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DESIGN AND PROPERTIES OF MORTAR WITH SEASHELLS FINE AGGREGATES

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Abstract

In this research coating mortars with partial replacement of conventional sand with mussel shell sand are investigated. Three different binders have been used to study the influence of mussel shell sand: cement, aerial lime paste and clay. The cement binder has been used because it is the most use done in conventional construction. On the other hand, lime and clay have been used because they are in accordance with bio-construction principles. Reference mortars and mortars with mussel shell sand as a substitute of conventional sand in different rates: 25%, 50%, 75% and 100%, have been tested. Results show that the use of mussel shell sand increases consistency and reduces compressive strength. These effects are more remarkable as higher the substitution rate is.

Keywords:

Mussel shell; Bivalve shell; Mortar; Cement; Lime; Clay

1 INTRODUCTION AND OBJETIVES

Aquaculture and cannery industry are really important economic sectors in Galicia. They generate big profits and create thousands of employment. However, they also produce loads of waste, in which bivalve shells are remarkable because of their volume. Galicia generates around 25,000t of mussel shell residue every year that usually are disposed in dump sites producing a great environmental impact. Nevertheless, some research works have proved that it is possible to reuse shells in several industrial activities, including construction.

In some of these studies the incorporation of oyster shells [Y. Gil-Lim 2003,S. Hyunsuk Yoon 2004, W. Her-Yung 2013] in the manufacture of cement mortars are analyzed. The resulting aggregate after crushing the shells were used as substitutes for natural sand in different percentages. This concluded that the fluidity, density and compressive strength decrease when proportion of shell used increases. Consistency increases because bivalve shells have a more irregular shape and its mixing water absorption is higher than conventional sand one. This special characteristic of oyster particles makes the mortar more porous and increases the pore volume. Consequently, density and compressive strength decrease.

Thus, this study aims to analyze the effect of replacing natural aggregate by mussel shell in mortars. Three different binders have been used: cement, lime and clay. Cement has been used because it is the most common binder in conventional construction. On the other hand, aerial lime paste and clay have been used because they are environmentally friendly and in accordance with bio-construction principles. Density, consistency and compressive strength at different ages are the properties studied in coating mortars with natural sand by bivalve shell sand substitution rates of 0% (standard) 25%, 50%, 75% and 100%.

In spite of their results are presented together in this study, it is not appropriate to compare the mortars with different binders among them. They are materials of very different nature and different dosages were adjusted for each one. The only one aim is to know the effect of mussel shells using every binder, individually.

2 EXPERIMENTAL WORKS

2.1 Material properties

The cement used was CEM II/A-M (V-L) 42.5R, Portland cement with additions (CEM II), mixed (M) with a 6-20% (A-M) of siliceous fly ash (V) and limestone (L), and a 0-5% of minor components, compressive class 42.5 and high initial strength (R) (EN 197-1).

The aerial lime paste used was a CL 90-S PL, calcium aerial lime (CL) with more than a 90% of calcium oxide and magnesium, hydrated and supplied in paste (S_PL) (EN 459-1). It is calcium hydroxide without any hydraulic or pozzolanic addition.

The clay minerals used come from a local quarry and they are made of kaolin and kaolin clay in 20% and 80% proportion respectively. It is considered [G. Minke

1994, A. Weismann 2008], that only particles with a particle size under 2µm contribute to binder properties. The rest of the mineral (>2 µm) act like a very fine sand which is combined with the natural one.

The natural sand used comes from crushed limestone and it has got a maximum size of 4 mm. Since its particle size distribution was not suitable for producing coating mortars, a size separation by sieving was performed. Then the size fractions were combined, resulting in suitable sand with a maximum size of 2 mm (NS).

The mussel sand used was obtained from the mixture of two supplied fractions: coarse sand obtained by crushing (CMS) (Fig.º1) and fine sand obtained by grinding (FMS) (Fig.º2). These two sands were combined to obtain a new sand, mussel shell sand (MS) with equivalent particle size distribution to the natural one (NS). The mix percentages used were 88.5% of FMS and 11.5% of CMS. Tab.º1 shows the natural and mussel shell sand properties. According to the results of the X-ray diffraction (XRD) characterization, mussel shells are composed mainly of calcium carbonate (95%) (Tab.º2, Fig.º3).

Fig. 1: Coarse mussel shell sand (CMS).

Fig. 2:Fine mussel shell sand (FMS).

Tab.1.Sands properties.

	CSM	FMS	NS
Heat treatment	30min at 135ºC	30min at 135ºC	No
Crushing process	Crushed	Ground	Crushed
Sieve modulus	1.9	4.64	3.71
Particle density (kg/dm^3) UNE-EN 1097-6	2.65	2.73	2.67
Water absorption (%) UNE-EN 1097-6	2.56	4.12	2.22
Chlorides (1%) UNE-EN 1744-1	0.28	0.51	0
Soluble sulfates (%) UNE-EN 1744-1	0.63	0.59	0
Total sulfates (%) UNE-EN 1744-1	1.6	1.3	-
Organic matter (visual) UNE-EN 1744-1	Clearer	Darker	-
Light particles (%) UNE-EN 1744-1	0.1	-	-
Organic matter (%) UNE 103204:93	1.49	2.15	0
Sand equivalent(%) UNE-ENE 933-8	99.3	68.2	64

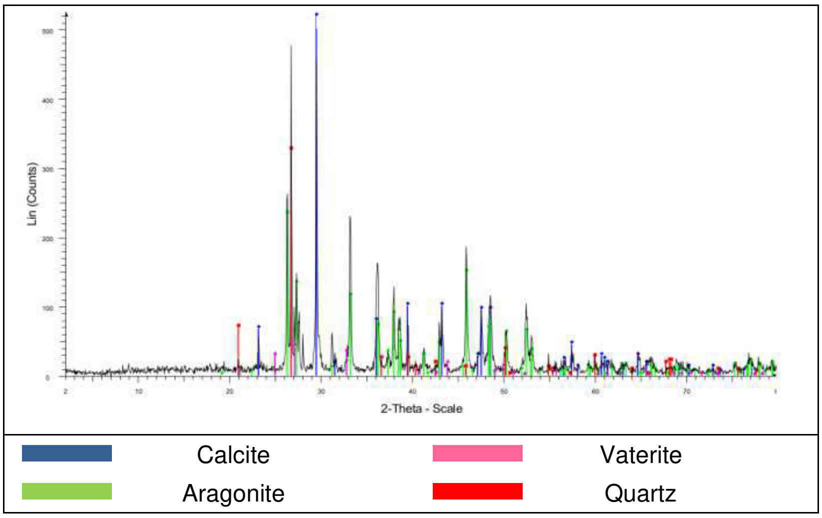

Fig. 3: FMS diffraction pattern.

Tab. 2: CMS and FMS chemical composition (%). Stoichiometrically calculated.(Energy Dispersive X-ray Analysis-EDX)

	CMS	FMS
$CaCO_3$*	95.088	94.664
SiO_2	1.112	2.580
Na_2O	0.354	0.508
Al_2O_3	< 0.01	< 0.01
SO_3	0.176	0.308
MgO	0.205	0.277
Fe_2O_3	< 0.005	< 0.005
SrO	0.116	0.192
K_2O	< 0.006	< 0.006
P_2O_5	0.087	0.105
Cl	< 0.009	< 0.009
Br	0.009	0.012
ZnO	< 0.004	< 0.004
CuO	0.010	0.011
ZrO_2	0.005	0.010
Loss at 550ºC	4.058	4.280
Loss at 975ºC	44.208	42.108

2.2 Mixes design

As mentioned, mortars with different binders (cement, aerial lime paste and clay) were designed. For every binder mortar, substitution rates of natural sand with mussel shell sand by volume were 25%, 50%, 75% and 100%. Regarding clay mortars, substitutions were made just by natural sand, however when if it is considered that clay contributes to the sand quantity (particles higher than 2µm) these percentages become in 22.5%, 45%, 67.5% and 90%. In any case, to keep the nomenclature, in this work clay mortars are named with the percentages referred only to natural sand. Finally, mix proportions were chosen to ensure high enough workability, in order to allow the use of high percentages of mussel shell sand.

Tab.º3 shows the basic parameters of the three different reference mortars. Regarding the cement mortar it is proposed a cement:sand ratio of 1:4 (by volume) and a water/cement ratio of 1 (by weight), so using the replacement percentages, five mussel shell cement mortars were obtained: CeM0, CeM25, CeM50, CeM75 and CeM100. Regarding the aerial lime paste mortar, in accordance to other authors [ANCADE 2011, F. Castilla 2004], a lime:sand ratio of 1:2 (by volume) is fixed and a water/lime ratio of 1.7 (by weight) is used. As a result five types of lime mortars were obtained: LM0, LM25, LM50, LM75 and LM100. Regarding the clay mortars, the percentage of binder (clay particles less than 2µm) by weight over the amount of clay minerals (kaolin and kaolin clay) and sand (natural and mussel shell sand) was 2% [G. Minke 1994, A. Weisman 2008]. In addition, the quantity of water that provides a water/binder ratio (by weight) of 10 was used. In this way, five clay mortars were obtained: CM0, CM25, CM50, CM75 and CM100. In spite of being an important element to control shrinkage in clay mortars, vegetable fiber hasn't been used. This decision was made to simplify the material and to analyze clearly the influence of the mussel shell sand in mortars. Tab. º4 shows the mix proportions of the reference mortars and of the mussel shell sand ones.

For each mortar, several batches were made to measure air content and consistency using the flow table method. Prismatic samples (40x40x160mm) were made to test density and compressive strength.

Tab. 3.Reference mortars dosage.

CeM	LM	CM
Cement:sand	Lime:sand	Mass of clay
bulk volume rate = 1:4	bulk volume rate = 1:2	over whole solid matter = 2%
Water/cement	Water/(dry lime paste)	Water/binder (2µm smaller
mass rate = 1	mass rate = 1.7	particles) mass rate = 10

Tab. 4: Reference and mussel shell sand dosages (g per liter of mortar).

		Substitution rate (%)				
		0	25	50	75	100
CeM	Cement			357.17		
	Water			346.42		
	NS	1508.2	1146.15	764.10	382.05	0.00
	MS	0.00	363.74	727.49	1091.23	1454.97
LM	Lime paste (dry lime and water)			611.70 (263.03 of lime and 348.67 of water)		
	Added water			101.00		
	NS	1237.58	928.19	618.79	309.40	0.00
	MS	0.00	249,57	589.14	883.71	1178.28
CM	Kaolin and kaolin clay			180.41		
	Water			363.10		
	NS	1500.54	1125.41	750.27	375.14	0.00
	MS	0.00	382.16	764.32	1146.48	1528.64

3 RESULTS AND DISCUSSION

3.1 Consistency (flow table test).

The consistency tests were performed using the flow table test (Fig.º5). Fig.º4 shows the spread diameter in mm depending on the percentage of mussel shell sand used. As expected, the mussel sand particle shape (with a high percentage of flaky particles) increases the water demand. This fact joined to the high water absorption capacity of this type of aggregates leads to a decrease in the spread diameter.

The results indicate that the consistency of cement mortar varies linearly (between 5% and 10%) with each replacement ratio. Though when lime and clay mortars are analyzed, it can be observed that the decrease is remarkable for 25% and 50% ratios, tending to stabilize, however, from this percentage on. In this way, analyzing the 100% replacement rate, it can be seen that the spread diameter decrease a 31%,a 28.5% and only a 17.8% for cement, clay and lime mortars respectively (compared with their reference mortar).

3.2 Density and air content

The fresh and hardened mortar density and the air content were evaluated (Fig.º8).

Fig.º6 and º7 show the fresh and hardened density values of each mortar. As can be seen, the density decreases in general with the mussel shell content. Once again, the irregular and flaky particles shape of mussel shell sand causes this reduction. Also, in this case, the reduction in cement mortars is different than in lime and clay ones. The cement mortars density decreases significantly with the increase in percentage of mussel sand used (a 14% is observed when CeM25 density in the hardened state is analyzed). However, the decrease is much lower when lime and clay mortars are studied (a 1% and a 5% for LM25 and CM25 respectively).

The results in air content test confirm this effect (Fig. º8). Thus, the air content of the CeM100 was about 6 times higher than that obtained with its reference mortar, CeM0. Meanwhile, the LM100 and CM100 air content was only about 1.5 and 1.7 times respectively higher than that found with their reference mortars, LM0 and CM0.

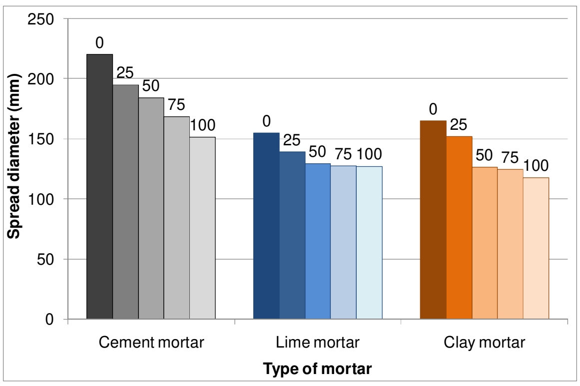

Fig. 4: Spread (mm).

Fig. 5: Flow table of cement, lime and clay mortar.

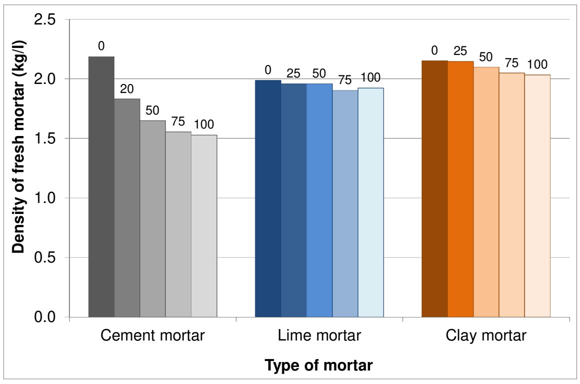

Fig. 6: Fresh mortar density (kg/l).

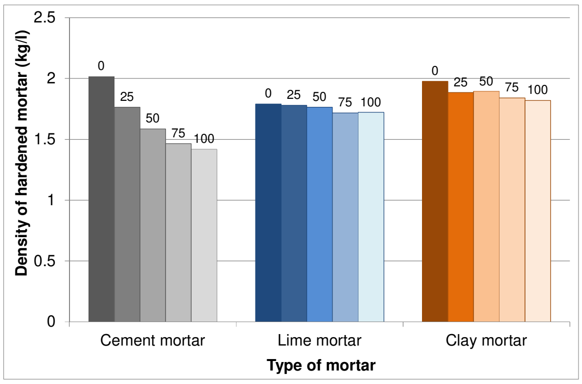

Fig. 7: Hardened mortar density (kg/l).

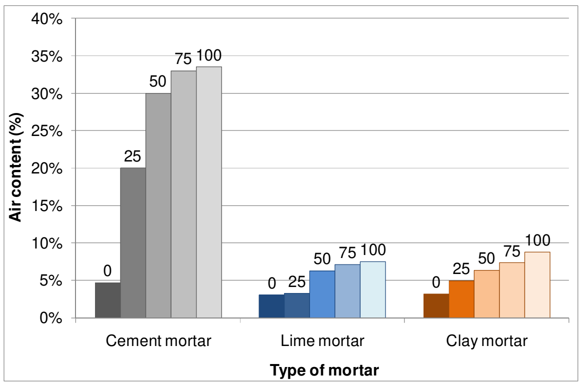

Fig. 8: Air content (%).

Fig. 9: Air content test (UNE EN 1015-7).

3.3 Compressive strength

The study of compressive strength provides the results shown in Fig.º10 and º11. After analyzing these results it can be concluded that the incorporation of mussel shell sand significantly decreases the compressive strength. Once again, the irregular and flaky particles shape of the mussel sand introduces pores and weakens the paste to aggregate bond, which reduce the compressive strength as the mussel shell sand content increases.

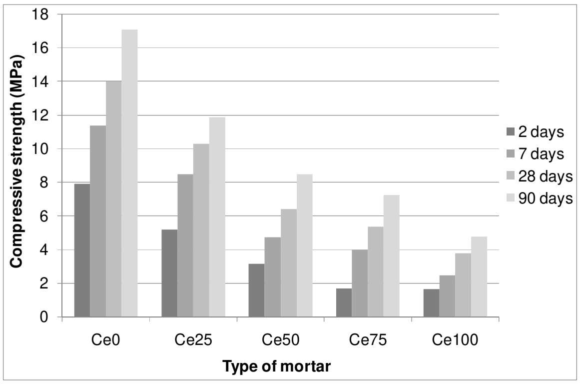

Fig. 10: Compressive strength at 2, 7, 28 and 90 days (MPa).

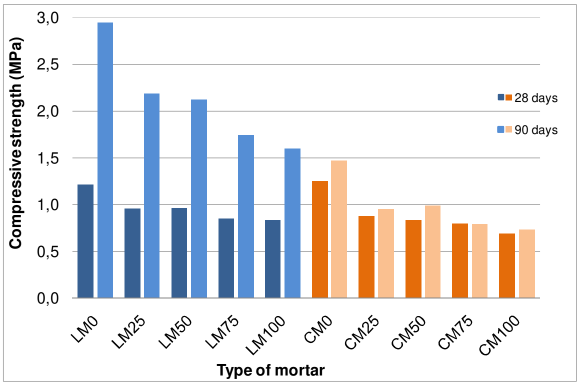

Fig. 11: Compressive strength at 28 and 90 days (MPa).

Regarding the cement mortars, the strength reductions were higher than those obtained with lime or clay mortars. At 28 days CeM100 shows a 72% of decrease, while LM100 and CM100 show a reduction of 31% and 45% respectively, always compared with their reference mortars.

As it was expected, the compressive strength values obtained with lime and clay mortars are considerably lower than those obtained with cement mortars at any age. Moreover, it can also be seen that lime mortars, due to the carbonation process, acquire their strengths at later ages (the difference between compressive strength at 28 days and at 90 days is high). Finally, regarding clay mortars, their compressive strength is very low, however, it should be remember that they have been made without fibers.

4 CONCLUSIONS

This work studies the use of mussel shell sand as a substitute of natural sand in coating mortars. Cement, aerial lime paste and clay have been used as binders, resulting in three types of mortars (CeM, LM and CM respectively). Different replacement rates of natural aggregate with mussel shell aggregate (25%, 50%, 75% and 100%) were used, so a total of 15 mixtures were studied. The results obtained allow drawing the following conclusions:

• The mussel shell sand, with a high percentage of flaky particles, increases the water demand in mortars. This fact joined to the high water absorption capacity of this type of aggregates leads to increase the consistency with the replacement ratio. This effect is more significant in cement mortars than in clay or lime ones.

• The more mussel shell sand is employed, the less density the mortars present. The shape of the aggregate particles introduces occluded voids that cause this density decrease. Furthermore, the air content increases with the percentage of mussel shell used.

• Adding mussel shell aggregate decreases compressive strength significantly. Once again, the introduction of void sand the reduction of the paste-aggregate bond, caused by irregular and flaky mussel particles shape, weaken mortars with high mussel shell content. The strength reductions obtained with cement mortars were higher than those achieved with lime or clay mortars.

In conclusion, as a first approximation, it has been proved the possibility of production cement, lime and clay coating mortar with replacement rates of natural sand with mussel shell sand, ensuring a suitable behavior up to a replacement ratio of 50%.

5 ACKNOWLEDGEMENT

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