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Influence of red mud addition on rheological behavior and hardened properties of mortars

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HIGHLIGHTS

- An attractive alternative for employing the waste from bauxite refining was presented.
- The technical viability of introducing up to 20 wt% of red mud in mortars was proven.
- The individual and combined effect of red mud and water/binder ratio were estimated.
- The properties studied were mainly governed by W/B ratio.

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ABSTRACT

This experimental research evaluates the individual and combined influence of red mud particles (RM) and water/binder weight ratio (W/B) on the fresh–hardened properties and durability of cured mortars up to 360 days. Samples containing up to 40 wt% RM and 0.47–0.58 W/B were prepared keeping the workability constant. Samples with similar workability showed distinct rheological behavior along time. The yield stress was the best rheological parameter to represent such variations. The maximum values of exothermic peak reduced when the Portland cement was replaced by RM. Deeper negative changes in the apparent porosity, water absorption, compressive strength and carbonation extent were also observed changing the W/B ratio from 0.47 to 0.58 in the 20RM-containing mortars. In fact, the compressive strength of mortar 20RM + 0.47W/B reduced 13% in comparison to RM-free mortar at 360 days, while 20RM + 0.58W/B reduced 46%. Although the extra voids created in the matrix by using 0.58W/B implied in a positive effect to the alkali–silica reaction, adjusting a dosage of water similar to the one of RM-free mortar makes RM an attractive alternative without compromise the materials' properties studied in this work.

1. Introduction

Every day a large amount of wastes is generated from industrial activities worldwide. The utilization of residues as raw materials is gaining attention, since their incorrect disposal in the environment may cause serious problems. Additionally, disposal practices are becoming more expensive and legally difficult, since they are not considered as first priority in the waste management hierarchy. Cement based materials are obvious attractive targets, since the production rate and availability are very high. However, the success of any recycling route depends on preliminary identification of eventual problems and on the design of solutions to maintain the performance of final products.

Red mud (RM) is a complex residue generated in large scale from the Bayer process, used in the production of alumina from bauxite ore [1]. A concentrated caustic soda (NaOH) solution at high pressure and elevated temperatures (~270 °C) is used to obtain alumina trihydrate ($Al_2O_3{\cdot}3H_2O$) [1,2]. Due to its composition, it generates highly alkaline (pH 10–12.5) slurries when mixed with water, since it releases OH^- ions [1,3]. The exact composition of the mud depends on the origin of bauxite and on processing

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conditions, but generally it is composed by goethite (α-FeOOH), hematite (γ-Fe_2O_3), boehmite (α-AlO(OH)), quartz (SiO_2), sodalite ($Na_8Al_6Si_6O_{24}Cl_2$), and gypsum ($CaSO_4 \cdot 2H_2O$) as major phases, and calcite ($CaCO_3$), whewellite ($CaC_2O_4 \cdot H_2O$), gibbsite ($Al(OH)_3$), and rutile (TiO_2) as minor components [1].

Several initiatives have been driven by researches towards the use of RM as a raw material for the construction. In general, Portland cement clinker with RM [4] and cement containing RM and lime + bauxite, or lime + gypsum + bauxite [5] exhibited a comparable performance to that of ordinary Portland cement. When RM is calcined between 600 and 800 °C it can generate a pozzolanic pigment [6], while the filler effect can lower the chloride diffusivity in RM-containing concrete [7]. In addition, RM particles in alkaline solution adhere to iron and carbon steel surfaces, making RM a good alternative for acting as steel passivation promoter in alkaline media [8]. Promising alternatives involving the use of RM as raw material in mixtures with clay for the production of ceramic bodies are also reported [9].

Composite materials containing RM particles have shown several benefits under distinct perspectives for sustainable construction practice. However, a considerable drawback regarding RM-fine particles is the tendency of mixtures to hinder the flowability [10]. Sometimes, the mixtures become too stiff and the poor fresh mixture compactness implies in deficient development of hardened properties. By contrast, the use of distinct dosage of water – a common procedure followed to control the misadjusted workability of samples – implies that the functional properties of materials cannot be considered solely due to the RM addition, but might be controlled by the amount of water added.

Table 1
Chemical composition of Portland cement CEM I – 42.5R and red mud determined by XRF.

Component	Cement (wt%)	Red mud (wt%)
SiO_2	20.4	5.54
CaO	63.1	3.27
Al_2O_3	4.78	18.8
Fe_2O_3	2.96	51.8
SO_3	3.70	0.23
MgO	2.02	–
Cl^-	0.02	0.02
Na_2O	–	6.84
K_2O	–	0.08
TiO_2	–	11.2
MnO	–	0.04
Loss on Ignition	2.37	0.16

Thus, a systematic study that clarifies the role of each individual mixture component and the synergetic action on a particular characteristic of the material is crucial to optimize its rheological, chemical and mechanical behavior [11–14]. Therefore, the purpose of this experimental research is estimating the individual and combined influence of RM particles and W/B ratio, in order to define an optimized formulation according to its application. Several properties will be evaluated, covering the fresh stage (rheology) and after curing (unrestrained shrinkage, weight variation, apparent porosity, water absorption, compressive strength, alkali–silica reactivity and carbonation) up to 360 days.

2. Experimental

2.1. Materials

Portland cement (OPC – type I 42.5R, according to EN 197-1 [15] was used as binder. It has an average particle size of 14 μm and specific area of 0.35 m^2/g (Blaine fineness), and its chemical composition is given in Table 1. Red mud (RM) slurry (Alcoa, Spain) was used as partial substitute of Portland cement, and contains about 60 wt% solid particles, whose specific area is 20 m^2/g and size ranging from 0.1 to 7 μm (average 0.78 μm). The RM concentration of chlorides leached and the chemical composition (Table 1), was determined according to EN 1015-17 [16] and by XRF, respectively. The superplasticizer (SP) used to adjust the plasticity of fresh mortars is based on a polycarboxylic ester (Glenium 52, BASF – SE, Germany), with a density of ~1.9 g/cm^3 and containing ~20 wt% solids. In addition, the sand used as aggregate has a quartzitic origin and is composed by four particle size fractions 2.36–1.18 mm (10 wt%), 1.18–0.6 mm (37.5 wt%), 0.6–0.3 mm (37.5 wt%) and 0.3–0.15 mm (15 wt%), as suggested by ASTM 1260 [17]. The particle size fraction 4.75–2.36 mm was disregarded since the available rheometer defines the maximum particle size as ~2 mm.

2.2. Rheological and flow table characterization

The rheological behavior of fresh samples was measured in an appropriate rheometer (Viskomat PC, Germany) used for testing cement pastes and mortars (Fig. 1a). Distinct mathematical approaches are given in the literature to describe the properties of flow curve of mortars and concrete [18,19], but the Bingham model is often used to represent the rheological behavior of mortars:

$$\tau = \tau_o + \mu_p \cdot \dot{\gamma}$$

where τ (Pa) is the shear stress, τ_o (Pa) is the yield stress, μ (Pa s) is the plastic viscosity and $\dot{\gamma}$ (s^{-1}) is the shear rate. The Bingham model can be also described by the relationship between torque, T, and rotation speed, N:

$$T = g + h \cdot N$$

where g (N mm) and h (N mm min) are directly proportional to the yield stress and plastic viscosity, respectively.

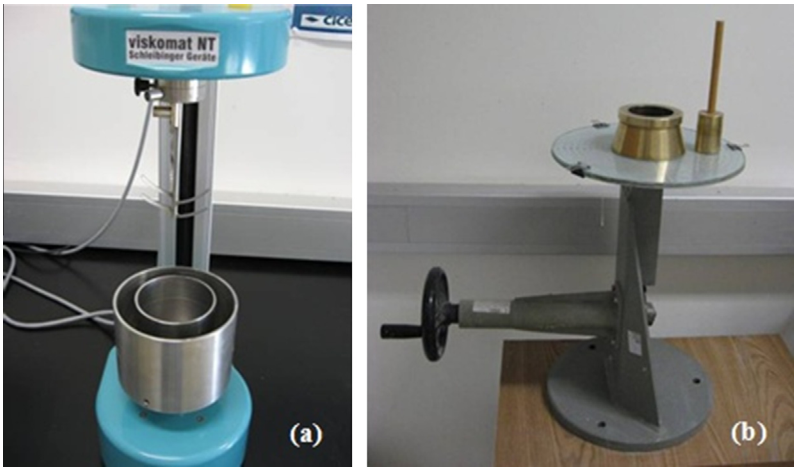

Fig. 1. (a) Rheometer and (b) flow table test.