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Investigation of Mechanical Properties and Hydration Behavior in Cement Mortars Partially Substituted with Water Treatment Sludges

Leila Djekoune, [1] Aziz Maaliou, [2*] Dalila Ziani , [2] Abderzak Moussouni, [3]

[1] University of Sciences and Technology Houari Boumediene, POBox 32 El-Alia-Bab-Ezzouar, 16 111 Algiers, Algeria. Laboratory of Industrial Process Engineering Sciences (LSGPI) Faculty of Mechanical and Process Engineering, Algeria

[2] University of Science and Technology Houari Boumediene, Faculty of Civil Engineering, LEGHYD Laboratory POBox 32; 16111, El-Alia-Bab-Ezzouar , Algeria

[3] University Center of Mila, POBox N°26 RP Mila 43000, Algeria

*amaaliou@usthb.dz

ABSTRACT

This study delves into the mechanical behavior and hydration characteristics of cement mortars incorporating varying percentages (5-25%) of water treatment sludges. The research explores the evolution of compressive strength over curing periods, revealing a notable increase in mechanical strength for all sludge content levels. This phenomenon affirms the pozzolanic activity of the partially replaced cement mortars with sludges from water treatment units. Notably, mortars with 5% sludge exhibit compressive strength values comparable to reference mortars. Conversely, an investigation into the influence of sludge addition indicates a proportionate reduction in mechanical strength, with a significant impact observed at higher sludge percentages (15-25%). The study further identifies a deceleration in hydration rates due to the presence of organic matter in the sludges, hindering cement hydration and extending the mortar setting time. Overall, this research sheds light on the nuanced effects of water treatment sludge incorporation in cement mortars, offering valuable insights for sustainable and effective waste utilization in construction materials.

Keywords: Water Treatment Sludges, Cement Mortars, Compressive Strength, Pozzolanic Activity, Sustainable Construction Materials

1. Introduction

The primary objectives of this study are twofold. First, to investigate the mechanical properties and hydration behavior of cement mortars through partial substitution with water treatment sludges. This involves a meticulous examination of the sludges' impact on compressive strengths, mineralogical compositions, and microstructural characteristics, utilizing XRD analysis to elucidate the influence on hydrated compounds like C-S-H, portlandite, and quartz in cement matrices. Additionally, IR spectra will be scrutinized to understand chemical changes, such as the appearance of C-S-H absorption bands at 970 cm-1 and the reduction in calcite bands. Second, the research aims to explore the microstructure of hydrated products through SEM analysis, examining the morphology of phases like C-S-H, portlandite, and ettringite to unravel the complex interactions dictating the mechanical performance of cementitious materials. The study seeks to contribute to the discourse on sustainable construction materials, highlighting the potential role of water treatment sludges in achieving dual objectives of effective waste management and the development of sustainable construction materials.

2. Materials and Methods

2.1. Equipment

a. Hydraulic binder: The study employs a Portland cement type CEM II (LAFARGE Company) with a high compressive strength of 32.5 MPa after 28 days of curing.
b. Standardized sand: Delivered in 1,350 g ±5 g plastic bags, the sand is provided in separate or mixed fractions. The bag material does not affect the strength test results.
c. Addition: Alum sludge and ferric sludge from water purification units are used.

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2.2. Specimen Manufacturing Tools

a. Mixer: A CONTROLAB mixer with a maximum capacity of 4 kg is used (Figure 1).
b. Mould: Comprising three horizontal compartments, the steel mould allows the simultaneous preparation of three 40×40×160 mm3 prismatic specimens (Figure 2).

Figure 1: Mixer

Figure 2: Mould

Figure 3: Mechanical Test Apparatus

2.3. Mechanical Tests

Mechanical Testing Machine: Compliant with EN ISO 7500-1 standard, the testing machine determines compressive strength and bending. It has an accuracy of ±1.0% of the recorded load, a maximum load rate of 2400±200 N/s, and an automatic system for adjusting loading speed and result recording (Figure 3).

2.4. Method of Manufacture of Specimens

To investigate the influence of mineral addition on mechanical properties, specimens are prepared by substituting a quantity of cement with sludge from water units. Following the EN 196-1 (2005) standard, an ordinary dosage is used for control specimens.

2.5. Formulation Determination

Five mixtures are prepared for each sludge type, with water-to-solid (I/O) ratio set at 0.5. After manufacture and demoulding, compression tests are conducted at specific time intervals: 2 days ± 1 hour, 7 days ± 2 hours, 28 days ± 8 hours, and 90 days ± 24 hours, following the EN 196-1 (2005) standard.

3. Results and Discussion

The addition of slurry decreased the mechanical strength of all cement mortar samples, as shown in Figure 4. This decrease is proportional to the percentage of sludge added. Thestrength values of all mortars are lower than the values of the control mortars (0% sludge). For specimens containing 10% slurry, a decrease in compressive strengths is less than 25% compared to reference mortars. However, for 15%, 20% and 25% specimens, the decrease in strength is greater at 25%. The same phenomenon has been observed by the work of [1]; [2]; [3]; [4] and [5] on the use of sludge from water units to be purified in portland cement and concrete matrices. As shown in Figure 5, the addition of alum sludge does not result in the formation of new hydrated compounds, with the exception of the presence of Albite, which could be an alum sludge compound. All samples show the main crystalline phases: hydrated calcium silicate (C-S-H), portlandite (P) and quartz (Q). Peaks of calcite (C) are also detected, due to the presence of a mineral addition of limestone in the cement and also in the alum slurry.

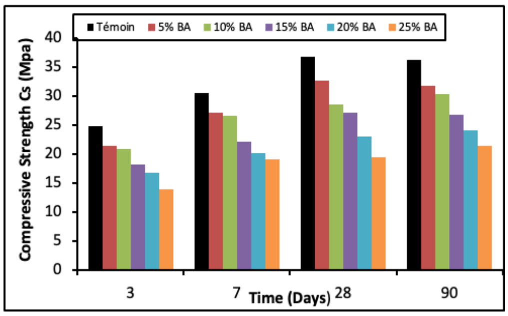

Figure 4: Evolution of the compressive strength of mortars substituted by alum sludge at different percentages.

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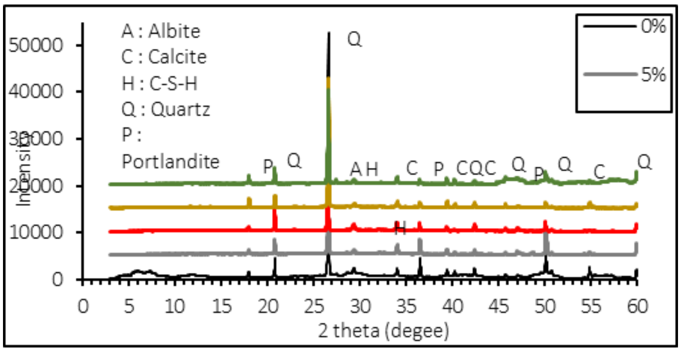

Figure 5: Evolution of the compressive strength of mortars substituted by alum sludge at different percentages.

It is clear that calcite peaks decrease with sludge content, which is likely due to the organic matter present in the sludge that reacted with the calcium cations contained in the pore water ([6]; Liu et al, 2020).

4. Conclusions

The compression strength of all mortars increases at different curing ages. The mortar with 5% sludge by weight exhibits compressive strengths close to those of the control mortar. Infrared results reveal the appearance of portlandite and C-S-H bands, with the siliceous band at 1050 cm^{-1} replaced by C-S-H absorption bands at 970 cm^{-1}, indicating pozzolanic reaction. XRD analysis shows a decrease in portlandite peaks and the emergence of C-S-H peaks, confirming pozzolanic activity. However, the partial replacement of cement with sludge significantly decreases compressive strengths for mortars containing over 10% sludge. The presence of organic matter and the high water absorption capacity of sludge hinder the formation of calcium hydroxide, prolonging the hydration of calcium silicate, the main source of mortar strength. SEM results indicate that the quantity and density of calcium silicate hydrates formed by pozzolanic reaction decrease with increasing sludge content, leading to a more porous structure due to sludge's water absorption capacity. After 28 days, all mortars meet the requirements for both non-load-bearing blocks (7.5 MPa) and load-bearing blocks (12.5 MPa) according to the BSEN771 (2011) standard. The compressive strengths exceed the recommended value for filling concrete (1.25 MPa). Considering the low water absorption rate of the sludge, its use as a construction material is potentially applicable in arid regions.

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