Valorisation of oyster shell powder in mortars as partial replacement of cement

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ABSTRACT The reuse of waste materials in concrete has been a major concern of researches in the past decades. This process has an interesting ecological and economic impact. In this paper, the recycling of shell waste into a filling material in mortars is investigated. The influence of the incorporation of oyster shell powder (OSP) as a substitution of cement on the mechanical behavior of the mortars is determined. The oyster shell powder was first characterized for filler application. Then, compressive and flexural tests were conducted on mortars made with 0 to 60% of OSP. The mortars were observed under an optical microscope to characterize the microstructure. On the one hand, the study revealed that even if the substitution of cement by OSP induces a decrease in compressive and flexural strengths of mortars, it allows producing materials with good mechanical properties using OSP as calcareous filler. On the second hand, OSP increases the open porosity of the mortars that might give to mortars with high OSP rate, interesting insulation properties.

Keywords Oyster shell powder, mortars, replacement of cement, mechanical properties, optical microscope

I. INTRODUCTION

In France, the construction industry is responsible for 44% of the total energy consumption (Ministry for the Ecological and Inclusive Transition, 2017). The ever-increasing demand for construction materials has led to irreversible environmental damage, due to the consumption of great amounts of natural resources or due to the increase of CO_2 emissions responsible for the greenhouse effect (Moumin et al., 2020). One of the many solutions to this problem is by replacing one or many of the construction material's constituents (such as the cement) by waste materials (eg. Kim and Choi, 2012; Nguyen et al., 2013; Usman et al., 2018). An interesting waste material to be used is oyster shells, notably retrieved from the fishing activity. Fishing and shellfish farming activities produce an annual production of about 200,000 tonnes of shells in France generating thousands of tons of seashell by-products (Nguyen et al., 2017).

As a preliminary study, this paper investigates the possibility of shell recycling into a cement replacement. The substitution of the cement by oyster shell powder provides two clear advantages; the first one is the consumption of wastes that would otherwise be dispersed in the environment, and the second one, even more relevant, is the reduction in cement consumption, so the reduction of CO_2 emissions needed for its production.

For this purpose, standardized mortars were formulated by incorporating various amounts of oyster shell powder (OSP) as a replacement for ordinary Portland cement. The influence of shell powder incorporation is examined in terms of mechanical properties.

II. MATERIALS AND METHODS

A. Materials

For the production of tested mortars and concretes the following materials were used :

- CEM 1 Portland cement 52.5 N
- CEN-referenced sand, which is a natural siliceous sand, with rounded grains of a silica content of at least 98%. Its grain size varies from 0.08 to 2.00 mm
- Oyster shell powder, obtained by crushing oyster shells into a powder with a grain size of 0/1 mm. It has an apparent density of 803 g.m^{-3} and a real density of 2575 kg.m^{-3}. It presents an intraparticular porosity, that can be beneficial with regards to hygrothermal properties as the oyster shell powder has an absorption coefficient of 30.2%.

B. Mortar mixes

Mortar specimens have been prepared according to the procedure described in (AFNOR NF EN 196-1, 2006), with a cement:sand ratio of 1:3. Various amounts of oyster shell powder, namely 5% – 10% – 15% – 20% - 40% – 60 % by weight, have been added as a substitution of CEM I 52.5N cement. A reference mixture is studied as well, for the sake of comparison. The total water content has been increased to take into account the absorption of the OSP. The mortar mixes are given in table 1.

TABLE 1. Mortar mixes

Mortar	OSP (%wt)	OSP (g)	Cement (g)	Water (g)	Sand (g)
PMI_0%	0%	0	450.0	225.00	1350
PMI_5%	5%	22.5	427.5	231.75	1350
PMI_10%	10 %	45.0	405.0	238.50	1350
PMI_15%	15 %	67.5	382.5	245.25	1350
PMI_20%	20 %	90.0	360.0	252.00	1350
PMI_40%	40 %	180.0	270.0	279.00	1350
PMI_60%	60 %	270.0	180.0	306.00	1350

B. Methods

The mineralogical composition of the oyster shell powder was determined by X-ray diffraction analysis (XRD) using a D2 Phaser Bruker Diffractometer (Co Kα, $\lambda = 1.79°$). And the blue methylene test, which identifies the reactivity of the clay fraction, was carried according to (AFNOR NF P94-068, 1998).

The mortar specimens were tested at 7 and 28 days of cure. The flexural strength test was performed on three prismatic mortar samples (40 x 40 x 160 mm) using an Instron 5 with a loading rate of 50N/s. The compressive strength test was performed on the six prismatic pieces obtained using an AMSLER press with a loading rate of 2400 N/s. Microscopic observations were carried visually and with a KEYENCE VH-Z100R optical microscope.

III. RESULTS

The XRD diffractogram of oyster shell powder is given in figure 1. It shows that it essentially consists of calcite ($CaCO_3$), which makes it possible to be used as calcareous material. It has a value of methylene blue VBS of 0.13 g/100g indicating a low fine content (<80µm) (AFNOR NF EN 933-9, 2013).

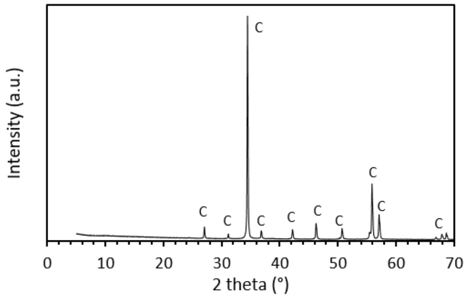

FIGURE 1. XRD diffractogram of oyster shell powder. (C: calcite)

Results of the flexural and compressive strength tests carried on the hardened mortars at 7 and 28 days are shown in figure 2. For all the substitution range, flexural and compressive strength, Rf and Rc, respectively, declined compared to the reference mortar PMI_0. This is due to the reduction of the cement for 5% but the decrease is not relative to the dilution effect regarding PMI_10, PMI_15 and PMI_20 with similar compressive strength at 7 days. At 28 days, Rc decreases with the increasing rate of OSP until 10%wt, then, the impact is similar from 10 to 20%wt of OSP. The decline is significant for the mortars with a substitution of 40 and 60%wt, the total amount of water required for the mortar mix due to high absorption coefficient of OSP might lead to an increase of porosity which, added to the decrease of cement content, makes the mortar specimens less resistant.

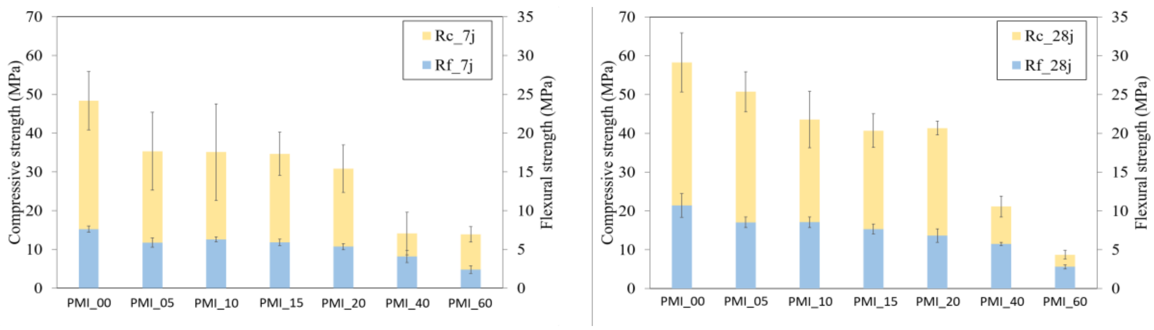

FIGURE 2. Flexural and compressive strength of the tested mortars at 7 and 28 days

Qualitative microscopic observations were conducted to qualify the microstructure of mortars. The porosity of mortars is impacted by adding oyster shell powder shell modifying the poral space. The size of the apparent pores, as well as their number, are affected (figure 3). A more precise characterization by MIP technique will be very interesting to identify these modifications. The high substitution rate of cement (40 and 60 %wt) induces an increase in open porosity which can be interesting as it decreases the thermal conductivity of the material, and would them better thermal insulation properties (Felipe-Sesé et al., 2011).

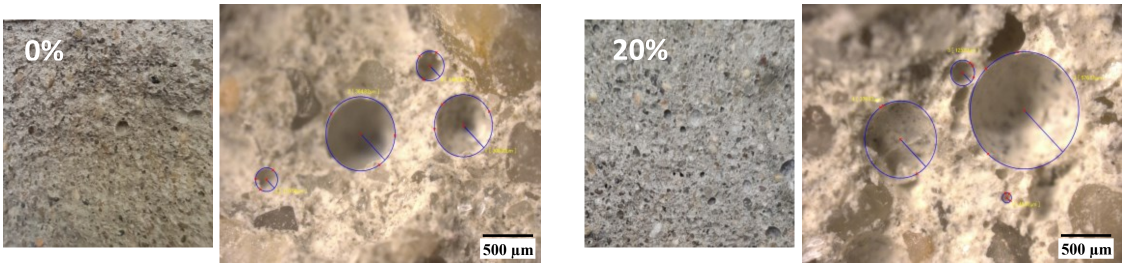

FIGURE 3. **Microscopic observation of PMI_0 and PMI_20 (0% and 20%wt of substitution)**

IV. CONCLUSION

This study proposed the use of oyster shell powder (OSP) in mortars with partial replacement of cement. Mortars with partial replacement of cement by OSP were studied through the monitoring of mechanical properties and the observation of the microstructure. The incorporation of OSP causes a decrease in mechanical properties from 5%wt replacement of cement at 7 days and with the increasing rate of oyster shell at 28 days until 10% replacement. From 10 to 20%wt, the powder seems to have the same impact on mechanical properties. Consequently, it seems possible to use OSP as filler, nevertheless, the workability properties are modified. Rheology tests will, therefore, be carried out in the near future. Regarding the results for a high percentage of replacement (40 and 60%wt), they show that, according to mechanical properties and microscopic observations, the number of pores increased. As a perspective, it would be interesting to carry a complementary study about the valorization of these materials as insulating products via a hygrothermal and thermal characterization of these materials.

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