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Effect of some waste additives on the physical and mechanical properties of gypsum plaster composites

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HIGHLIGHTS

- Gypsum plaster composites were synthesized by blending with some wastes.
- The composites consume cheap available materials or some wastes.
- Plaster composites clean environment and used for low-economical lightweight units.

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ABSTRACT

Gypsum plaster composites were synthesized by blending plaster with 0.2–10% of unburnt rice husk, blast furnace slag, calcium carbonate or commercial poly vinyl alcohol polymer (PVA). The normal consistency (NC) and setting time (ST) in addition to apparent porosity (AP), bulk density (BD) and compressive strength (CS) of the composites were determined after 7 and 28 days. Results indicated that rice husk, polymer and calcium carbonate increased while slag decreased NC. All additives delayed the setting time, increased the AP and decreased BD of their corresponding composites. The effect of their addition is exaggerated with increased added ratios of either of them. Their compressive strength, on the other hand, increased with slight addition of either of them then it decreased by further increased additions. Physicomechanical properties elucidated that the added wastes exist in the interstitial pores and spaces of the plaster matrix in the composites without any sign of interaction between either of them and set plaster. The formed composites although did not much improve their mechanical properties yet they consume in their formation either cheap available materials or some wastes. The synthesized plaster composites help to clean environment and can be used for low-economical cheap lightweight units suitable for load bearing non-concrete low-height walls of buildings.

1. Introduction

Hydration of gypsum plaster gives a hard material whereas the water needed for setting (normal consistency, NC) comprises two types: the stoichiometric demand for hydration, amounting to 18.6 ml per 100 g plaster, in addition to an excessive amount necessary for workability [1]. The latter type usually expels on ageing and drying leaving behind air voids and pores in the hardened set material which decreases its mechanical properties. The different applications of plaster are primarily based on its peculiar properties. Some disadvantages, however, appear when neat plaster is used; it may need relatively high amounts of water for mixing and the setting time will, accordingly, be too long or even gives fair mechanical properties [2]. Most gypsum plaster properties, however, are merely improved by incorporation with other additives forming composites; the downside is that such composites are often more expensive than individual materials [3,4]. Gypsum plaster is essential in various applications meanwhile; huge extensive high-grade gypsum ores are available at different localities in Egypt [5] whereas by-product wastes are annually accumulated and constitute one of its major ecological problems.

Various authors attempted to add different materials to improve and optimize the physicomechanical and hydrophobization properties of plaster, hold the structures from corruption or disintegration and increase its applications [6]. Different modes of silica were added to plaster forming the plaster/silica composites which improved their physicomechanical properties whereas it was concluded that each additive occupies the interstitial pores of the set plaster grains in the composites rather than combine with any of them [7].

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Rice husk is a by-product of the cultivation and processing of rice as a foodstuff whereas between ~20% and 25% of the rice paddy is an indigestible outer husk, which is usually removed and locally burnt to create steam. It was mentioned that rice husk is a good reinforcing material with a slight resistance effect on the absorption of water, moisture and steam in addition to resisting acids and sulfate into the composite boards [8,9].

Blast furnace slag, on the other hand, is a waste generated during pig iron industry and is normally dumped in open areas through granulation by air or water quenching methods. It reacts very sluggish with water to form aluminosilicates hydrates but reveals expansion with age, which is considered a limiting factor when used in civil cement construction [10–13]. Lime carbonate was added to plaster as a plasticizer or passive fire protector among other applications [14]. On the other hand, huge and extensive different grades purity lime carbonate deposits and industrial by-products are available in different industrial plants in Egypt and is currently used in different industries e.g. free lime production, Portland cement, basic refractories, smelting iron, light weight concrete production, etc. [5]. Gypsum and/or anhydrite are major constituents in the formation of supersulphated cement or geopolymer [15]. Plaster/polymer composites were attempted for performance in various applications [16]. Water proofing polymers were applied to form impervious coating that prevent liquid water, steam or water soluble salts into gypsum boards; among the most widely used admixtures are metal stearates, siliconates, acrylics or methacrylates [17].

The present work aims to synthesize plaster composites using wastes of rice husk, slag, calcium carbonate or commercial PVA polymer. The effect of blending 0.2–10% of each of these additives on the physicomechanical properties of the composites was followed. It was planned to form composites, minimize accumulation of wastes, and improve their properties which can increase uses and produce cheap lightweight units suitable for various applications.

2. Materials and methods

2.1. Materials

The materials used in the present study included industrial gypsum plaster which was blended with rice husk, air-cooled blast furnace slag, calcium carbonate or PVA polymer. Gypsum plaster was produced by rotary kiln at Sinai Gypsum Company (Gypsina, Sinai Egypt) using very high grade gypsum ores. It was stored in airtight containers to avoid hydration. The constitution and some of the physical properties of the starting materials was previously investigated using DTA, XRD, IR, XRF and their BET surface area isotherms respectively while the results were published elsewhere. Their chemical constitution and BET are summarized in Table 1 and it was concluded that they are almost pure fine-grained materials with minor impurities [18].

2.2. Methods

Plaster composites were prepared by blending 0.2% up to 10% of rice husk, slag, lime carbonate or PVA polymer for about 15 min and until good homogeneity is reached. Prepared composites were left at lab conditions (relative humidity (RH) ranges between about 60–70% and temperature between ~20 and 25 °C to be used for the determination of their physicomechanical properties. The latter include their normal consistency and setting time in addition to apparent porosity, bulk density, and compressive strength after 7 and 28 days. ST, AP, BD and CS of the composites were determined by blending plaster powder with the determined NC in each case. The procedures and experimental precautions published before were always followed and carefully considered [7,19].

3. Results and discussion

3.1. Normal consistency (NC)

Results of the NC {ml water/100 g powder, (water/solid ratio)} of the plaster composites are given in Table 2 from which it is clear that:

(1) The NC of the neat plaster amounts to 60% which means that each 100 g plaster powder blends 60 ml water for its normal consistency which is in harmony with the previous findings [7]. Very minute addition, up to ~1%, rice husk slightly affects the NC of the plaster/husk composites. As the rice husk content increases a detected increase in the NC of the formed composites takes place due to the fact that rice husk is an agro waste material which needs some excessive water for wetting its fibers. Extra water, accordingly, increases as the rice husk content is increased [1]. It should be added that on using high husk content (up to 10%) the plaster/rice husk composites revealed inconsistency and liquid water was squeezed out of the composite pastes.

(2) Up to ~3.0% slag addition slightly increased the NC of the plaster/slag composites whereas when the slag content increases a slight increase in the NC of the formed composites is detected. This may be visualized as slag is a hydraulic material that reacts with water giving aluminosilicate hydrates consuming some of the added excess water. Moreover, slag contains a lot of pores, formed by its sudden cooling and quenching, that need another additional water to be filled which, accordingly, increases as the slag content is mutually increased [10].

(3) Up to 3% addition of calcium carbonate or ~1% polymer to plaster slightly decreased the NC of each corresponding composite. Increased addition (up to 10%) of either of them, on the other hand, gives a decrease in the NC of the corresponding composites due to the fine particles of either carbonate or polymer which acted as a plasticizer increasing the plasticity of the formed paste and decreasing thus the water needed for wetting any of them among its NC.

(4) Generally, addition of any additive is actually a dilution of the plaster content; 10% for instance, decreases the plaster content from 100% to 90%, which needs actually 54 ml of water as a NC for plaster/additive composite instead of 60%. This means that any additive actually slightly increases the NC of the composites by incorporating additional water almost used for wetting the grains of the additive. The difference between the determined NC (60%) and the calculated amount of water for consistency (54%) will stay free in the composites; some of it will be used for wetting the additive grains. Increased amounts of any additive progressively increased the NC of its formed composites

Table 1
Chemical constitution (%) and BET surface area of the starting materials [Ref. [18]].

Element oxides	SiO_2	R_2O_3[a]	CaO	MgO	BaO	SO_3	$Na_2O + K_2O$	H_2O	CO_2 and volatiles	BET (m^2/g)
Plaster	0.46	0.17	37.61	0.12	Nil	53.66	0.03	6.16	1.59	35.34
Rice husk	17.94	0.99	0.77	0.95	Nil	0.12	2.16	4.82	70.78	45.84
Slag	32.51	11.53	35.1	5.03	5.14	3.34	2.08	2.12	Nil	10.61
Lime carbonate	0.53	0.21	54.91	0.59	Traces	0.15	0.05	1.15	42.37	12.34

[a] $R_2O_3 = Al_2O_3 + Fe_2O_3 + TiO_2$.