ABOUT A POSSIBLE USE OF DREDGED MARINE SEDIMENTS IN PARTIAL SUBSTITUTION OF CEMENT IN THE MANUFACTURE OF MORTARS

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ABSTRACT

The disposal of dredged marine sediments has become a major economic and environmental issue in the world. In this study, the marine sediments dredged in the harbor of Dunkirk (France), dried and ground afterwards, were used in partial substitution of cement in the manufacture of mortars. The physico-chemical characterization of sediments showed that they have a higher specific surface area and a lower density than the cement. Thus, it was decided to maintain a constant cement paste volume for mortars: a given volume of cement has been replaced by the same volume of sediment for three substitution contents(10%, 20%, 30%) of a Portland cement CEM I 52.5 during the preparation of mortars. Standard siliceous sand was used for the manufacture of the mortars. Two reference mortars were produced without sediments using two types of Portland cement (CEM I 52.5 and CEM II/A-LL 32.5).

The results showed that the flexural and compressive strengths of mortars decreased when the sediment replacement content increased. However, the mechanical properties of the mortar with 20% replacement of cement with sediments were better than those of the reference mortar made from cement CEM II/A-LL 32.5 containing a similar proportion of limestone that is known to have a beneficial physico-chemical effect on cement hydration. The total porosity measured by mercury intrusion porosimetry of different types of mortars showed that the porosity of CEM I 52.5 mortar increased as the substitution content increased. The porosity of the mortar with 20% replacement of cement by sediment was nevertheless lower than that of the mortar with cement CEM II/A-LL 32.5, that is consistent with the results of compressive strength measurements. The dried and finely ground sediments have thus a beneficial effect on cement hydration.

Keywords: Sediments, Mortar, Substitution of cement, Mechanical properties, Porosity

INTRODUCTION

A large amount of sediment is dredged for navigation every year. In France, about 50 million m^3 of sediment are produced from harbors. While in China, about 400 million m^3 of sediment are dredged annually. Thus, the disposal of dredged sediment has become a major economic and environmental issue in the world [1]. So far, there is a lot of research on the reuse of sediments in road construction [2-4]. However there is little research on the reuse of sediments in the concrete industry [5]. As we all know, concrete is the second material used in the world after water. Therefore, it is really interesting to use the sediment in the manufacture of mortars and concretes [6].

In this study, the marine sediments dredged, dried and then ground, were used in partial substitution of cement in the manufacture of mortars. The physico-chemical characterization of the sediments originally showed that they have a higher specific surface area and a lower density than cement. Thus, it was chosen to maintain a constant cement paste volume for mortars: a given volume of cement has been replaced by the same volume of sediment for three substitution contents (10%, 20%, 30%) of a Portland cement CEM I 52.5 during the preparation of mortars. Two reference mortars were also produced without sediments using two types of Portland cement (CEM I 52.5 and CEM II/A-LL 32.5). The fresh properties such as fresh density, slump and the mechanical properties of mortars were measured and the microstructural properties of mortars were also studied.

MATERIALS AND EXPERIMENTS

Sediments and cements

The marine sediments used were dredged in the port of Dunkirk (France). Then it was dried at 40°C until constant weight and then ground in a laboratory mill. In this study, the fraction 0/80 µm was used for partially replacing cement in the manufacture of mortars. The organic matter content was measured as 13.8% according to the standard XP P94-047 by calcination in oven at 450°C for 3h. The true density was 2.48g/cm^3 measured by helium pycnometer, which is lower than Portland cement.

Portland cement CEM I 52.5 and CEM II/A-LL 32.5 were used for the manufacture of mortars. The density of these two cements measured by helium pycnometer was 3.12 and 2.99 g/cm^3 respectively. Table 1 shows the mineralogical composition of two cements which was determined by XRD using Rietveld method. Table 2 shows the chemical elements of sediment determined by X-ray fluorescence. The major chemical elements of the sediment were oxygen, silicon, calcium, aluminum and iron that are similar to those present in cement.

Table 1 Mineralogical composition of cements determined by XRD-Rietveld method

	C_3S	C_2S	C_3A	C_4AF	Anhydrite	Gypsum	Quartz	Calcite
CEM I 52.5	68.11	22.62	0.68	7.81	0.05	0.53	0.2	0
CEM II/A-LL 32.5	52.93	13.91	7.42	-	0.74	2.63	2.31	17.31

Table 2 Chemical elements of sediment determined by X-Ray fluorescence

Element symbole	Element name	Percentage (%)
C	Carbon	Present
O	Oxygen	50.2
Na	Sodium	1.8
Mg	Magnesium	1.1
Al	Aluminium	4.6
Si	Silicon	16.5
P	Phosphorus	0.1
S	Sulfur	1.5
Cl	Chlorine	2.1
K	Potassium	1.5
Ca	Calcium	16.2
Ti	Titanium	0.3
V	Vanadium	Traces<0.1
Cr	Chromium	Traces<0.1
Mn	Manganese	Traces<0.1
Fe	Iron	3.7
Cu	Copper	Traces<0.1
Zn	Zinc	Traces<0.1
Sr	Strontium	Traces<0.1
Zr	Zirconium	Traces<0.1
Pb	Lead	0.1

Figure 1 shows the particle size distributions of cements and sediment used in mortars. The sediment contained a higher proportion of 1 µm to 10 µm than cements. Table 3 presents the specific surface determined by Blaine (according to standard EN 196-6) and by the N_2 BET method. The specific surface area of sediment was three times larger than that of the cements according to the Blaine method, and 10 times larger than the cements according to the BET method.

Table 3 Specific surface area of cements and sediment

	CEM I 52.5	CEM II/A-LL 32.5	Sediment
Blaine test (m^2/g)	0.33	0.29	0.82
BET test (m^2/g)	0.8	1.1	9.1

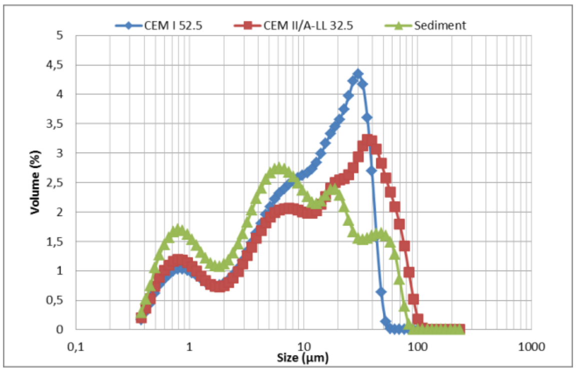

Fig.1 Particle size distributions of cements and sediment used in mortars

Sand

Standard siliceous sand (according to standard EN 196-1) was used for the manufacture mortars. This sand had a density of 2.62g/cm^3 measured by helium pycnometer, and water absorption of 0% according to standard EN 1097-6.

Experiments

Four mortars were made from cement CEM I 52.5 (noted as M0-52.5, M10-52.5, M20-52.5, M30-52.5 which corresponds to 0%, 10%, 20% and 30% of cement being replaced by the same volume of sediment respectively. A mortar was made with cement CEM II/A-LL 32.5 (noted as M0-32.5). Table 4 shows the compositions of the studied mortars.

Table 4 Compositions of mortars

	M0-52.5	M10-52.5	M20-52.5	M30-52.5	M0-32.5
Sand (g)	1350	1350	1350	1350	1350
Cement (g)	450	405	360	315	450
Sediment (g)	0	35.77	71.54	107.31	0
Efficient water (g)	225	225	225	225	225
$E_{eff}/(C+S)$	0.5	0.51	0.52	0.53	0.5

A precise mixing procedure was followed according standard EN 196-1. After mixing, the slump of mortar was measured with the mini MBE cone ("Mortiers de Béton Equivalent") [7]. The preparation of specimens (40mm×40mm×160mm) for mechanical strength tests was followed according to standard EN 196-1.

The flexural and compressive strengths of hardened mortar were determined in accordance with standard EN 196-1. These two mechanical tests were carried out with an INSTRON 5500R 4206-006 (loading capacity of 1500 KN) after being cured 7 and 28 days in water. The porosity of mortar was tested by using Mercury Intrusion Porosimetry (MIP) technique (Micromeritics Autopore IV).

RESULTS

Fresh properties of mortars

Figure 2 shows the variation of slump as a function of types of mortars. As can be seen, for the four mortars made with cement CEM I 52.5, the slump value of mortar decreased when the substitution of sediment increased. This trend could be due to higher specific surface area of sediment compared with cement. Thus, part of the mixing water was adsorbed to the sediment and thereby the free water quantity was decreased, leading to the decrease of workability.

Figure 3 shows the fresh density of mortars as a function of types of mortars. The fresh density of the mortar slightly decreased as the substitution of sediment increased, which is certainly linked with the lower density of sediment compared with cement.

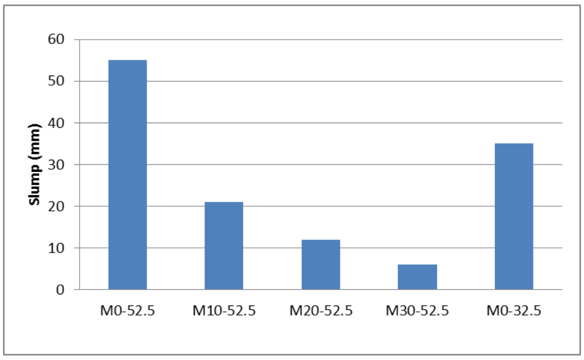

Fig.2 Slump as a function of types of mortars

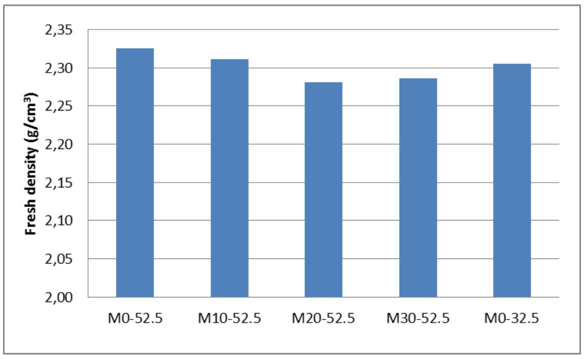

Fig.3 Fresh Density of mortars

Mechanical properties of mortars

Figure 4 shows the mechanical strengths of mortar as function of types of mortars. The flexural and compressive strengths of mortars decreased when the substitution of sediment increased. This is the consequence of substitution of cement by little or no chemically reactive constituents. Nevertheless, the mechanical strength of the mortar with 20% replacement of cement by sediment was similar to that of mortar with cement CEM II/A-LL 32.5 that contained about 20% of limestone and that is known to have a beneficial physico-chemical effect on the cement hydration. A high degree of substitution led to reduce the beneficial impact of the sediment as it is also the case for the limestone.

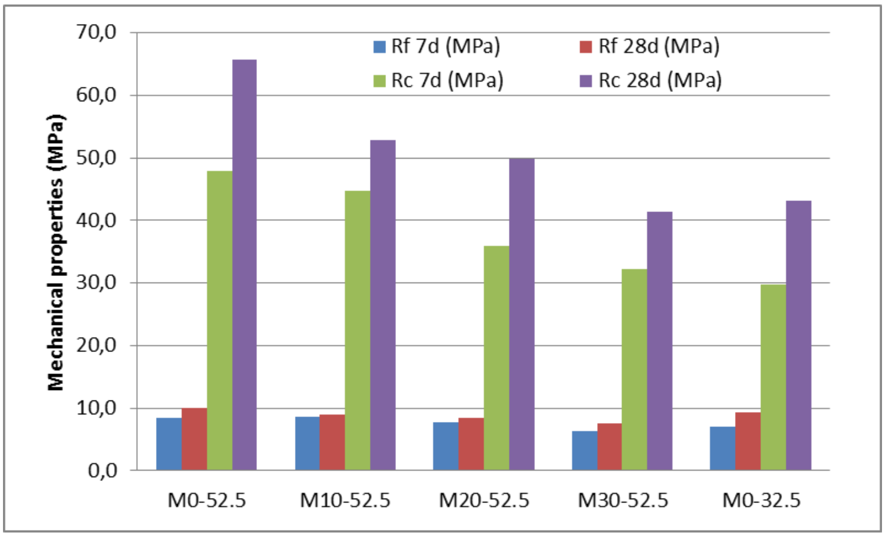

Fig.4 Flexural and compressive strengths of mortars

Microstructural properties of mortars

Figure 5 shows the total porosity of mortar after 28 days curing in water measured by mercury intrusion porosimetry. The total porosity of mortar increased as the substitution of sediment increased for the series made with CEM I 52.5. The porosity of the mortar with 20% replacement of cement by sediment was nevertheless lower than that of the mortar with cement CEM II/A-LL 32.5. This is consistent with the results of compressive strength. Sediments did not appear to significantly reduce the initial compactness: the increase of cement hydration degree in the presence of sediment would therefore lead to only compensate partly of volume loss of hydrates due to the decrease of cement content. Therefore, it only reduced the resistance drop compared to a simple substitution of cement with a inert filler or less reactive filler. Finally, it appears that sediments had a better physicochemical beneficial effect on the cement hydration than limestone.

Figure 6 shows the pore size distribution of mortars measured by MIP. For the CEM I 52.5 series, when the substitutions of sediment increased, the pore volume between 0.006 and 0.05 microns increased, but the pore volume between 0.06 and 0.1 micron decreased. Sediments allowed for a finer distribution of porosity, which is beneficial for the mechanical strength but also for durability.

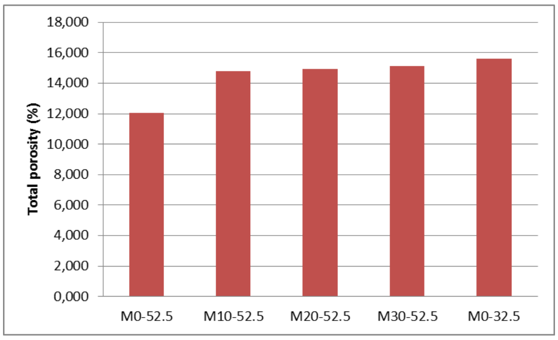

Fig.5 Total porosity of mortars measured by MIP

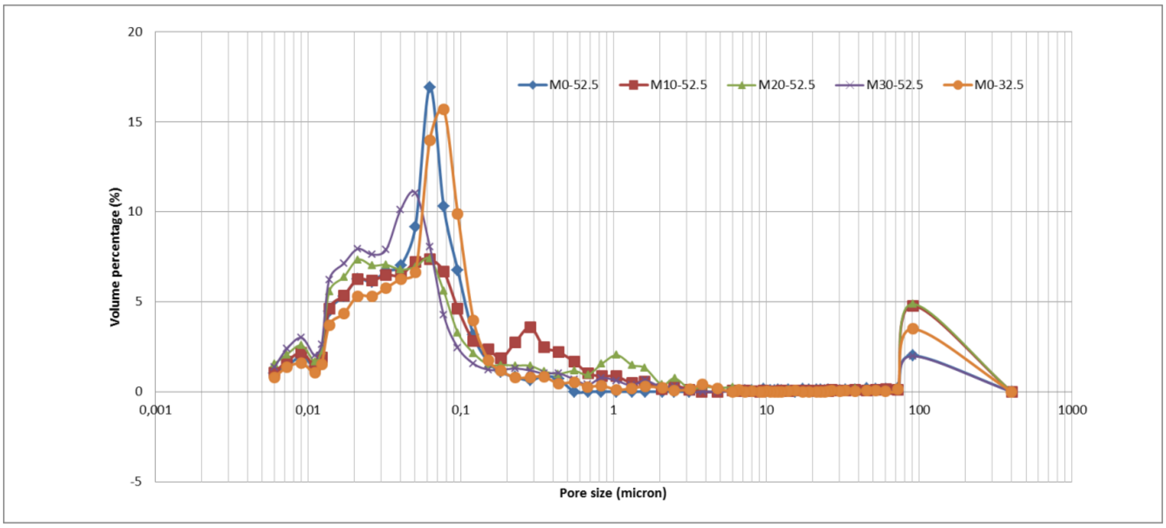

Fig.6 Pore size distribution of mortar measured by MIP

CONCLUSIONS

In this study, uncontaminated marine dredged sediments, dried and then ground, were used in partial cement replacement in the manufacture of mortars. The physico-chemical characterization of sediments initially showed that they have a higher specific surface area than the cement and a lower density.

The results show that the flexural and compressive strengths of mortars decrease when the substitution of sediment increases. However the mechanical properties of mortar with 20% substitution of sediments are better than those of a reference mortar made from cement CEM II/A-LL 32.5 that contains approximately the same amount of limestone. Finally, fine fraction of dried marine sediments can use as a potential future partial substitute of cement clinker or by direct addition in the concrete. Indeed for reasonable substitution amounts (<20% in volume), the impact is less than the effect of the dilution of the cement which suggests that sediments positively influence the hydration of cement and even more effectively than limestone.

However several aspects require further research. For example what is the mechanism of sediment on the hydration of cement? Is it a heterogeneous nucleation effect of C-S-H on the sediment as in the case of limestone?

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REFERENCES

[1] Agostini F., Skoczylas F., Lafhaj Z., “About a possible valorisation in cementitious materials of polluted sediments after treatment”, Cement and Concrete composites, Vol.29, 2007, pp.270-278.

[2] Kamali S., Bernard F., Abriak N., Degrugilliers P., “Marine dredged sediments as a new materials resource for road construction”, Waste Management, Vol.28, 2008, pp.919-928.

[3] Zentar R., Wang D., Abriak N., Benzerzour M., Chen W., “Utilization of siliceous-aluminous fly ash and cement for solidification of marine sediments”, Construction and Building Materials, Vol.35, 2012, pp.856-863.

[4] Wang D., Abriak N., Zentar R., Xu W., “Solidification/stabilization of dredged marine sediments for road construction”, Environmental Technology, Vol.33, 2012, pp.95-101.

[5] Meyer C., “The green of the concrete industry”, Cement and Concrete composites, Vol.31, 2009, pp.601-605.

[6] Zhao Z., Benzerzour M., Abriak N., Damidot D., “Valorisation des sédiments marins dragués en substitution partielle du ciment dans la fabrication de mortiers”. 2e édition de la Conférence Internationale Francophone: Nouveaux Matériaux et Durabilité, Douai, France, 5-6 Novembre 2015.

[7] Zhao Z., Remond S., Damidot D., Xu W., "Influence of fine recycled concrete aggregates on the properties of mortars", Construction and Building Materials, Vol.81, 2015, pp.179-186.