dredging sediments have changed due to the evolution of the environmental regulations.

In France, the reuse of sediments as a material in civil engineering is considered by a solidification/stabilisation with hydraulic binders (BOUTOUIL, 1998; REY, 1999; COLIN, 2003; DUBOIS, 2006; REKIK, 2007; DUAN, 2008). This process reduces the environmental impact of the material (chemistry) and improves its mechanical properties (structure) (BOUTOUIL & LEVACHER, 2000). Some projects of management already integrate this solution (DAMIDOT et *al.*, 2006; GROSDEMANGE et al., 2008; BOUTOUIL, 2010).

Nevertheless, the treated fine sediment has a high porosity and a relatively low resistance (BOUTOUIL & LEVACHER, 2001; REKIK & BOUTOUIL, 2009). The use of a complementary granulometric corrector (COLIN, 2003; SANNIER, 2008) improves the granular skeleton. It modifies the particle size distribution (PSD) of material and reduces the void ratio. The compressibility is weaker and the mechanical resistance is higher. Moreover, it makes it possible to reduce influence of water, organic matter (O.M.) and clays (LEVACHER *et al.*, 2006).

In this experimental study, a fine non-contaminated sediment from Ouistreham harbour (Normandy, France) is mixed with CEMII/B-M (S-LL)32.5 R cement and sands in various formulations. Mechanical resistances and microstructure evolution (granulometry and SEM observations) are analysed.

2. Materials and testing methods

The particle size distribution (PSD) of the sediment is characterized by 93% of particles lower than 80µm (XP P 94-041) including 25% of clay (NF P94-057). Its methylene blue test value (NF P94-068) is 3.5 g/100 g of dry sediment. The organic matter (O.M.) content is 7% (XP P 94-047). This content is not modified during this study. The moisture content is 127% (NF P94-050) at extraction. It reaches 90% at the time of the study, after 3 years of storage. The sediment will then be used with this moisture.

The sediment is treated with 10% of CEMII/B-M (S-LL) 32.5 R cement (with σ_{c28} of 46,2MPa) compared to its wet mass (that is to say 19% compared to its dry mass), taken as reference according to Rekik's investigation (REKIK, 2007). Treated sediment Proctor optimum is a moisture content of 38% and a dry density of 1.11 t/m^3 (REKIK, 2007).

Sand correctors contents of 35, 40 and 45% compared to the mass of the dry components (dry sediment and cement) are added. These contents are chosen regarding the contents of 30 and 50% selected by Colin (2003).

Two distinct sand correctors are used. Their PSD curves are reported in figure 1. The first is a 0/4 siliceous smooth sand, with an uniformity coefficient C_U of 0.47, a

curvature coefficient Cc of 0.95 and a fineness modulus FM of 2.1, characteristics of a fine and poorly graded sand.
The second is a 0/4 red arkose crushed sand, with a C_U of 50, a C_C of 0.78 and a FM of 3.2, characteristics of a coarse and well graded sand. Its PSD is more spread compared to the smooth sand.

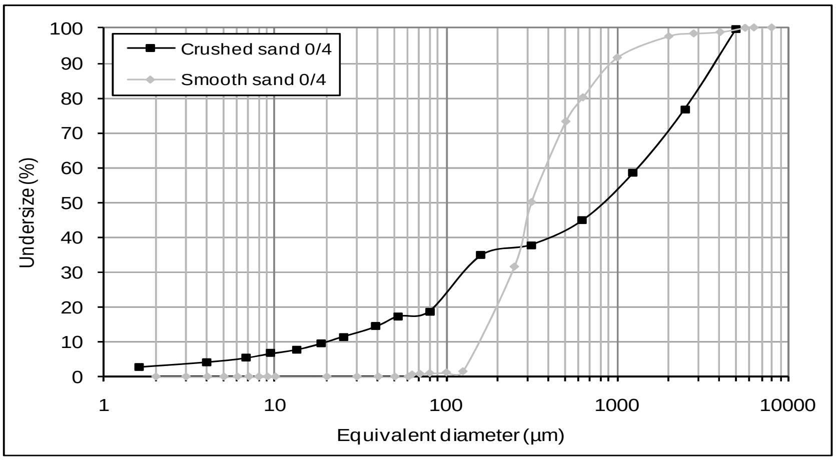

Figure 1. Granulometric curves of the sand correctors used.

The sediment, at its initial moisture content is mixed with the sand and cement correctors and compacted in the form of 5×5 and 5×10 cm cylindrical samples to approach normal Proctor density of 1.11 t/m^3. These dimensions correspond to the recommendations of the technical guide for soil treatment (GTS) (SETRA-LCPC, 2000).
The use of the sediment at its initial water content prevents a classical confection by static compression. The samples are manually compacted, in three layers, each being settled by a quick succession of 25 hits to reach the required height. The higher water content prevents from reaching the optimal dry density.
Three manufactured samples are made for each parameter. They are stored in hermetic mould (standard cure) or in air at 20±2 °C. Then, they are tested at 7 and 28 days. In this study, results of unconfined compression strength (UCS) (NF P98-232-1) and diametral compression strength (NF P98-232-3) tests at 28 days are presented. After test, the samples are dried at 50 °C and subjected to PSD (NF P94-056 and NF P94-057) and SEM analysis (JEOL JSM 5300 LV in SE).

3. Results and analysis

3.1. Mechanical strength

3.1.1. Influence of sand corrector content

The unconfined compressive strength (UCS) must reach 1 MPa for reusing in road construction (SETRA-LCPC, 2000). Figure 2 shows the results of the tests for samples stored in standard cure during 28 days. Sand corrector improves UCS of the treated sediment, whatever its nature and its proportion. For maximal content of the studied interval, 45%, the mechanical performance is doubled.
Addition of crushed sand allows the treated material to reach 0.44 MPa, whatever contents. In spite of the measures dispersion, it seems that the average value increases with the increase of sand corrector content, in the studied interval of addition. Integration of smooth sand with 35 and 40% allows to reach a UCS of 0.32 MPa. For 45% UCS reached 0.55 MPa: it is the most powerful formulation.

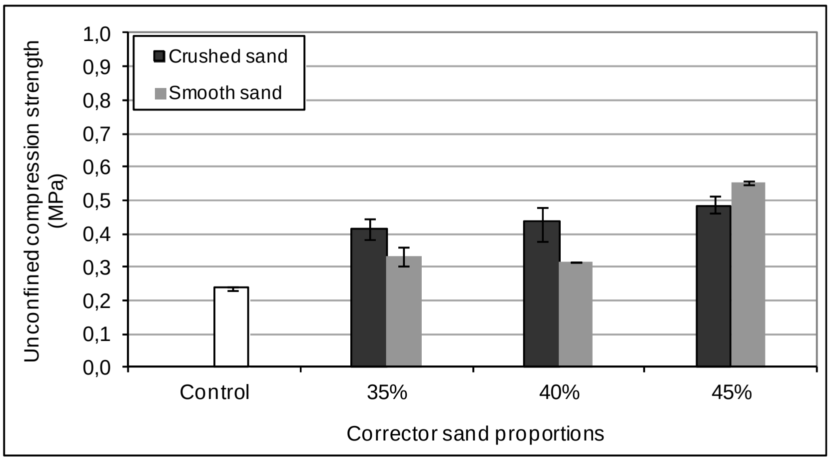

Figure 2. UCS at 28days (mean and standard deviation SD) of treated sediment with 10% of cement, without or with 35, 40 and 45% of sand corrector, stored in normal cure.

The results of diametral compression strength on samples stored in standard cure during 28 days, reported in figure 3, confirm the advantage of the sand correctors by an improvement of 10% compared to the treated sediment. It must reach 0.25 MPa for reusing of material in road engineering. It is only of 0.10 MPa for the majority of the suggested formulations and reaches a maximum value of 0.14 MPa with integration of 45% of smooth sand.

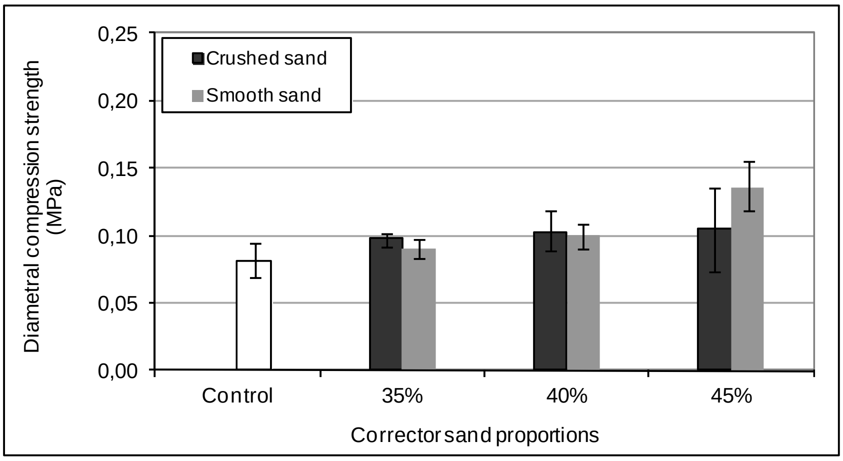

Figure 3. Diametral compression strength at 28days (mean and SD) of treated sediment with 10% of cement, without or with 35, 40 and 45% of sand corrector, stored in normal cure.

3.1.2. Influence of the sand corrector nature

Nature, mineralogy and PSD of the sand correctors differ. In figure 2, UCS show overall lower performances with smooth sand. To establish the influence of the nature and PSD of corrector sand, the PSD of crushed sand is modified to correspond to that of smooth sand, with same C_U. UCS are repeated with this modified sand corrector (figure 4). In this case, the samples are stored in air during 28 days before test.

UCS with modified crushed sand are improved compared to the treated sediment, without sand corrector.

UCS with modified crushed sand are improved also compared to the treated sediment with smooth sand: the nature of the sand influences the UCS.

But the UCS with modified crushed sand are weaker than with the sand crushed in its initial configuration. So, this new PSD is not the most favourable to the development of the mechanical performances. The integration of a sand corrector with a close PSD at the mixture lead to a less dense pile than with a sand corrector with a spread PSD.

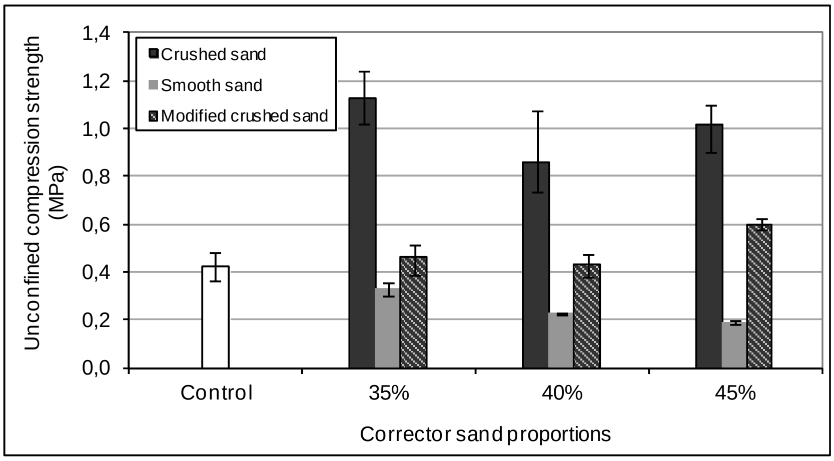

Figure 4. UCS at 28days (mean and SD) of treated sediment with 10% of cement, without or with 35, 40 and 45% of sand corrector, stored in air.

The dispersion of measurements of solidified material with crushed sand, under its initial form, does not make it possible to conclude with a preferential formulation. This observation is the same in figures 2 and 4. Uncertainty of measurement is explained by a random sampling which does not guarantee the representation of the totality of the granular spectrum.

3.2. <u>Structure of solidified sediments with sand corrector</u>

3.2.1. *Granulometric analysis of the solidified sediments*

The structural modifications induced by the treatment with cement and the contribution of 45% of sand corrector are analyzed through the PSD of new materials (figure 5).
After strength test at 28 days on samples stored in standard cure, samples are oven dried at 50 °C, and manually crushed in a porcelain mortar, for a sedimentometry analysis. The results presented give information on the structural evolution after the immediate modifications generated by the added compounds, the sand corrector and the hydraulic binder.
The PSD of the new material is coarser compared to the sediment before or after cement treatment. The treatment results in an immediate process of flocculation followed by a phase of slow cementing. The contribution of a new element of structure led to an immediate reduction of the water, organic matter and clay contents, without real modification of the granulometric distribution of the treated sediment.
The clay and the fine fraction are reduced, more under the treatment influence than that of the sand corrector addition. So, if the PSD of the crushed sand, more spread and uniform, seems more favourable to improve compactness, the close PSD of the solidified material is not sufficient to explain the increase of mechanical strength.

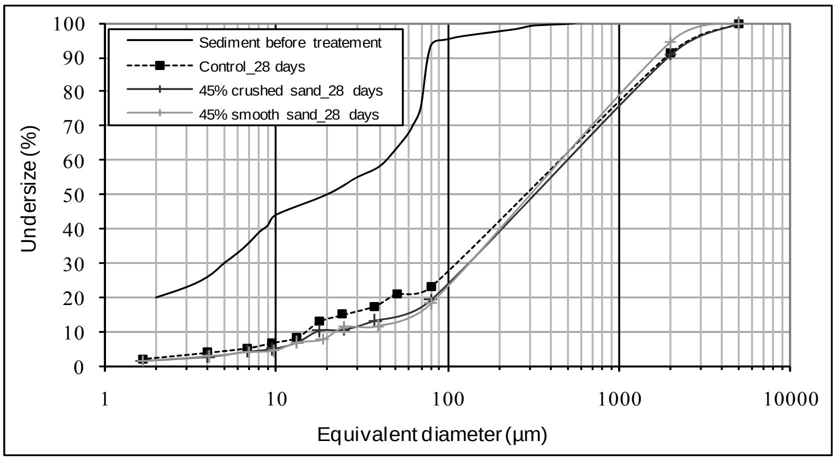

Figure 5. Granulometric analysis at 28 days of treated sediments without or with 45% of sand corrector.

3.2.2. *Scanning Electron Microscope (SEM) observations*

The evolution of the microstructure of new material is followed by SEM observations.

At 7 days, the hydrates of tricalcium silicates (HCS), products of hydration of cement, ensure already the cohesion of the mixture, initiating bonds between grains of sediment and corrector sand.

The photographs of the figure 6 give an idea of the material structure after 28 days of standard cure. With enlargement ×200, the HCS, which developed with the time, are species mainly present. The sediment and sand corrector grains are difficult to distinguish in the mass of hydrates.

In the photographs of figure 6, with enlargement ×1500, it is possible to differentiate the quality of influence from the HCS on the sand corrector grains: crushed sand, characterized by an angular form, is included in the matrix while the contacts with smooth sand seem to be more limited.

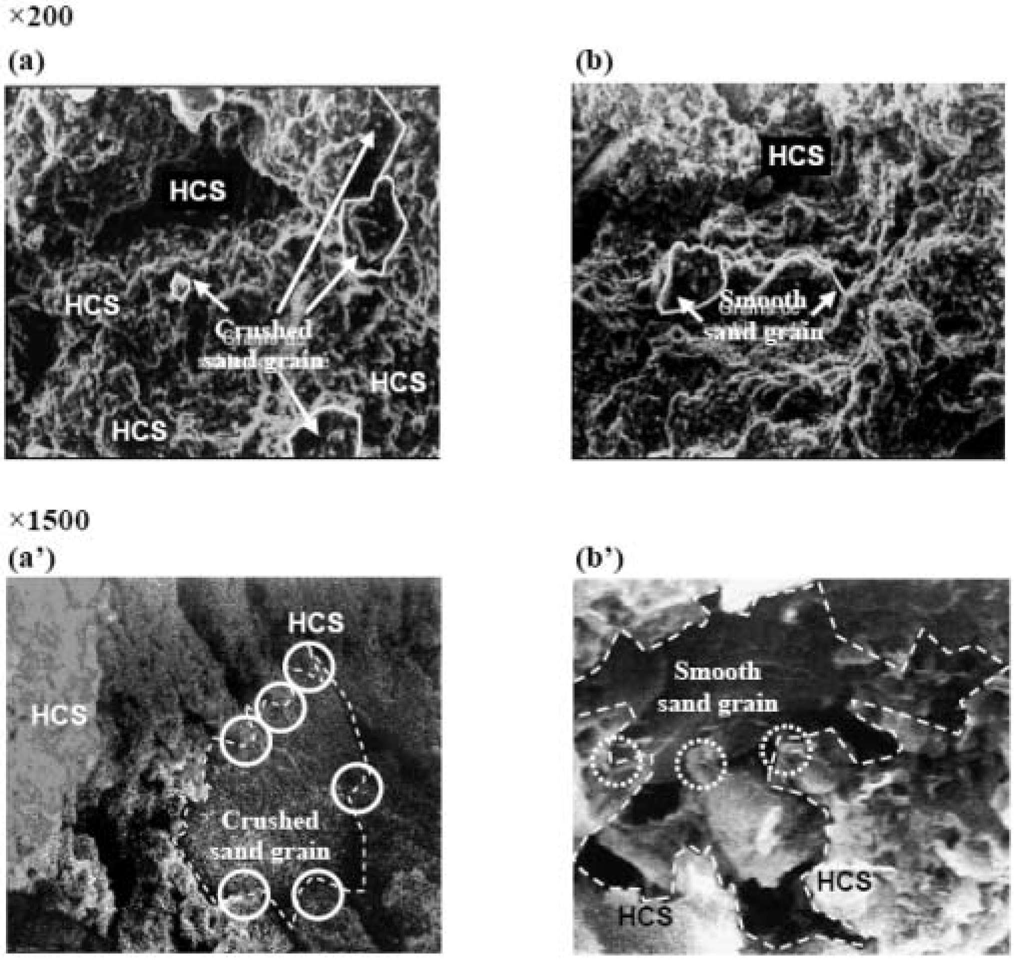

Figure 6. Photographs in secondary electrons at 28 days of the treated sediments with 10% of cement with 45% of sand corrector: (a) and (a') crushed sand, (b) and (b') smooth sand.

4. Conclusions and prospects

The sand corrector enhances the structure of the treated sediment, allowing the UCS to increase about 100% and the diametral compression strength by 10% at 28 days.

A well graded sand, with important C_U, added with content of 45%, is more favourable to enhance the granular skeleton.

The PSD of the solidified material is coarser, on the one hand by the contribution of a new element of structure, on the other hand by the presence of HCS around the grains of sediment and sand corrector.

It would seem interesting to detail these results by a longer study, with finer microstructural analysis. The choice of corrector must be optimized, as well on its nature as sieve parameters.

The present study was led on empirical bases, without confrontation with the existing scientific bases in terms of granular optimisation, with controlled pile and compactness. The correction could then be envisaged with noble materials or reusable wastes.

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