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Effect of citric acid on properties of recycled gypsum plaster to building components

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HIGHLIGHTS

- Citric acid increases the fluidity of recycled gypsum plaster.
- Retarding effects are higher with high content of the admixture.
- Mechanical properties are diminished with the increase on admixture addition.
- Crystal structure has changed significantly with citric acid addition.

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ABSTRACT

Gypsum plaster recycling shortens the setting times, changing the workability and becomes difficult to work with it. The works found in literature studied the α-hemi-hydrate. Few works studied the gypsum plaster recycling with β-hemihydrate. This experimental work evaluates the performance of recycled gypsum plaster with citric acid to improve the setting times and workability to building components. Recycled gypsum plaster with five admixture contents was used: 0%; 0.025%; 0.05%; 0.1% and 0.25%. The water/plaster ratio was kept constant (1.0) for all the mixtures. The results showed that the citric acid decreases the recycled gypsum plaster consistency, increasing the fluidity. The setting times were increased, but the compressive strength and hardness were diminished. The microstructure also changed with the admixture addition. Even with these changes in gypsum plaster properties, the recycled material can be used to make components because it reaches the minimum values required by the component standards.

1. Introduction

Gypsum plaster has been a material used since long time ago: in Egyptian pyramids and tombs at least 2000 years BC, in Greece 1000 years BC and by the Romans later [1] and is still extensively used in building construction for indoor wall renderings, blocks, plates and components. The gypsum plaster use is widely spread due to its easy fabrication feature, environmental friendliness, low price and aesthetics [2,3].

The hemihydrate ($CaSO_4{\cdot}0.5H_2O$) is obtained by thermal dehydration from calcium sulfate dihydrate ($CaSO_4{\cdot}2H_2O$) in rotary kilns. In this process forms different solid phases, depending on heating temperature: hemihydrate ($CaSO_4{\cdot}0.5H_2O$), anhydrite I ($CaSO_4$), anhydrite II ($CaSO_4$) and anhydrite III ($CaSO_4{\cdot}\varepsilon H_2O$) [4,5].

In the kiln, the dihydrate takes two steps of endothermic decomposition reactions [6]. In the first step, gypsum plaster is converted to hemihydrate (Eq. (1)). The dehydration temperature and the required energy to the dehydration reaction depends on the composition of the raw material and the microstructure of the investigated material [3]. In the second dehydration step, the hemihydrate is converted to anhydrite (Eq. (2)).

$$CaSO_4 \cdot 2H_2O + heat \rightarrow CaSO_4 \cdot 0.5H_2O + 1.5H_2O \quad (1)$$

$$CaSO_4 \cdot 0.5H_2O + heat \rightarrow CaSO_4 + 2H_2O \quad (2)$$

The hemihydrate hydration reaction takes place immediately after mixing with water (Eq. (3)). The reaction is a

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through-solution mechanism: the hemihydrate dissolves and needle like crystals precipitate from the solution in an exothermic reaction [7,3].

$$CaSO_4 \cdot 0.5H_2O + 1.5H_2O \rightarrow CaSO_4 \cdot 2H_2O + heat \quad (3)$$

The water/plaster ratio is a parameter of influence on the kinetics of hydration reaction and consequently on the plaster setting time. However, other factors as water temperature, raw material and the procedure used on the plaster production as well as the energy used in the process of the paste mixing can accelerate the hydration reaction by improving the plaster powder dispersion in the water [8].

Due to the fast hydration, setting times are very short. The paste workability is maintained for only a few minutes, which, in practice, does not meet the time necessary to place and finish the work with the gypsum-based material, showing a great material loss. The values of this loss vary from 20% to 47% [8]. The gypsum plaster waste from rendering is a significant source of material lost. This waste is no longer permitted in the mixed landfill because the sulfates may react with organics to form hydrogen sulfide. A limited number of cells have been built for receiving sulfate waste which may encourage this waste transfer to special recycling stations. Due to this great material loss that happens during the use of the β-hemihydrate in walls renderings, it becomes useful and necessary a study how is its performance when recycled.

Gypsum waste is composed by dihydrate ($CaSO_4{\cdot}2H_2O$) and some impurities, depending on the gypsum waste source. The recycled gypsum plaster is obtained by a simple process of crushing, sieving and heating at relatively low temperatures [9]. The dehydration of the hydrated gypsum plaster (gypsum waste) is in temperature up to 180 °C. The use of this waste provides a saving of raw materials and a reduction of the environmental impact.

Previous works show that recycled gypsum plaster has fast setting and lack of workability [10,11]. Selection of suitable retarders and dosage can adjust the setting times of recycled gypsum plaster to a desired level to use this material again in construction works or to make components.

Gypsum retarders have been studied intensively, but the emphasis was always laid on commercial gypsum. Table 1 shows some works on the use of gypsum retarders. The related works used commercial gypsum plaster and the use of citric acid prevails (67%), and any work of this list used recycled gypsum plaster.

Although great achievement has already been obtained in using retarders with gypsum plasters, topics about the properties and the problems caused by the gypsum waste recycling is still poorly understood.

The present study investigated the properties of recycled gypsum plaster produced from a gypsum plaster waste with added citric acid to improve the performance in fresh and hardened states. The consistency, the setting times and kinetics of temperature, and physical, mechanical properties and microstructure were evaluated. The technical performance of the recycled gypsum plaster is discussed to the requirements of the Brazilian Standards to make building components. With the results it is possible to give an answer to the question about the reuse gypsum plaster waste in building construction.

Table 1
Some works on admixtures on gypsum-based binders.

Year	Author	Retarder
1952	Cunningham et al. [12]	Citric acid
1961	Ridge and Surkevicius [13]	Egg albumin, sodium hexametaphosphate, calcium acetate, borax, calcium borate, sodium citrate, Sucrose
1964	Combe and Smith [14]	Acetic acid, potassium acetate, calcium acetate
1965	Combe and Smith [15]	Tartaric acid, potassium tartrate, calcium tartrate
1966	Combe and Smith [16]	Citric acid, potassium citrate, calcium citrate
1984	Koslowski and Ludwing [17]	Citric acid
1994	Lewry and Williamson [18]	Potassium sulfate
1997[a]	Henao and Cincotto [19]	Citric acid, sodium citrate, ammonium acetate, sodium acetate, borax, tartaric acid, potassium phosphate, casein, peptone
1997[a]	Hincapie and Cincotto [20]	Citric acid, borax, casein, gelatin
1999	Badens et al. [21]	Aipic, D,L-malic, mesotartaric and citric acid
2000	Boisvert et al. [22]	Sodium salt of poly(acrylic acid) (PANa)
2003	Prisciandaro et al. [23]	Citric acid
2004	Vieira et al. [24]	Fructose, glucose, sucrose, tannic acid
2005	Singh et al. [25]	Malic, succinic, tartaric and citric acid
2005	Prisciandaro et al. [26]	Citric acid
2006	Vellmer et al. [27]	Malic, succinic, tartaric and citric acid
2006	Ersen et al. [28]	Malic and citric acid
2006	Prisciandaro et al. [29]	Nitrilotrimethylenephosphonic acid
2007	Singh and Middendorf [5]	Citric, malic, succinic, and tartaric acid
2009	Magallanes-Rivera et al. [30]	Citric and malic acid
2011	Pritzel and Trettin [31]	Citric acid
2011	Teng et al. [32]	Citric acid, ethylene diamine tetraacetic acid (EDTA) and succinic acid
2011	Chindaprasirt et al. [33]	Glucose, citric acid and sodium bicarbonate
2011	Qu et al. [34]	Citric acid and sodium polyphosphate and bone glue
2012	Lazón and García-Ruiz [7]	Citric acid
2013[a]	Baltar et al. [35]	Corn starch, dextrin 5, cellulose, sodium carboxymethylcellulose
2013	Trivedi et al. [36]	Ethyl acetate, glycerol, isopropyl alcohol, dimethylformamide, oxalic acid, and propylamine
2014	Rabizadeh et al. [37]	Citric, maleic and tartaric acid
2014	Prisciandaro et al. [38]	Citric acid, NTMP, PBTC

[a] Brazilian works about this subject.

2. Experimental program

2.1. Materials and mixtures

In this experimental work commercial gypsum plaster (β-hemihydrate – $CaSO_4{\cdot}0.5H_2O$), gypsum plaster waste (dihydrate – $CaSO_4{\cdot}2H_2O$) and citric acid as admixture was used. Commercial plaster is found in the market and the recycled gypsum plaster (RGP) was obtained from the waste of hydrated gypsum from construction sites.

The recycled gypsum plaster (RGP) was produced by crushing and heating gypsum waste from construction sites. The preparation of the waste was made in the Laboratory of Binding Materials and Wastes at University of Campinas, Brazil. The gypsum plaster waste was pulverized and then screened to remove any impurities. After that the pulverized material was placed on a plate and followed the process of heating in a stationary kiln at controlled temperature of 150 °C for a certain time to remove the chemically bonded water, resulting in a hemi-hydrate calcium sulfate ($CaSO_4{\cdot}0.5H_2O$). After burning it was cool, the batches