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A new consolidation process and properties for expanded perlite particles

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Abstract

A new process for expanded perlite particle consolidation with starch binder is studied for applications in building materials. Compressive modulus and strength of manufactured perlite foams were characterized for a range of relative foam densities (0.1 - 0.4) and compared with gypsum board. Compressive strength of perlite foam with a density of 0.3 was found to be compatible with foamed gypsum with a range of densities, 0.7-0.9. 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

Keywords: Process. Method, Floatation, Buoyancy, Perlite, Syntactic foam, 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 on to 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[Luongo].

The slurry moulding methods employ a mixture consisting of two phases – one is liquid phase and the other solid particle 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 practical 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 reference[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 pearlite 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 pearlite 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.[^{20,21,22,23,24,25,26,27}] 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 for the current work. 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/cm³ and 1.5 g/cm³ 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 (100ml, 28mm Diameter, from 500 taps) and found to be an average of 0.090 g/cm³ and 0.85 g/cm³ for expanded perlite and starch particles respectively.

3. Process for manufacturing perlite foams

The process adopted is outlined in **Figure 1**. It consists of different stages and units for gelatinization of starch, feeding of expanded perlite particles, mixing and floatation, characterization of formability for wet-mix consisting of perlite particles and starch binder, and compaction.

3.1 The flotation process

The pre-mould process[Mainul] 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 minutes at $65-70^{\circ}$ 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 a prepared binder of the mixing container and followed by stirring/tumbling (about 300 strokes). 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 several hours 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 (110mm x 30mm x 16mm) 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 (3g starch in 100 ml water) and given in **Figure 2**. 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). The Stage III is defined as the final stage where the binder is solidified and therefore cracking (damage) occurs if external forces are applied - its damage is irreversible without extra binder.

A batch of wet-mix at a ratio of starch to water (2.5g starch/100ml water) in a drying mould at 80°C was prepared and measurements were conducted to identify the three Stages. For consistency, the tactile testing was conducted with a finger pressure impression for a depth of about 5mm on the wet-mix surface for initially wet-mix of 11 to 16 mm thick. It was found that 0-40 minutes for Stage I, 50-110 minutes for Stage II and longer than 120 minutes.

3.4 Compaction for mechanical testing specimen preparation

For manufacturing mechanical test specimens, three different volumes of wet mix were prepared for pouring into cylindrical moulds at Stage 2. The cylindrical moulds were in three different sets of dimensions (a constant diameter of 30mm with three different heights 50mm, 95mm or 125mm) for the three different volumes of wet-mix respectively. The larger mould volume the higher density can be produced for a constant final compacted volume with 32mm high and 30mm in diameter (ASTM C365/C365M – Standard test method for flatwise compressive properties of sandwich cores). Each moulding was compacted to have a range of different densities. A Shimadsu universal testing machine was used for compaction at a crosshead speed of 10 mm/min. Two different density types of manufactured specimen i.e. wet and dry densities were measured and are given in **Figure 3**. The wet density and dry density were obtained before and after drying respectively following the compaction. The relation between density and densification pressure appears to be linear with a correlation coefficient (*r*) of 0.923 and y = 0.1641x + 0.3759 for wet and correlation coefficient (*r*) of 0.960 for y = 0.0791x + 0.1379.

4. Mechanical test results and discussion

Compressive tests were conducted at a crosshead speed of 10 mm/min. Compressive strength and modulus as a function of density are given in **Figure 4**. It appears that the compressive strength with the least square line y = 5.3895x - 0.5626 and a correlation coefficient (r) of 0.9801 appears to be very linear so that its trend is easily predictable whereas the modulus tends to have a high scatter. (The modulus was obtained using a tangent line to stress-strain curve at the inflection point.) The compressive strengths at a density of about 0.3 appears to be compatible with those of foamed gypsum[Colak] which has a range of 0.41 - 1.8 MPa at a density range of 0.7-0.9 g/cc. Therefore, they may be adoptable for practical products with the benefit of much lower densities.

In genral, the load-displacement curves (Figure 5) were found to be similar to those for syntactic foam made of cenospheres and starch [Chapter and MainulJMS] but different from those for syntactic foam made of 3M Scotchlite Glass K1 microspheres and epoxy[Kim and Plubrai]. The load-displacement curves were found to have a typically single peak without substantial rising part for the densification as shown in Figure 5 (a)-(c) with specimens under compression unless double peaks appeard occasionally as shown in Figure 6. The failure modes with loaddisplacement curves provide an useful information about bonding state between particles, relative properties (e.g.strength and load carrying capacity) between particle and binder, and adequacy of binder content. In general, three different failure modes under compression [i.e. logitudinal splitting (LS), sliding failure on 45° shear plane (SF), and layered crushing (LC)] have been identified in the previous syntactic foam research[Plubrai, Mainul pre, Chapter]. In the current work, the LS mode was found for very low [Figure 5(b)] or very high [Figure 5(a)] densities and SF mode was also found for medium to high densities. However, LC mode was not found in the current perlite foam unlike 3M Scotchlite Glass K1 microspheres, indicating that perlite cell structure may be sufficiently strong not to have the layered crush. Also, two different types of the SF mode were found: one type is with a single sliding shear plane [Figure 6] and the other with multiple sliding shear planes at slightly different angles [Figure 5(c)].

If cracking [on shear plane(s)] takes place at the (first) peak for SF mode, it is expected that the single sliding plane facilitates an easier sliding motion under loading than the mutiple sliding planes because the multiple sliding planes do not provide an easy path for the sliding motion

without breaking through neighbouring material. This allows us to hypothesize that the former (single sliding plane) leads to a lower modulus for a given density and latter to a higher modulus. To test the hypothesis, data points in **Figure 4(b)** were examined against individual failure types. It was found that data points for high densities with low moduli correspond to the single plane SF mode and those for high densities with high moduli correspond to the multiple plane SF mode, supporting the hypothesis. However, it was not clear when such multiple sliding planes formed. The finding, nonetheless, explains why a high scatter of data points for modulus [**Figure 4(b)**] appear compared to those for compresive strength [**Figure 4(a)**]. The double peaks in the load-displacement curve for the single plane SF mode can be also explained as follows: if a specimen longer than that with a critical aspect ratio as is the current case, the bottom or the top of the sliding plane moves and then touches the testing platten during loading; then, the material sliding stops and partially densification process as well as deformation takes place to form the second peak.

Another factor which might affect the failure mode would be a density variation in the longitudinal direction of the specimen. The variation takes place due to the friction between wetmix and mould wall during compaction, and appeared as slightly different textures on a specimen surface. Such a density variation tends to be high for high specimen density. For relatively high density specimens, a consistant cracking initiation location was found to be at the low density side of each specimen as expected. However, no evidence was found for the failure mode change caused by the density variation.

5. SEM exmination and discussion

One of the issues for expanded perlite particles is damage appearing in a form of debris during compaction. Scanning electron microscopy (SEM - Philips XL 30) was employed for visual examinations to find debris proportions. Figure 7 (a) shows an expanded perlite particle prior to the manufacturing process revealing a cellular structure through open parts of the particle surface. Figure 7 (b) shows manufactured perlite foam surface with a density of 0.29 g/cm³ after compaction, displaying debris due to the direct contact with a mould wall surface during compaction. Figure 7 (c) shows fracture surface (density 0.38 g/cm^3) after compression test, displaying partially broken particle surfaces and undamaged part of particle surfaces. These features appear to be useful for understanding structural particle damage during compaction or after compression although they are qualitative. For further quantitative damage, sample surfaces were prepared by either manually breaking for bending or with pencil knife cuts in a longitudinal or transverse direction and air brushed for statistical image analysis. Not much difference between two different ways of preparation was statistically found. Up to 9 points with approximately equal spacings were chosen on each SEM sample for viewing and image analysis using a software (ImageJ) to calculate damage areas consisting of debris. Figure 8 (a) is one of images for surface prepared by hand breaking for a density of 0.21 g/cm^3 . The damaged area made of crushed debris is seen on the bottom right hand side. Figure 8 (b) is another one of images prepared with a pencil knife cut in the longitudinal direction for a foam density of 0.29 g/cm³. It displays a distinctive texture in a dark area for debris. The damage areas calculated are summarized in Table 1. They are about 15 to 16 % of image areas for debris for a foam density of 0.21 g/cm³ and 21-29% for a density of 0.29 g/cm³. As expected, the higher damage is found for the higher density.

6. Conclusion

- The perlite particles have been consolidated successfully using the flotation method with a densification technique as a new process for manufacturing composites consisting of perlite particles and starch.
- Three different stages for perlite wet-mix have been defined and identified for consolidating perlite particles.
- Compressive strengths of the manufactured perlite composites at a relative density of about 0.3 have been found to be compatible with those of foamed gypsum.
- Failure mechanisms under compression have been identified.
- Some damage occurred during compaction have been quantified.

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References

¹ Le Maitre RW, Streckeisen A, Zanettin B, Le Bas BM, Bonin B, Bateman P, Bellieni G, Dudek A, Efremova S, Keller J, J. Lamere, Sabine PA, Schmid R, Sorensen H, Woolley AR. Igneous Rocks: A Classification and Glossary of Terms, Recommendations of the International Union of Geological Sciences, Subcommission of the Systematics of Igneous Rocks. 2nd ed. West Nyack, NY: Cambridge University Press; 2002.

² Singh M, Garg M. Perlite-based building materials – a review of current applications. Construction & Building Materials 1991;5:75-81.

³ Burriesci N, Carmelo A, Antonucci P. Physico-chemical characterization of perlite of various origins, Materials Letters 1985; 3 (3): 103-110.

⁴ Johnstone SJ, Johnstone MG. Minerals for the chemical and allied industries. 2nd ed. London: Chapman and Hall; 1961

⁵ Yilmazer S, Ozdeniz MB. The effect of moisture content on sound absorption of expanded perlite plates. Building and Environment 2005; 40:311-318.

⁶ Dube WP, Sparks LL, Slifka AJ. Thermal conductivity of evacuated perlite at low temperatures as a function of load and load history. Cryogenics 1991; 31: 3-6.

⁷ Luongo JS. Strengthened, lightweight wallboard and method and apparatus for making the same, Jun 2001;US Patent No 6,251,979 B1,.

⁸ Colak A. Density and strength characteristics of foamed gypsum. Cement and Concrete Composites. 2000; 22:193-200.

⁹ Arsalani N, Hayatifar M. Preparation and characterization of novel conducting polyaniline–perlite composites, Polymer International 2005; 54:933–938.

¹⁰ Gray B. Building material. Aug 1977: US Patent No 4,042,406.

¹¹ Shepherd PB and Dolin RL. Lightweight building material board. Oct 1993: US Patent No 5,256,222.

¹²Hill JH. Perlitic insulation board. Nov 1978: US Patent No 4,126,512.

¹³ H. Aglan, M. Morsy, A. Allie, and F. Fouad, "Evaluation of fiber reinforced nanostructured perlitecementitious surface compounds for building skin applications", Construction and Building Materials, Vol 23, pp.138–145, 2009.

¹⁴Miscall J,Rahr CE. Building board of fiber and asphalt coated perlite. Jan 1953:US Patent No 2,626,864.

¹⁵Sherman N, Cameron JH. Method of manufacturing improved mineral board. Oct, 1981: US Patent No 4,297,311.

¹⁶ Seybold HG, Wallboard composition and method of making same. Mar 1955: US Patent No 2,705,198.

¹⁷ Rodsky B, Building material. Oct 1958, US patent No 2,858,227.

¹⁸Takahashi M. Chapter 1.9 Kneading and plastic forming. In: Powder Technology Handling and Operations, Process Instrumentation, and Working Hazards", Masuda HM, Higashitani K, Yoshida H, editors. Powder Technology Handling and Operations, Process Instrumentation, and Working Hazards, CRC Press; 2006, p.115-119.

¹⁹ Islam MM, Kim HS. Manufacture of syntactic foams using starch as binder: post-mold processing. Materials and Manufacturing processes 2008; 23:884-892.

²⁰ Kim HS, Islam MM. Chapter 1 Syntactic foams as building materials consisting of inorganic hollow microspheres and starch binder. In Cornejo DC and Haro JL, editors. Building Materials: Properties and Performance and Applications, Nova publishers, 2009, p.1-56.

²¹ Kim HS. Syntactic foam. Aug 2009:AU Patent No PS0855, IP Australia,.

²² Kim HS. Method for forming syntactic foams. Sep 25 2008: US 2008/0233384 A1.

²³ Kim HS, Plubrai P. Manufacturing and failure mechanisms of syntactic foam under compression. Composites Part A: Applied Science and Manufacturing 2004; 35:1009-1015.

²⁴ Islam MM, Kim HS, Novel syntactic foams made of ceramic hollow micro-spheres and starch – theory, structure and properties, Journal of Materials Science 2007;42:6123-6132.

²⁵ Islam MM, Kim HS, Manufacture of syntactic foams: pre-mold processing, Materials and Manufacturing processes 2007;22:28-36.

²⁶ Islam MM, Kim HS, Manufacture of syntactic foams using starch as binder: post-mold processing. Materials and Manufacturing processes 2008;23:884-892.

²⁷ Islam MM, Kim HS, Pre-mould processing technique for syntactic foams: Generalised modelling, theory and experiment. Journal of Materials Processing Technology 2011; 211:708-716.

Sample	Foam density (g/cm ³)	Average debris area (%)	Standard deviation
Horizontal	0.21	15	5.3
Vertical	0.21	16	3.6
Horizontal	0.29	21	4.1
Vertical	0.29	29	10.8

Table 1 Debris area estimation during compaction.



Figure 1 Manufacturing process.



Figure 2 Mass reduction per unit volume (g/cm^3) of wet-mix versus drying time at 80°C after moulding. Starch content ratio in binder was 3g starch/100ml water.



Figure 3 Density as a function of densification pressure: (a) wet density before drying with a correlation coefficient (r) of 0.923 for the least square line y = 0.1641x + 0.3759; and (b) after drying with a correlation coefficient (r) of 0.960 for the least square line y = 0.0791x + 0.1379.



(a) (b) **Figure 4** (a) Compressive strength with the least square line y = 5.3895x - 0.5626 and a correlation coefficient (r) of 0.9801. (b) Modulus versus density.





Figure 5 Load-displacement curves with a single peak, and specimens cracked after the peak: (a) splitting failure mode for a high density specimen (0.29 g/cm^3) ; (b) splitting failure mode for a low density specimen (0.079 g/cm^3) ; and (c) multiple sliding planes for a high density (0.37 bg/cm^3) [dashed lines are superimposed to indicate the multiple sliding planes].



Figure 6 Load-displacement curve with double peaks, and specimen with a foam density of 0.32 g/cm³ showing a single sliding plane before reaching the second peak.



(a)



(b)



6

Figure 7 (a) A perlite particle showing some internal cellular structure. The scale bar indicates 0.5 mm. (b) Perlite foam surface after compaction for a density of 0.29 g/cm³, displaying bebris due to the direct contact with a mould wall surface during compaction. (c) Fracture surface (Size 3-4, density 0.38 g/cm³) after compression test, displaying partially broken particle surfaces and intact part of particle surface.



(a)



Figure 8 (a) Surface prepared by hand breaking for bending, displaying areas of localized debris but patchy on the left hand side for a density of 0.21. (b) Surface prepared with a pencil knife cut in the longitudinal direction and air brushed for a foam density of 0.29. It displays a distinctive texture in dark area for debris.