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Development of eco-friendly mortars incorporating glass and shell powders

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HIGHLIGHTS

- Incorporation of waste materials in manufacturing of ecofriendly mortars was investigated.
- Partial replacement of sand with glass and mussel shell powders was evaluated.
- Thermal insulation, compressive strength, and resistance against chloride of mortars can be improved with an optimum ratio.
- Glass and mussel shell as wastes meet construction requirements in terms of natural resources replacement.

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ABSTRACT

Nowadays, since thermal insulation, enhanced mechanical properties and durability have become extremely important in construction elements. The concept of developing new economical and eco-friendly mortars that incorporate various types of wastes as a partial replacement of cement and sand has gained a great interest. In this paper, sand was partially substituted (20, 40 and 60% by weight) with either glass powder or mussel shells powder with water to cement ratio of 0.6. Mortar's thermal conductivity, volumetric heat capacity, compressive strength and resistance to chloride ingress were evaluated and compared with those of ordinary mortar. Glass powder and mussel shells can improve thermal insulation by reducing their thermal conductivity. An optimum ratio 40% by weight of glass powder improves compressive strength of mortars. Besides, High glass powder content can significantly improve mortars resistance to chloride penetration.

1. Introduction

The increasing generation of waste has become a strategic issue all over the world, primarily due to the drastic growth of population and industrialization. On the other hand, the traditional mortar-making process affects negatively the environment besides significant amount of greenhouse gases emissions caused by cement-manufacturing. The excessive extraction of natural aggregates has serious environmental impacts. Nowadays, the development of an effective waste utilization process becomes more critical. Extensive efforts have been conducted to investigate the possibility of using various types of wastes as ingredients in mortar mix as a partial replacement of cement and fine aggregates.

Thermal insulation plays an important role in building energy savings. Several studies have appointed on improving the energy efficiency of building materials. Insulating concrete is a type of material that is designed to reduce heat loss through its insulation effect [1–3]. For this reason, many researchers have implemented new alternatives as adding wastes as raw materials. Typical wastes are used as plastic particles [4], expanded glass granules [5], and glass fiber [6].

Due to its non-biodegradable properties and its disposal issues, glass waste is developing environmental problems all over the world. As a consequence, several studies have been carried out on utilizing glass waste in the construction industry. Regarding mechanical properties, while some researchers [7,8] reported that the compressive strength is increased with the replacement of cement and fine aggregates with waste glass. Other studies [9–12], have demonstrated that the incorporation of waste glass can negatively affect the mechanical behavior of mortars.

In terms of thermal behavior, recent experimental investigation has shown that sand substitution with glass waste reduces the thermal conductivity and improves thermal insulation properties of mortars. This positive effect may be attributed to the fact that since glass is less thermally conductive than natural sand, it can

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reduce the ability of sand to transfer heat [13,14]. Besides mechanical strength and thermal insulation, resistance to chloride penetration is an essential characteristic of mortar durability. According to many researchers [12,15,16], the use of glass has been proven to help a decrease of chloride ingress through mortars.

Moreover, mussel shells can be used as an effective alternative not only to save costs and landfill space but also to reduce the environmental impacts of mortar materials. Considerably, few studies have been conducted [17–19] on the impact of mussel shells on mortar properties, which have been shown to considerably reduce thermal conductivity allowing the mortar to achieve adequate insulation behavior. Ballester et al. [17] have found that the addition of mussel shells into mortars improves their compressive and flexural strengths. Other studies [18,19] have demonstrated that due to their smooth surface and their large particle size, shell powders may impact negatively mechanical properties of mortar. However, using shell powder in mortars can show the same class of the Portland cement mortar [20].

In this context, the present paper has attempted to study the use of glass and mussel shell powders as partial replacement of sand in mortar with different replacement levels 20, 40 and 60% by weight, in order to evaluate their impact on thermal insulation properties, compressive strength and resistance against chloride diffusion of mortar.

2. Materials and methods

2.1. Materials

The used materials for this study consisted of cement, natural sand, glass powder (GP) as well as mussel shells powder (SP) which were used as partial sand replacement in mortar production. Portland cement CPJ35 used in mortar mixes which is composed of clinker (>65% by weight) is conformed to Moroccan standard NM 10.1.004 [21]. Commercial sand used in this study has been washed and dried; the particle size distribution is shown in Fig. 1. Broken glass has been washed and air-dried, crushed and then ground into fine powder using Micro fine grinder MF 10.2 IKA®, which is equipped with a 0.5 mm sieve. Mussel shells were collected from the coast line of Salé, Morocco. These shells were washed and air-dried, then turned into a fine powder by crushing and grinding with 1.0 mm mesh sieve.

After adding glass and shell powders, the fineness modulus of the aggregates is kept between 2.3 and 3.1 which meet the fine aggregate grading according to the specification outlined in ASTM C33 [22].

2.2. Mortar samples preparation

A total of six different types of specimens were prepared and tested. In these mixtures, natural sand was partially substituted 20, 40 and 60% by weight with either glass powder (GP) or mussel shells powder (SP). Additionally, a specimen prepared without any additives was used as ordinary mortar (OM). For all mixtures, the water cement ratio (W/C) was maintained constant at 0.6. The studied mortar mixtures and their mix proportions are summarized in Table 1.

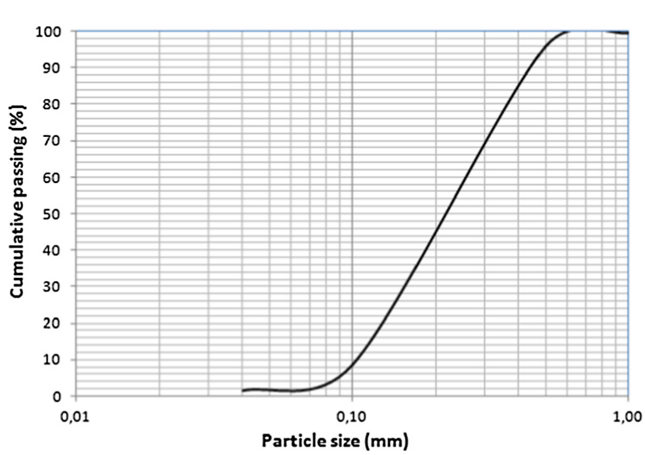

Fig. 1. Particle size distribution of sand.

After the mixing process, mortars were cast into molds according to ISO 22007–2 [23]. For each mixture, two parallelepiped specimens (70 × 70 × 40 mm) were used for thermal conductivity and compressive strength testing. As for chloride diffusion test, cylindrical specimens of 45 mm diameter and 35 mm height were prepared. Finally, after 24 h of ambient drying, mortar specimens were demolded and cured in water at 20 ± 2 °C for 28 days.

2.3. Test program

The experimental program consisted of three parts: the first part was concerned with measurements of mortars thermal properties including thermal conductivity and volumetric heat capacity. The second part dealt with their mechanical performance and finally chloride diffusion properties were also investigated.

2.3.1. Thermal properties test

Parallelepiped specimens were dried in an oven at 60 °C for 48 h and stored in desiccators to cool to room temperature. Thermal conductivity and volumetric heat capacity were measured using CT-meter device (Fig. 2-a). The measurement is based on monitoring the temperature increase for a measurement time of 300 s using a ring sensor in which are associated a heating element with a temperature sensor. In order to provide an excellent thermal contact, the ring sensor which has a radius of 15 mm must imperatively be sandwiched between flat faces of two identical specimens as shown in Fig. 2-b.

2.3.2. Strength measurement

Mechanical properties of mortars were verified by testing their compressive strength. The test was carried out on the same parallelepiped samples previously used in thermal properties measurement. The compressive strength of each sample was an average of two values.

2.3.3. Chloride diffusion test

The test procedure is described as mentioned in the LCPC test method No58 [24]. After 28 days of curing, cylindrical specimens were completely saturated in a 0.1 M NaOH solution under vacuum for 24 h. After that, all faces of each specimen were coated with polyurethane resin except the bottom face which will be exposed to chloride solution then, they were partially immersed in a saline solution containing 0.5 M NaCl and 0.1 M NaOH. The solution level was maintained at 10 mm above the bottom surface of the specimen, and after an exposure period of 10 and 30 days specimens were removed from the saline solution and uncoated. Each specimen was split into two identical halves using the Accutom-5 cut-off machine (Fig. 3-a); one half of each specimen was sprayed with a 0.1 M silver nitrate solution and chloride penetration depth was measured from white silver chloride precipitation. Finally, apparent chloride diffusion coefficient was calculated from the measured X_d using Eq. (1).

$$D_{app} = \frac{X^2}{4t} \quad (1)$$

where, $\boldsymbol{D_{app}}$ is the apparent chloride diffusion coefficient (m^2/s); $\boldsymbol{X}$ is chloride penetration depth (m) and $\boldsymbol{t}$ is the exposure time (s).

The second half of these specimens was cut into three 5 mm thick slices from the immersed surface and the slice from the top as shown in Fig. 3-b. Each slice was ground into fine powder to measure the chloride content according to the chemical titration [24,25].

3. Results and discussion

3.1. Thermal behavior

Thermal behavior values of mortars containing various amounts of added SP and GP are presented in Fig. 4. As shown, it is obvious that control mortar has high thermal conductivity which is 1.24 W/m·K, compared to those of mortars with SP (Fig. 4-a). The increase up to 60% of SP content showed an important reduction of 34% in thermal conductivity. The incorporation of these shells as a partial replacement of sand can be considered as an effective way to improve thermal insulation by reducing thermal conductivity of mortars. Similar results have been reported previously by Lertwattanaruk et al. [18]. When mussel shells are added to mortars, significant improvement of thermal insulation may be related to the low specific surface area of these shells, leading to increase the capillary pore size and thereby decrease thermal conductivity and increase insulation properties. The addition of high content of SP, like other seashells, can cause a lower density and an increase in porosity of mortar, leading to a decrease in thermal