THE EFFECT OF CURING TIME AND TEMPERATURE ON THE STRENGTH OF ROAD MATERIAL MADE OF SEDIMENTS

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ABSTRACT

The dredging operation generates each year, more than 50 Mm^3 of sediment in France. In the context of beneficial use of these materials, several methods and techniques are used.

In the framework of beneficial use in road construction of dredged sediments, it's important to predict as soon as possible the characteristics of the developed mix on the basis of tests undertaken at an early stage.

In this work, an experimental program in the laboratory is performed in order to explore the effects of curing time at given temperature and humidity on the increase of the mechanical characteristics of the samples including sediments and binders.

Keywords: Dredged sediments, Road material, Curing time, Temperature, mechanical characteristics.

INTRODUCTION

Every major harbors of the world require, at one point, new dredging operation to broaden and deepen the access channel and reach the depth appropriate water along the installations at the water's edge. This operation is vital for the maintenance of maritime and fluvial transports and constitutes an important factor for the functioning of the port economy.

Each year, this operation generates a considerable quantity of dredging sediments, approximately 600 Mm^3 in the world [1], 250 Mm^3 in Europe [2] and 50 Mm^3 in France [3]. These dredging materials, after dredging, could be characterized as a waste according to the European decree [4]. The traditional methods of sediment disposal such as the dumping in the sea and the inland deposit are increasingly restricted by the environmental constraints. The use of dredging sediments in construction materials is an alternative and a promising choice for the valorization of these materials. Parallel to the dredging sediment problems, the Civil Engineering fields consumes annually in France more than 400 million tons of granular materials which more than half in the road construction field [5].

The access to materials deposit is a long way. Opening a quarry falls within of studies and procedures often lengthy. The quarries are authorized for a limited period, unlike most of the classified installations. The maximum period is thirty years, but it is often between fifteen and twenty years [6], because the duration of the operational period that is given to quarries is strictly regulated in time. They are subject to the laws of classified installations for the environmental protection. The opening of new quarries requires, on the one hand, ensuring the final restoration of the site at the exploitation end date. On the other hand, investing in solutions to be implemented to reduce environmental impact at the exploitation time. All costs necessary for the exploitation of quarries could balance the costs generated by the treatment of the dredged sediments to be an alternative resource of materials for the civil engineering field.

The beneficial use of dredging sediments for materials road has been studied in laboratory by several authors ([7], [8], [9], [10], [11], [12], [13], [14]). In this context, this study aims to determine the physical and geotechnical characteristics of marine dredging sediment. The second step consists to explore the effects of curing at given temperature and humidity on the increase of the mechanical characteristics of sample of marine sediment treated with hydraulic binders and granular corrector.

MATERIALS AND METHODS

In this work, the studied sediment was dredged in a harbor at the South East of France. It was delivered in plastic barrels per truck at the department of Civil Engineering and Environmental of Mines de Douai. Upon their arrival, this material has been emptied into a polyethylene tarp reinforced high density in order to carry out some visual observations. It appears that this material has a sandy texture and low initial water content. Before sampling to perform the tests, the studied sediment was homogenized using a shovel as shown in Figure 1.

Fig. 1: Homogenization and quartering sample Of sediment (a, b), and their conservations (c and d)

The choice of granular corrector must meet the technical, economical and environmental constraints. In this sense, one type of sand was chosen to optimize the particle size distribution of the studied sediment. This sand is of class 0/6.3 mm.

The cement used in this study is of type CEM III / B 42.5 - PM produced in the South of France. It is a blast furnace cement composed of at least 20 % of clinker and at most 80 % of slag and a calcium sulphate addition. It was selected for its aggressive water resistance, its good frost resistance and its low price. This cement is suitable for soil stabilization, characterized by its fine grinding size, giving it a large specific area of 5390 (cm^2/g), an absolute dry density of 2.99 (g/cm^3).

The experimental program conducted in this laboratory study includes: Firstly the measurements of the initial water content, the grain size distribution, the Atterberg limits, the organic matter content, absolute dry density. Secondly, determine the compaction characteristics by modified Proctor compaction tests. These geotechnical characteristics are needed for the realization of cylindrical specimens allowing to evaluate the mechanical performances of the studied material.

Finally, the effects of curing time at given temperature and humidity on the increase of the mechanical characteristics of cylindrical samples including the sediment, the hydraulic binders and the sand was explored.

RESULTS AND DISCUSSION

1 CHARACTERIZATION OF THE RAW SEDIMENT

The Figure 2 shows the particle size distribution curves of the studied sediment. This sediment was composed mainly of sand; about 91.5 % of the particles were greater than 63 µm. It also shows that the clay particles proportion (particle size < 2 µm) was very low.

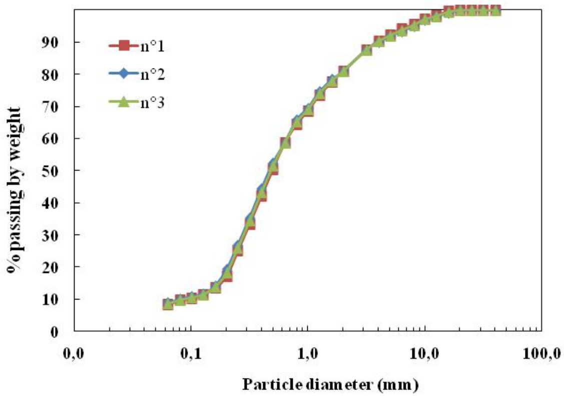


Fig. 2: Grain size distribution of the studied sediment

In Table 1 the results of the characterization tests of the studied sediment are reported. The values in this table are the average of three measurements. The initial water content measured by drying at 105 °C until the full stabilization of the mass is around 9 %. Compared to the water content typically measured in the marine sediments, this value was very low. The methylene blue value (V_{BS}) measured of this material was very low. This value can be explained by the percentage of the clay particles in the sediment composition. The plastic limit could not be determined by the roll method defined in the standard [15]. It appears that the studied sediment break down during the rolling phase. This phenomenon occurred when the plasticity range is very low. Therefore, the liquid and plastic limits values are practically close to each other. In this case, for the sediment classification according to the French guide for materials classification for road construction, the methylene blue value should be used. The studied sediment presents 81 % of aggregate particles passing 2 mm sieve size. It is therefore classified as a B2 type of material. This materials category includes sands poor in clay content and clayey sands.

The studied sediment is characterized by low organic matter content. It was determined by the method of loss mass by ignition at 450 °C and 550 °C and the values were shown in the Table 1. The density of the solid particles (ρs) is measured using a helium pycnometer of type Accupyc. The measurements show that the value measured on the studied sediment is equivalent to the values measured on inorganic materials (2.70 to 2.80 g/cm^3). The density of the solid particles of the studied sediment, ignited at 450 °C and 550 °C could confirm that the studied sediment present a low organic matter content as shown in Table 1

Table 1: Physical characteristics of the studied sediment

Parameters	Studied sediment	standards	
Water Content (%) at 105 °C	9.00	NF P 94-050	**[16]**
Methylene blue value (V_{BS})	0.30	NF P94-068	**[17]**
Plastic limit (%)	≈ 27.20	NF P94-051	**[15]**
Liquid limit (%)	27.20	NF P94-051	**[15]**
Plasticity index (%)	≈ 0.00	NF P94-051	**[15]**
% > 2 mm	81.00	NF EN 933-1	**[18]**
% < 63 µm	8.50	NF EN 933-1	**[18]**
Loss on Ignition at 450 °C	2.25	XP P94-047	**[19]**
Loss on Ignition at 550°C	2.95	NF EN 15169	**[20]**
Specific density (ρs)	2.66	NF EN ISO 18753	**[21]**
Specific density of sediment calcined at 450 °C	2.67	NF EN ISO 18753	**[21]**
Specific density of sediment calcined at 550 °C	2.67	NF EN ISO 18753	**[21]**

2 CHARACTERIZATION OF THE TREATED SEDIMENT

The experimental methodology followed in this study in order to evaluate the effect of curing time and temperature on the mechanical resistances includes, on the one hand, the determination of optimal compaction characteristics required for preparing samples, the production of cylindrical specimens and their conservation. On the other hand, submit these samples kept in a sealed plastic box to two different temperatures, in a humidity chamber at room temperature maintained at 20 °C and in a laboratory oven fixed at 40 °C with a relative humidity close to saturation 95 %.

2.1 Geotechnical characterization

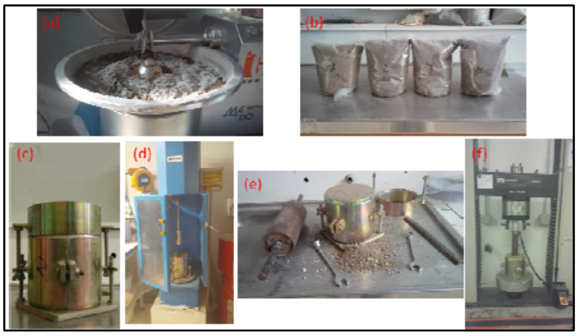
The compaction is the most economical process always used in the road construction for improving the soil dry density. This is an instantaneous reduction in the soil volume due to the reduction of air voids. The compaction study is carried out using the Proctor compaction test. The modified Proctor test has been used in order to evaluate the use in the pavement layers.

In the preliminary study, several formulations have been tested in the laboratory. The chosen formulation of this study made up of sediment and the addition of granular corrector in combination with the hydraulic binder. The proportion of each component is shown in Table 2.

Table 2: Proportion of the components in designed material

	Studied sediment	sand	cement
Studied formulation	28.2	65.8	6

The compaction ability of the studied formulation was evaluated through the modified Proctor test according to the standard [22]. Five mixtures of different water contents were prepared to establish the Proctor curve. For each mixture, according to a given process and energy, the wet density was measured. The wet density value is used to calculate the dry density of the mixture which is used for representing the Proctor curve. The compaction characteristics of the studied formulation (dry density and optimum water content) are determined by the relationship between the water content and dry density. In association with the modified Proctor test, the punching measurements on compacted specimens are performed to assess the Immediate Bearing Index (IBI) according to the standard [23]. The modified Proctor-IBI studies of the studied formulation were conducted using an automatic compacting machine for performing modified Proctor as indicated in Figure 3.



(a: Soil cutter; b: Mixtures conservation; c: CBR mold; d: Compacting machine; e: CBR mold after compaction; f: Press machine for IBI measurements)

Fig. 3: Modified Proctor-IBI Materials

The modified Proctor-IBI results of the studied formulation are indicated in Figure 4 and the optimal characteristics of these tests are shown in Table 3.

The results presented in Figure 4 indicate that the studied formulation has a low water content at the optimum Proctor. This finding can be explained by the sandy texture of this formulation.

Regarding the Immediate Bearing Index, the measured values decrease quickly with increasing water content after the optimum Proctor. Which might predict an important water sensitivity for this formulation. For the reference value measured at the optimum water content, this Immediate Bearing Index result ensures, according to the earthworks guide, an easy movement of compaction equipments on the building site.

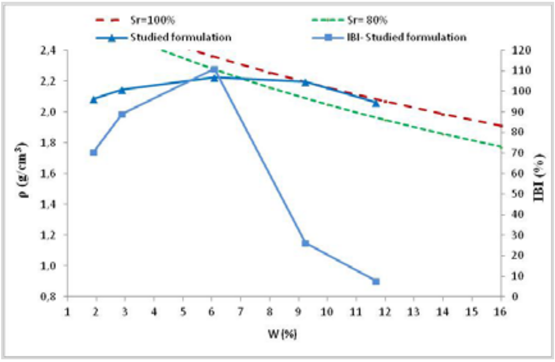


Fig. 4: Compaction and IBI curves of the studied formulation

Table 3: Optimal characteristics of the modified Proctor-IBI tests

	W_{OPM} (%)	ρ_{OPM} (g/cm^3)	IPI_{OPM} (%)
Studied formulation	7	2.215	90

2.2 Mechanical characterization

a) Realization of test specimens

The cylindrical specimens of dimensions 10 cm long and 5 cm diameter are used to perform mechanical tests, in view of the fact that the maximum material size is less than 6.3 mm as prescribed by the standard [24]. The static compression is used for preparing of cylindrical specimens, the molds description and the conservation procedures are respected by following the standard recommendations [25].

Regarding specimen preparation, After determining the optimum compaction characteristics, the amount of wet material of each sample is computed according to the following equation:

$$M = \frac{(100 + W_{OMP})\ x\ V\ x\ \rho_{OMP}}{100}$$

M (g): Theoretical mass needed for sample preparation;

ρ_{OMP} (g/cm^3): Dried density at optimum modified Proctor;

W_{OMP} (%): Water content at optimum modified Proctor;

V (cm^3): Specimen volume.

b) Short-term mechanical performance

The uniaxial compressive strength and the tensile strength of the cylindrical specimens have been evaluated at 1, 3, 7, 14, 28 and 90 maturation days. The tensile strengths are obtained by the diametrical compression test according to the standard [26].

At least three samples are performed for each measuring point, which gives us a total of seventy two samples, equivalent to 33.500g of materials only for mechanical characteristics. The obtained results are given in Figures 5 and 6 .These Figures show the development of the uniaxial compressive strength and the tensile strength of the studied formulation versus curing time and temperature. Depending on the treatment duration, these strengths follow the same trends for both studied temperatures.

For sample conserved in a laboratory oven fixed at 40 °C with a relative humidity of 95 %, a rapid growth of uniaxial compressive strength to achieve the maximum value of 5.28 MPa at 14 days was observed. Subsequently, this resistance is stabilized around the same value. For sample conserved in a humidity chamber at room temperature maintained at 20 °C, the uniaxial compressive strength is experiencing gradual increase throughout the studied period. The maximum value reached at 90 days with the treatment at 20 ° C corresponds to a value reached after 10 days at 40 °C. In order to save time during preliminary studies, the treatment at 40 °C could be used to predict on short term the observed behavior on long term in standard conditions of testing. This could result in an important gain of time.

For the tensile strengths, the samples treated at 40 ° show an increase and stabilize at 28 days. The maximum value reached at 90 days was 0.68 MPa against 0.66 MPa at 28 days, which represents a difference of 3%. For sample at 20 °C, the maximum value reached at 90 days is 0.65 MPa. This value could correspond to a value measured after 20 days at 40 °C. This result represents also an important gain of time.

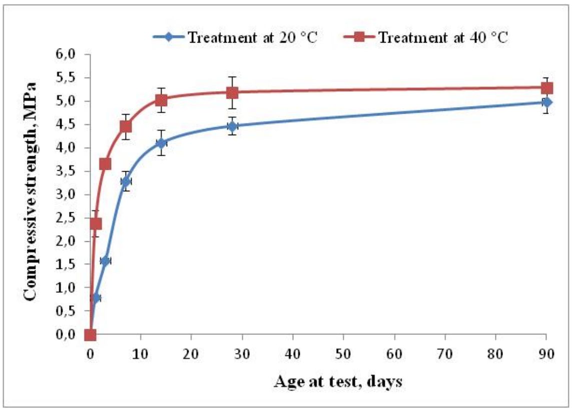


Fig. 5: Development of the uniaxial compressive strength of the studied formulation at different curing time and temperature

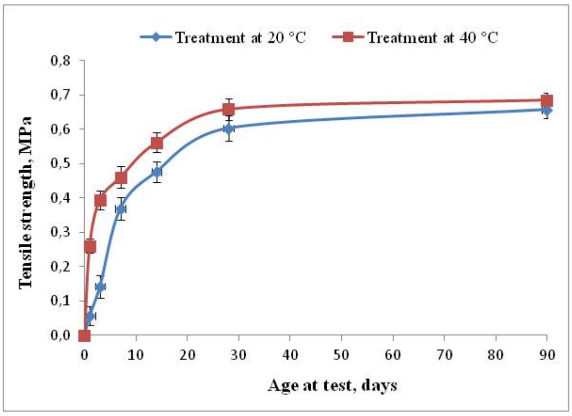


Fig. 6: Development of the tensile strength of the studied formulation at different curing time and temperature

CONCLUSION

Dredging sediment is required to maintain depths necessary for navigation. The materials derived from this operation need a sustainable management. In this research works, an alternative solution is proposed for the use of dredged sediment in the construction of road materials.

The proposed methodology consists of mixing the sediment with quarry sand in order to reduce the fines content of the mixture and increase its compactness. Thereafter, the mixture is treated with a hydraulic binder to increase its mechanical performances. After determining the physical characteristic required to a good knowledge of the studied sediment, the treatment with sand quarry in combination with cement has been proposed in order to improve the weak mechanical performances of this material.

The data presented in this study show clearly that the proposed treatment causes an increase in the uniaxial compression strength and the tensile strength in the short to medium term. The results of mechanical strengths show that we could predict the compressive strength results of 90 days at 20 °C by using a treatment of 10 days at 40°C and the tensile strength results of the same maturity by using treatment of 20 days at 40°C. The comparison between two treatments at 20 °C and 40 °C reveals an important saving time.

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