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A new consolidation process for expanded perlite particles

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HIGHLIGHTS

- A new process for expanded perlite particle consolidation with starch binder is developed for building materials.
- Compressive modulus and strength of perlite foams were characterized for a range of foam densities (0.1–0.4 g/cm^3).
- Compressive strength of perlite foam with a density of 0.3 g/cm^3 was found to be compatible with a heavy gypsum.
- Failure modes of perlite foam are identified as those characterized with longitudinal splitting and shear planes.
- Damage occurred during compaction is quantified using image analysis.

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ABSTRACT

A new process for expanded perlite particle consolidation with starch binder is studied for building material applications. Compressive modulus and strength of manufactured perlite foams were characterized for a range of foam densities (0.1–0.4 g/cm^3) and compared with gypsum. Compressive strength of perlite foam with a density of 0.3 g/cm^3 was found to be compatible with foamed gypsum with a range of densities, 0.7–0.9 g/cm^3. Failure modes under compression were identified as those characterized with longitudinal splitting and shear planes. Damage occurred during compaction was quantified using image analysis. As expected, more damage was found for a higher density of perlite foam.

1. Introduction

Perlite is a naturally occurring hydrated volcanic glass with a rhyolithic composition [1], which can be processed into an expanded form for cellular structure formation [2,3]. The expansion takes place due to the presence of water in perlite when it is heated to about 649–816 °C [4]. Expanded perlite particles have an excellent potential for building material applications in the first instance, given that they are inexpensive, light and possess good acoustic [5] and insulation properties [6]. Also, they are environmentally friendly because they do not react with, or leach into, ground water [7], and are therefore potentially excellent candidate core materials of sandwich composites in general. In building industry, material cost is a driving force in selecting materials as large quantities of materials are required. In applications for interior walls and ceilings, material weight is an important consideration for installation and performance. There have been efforts to reduce the material density in such applications by forming gas bubbles in the case of gypsum but with marginal success [8].

Various mixing and moulding methods have been previously developed for expanded perlite particle consolidation, including polymerization onto perlite for polyaniline–perlite composites before compaction for electrical conduction applications [9]; dry/wet-mixing for Portland cement and perlite for blocks [10]; and dry/wet-mixing for perlite/sodium silicate using a Hobart mixer and moulding [11]. The dry-mixing/slurry moulding has been used for various applications, including roof insulation panels made of fibers and bituminous material [12], perlite–cement composites [13], building boards made of fiber and asphalt coated perlite (rotary vacuum filter) [14] or made of urea–formaldehyde resin/mineral fibers/ gypsum/glass fibers [15], fibres–sodium silicate composite [16], concrete blocks [17], and moisture resistant gypsum boards modified with perlite and starch [7].

The slurry moulding methods employ a mixture consisting of two phases – one is liquid phase and the other solid particle

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mixture phase before pouring the mixture into a mould. The slurry state is useful for shear-mixing for homogenization of the fragile perlite-dominant-mixture with the benefit of a liquid phase. The liquid phase, however, is an unwanted excess in a mould or in a forming process unless it is required for chemical reactions. Therefore, the smaller liquid phase the better at the final forming stage of consolidation for drying. However, the larger liquid phase the better for homogenization to some extent for mixing constituents.

In a slurry moulding, the excessive liquid phase should be removed requiring another mechanism for its drainage to obtain a wet-mix (consisting of capillary, funicular, and pendular stages – see Ref. [18] for definitions). When drainage is allowed, the solid constituents are washed away by the slurry flow unless felt-like material is used underneath for holding solid constituents. Therefore, it is not suitable for making a sandwich board with facing skin materials which do not have such a drainage function (e.g. paper skin). Also, the slurry flow after moulding is potentially harmful for maintaining a consistent composition (e.g. for particle binder [19]) if the layer of mixture on the felt-like material acts as a filter. Concurrently, the less liquid phase in the mixture, the higher chances to damage the perlite particles are expected during shear-mixing for homogenization.

The dry/wet-mix moulding is to improve the methods by removing the slurry moulding stage. It employs spraying or fine streaming to obtain the wet-mix before moulding. However, not only it increases the chances of damaging the perlite particles during the shear mixing but also the efficiency of mixing is not as good as the slurry mixing. It is, therefore, limited to small perlite particle sizes. Thus, the size of liquid phase has been a trade-off between mixing efficiency and particle damage in various manufacturing methods.

An alternative moulding method for perlite moulding without the trade-off may be the flotation method based on the buoyancy principle to obtain a wet-mix to eliminate the drainage process before moulding. It has been used for hollow microsphere consolidation for manufacturing syntactic foams [20–27]. It is capable of separating phases due to the buoyancy and attractive forces between particles and binder following slurry mixing for homogenization, and then collecting constituents as a wet-mix but without damaging fragile constituents before moulding. In this paper, the flotation method in conjunction with a compaction technique for consolidating expanded perlite particles is proposed as a new process, and some basic properties and failure behavior of manufactured foams are analyzed and characterized.

2. Perlite and starch particle characterization

Expanded perlite particles (P400) were provided by Ausperl Pty Ltd and were sieved using custom made sieves of hole diameters between 3 and 4 mm. A batch of potato starch particles (Tuan Chun Soy and Canning Company, Hong Kong) was used as binder for consolidating expanded perlite particles.

Particle densities were measured using an air pycnometer (Micrometrics AccuPyc 1330) and an average from at least three measurements was used. Particle densities of 0.61 g/cm^3 and 1.5 g/cm^3 were found for expanded perlite and starch particles respectively. Bulk densities for the same particles were also measured using a tapper with a glass cylinder (100 ml, 28 mm diameter, from 500 taps) and found to be an average of 0.090 g/cm^3 and 0.85 g/cm^3 for expanded perlite and starch particles respectively.

3. Process for manufacturing perlite foams

The process consists of different stages and units for gelatinization of starch, feeding of expanded perlite particles, mixing and flotation, characterization of formability for wet-mix consisting of perlite particles and starch binder, and compaction. The details are given below.

3.1. The flotation process

The pre-mould process [25] was adopted to consolidate the expanded perlite particles. The gelatinization process was conducted by mixing potato starch particles in water and then heating for 20 min at 65–70 °C with continuous stirring. The obtained binder was cooled to room temperature with further stirring to avoid any kind of non-homogeneous formation.

Dry perlite particles were poured into mixing container containing the prepared binder followed by stirring/tumbling (about 300 strokes) of the mixture. The mixing container was left until perlite particles float to the surface and starch settles down. As a result, three different phases were formed in the mixing container: top phase made of perlite particles with gelatinized starch and water, middle phase made of water, and bottom phase made of gelatinized starch and water. The top phase was formed immediately but the bottom two phases were formed after 5–7 h following the separation into two phases. It is a wet mix as distinct from the slurry in the presence of the buoyancy of perlite particles.

3.2. Characterization of formability for wet-mix

Drying of the wet-mix after moulding into rectangular moulds (110 mm × 30 mm × 16 mm) was conducted in an oven at 80 °C for characterization of formability. As a result, mass reduction per unit volume versus drying time was obtained for a ratio of starch to water (3 g starch in 100 ml water) and given in Fig. 1. It is expected after moulding that the wet-mix consists of capillary, funicular, and pendular stages, but, as the drying time progresses, it loses the capillary stage first, then the funicular and finally the pendular stage before the final solid stage.

In order to find suitable manufacturing conditions for mechanical testing samples, three drying stages were defined for tactile and visual testing. The Stage I is defined as the initial stage where, when it is finger pressed/touched, the following take place: (a) the liquid phase (or binder) is oozed out and its glossy surface is visible or (b) fingers can get wet. It may be suitable for sandwich composite manufacturing because the binder may easily stick to the facing skins without additional binder. The Stage II is defined as an intermediate stage following the Stage I where only the finger can get damp. At this stage, the wet-mix was still reversibly deformable and can be unmoulded but without disturbing its moulding shape. It may be suitable for the preparation of mechanical testing samples such as core of sandwich composites (without facing skins).

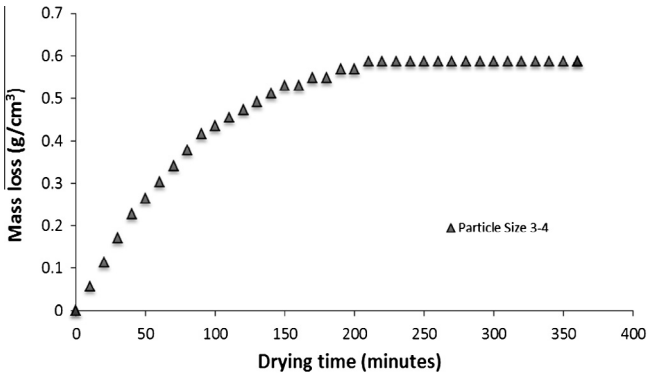

Fig. 1. Mass reduction per unit volume (g/cm^3) of wet-mix versus drying time at 80°C after moulding. Starch content in binder was 3 g starch/100 ml water.