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# Utilization of sludge from ready-mixed concrete plants as a substitute for limestone fillers

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## HIGHLIGHTS

- Environmental impacts of sludge coming from ready-mixed concrete plants.
- Substitution of limestone fillers by sludge coming-from ready-mixed concrete plants in mortars formulation.
- Mechanical characterization of mortars made with sludge coming from ready-mixed concrete plants.

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## ABSTRACT

This study deals with the incorporation of sludge coming from ready-mixed concrete plants into mortars. Preliminary environmental investigations, made through leaching tests, showed the importance of managing those waste as they can be potentially pollutant regarding to their arsenic and chromium contents. Thus, management of the sludge can be environmentally and economically difficult. Reincorporation of those sludge into a closed loop concrete production is of particular interest. Also, it represents an interesting way to save raw materials (water, sand and limestone fillers). Yet, two main disadvantages were observed when using those sludge as limestone fillers substitute:

– a decrease in the workability of the fresh state mortar, calling for a higher superplasticizer content;

– a variability in the compressive strength of the hardened state mortars, between −30% and +17% when comparing to a reference mortar.



## 1. Introduction

European ready-mixed concrete production has notably increased over the last decades. Since 2010, around 370 million cubic meters of ready-mixed concrete are produced each year in Europe, of which around 10% come from the French production [1]. From this high production results a high level of by-products. Indeed, it has been estimated that a 9-m$^3$ truck contains daily around 300 kg of returned concrete [2]. Generally, this leftover concrete is discharged in large containers. The hardened concrete can be then crushed and easily used as recycled aggregates for road construction. After the leftover being discharged, the truck is washed out with huge amounts of water, up to 1300 L per truck, and the suspended matter is allowed to settle in large sedimentation basins. Wash-waters from mixers are also directed to those basins. Several studies have been focused on the reuse of the clarified water of those basins, which presents a high up to 12 pH. This water can be partially reused for trucks washing or in concrete production [3,4,5]. Su et al. showed that, according to the total suspended solids content, shorter setting times and a lower flowability are obtained [3]. On the opposite, Chatveera et al. highlighted a time lag when using sludge water and no additives nor admixtures, but reported a flowability decrease as well [5]. In another study, the use of the wet sludge as partial cement or sand substitute leads to a decrease in the compressive strength [6]. Recently, a study was led on the use of the sludge as a new raw material for Portland clinker production [7]. The variability in the chemical composition of the sludge leads to an impossibility in their reuse for Portland clinker production, due to their high chemical variations, as well as their high alkali, $SO_3$ and MgO contents.

Yet, not many studies have dealt with the utilization of the settled sludge, made of the fines particles (cement, mineral additions, etc.) as well as sand and aggregates. Though, it represents a large available quantity of raw material. As around 1 m$^3$ of wet sludge is created by the production of 90 m$^3$ of concrete, around 4 millions of cubic meters are produced every year in France [8]. Wet sludge is collected several times a year at the bottom of the basins and stored on the ready-mixed concrete plant area so that the water content decreases. When the water content is low enough, the

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material can disposed of at controlled landfills for inert wastes, regarding to the French decree on passive wastes [9]. Up to now, not many characterizations of this sludge have been led in the literature. However, their hazardous behavior has already been highlighted, due to their high alkalinity and their high heavy metals and metalloid elements content [10]. All these factors lead to a high whole total disposal cost of the sludge. That is why new environmental friendly strategies must be found for sludge managing.

We herein propose a new original way to valorize sludge as limestone fillers substitutes in a closed loop concrete production, avoiding any environmental and economical impacts. Nevertheless, for now, the European standard does not allow the utilization of non-standard mineral addition in concrete [11]. Thus, the objective of this study is to prove the feasibility of incorporating sludge into concrete. To reach that aim, the sludge coming from four French ready-mixed concrete plants were firstly characterized from a chemical and physical point of view. The activity index of the dry sludge, as well as their chemical activities were determined. Giving those results, utilization of the studied sludge into mortars compositions was studied using the concrete equivalent mortar concept [12]. Compressive strength and porosity were studied at various due dates, and relationship between mortars composition and compressive strength was stated.

## 2. Experimental program

### 2.1. Raw materials

The studied sludge were sampled at four ready-mixed concrete plants (C1, C2, C3, C4) located in the Poitou-Charentes area, France (Fig. 1). Those four plants produce basically the same main concrete, whose formulation will be given later. The samples had a high water content, between around 50 and 120%, depending on the weather conditions and the storage duration. The moisture contents are presented in Table 1.

The raw materials were then split in two fractions: one finer than 100 μm (fraction A) and one coarser than 100 μm (fraction B).

Limestone filler (designed as LF), CEM II/A 42.5 and CEM I 52.5 cements were provided by Carmeuse (Saint Porchaire, France), Calcia (Airvault, France) and Lafarge (Saint Pierre La Cour, France) companies, respectively. Their properties are given in Table 2. 0/4 mm sand from Sablimaris Pallice (La Rochelle, France) was used in the studied mortars. For the determination of activity index, a standard sand from the SNL Company (Leucate, France) was used. Chrysofluid Optima 220 superplasticizer was used for the fabrication of mortars.

### 2.2. Characterization of raw materials

#### 2.2.1. Leaching tests

Leaching tests were performed following the French standard dedicated to sludge characterization [13]. Basically, a test portion of sludge containing 90 g of dry matter is poured into a 1L HDPE flask. Deionized water is added so that the total water content is 900 mL. The whole mixture is kept under continuous mechanical

**Fig. 1.** Picture of the raw materials coming from the C4 ready-mixed concrete plant.

**Table 1**
Water contents of the sludge

| | C1 | C2 | C3 | C4 |
|---|---|---|---|---|
| Water content (%) | 47.1 | 99.5 | 120.3 | 155.2 |

stirring for 24 ± 0.5 h (Fig. 2). The mixtures are then filtered over a 2 μm filter with a Büchner apparatus and the filtrate is recovered for further analysis. Right before the analysis, samples were filtered on 0.45 μm syringe filter.

All the leachates are diluted tenth and hundredth in a 5% $HNO_3$ solution (77 mL of $HNO_3$ – FisherScientific, Trace Metal Analysis quality – completed to 1 L with milli-Q water). Ba, Cr, Cu, Mo, Ni, Pb and Zn were analyzed with a Varian Vista Pro ICPOES and As, Cd and Se with a ThermoFischerScientific Xseries2 ICPMS. The quantification limits (μg $L^{-1}$ solution) were 2 (As), 2 (Se), 0.1 (Cd), 50 (Ba), 10(Cr), 10 (Mo), 10 (Ni), 10 (Pb) and 50 (Zn). To check the analytical data precision, all samples were analyzed in duplicate.

Ionic chromatography was also performed on the leachates. A Metrohm apparatus with a Metrosep A Supp 5 100/4.0 column and an automatic sample changer was used. A $Na_2CO_3$ 3.2 mM/$NaHCO_3$ 1.0 mM (1:1, v/v) eluent was used, with a 0.7 mL/min flow. $F^-$, $Cl^-$ and $SO_4^{2-}$ were so quantified. Sodium salts from Sigma-Aldrich company were used as standards. The quantification limits were 0.5 mg $L^{-1}$ for $F^-$, $Cl^-$ and $SO_4^{2-}$.

#### 2.2.2. Physical and mineralogical characterization

Water content of sludge (defined as mass ratio of water over dry matter) was determined by drying at 80 °C until constant weight. Specific surfaces of the dry raw materials were determined with a Blaine apparatus, allowing the measurement of the resistance of the air passing through a porous bed of powder [14]. The densities were determined using a water pyknometer according to the European Standard NF EN 1097-7 [15].

The particle-size distribution of the dry sludge was determined by sieving 500 g of powder at 4, 2, 1.25, 0.5, 0.25, 0.125 and 0.100 mm. The 100 μm passing fraction was characterized by dynamic light scattering with a CILAS 1190 apparatus, used in dry mode. Calculations were performed using the Mie theory [16].

Powder X-Ray Diffraction (XRD) was carried out with a Brücker diffraction instrument, with Cu Kα1 radiation. Measurement range was from 5 to 70° 2Θ, with a 0.02° step. Identification of the peaks was performed by comparison to a database references.

Thermogravimetric analysis (TGA) was performed on a Setaram Setsys Evolution 16/18 apparatus. Around 100 mg of samples were heated from 20 °C to 1000 °C at a 10 °C/min heating rate, under neutral argon atmosphere. To get more accurate results, data were analyzed through the differential thermogravimetric curves.

ICP-AES analysis were performed sludge materials after their drying at 80 °C and after being grinded to 80 μm. Basically, around 100 mg of dry materials was digested using 4 mL of a 67–70% $HNO_3$ – 34–37% HCl 2:2 (v/v) solution (FisherScientific, Trace Metal Analysis quality). Acidic digestion of the samples was carried out overnight at room temperature. Each sample was completed to 50 mL with milliQ water. Al, Ca, Fe, S and Si were analyzed with a Varian Vista Pro ICPOES. The quantification limits (μg $g^{-1}$ dry weight) were 500 (Ca), 100 (Al), 50 (Si), 10 (S) and 5 (Fe).

#### 2.2.3. Determination of sludge activity

The potential activity of sludge was evaluated through compressive tests on standard mortars. We focused on the sludge fraction lower than 100 μm which should contain the most reactive elements. For this purpose, an activity index was determined according to the French standard dedicated to limestone additions [17]. A mortar made of CEM I cement, deionized water and standard sand was made and used as reference. A second mortar was made by substituting 25% of the cement mass by the 100 μm passing fraction of the sludge. Mortars compositions, as well as the water-to-cement ratio (W/C) are given in Table 3. Compressive strengths were determined on 28-day old mortars kept in water. The activity index (denoted i) of the sludge was defined as the ratio between the compressive strength of the mortar with sludge and the one of the reference mortar.

The activity of sludge was also investigated through ionic conductivity measurement. This test is based on the measurement of time-evolution of the ionic concentrations during the cement hydration in aqueous suspension. As done in the case of activity index, only the 100 μm passing fraction of sludge was used. The ionic conductivity time-evolution of the cement and blends (“limestone filler + cement” and “dry sludge + cement”) were obtained by measurements in dilute medium. In the blends, the ratios between cement and dry sludge or limestone filler were the same as the ones used for the CEM mortars. The same cement as the one used in the concrete formulation was used. The composition of the blends is given in Table 4.

Briefly, 300 mL of deionized water are poured into a cell equipped with a conductivity probe. The whole system is kept at 25 °C and under perpetual mechanical stirring. A 1–5 solid-to-liquid ratio is applied, which allows a good sensitivity, as