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Reuse of base-metal tailings as aggregates for rendering mortars: Assessment of immobilization performances and environmental behavior

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HIGHLIGHTS

- We studied environmental behavior of mortars that used base metal tailings as aggregates.
- Good mechanical and durability performances of tailings-based mortars were obtained.
- All leaching tests results indicated that risks of metals release from tailings-based mortars are minor.
- The use of base-metal tailings as aggregates may constitute a sustainable alternative method for efficient tailings management.

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ABSTRACT

The management of mine tailings has become a worldwide environmental concern. In essence, with the increasing ecological disruptions related to tailings storage facilities, there is a pressing need to develop sustainable alternative methods for the management of these hazardous materials. In parallel, abandoned base-metal tailings that contain residual metals are increasingly used in some developing countries as aggregate for mortars without any control or environmental concern. Consequently, there is an additional necessity for improved knowledge of tailings eco-compatibility when reused as construction material. This paper approaches these issues by assessing the geochemical behavior and immobilization performances of two low sulfide tailings-based mortars, commonly used in the upper-Moulouya region (eastern Morocco) as surface finishing mortars. The mechanical and durability performances of these mortars were also presented to endorse their reuse potential. The obtained results showed firstly that the reuse of base-metal tailings with low sulfide content and relatively minor residual-metal concentrations ($As \approx 30$ mg/kg, $Cr \approx 60$ mg/kg, $Pb \approx 4500$ mg/kg, $Zn \approx 250$ mg/kg) generates mortars with good mechanical and durability performances. Additionally, all leaching tests results (batch test, acid neutralization analysis, selective dissolution, tank leaching test and weathering cell test) indicated that risks of metals release from tailings-based mortars are minor and their reuse as surface finishing renders may constitute a sustainable alternative method for efficient tailings management.

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1. Introduction

1.1. Background

Mine tailings refer to a mixture of waste by-products generated when recovering useful and precious minerals, metals, and other resources from the ores using mineral processing and hydrometallurgical processes [1]. During exploitation, these residues are generally transported as slurry to large surface storage facilities (e.g., ponds or impoundments) where they remain contained. This surface disposal of tailings constitutes a low-cost recognized technology that has been widely used by the mining industry. However, this approach does not provide a long term tailings management solution and may generate, if not properly monitored, important environmental problems and significant ecological disruptions such as acidic drainage, water contamination, tailings dam failures and soils pollution [2–6].

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In recent years, new methods and technologies such as environmental desulphurization [7–9], backfill [10], and covers [11,12] have been established to properly manage tailings storage facilities. Nevertheless, these techniques can be costly to implement, need careful monitoring, and their long-term sustainability is still inaccurate [13]. Moreover, the challenges associated with tailings management are constantly growing, especially with the increasing restriction on landfills and the stringent environmental regulations.

Currently, the most efficient hierarchy method for sustainable tailings management is to first reduce their production, then recycle and reuse tailings where possible [14]. In this context, a number of recent studies have been conducted to assess the recycling of different type of tailings, especially in the construction sector. For example, the reuse of copper tailings was evaluated for the manufacture of cement mortars [15], cement concrete [16], autoclaved aerated concrete [17], autoclaved sand–lime brick [18] and eco-friendly bricks [19]. Tungsten mine tailings were also evaluated as cement replacement for the manufacture of mortar [20] and geopolymeric binder [21]. Iron tailings were used as raw materials for the preparation of cementitious material [22] and eco-friendly construction bricks [23].

From all the research conducted, one can retain primarily that the recycling method and the technical requirements (substitution level, water/cement ratio, additives) are specific to each individual mine tailings. In addition, all the studies conducted are still at laboratory stages and the reuse of tailings as construction material is yet subject of numerous concerns, particularly their social acceptance, chemical stability and eco-compatibility. In fact, on the opposite of the well documented stabilization/solidification technique (using a low water/cement (W/C) ratio, and a specific hydraulic binder proportion) [24], the immobilization performance of mortars or concrete when incorporating tailings is still inaccurate. Actually, the presence of residual metals and sulfates in tailings as well as the higher W/C ratio used to insure good workability of mortars or concretes could modify the hydration processes and the stabilization performances of mixtures. Moreover the detrimental field conditions (e.g., carbonation, deterioration) may change the long term leaching behavior of mortars and concretes [25]. Consequently, there is a growing need for improved knowledge of environmental behavior and eco-compatibility of tailings when used in the construction sector.

1.2. Uncontrolled use of mine tailings

There are a number of abandoned mine sites in developing countries that carry a negative legacy of environmental impacts and risks related to tailings storage facilities. In fact, million tons of mine tailings that contains significant levels of heavy metals were abandoned, after mines closure, without neither confinement nor pollution control. Moreover, at some abandoned mine sites, tailings ponds (containing apparently-clean residues) are subjected to a wide uncontrolled exploitation as source of fine aggregates [26]. These tailings are considered as a low-cost substitute to natural sands and are commonly used for the manufacture of surface finishing mortars without neither engineering bases nor environmental evaluation.

In Morocco, this uncontrolled use is principally located in the upper-Moulouya region (eastern Morocco), which constituted one of the largest Pb-district of Morocco with three main Pb deposits (named Aouli, Mibladen and Zeida). This region is also characterized by a low population density (less than 20 inhabitants per km^2) and poor economic conditions [27]. Presently, there are approximately 15 Mt of abandoned Pb tailings, especially in Zeida and Mibladen mine sites, that are intensively exploited as source of fine aggregates.

Mining activity has also produced huge environmental damages over the upper-Moulouya district. In addition to abandoned tailings, processing plants ruins and deep open pits filled with water occur in close proximity to living areas. Moreover, previous investigations [27–29] focusing on the environmental impact of mining activity at the upper-Moulouya, pointed-out the presence of significant As, Pb, Zn and Cu concentrations in soils and dispersed tailings around Zeida and Mibladen mine sites. These results have raised many public concerns and worries about the pollution potential of the resulting tailings-based mortars.

1.3. Significance of the research

The uncontrolled use of base-metal tailings has been experienced in the upper-Moulouya region for approximately fifteen years, which constitutes a unique case study illustrating the reuse of mine tailings in the construction sector. On one hand the assessment of the pollution potential of these tailings-based mortars will help quantifying risks in Moroccan constructions. On the other hand a better understanding of their mechanical properties and long term behavior will provide valuable information on the possible reuse of base-metal tailings in the construction sector.

This work started by presenting the main mechanical and durability performances of the two low sulfide tailings-based mortars (Zeida and Mibladen tailings), commonly used in the upper-Moulouya region as surface finishing mortars. A thorough environmental evaluation of both mortars sampled from wall construction and laboratory made specimens was subsequently conducted. Batch tests (BT), acid neutralization analysis (ANA), selective dissolution, tank leaching test (TLT) and weathering cell test (WCT) were implemented as the environmental assessment tools.

2. Materials

2.1. Mine tailings, cement and river sands

Tailings-based mortars used in the upper-Moulouya region are commonly made of Portland cement, Zeida or Mibladen tailings and water. In some cases, tailings are used as partial substitute and are mixed with natural river sands.

Tailings samples were collected from the principal take supply spots (Fig. 1) used by local constructors as source of fine aggregates at Zeida (Ze) and Mibladen (Mi) sites. natural river sands (Fi) complying with *EN 13139* (aggregates for mortar) [30] were used as reference samples. Before characterization, both tailings and river sands were dried, homogenized and sieved (1 mm) to insure similar grain size distribution. The cement used is an ordinary Portland cement (PC) class 32.5 R.

Physical properties and chemical composition of tailings, cement and river sands are shown in Table 1, while Figs. 2 and 3 show their particle size distribution (Malvern Mastersizer) and metals content (ICP-AES), respectively. As it can be seen, Zeida tailings (Ze) and river sands (Fi) have nearly the same bulk density and specific gravity corresponding to 2.7 g/cm^3 and 1400 kg/m^3, respectively. Conversely, Mibladen tailings (Mi) presents higher values (3.12 g/cm^3 and 1560 kg/m^3). In terms of metals content, tailings samples show relatively high and similar concentrations. Pb is dominant with values around 4200 mg/kg and 5000 mg/kg for Zeida and Mibladen tailings, respectively. As, Cr, Cu, Mo and Zn are also present in non-negligible values. The other elements not presented in Fig. 3 (Ag, Bi, Cd, Co, Li, and Ni) showed very low values or concentrations below detection limits for the ICP-AES. X-ray diffraction (XRD) analysis implementing Rietveld refinement [31], indicates that Zeida consist mostly of silicates (quartz, orthoclase and albite), barite and fluorite, while Mibladen consist essentially of carbonates (dolomite and calcite), quartz and barite. Sulfide minerals were not detected by XRD analysis in both tailings because of their low content. Scanning electron microscopy investigations showed that Pb occurrence is principally related to galena (PbS) and cerussite ($PbCO_3$) mineral phases. Pb is also present as lead oxide (PbO) in Zeida tailings. As and Zn occurred essentially as trace in hematite (Fe_2O_3) phases for both tailings. Zn was also present as trace in secondary iron oxides for Mibladen tailings. Pyrite was rarely observed in both tailings [26].

2.2. Mortars sampling and preparation

In this study both mortars sampled from walls constructions and mortars synthesized in laboratory were used for the characterization. Actually, ten render samples were taken from wall constructions (principally residences that used tailings as aggregates) located in the city of Midelt and in Zeida urban zone. When paintings

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