Production of durable expanded perlite microspheres in a Vertical Electrical Furnace

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Abstract. Expanded perlite constitutes one of the most competitive insulating materials that is widely used in construction and manufacturing industry due to its unique properties combination; it is white, natural, lightweight, chemically inert, and exhibits superior insulating properties (thermal and acoustic) and fire resistance. Conventionally, perlite expansion is performed in vertical gas-fired furnaces; the conventional perlite expansion process has certain disadvantages which affect expanded products quality, thus limiting their performance and range of applications. In order to overcome the drawbacks of the conventional expansion technique, a new perlite expansion process has been designed based on a vertical electrical furnace (VEF). In the current study, fine perlite samples (150 μm) from Milos Island, Greece, were expanded in the novel VEF and a conventional gas-fired furnace with the aim to evaluate and compare the main physical properties of the expanded products. The novel expanded perlite particles were characterised by superior properties, namely increased compression strength, competitive water and oil absorption capability, size homogeneity, spherical shape and decreased surface porosity in comparison to conventionally expanded samples.

1. Introduction

Perlite is a natural occurring volcanic rock that mainly consists of amorphous silica (70-76% wt SiO2) and low amounts of other metal oxides (Al2O3, K2O, Na2O, Fe2O3, CaO, MgO). Due to the presence of 2-6% chemically bound water in its structure, perlite can be expanded up to 20 times its original volume when heated rapidly at a temperature that exceeds its softening point (in the range between 700 and 1260 °C) [1,2], as the contained water vaporises and pushes its way out of the grain. Expanded perlite particles are characterised by an extensive network of air bubbles that has beneficial effect on their properties. Expanded perlite is a lightweight material (bulk density lower than 150 kg·m-3), inorganic, chemically inert, fire resistant, with superior thermal and sound insulating properties, while its properties are invariant in time.

More than 70% of the perlite world production is intended for construction industry, where perlite is used to reduce construction weight and improve thermal and sound insulation and fire resistance. Moreover, it is used in various other industrial sectors, like horticulture applications, food and chemical industry. The main physical properties of expanded perlite, like loose bulk density, thermal and acoustical properties, water retention, grain durability and stability, are mainly affected by the expansion conditions [2,3].

On industrial scale the perlite expansion is mainly conducted in vertical gas-fired furnaces, consisting of a vertical expansion chamber with a direct flame at its bottom-end directing a forced air flow upwardly [4,5]. Although this technique is in use for more than 50 years, it still remains an
empirical industrial process, despite the rapid increase and development of expanded perlite applications over the last decades. One of the major drawbacks of this technique is the lack of detailed knowledge and control of the expansion conditions (temperature and air velocity) inside the heating chamber, which have an adverse impact on the expanded particles properties and characteristics. Conventionally expanded perlite grains have irregular shape, extended network of open pores and obvious signs of structural destructions, resulting in lack of durability or stability [6]. These properties limit significantly the range of its applications in the construction and chemical industry. In order to meet the technical targets for innovative applications, there is need for expanded perlites with improved properties in respect to their mechanical and surface characteristics. [6,7].

In order to overcome these disadvantages and produce high quality expanded perlite, a new expansion process based on the use of a Vertical Electrical Furnace has been designed and constructed by the Laboratory of Metallurgy of the NTUA [6,8-10]. The new furnace is characterised by a) precise control and the flexibility of the expansion conditions, depending on the raw material characteristics and the required properties of the expanded product; b) broader range of grain sizes that can be sufficiently operated in the furnace, and c) the use of milder temperature profile [8,10].

In this work, the physical and structural properties of ultrafine perlite samples expanded in the new VEF and in a conventional gas-fired furnace under various expansion conditions were studied and compared. In detail, the effect of both expansion techniques on the loose bulk density (LBD), water repellency, oil absorption, compressive strength, surface morphology and particle size distribution was investigated.

2. Materials and methods

2.1. Materials

Two different raw perlite samples (CH and TR) were used in the present study, originating from two different quarries of S&B in Milos Island, Greece, and supplied by S&B Industrial Minerals S.A. The chemical composition of the two perlites are presented in Table 1. The chemical analysis was performed using Energy Dispersive X-Ray Fluorescence (EDXRF) instrument Xepos (SPECTRO A.I. GmbH Company), and the Al2O3 content was defined by flame Atomic Absorption Spectroscopy (FAAS, Perkin Elmer 2100 spectrophotometer) after dissolution in a HF/HClO4/HNO3/HCl mixture. Loss of Ignition (L.O.I) was determined by heating the dried, pulverized samples up to 1050 °C for 1 hour. Although both samples have a typical perlitic composition, TR is characterised by higher L.O.I., attributed to the bound water and volatiles [(CO, CO2, H2, I2, Cl2, F2) or (H2, CO2, CO, SO2, O2)] [11,12], and potassium (K2O) content. These elements play a significant role in the expandability of perlite, as they affect the melt dynamic viscosity [13]. The mineralogical composition was determined by X-Ray diffraction (XRD) on a SIEMENS D5000 diffractometer with Cu-Kα1 (Ni filtered) radiation, in the 2theta range from 5 to 75° and 0.02°/sec step, and indicated the dominance of amorphous silica, but also the presence of the crystalline phases quartz, alkali and plagioclase feldspars, and biotite (Fig. 1). The granulometry of the raw materials studied was below 150 μm, measured on a Malvern Laser Particle Analyser.

For the characterisation of the expanded materials Loose Bulk Density (LBD), water repellency, oil absorption and compressive strength were determined. The particles morphology was also studied through Scanning Electron Microscopy using a JEM 1600 analyser. The measurement of oil absorption was based on an ISO standard method [14], while the water repellency (determination of the absorbed water volume in the perlite sample after a saturation cycle) was measured using an internal test procedure that has been developed by S&B Industrial Minerals S.A. [15]. The compression strength measurement was based on the calculation through a hydraulic ram, of the pressure established at the sample surface when the sample height was reduced by 3 cm [16]. For the calculation of the LBD the total volume of the expanded material, including the solid volume (skeletal volume), the volume of closed and open voids, and the volume of the inter-particle space was taken.
into account. The expanded perlite particles size distribution was measured using a Malvern Laser Particle Analyzer for diameters below 500 μm and through sieving for the coarser particles.

### Table 1. Raw perlite chemical composition

| Oxides | CH (%) | TR (%) |
|--------|--------|--------|
| SiO₂   | 72.57  | 75.03  |
| Al₂O₃  | 13.73  | 12.70  |
| Na₂O   | 3.99   | 3.43   |
| K₂O    | 3.62   | 5.39   |
| CaO    | 1.39   | 0.84   |
| Fe₂O₃  | 1.25   | 0.91   |
| MgO    | 0.37   | 0.30   |
| TiO₂   | 0.15   | 0.08   |
| LOI    | 2.92   | 3.32   |

### 2.2. Methods

In this study, two different expansion techniques are considered, the one based on the use of the new VEF and the other on the use of the conventional vertical gas-fired furnace.

The VEF includes the: a. heating chamber consisting of a cylindrical tube with length 3m and diameter 13.4 cm made of Kanthal APM FeCrAl alloy [17]; b. heating sources consisting of 6 pairs of electrical Kanthal resistances (total heating capacity 24 kW, maximum temperature 1250°C), located around and along the tube, defining six heating zones, the setting points of which can be adjusted independently; c. raw material feeding system, d. the air supply system and e. particle collector [6]. The raw perlite particles are fed directly at the top of the heating chamber and as they are moving downwards through regions of progressively increasing temperature, they are expanded, and are collected at the bottom of the chamber. An air stream can be injected at the direction of the gravity force in order to better control the particle residence time in the chamber. Temperature measurements within each thermal zone are obtained via ceramic sheathed N-type thermocouple (Ni-Cr-Si/Ni-Si) placed at each zone centre. The particle heating rate and processing time can be controled by proper adjustment of the heating resistances temperature and air feeding rate.

The conventional expansion furnace consists of a vertical heating chamber, the cyclone and the aspiration system. The chamber contains a direct flame at its bottom-end directing a forced air flow upwardly. The perlite particles are introduced through side ports to the hottest region of the expansion chamber near the flame at 1450oC, where they expand almost instantaneously [4,7]. The lightweight particles are carried away by the hot off gases stream; the air-solid stream exits the heating chamber by means of the aspiration system. The average residence time of perlite particles in the expansion chamber is less than one second, except for the coarsest particles [5].

5 perlite samples were subjected to expansion both in the new VEF and in the conventional vertical gas-fired furnace, under various temperature and air feeding rate conditions, summarised in Table 2.

### Table 2. Studied expansion conditions in the VEF

| Parameter               | Value range                  |
|-------------------------|-------------------------------|
| Furnace temperature (°C)| 600-1200 (gradient in the 6 zones) |
| Air feeding rate (L/min)| 15-100                        |
| Perlite type            | TR, CH                        |
| Feed granulometry       | -150μm                        |
3. Results and Discussion

The studied properties of the expanded materials produced by both expansion techniques are shown in Fig. 2. The samples are compared in pairs. In each pair the same raw perlite sample has been expanded with the two difference techniques to produce two expanded samples of similar LBD. Regardless of the applied expansion technique, the lighter the material becomes the lower its compression strength gets. In all cases, the compression strength of the samples expanded in the VEF is 75 to 460% higher compared to the corresponding conventionally expanded ones. The percentage of improvement depends on the perlite type and it is much higher in the case of TR perlite (pairs 1, 2 and 3).

Figure 2. LBD, compression strength, water repellency and oil absorption of the various expanded samples

Contrary to compressive strength, the water repellency and oil absorption of the samples expanded in the VEF was not significantly improved compared to the corresponding conventionally expanded materials. Depending on the perlite type and LBD of the expanded material, the water repellency is up to 10% improved compared to the corresponding conventionally expanded materials, while the oil absorption is up to 20% improved. Generally, liquid absorption increases as LBD decreases, indicating that more extended porosity is created at higher expansion degree (lower LBD). For the same LBD, the improvement of oil absorption is quite higher than the improvement of water repellency, signifying a difference in the pore diameter of the VEF expanded materials and the corresponding expanded ones. These results are in agreement with the particles morphology as shown in the SEM photos of perlite samples expanded by both expansion techniques, presented in Fig. 3. Significant morphological differences are observed depending on the applied expansion technique, which corroborate the values of the measured physical properties; conventionally expanded samples consist of irregular particles with extended network of open pores on their external surface. On the other hand, perlite samples that have been expanded in VEF consist of spherical particles of smooth surface and limited number of pores or cracks on their surface.

Figure 4. Granulometry of the expandes perlite samples that have been expanded int he VEF (blacklines) and in conventional gas-fired furnace (coloured lines)
Evidently, the applied expansion technique affects the morphology and consequently the physical properties of the expanded products. The extensive surface porosity of the conventionally expanded particles is attributed to the violent heating conditions during expansion, leading to particle splitting, breakage or even explosion. On the other hand, the open porosity is limited in the cases where expansion has been performed in the VEF, where the particle heating is milder, resulting in a more gentle expansion performance. The spherical shape and closed surface of the particles expanded in the VEF is related to the increased mechanical strength of these materials.

The particle size distribution of all the expanded samples together with that of both raw materials (CH, TR) are presented in Fig. 4. The granulometry of the materials expanded in the VEF was narrower and their mean size was larger compared to conventionally expanded ones of similar LBD. These results indicated that VEF particles were better expanded and had a more uniform and spherical shape, as also shown in SEM photos of Fig. 5. Moreover, the high content of conventional expanded samples in fine particles can be attributed to their splitting during the violent expansion conditions.

![Figure 3. SEM micrographs of sample CONV1 (a), VEF1 (b), CONV5 (c) and VEF5 (d)](image)

4. Conclusions
In this study, the physical and structural properties of two different perlites originating from Milos Island, Greece, expanded with the application of a new expansion process based on the use of a Vertical Electrical Furnace (VEF) were investigated, and compared to those of conventionally expanded samples of similar density and perlite type.

The experimental results confirmed that the novel expansion process can produce well expanded perlite microspheres with superior mechanical properties and marginally improved liquid absorption compared to conventionally expanded perlite, as a result of the milder expansion conditions and the precise control of the expansion process that the furnace can provide. The perlite particles expanded in the VEF are characterised by 75 to 460% increased compression strength, up to 10% improved water repellency and up to 20% improved oil absorption. Moreover, the samples treated in the VEF have more homogeneous particle size distribution and larger mean size. Finally, the expanded particles have an almost spherical shape with limited surface porosity or cracks in contrast to conventionally expanded particles, which are characterised by extensive surface porosity and irregular shape.
Acknowledgement
This research work has been financed by the European Union FP7 under Grant Agreement Number CP-IP 228697-2 (“Efficient exploitation of EU perlite resources for the development of a new generation of innovative and high added value micro-perlite based materials for the chemical, construction and manufacturing industry”, EXPERL). Dr. P.M. Angelopoulos would also like to gratefully acknowledge the financial support of the Greek State Scholarships Foundation (IKY).

References
[1] Chatterjee K 2008 Uses of Industrial Minerals, Rocks and Freshwater Nova Science Publisher, New York
[2] Barker JM, Santini K 2006 Perlite, Industrial Minerals and Rocks (Kogel, J.E., Trivedi, N.C., Barker J.M. and. Krukowski, S.T. editors) SME, 685-702
[3] Karalis T, Taxiarchou M 2006 Current applications and future trends of perlite worldwide, Proceedings of the 2nd International Conference on Advances in Mineral Resources Management and Environmental Geotechnology AMIREG (Chania, Greece). 227-234.
[4] Papanastasiou DJ 1979 Perlite expansion in a vertical furnace – a simplified theoretical analysis, Perlite Institute Annual Proceedings (Dubrovik). 67-71.
[5] Sodeyama K, Sakka Y, Kamino Y, Seki H, J Mater Sci. 34, 2461-2468.
[6] Peppas A, Taxiarchou M, Koffa E, Karalis T, Amanatidis A 2006 Development of closed porous microcellular products from perlite Proceedings of the 2nd International Conference on Advances in Mineral Resources Management and Environmental Geotechnology AMIREG (Chania, Greece). 235-240.
[7] Klipfel A Founti M Zahringer K Martin J and Petit J 1998 Flow Turbul. Combust. 60 283-300
[8] Angelopoulos P Gerogiorgis DI and Paspaliaris I 2014 Appl. Math. Model. 38 1799-1822
[9] Angelopoulos PM Gerogiorgis DI and Paspaliaris I 2013 Ind. Eng. Chem. Res. 52 17953-17975
[10] Angelopoulos P Kapralou C and Taxiarchou M 2011 CFD modeling of vertical electrical furnace for perlite expansion: study of the air temperature and velocity profiles. In Proc of the 7th GRACM (Athens, Greece, June 30- July 2 2011) CD edition
[11] Dalakishvili AI 2005 Glass Phys Chem. 31, 820-822.
[12] Shackley D, 1988 Characterization and expansion of perlite. PhD Dissertation, Nottingham University
[13] Zähringer K, Martin J, Petit J 2001 J Mater Sci. 36, 2691–2705
[14] ISO 787-5 1980 General methods of test for pigments and extenders - Part 5 Determination of oil absorption value ISO Standards Handbook: Paints and varnishes Vol 3: Raw materials (2002) Ed.3
[15] S&B Industrial Minerals S.A., 2003. Method for water repellency test of expanded perlite. Internal Test Procedure (ITP) Documentation Greece
[16] S&B Industrial Minerals S.A., 2003 Method for durability measurement of 3-centimetres expanded perlite compression strength. Internal Test Procedure (ITP) Documentation Greece
[17] Kanthal  Company Website http://www.kanthal.com/en/products/materialdatasheets/tube /kanthal-apm. Access date: Feb 2014.