RECYCLING OF MARINE SEDIMENTS STEMMING FROM DREDGING FOR THE FORMULATION OF LIGHTWEIGHT CONCRETE USED FOR EMBANKMENT

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ABSTRACT

In 2014, the amount of dredged marine sediments in France is about 50 million cubic meters a year. Marine sediments stemming from the dredging have to be dumped on the ground according the legislation which considers them as waste. Balineau, a company of maritime works based at Pessac near Bordeaux decided to bet on this environmental and economic issue by financing this project. It consists in developing an innovative concrete which re-use marine sediments as raw material and as a replacement of gravels traditionally used for the concrete.

The swelling of the clay in marine sediments is an important point of this study. This concrete has the distinctive characteristic to be mixed during the manufacturing with an air-foam. Thus, the concrete has a porous structure and a lower density. This concrete could be used as embankment in the rehabilitation of maritime platforms. The study will be led by taking into account the conditions of implementation and the maritime environment of the concrete for this kind of application.

The experimental works aim to establish a method of formulation, a manufacturing process and a database about the concrete characteristics.

The method of the formulation is based on the determination of a parameter related to the liquidity index of marine sediments. It permits to fix the quantity of water in the manufacturing of the concrete.

The first work was to reduce the collapse of the air-foam during the manufacturing of the concrete. Mixing energy and the quantity of water have an effect on this phenomenon.

Keywords: Marine Sediments, Dredging, Air-foam, Strength,

INTRODUCTION

In 2014, about 50 million cubic meters a year of marine sediments are dredged in France [1]. Until in the 80s, the solution was the salting out. However this method represents a threat for the littoral ecosystem. Thus the dredged marine sediments must be dumped [2]. The valuation of marine sediments in the concretes is a real ecological and economic issue. This study presents the development of an innovative concrete made from marine sediments and by mixing an air-foam made with animal protein. It has thus a low density (around 1,2).

MATERIALS AND METHODS

The fraction under 2µm corresponds to the particles of clay. These are hydrated phyllosilicates of aluminum. Their crystalline structure is in layer. These layers are octahedrons $Al(OH)_6$ and tetrahedrons SiO_4 bounded by atoms O and OH. The clay is swelling on contact with the water. The molecules of water insert between the leaves of silica and alumina.

Within the framework of this study, marine sediments are from the bassin d'Arcachon (Port du Rocher). These marine sediments were characterized by measuring the physical characteristics of 5 samples (E1, E2, E3, E4, E5). These measures were made during a Master's degree internship in spring 2014 [4]. It has been completed during the doctoral thesis. The physical characteristics are;

- The value of the methylene blue test and the liquid limit. These both values permit to estimate the shaliness of sediments;
- The size grading by sieving.

The value of the methylene blue test is measured with the standard NFP 94-068. It is in grams of colouring agent per kilogram of marine sediments. The results are presented table 1 and indicate that the ground is muddy. The value of the methylene blue is noted VBS.

Chart 1. *Values of methylene blue test*

Samples	VBS	Shaliness
E1	0,999	Muddy
E2	1,488	Muddy
E3	0,994	Muddy
E4	1,486	Muddy
E5	3,465	Muddy - Clayey

The grading analysis has been carry out by sieving with a column of seven sieves (5mm, 2mm, 1mm, 0,4mm, 0,2mm, 0,1mm and 0,08mm). The sieving 0,08mm is correlated to the former standard. The new standard is carried out with a sieve 0,063mm to separate the sand of the silt. The grading curves presented on the figure 1 indicate a similar size grading for the five samples.

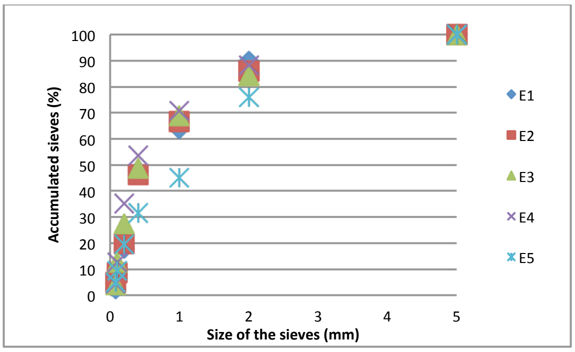

Figure 1. *Grain size distribution of the five marine sediments samples*

The liquid limit was measured on four samples of the same taking. The average value is equal to 98,85 %. The values are stable from one sample to an other. The variability of these measures is equal to 0,575 %.

The characteristics of marine sediments vary from one sample to the other. To address this variability an artificial soil is used. This artificial soil is constituted by calcic bentonite and by a calibrated sand. This calibrated sand has a diameter equal to 0,125mm. The particles of bentonites consist by two leave of silica and a leaf of alumina. The calcic bentonite is characterized by the presence of cation Ca^{2+} between the leaves of silica and alumina. The calcic bentonite is at the natural state. The proportions of the artificial soil is fixed to obtain a liquid limit close to the one taken at the Bassin d'Arcachon (Port du Rocher). The figure 2 shows that more the percentage of bentonite is important more the liquid limit increases. Indeed the bentonite has an important capacity of swelling. The particles of bentonite absorb water molecules. The contribution of water will be important all the more for obtaining the transition enter the plastic state to the liquid state for the measure of the liquidity limit. The composition of the artificial soil correspond to 80 % of bentonite and 20 % of calibrated sand (0,125mm).

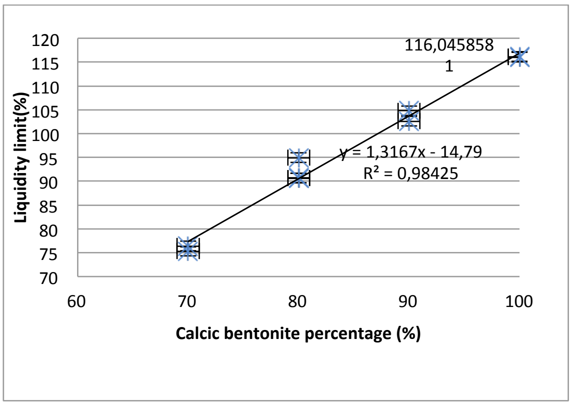

Figure 2. *Liquid limit curve*

METHODOLOGY

The mix design is based on the liquid limit [3]. The water content is fixed by the value of the ratio between the moisture of marine sediments (noted w) and the liquid limit (noted w_L). There is an optimal value of the ratio w/w_L. This optimal value is determined by drawing the density of fresh concrete in function of this ratio w/w_L. This optimal value depends on the percentage of cement by weight (noted C). The type cement is CEMI. The exact reference of the cement is CEMI 52,5 N PM-CP 2. The cement content is minimized. The percentage of cement by weight equal to 4%, 8%, 12% and 15% are tested.

For C=4%,The values w/w_L tested are {1,25 1,5 1,75 2}. The parameters fixed for a mix design are the percentage of cement by weight, the ratio w/w_L, the air-foam volume percentage of the total volume of concrete (noted M). The mix proportions are calculated in the following way;

- cement mass is calculated from the percentage of cement and the concrete mass.
- mixture "soil + water" mass is calculated by subtracting cement mass to concrete mass.
- water mass is calculated by considering the ratio w/w_L and the liquid limit (90%).
- soil mass is calculated with the water mass and the mixture "soil+water" mass calculated previously.
- Air-foam volume is calculated with the equation;

The mixing speed is equal to 30tr/min. The molds are cubic. The size is $100x100x100mm^3$. Before pouring the fresh concrete, molds are oiled to facilitate the demolding. The flow of the concrete is such as it is a self compacting concrete. The spreading in the cone of Abrams was measured. The results are presented figure 5. No process of implementation is used. As regards the curing conditions, for landing the phenomenon of fissuring and shrinkage, the specimen still in the molds are packed in a plastic film during 7 days. Specimens are demolded and put in a tank with a fix humidity equal to 90% and with a fix temperature equal to 20°C.

For C=4%, the air-foam volume in percentage of the total volume of concrete are equal to 0 %, 25 %, 50 %, 75 %. For a value of w/w_L, the ratio E/C is identical for various air-foam volume percentages. The chart 2 presents the mix design with cement content, water content, soil content and the parameter E/C.

w/w_L	1,25				1,5			
M(%)	0	25	50	75	0	25	50	75
E	716,61	537,46	358,31	179,15	769,33	577,00	384,66	192,33
C	56,40	42,30	28,20	14,10	55,80	41,85	27,90	13,95
S	636,99	477,74	318,49	159,25	569,87	341,92	60,81	142,47
E/C	12,71				13,79			
w/w_L	1,75				2			
M(%)	0	25	50	75	0	25	50	75
E	822,06	616,54	411,03	205,51	814,63	610,97	407,31	203,66
C	56,00	42,00	28,00	14,00	52,80	39,60	26,40	13,20
S	521,94	313,17	260,97	130,49	452,57	339,43	181,03	90,51
E/C	14,68				15,43			

Chart 2. *Mix proportion of the mix design with C=4%*

RESULTS AND DISCUSSIONS

The curves of density of fresh concrete according to the ratio w/w_L for various M and for a fix C are drawn (figure 2, figure). The results are in coherence with those of Horpibulsuk [HOR 14]. For low values of w/w_L, the values of density of fresh concrete for various percentages of air foam are almost identical. At some value w/w_L, the curves of density of fresh concrete fall. At this value w/w_L, the values according to various percentages of air-foam are different. These observations can be explained by the phenomenon of collapse of the air-foam. The cement involves mechanisms of hydration which require some water. The cement consumes the water of the air-foam so causing its collapse. The optimal value of the ratio w / wL corresponds to the end of the fall of the density. In our study, for the percentage of cement 4 %, the optimal value w/w_L corresponds to 1,6 (figure 3).

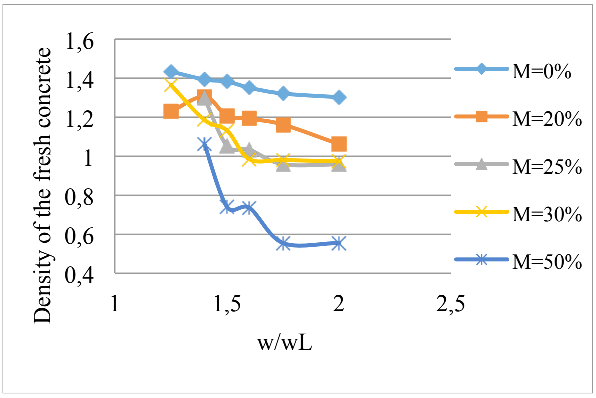

Figure 3. *Curves of the density of the fresh concrete according to w/wL for C=4%*

For the mix design with C=4%, during the demolding, some specimens were broken. The cement content is lower than that used in other studies about the lightweight concrete with marines sediments. The value were rather of the order of 200 kg/m^3 and at least equal to 75 kg/m^3 [HOR 14]. The mix design with M=50% and M=75% are given up because the densities are widely lower than the density aimed within the framework of our study (1,2). The mix design with C=8 % is tested. The chart 3 presents the contents of the mix design which is tested.

w/w_L	1,6			1,7		
M(%)	20%	25%	30%	20%	25%	30%
E(kg/m^3)	612,45	574,17	535,89	620,90	582,10	543,29
C(kg/m^3)	90,24	84,60	78,96	89,28	83,70	78,12
S(kg/m^3)	425,31	398,73	372,15	324,65	136,83	355,09
E/C	6,79			6,95		
w/w_L	1,8			2		
M(%)	20%	25%	30%	20%	25%	30%
E(kg/m^3)	637,12	597,30	557,48	624,55	585,51	546,48
C(kg/m^3)	89,60	84,00	78,40	84,48	79,20	73,92
S(kg/m^3)	314,63	368,70	344,12	346,97	260,23	242,88
E/C	7,11			7,39		

Chart 3. *Mix proportion of the mix design with C=8%*

The figure 4 represents the density according to the ratio w/w_L for M=20 %, M=25 % and M=30 % for C=8%. The result indicates an optimal value of w/w_L equal to 1,8.

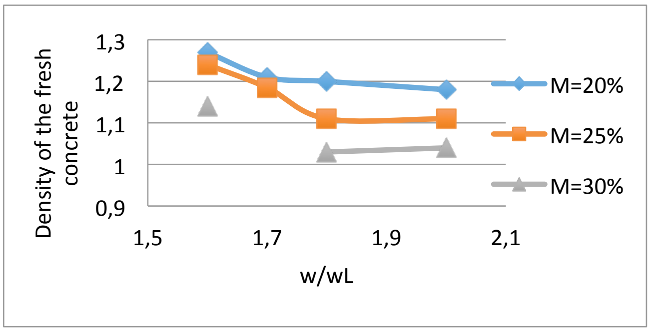

Figure 4. *Curves of the density of the fresh concrete according to w/wL for C=4%*

To characterize the rheology of the fresh concrete, the spread with the Abrams cone is measured. The figure 5 shows that when the ratio w/w_L increases, the spread also increases. The relation is almost linear. For a value w/w_L lower than 1,8, the values of spread for various M are very close. They differ from the value 1,8. This observation is in adequacy with the optimal value of w/w_L determined previously and equal to 1,8. Indeed it corresponds to a minimization of the collapse of the air-foam. This result shows that the phenomenon of collapse of the air-foam has an impact on the fresh concrete spread.

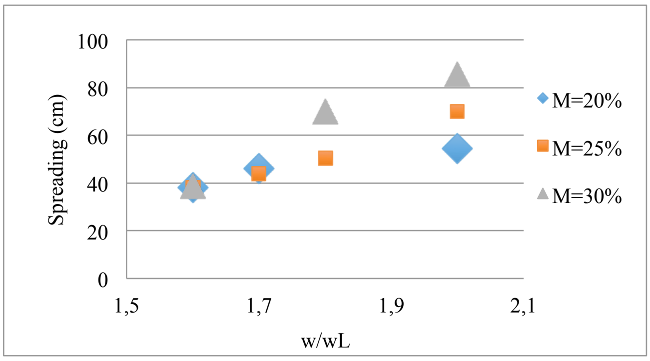

Figure 5. *Curves of the spreading with the Abrams cone according to w/w_L for C=8%*

For C=8%, specimens are mechanically tested with a press at 28 days. Six kinds of mix design are tested; the ratio w/w_L equal to 1,8 and 2 and with M=20 %, M=25 % and M=30 %. The press is piloted with the moving of a crossbar. The crossbar is moving forward with a speed equal to 0,0015mm/s. Four extensometers are fixed to the specimen to measure the strain; two extensometers in vertical and two in the horizontal (figure 5). The strain and the strength are measured every 0,02 seconds. From these data, the curves of the stress according to the longitudinal strain (extensometers A and B) were drawn for each test. The reliability of the tests is estimated by observing the difference of the curves of the extensometers A and B and between the other tests for one mix design. Figures 7 presents the superposition of the curves considered reliable for the mix design with M=20% and w/w_L=1,8. Globally, curves present a limited linear domain. Afterwards, the Young's modulus will be calculated by drawing a straight line to follow at the beast all the curves of one mix design.

Figure 6. *Photography of the mechanical system for the compression tests*

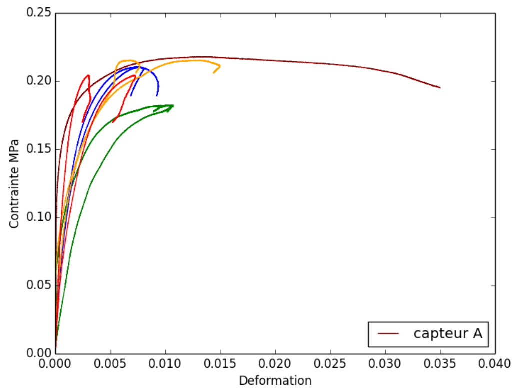

Figure 7. *Superposition of the curves for the mix design C=8% M=20% w/w_L=1,8*

The strength with penetrameter (noted p) is measured at 28 days. It is a local measure, so it is necessary to make it several times (about ten times within the framework of our study) to average all the measures. The chart 5 shows that the strength with the penetrameter is higher than the mechanical strength in the press (noted qu). One of the objectives of the study consisting in connecting these two types of strength to estimate the mechanical strength of the concrete at the young ages. However, the strength with the penetrameter present a rather important variability for one mix design and sometimes the measures broken the concrete. Moreover a linear regression presented on the figure 10 indicates a low coefficient of correlation. The penetrameter seems not appropriated for this concrete. Afterward, a sclerometer will be used to estimate the mechanical resistance in the young days.

w/wL	M(%)	C(kg/m3)	qu (MPa)	Average of qu	Variability of qu	p	Variability of p
1,8	20		0,21			0,36	
1,8	20		0,22			0,38	
1,8	20		0,18			0,37	
1,8	20		0,21			0,32	9%
1,8	20	89,6	0,22	0,21	6%	0,29	
1,8	20		0,20			0,35	
1,8	20		0,19				
1,8	20		0,20				
1,8	20		0,22				
1,8	25		0,10			0,20	
1,8	25		0,11			0,22	
1,8	25	84	0,11	0,11	10%	0,17	20%
1,8	25		0,13			0,29	
1,8	25		0,12			0,18	
2	20		0,12			0,24	
2	20		0,12			0,19	
2	20	84,48	0,11			0,19	
2	20		0,11	0,12	6%		11%
2	20		0,13			0,23	
2	20		0,12				
2	25		0,08			0,18	
2	25	79,2	0,10	0,08	14%		11%
2	25		0,08			0,2	
2	25		0,07			0,12	

Chart 4. *Mechanical strength with press and strength with the penetrameter at 28 days for various mix designs*

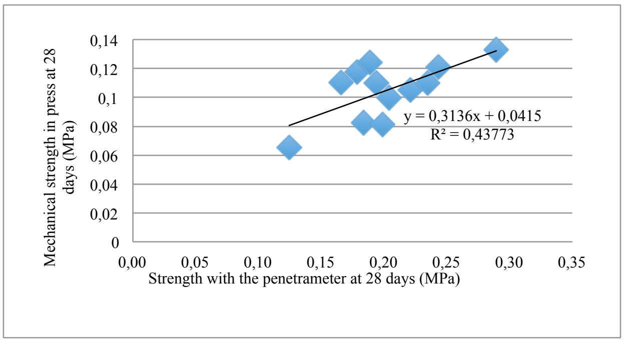

Figure 8. *Mechanical strength in press at 28 days according to strength with the penetrameter at 28 days*

For C=8%, the mechanical strength is lower than the required mechanical strength which have to be at least equal to 0,3MPa. Thus, mix design with a higher C (C=12% and C=15%) are tested.

For C=12%, the optimal value of the ratio w/w_L is equal to 1,9 for M=20% (figure 9). For M=25% and M=30%, the optimal value of the ratio w/w_L is equal to 2.

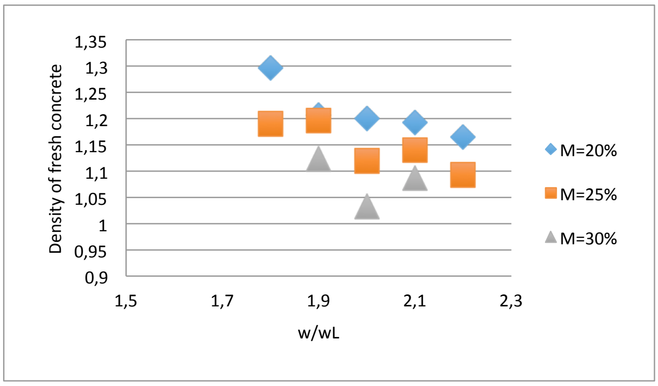

Figure 9. *Curves of the density of the fresh concrete according to w/w_L for C=12%*

For C=15%, the optimal value of the ratio w/w_L is equal to 2 for M=20% (figure 10). For M=25% and M=30%, the density is not stable. This can be due to the cement setting. Indeed the cement content is higher than the last mix design.

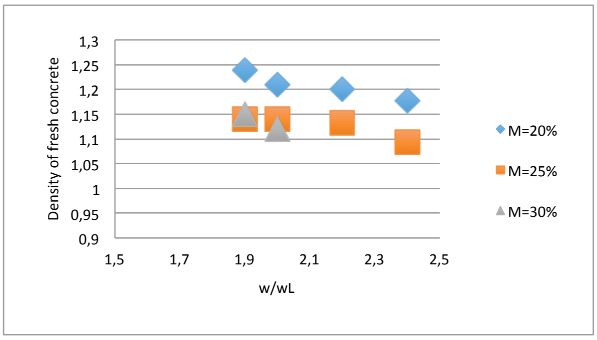

Figure 10. *Curves of the density of the fresh concrete according to w/w_L for C=15%*

CONCLUSION

The objective of this study is to develop a relieved concrete which reuses marine sediments stemming from the dredging. The first initiative consisted in setting up the mix design. The used method fixs a percentage of cement by weight, an air-foam volume in percentage of the total volume of concrete and a water content. The water content is fixed by the ratio w/w_L. w and w_L correspond respectively to the moisture content and to the liquid limit of marine sediments. The study permits to demonstrate that an optimal value of the ratio w/w_L exists for each C; for C=4 % and C=8%, the optimal values of w/w_L correspond respectively to 1,6 and 1,8. These mix designs do not allow to obtain a satisfactory mechanical strength. For C=12 %, two optimal values were chosen according to value of M. For M=20 %, the optimal value of w/w_L corresponds to 1,9 and for M=25 % and M=30 %, the optimal value corresponds to 2. For C=15 %, the optimal value for

M=20 % corresponds to 2. Afterwards the influence of the cement setting will be studied to check the optimal value for C=25% and C=30% for C=15%.

ACKNOWLEDGEMENTS

We thank the company Balineau for financing the project.

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