A Study on Some Factors Affecting on CO_2 Curing of Expanded Perlite Based Thermal Insulation Panel

Gökhan Durmuş[1(✉)], Onuralp Uluer[2], Mustafa Aktaş[3], İbrahim Karaağaç[2], Ataollah Khanlari[4], Ümit Ağbulut[5], and Damla Nur Çelik[6]

[1] Department of Civil Engineering, Faculty of Technology, Gazi University, Ankara, Turkey
gdurmus@gazi.edu.tr
[2] Department of Manufacturing Engineering, Faculty of Technology, Gazi University, Ankara, Turkey
{uluer, ibrahimkaraagac}@gazi.edu.tr
[3] Department of Energy System Engineering, Faculty of Technology, Gazi University, Ankara, Turkey
mustafaaktas@gazi.edu.tr
[4] Natural and Applied Science Institute, Faculty of Technology, Gazi University, Ankara, Turkey
[5] Department of Manufacturing Engineering, Faculty of Technology, Düzce University, Düzce, Turkey
[6] Department of Civil Engineering, Faculty of Engineering, Antalya Bilim University, Antalya, Turkey

Abstract. Energy, which is needed for every aspect of life, plays a key role for the development of the countries. Countries need to use energy efficiently to be advantageous in the global competition and ensure the sustainable development. Countries using the energy efficiently succeed economically and have leading the field in the competition. The purpose of this study is to put forward to the role and importance of energy efficiency for the sustainable development of the countries. In this study, energy efficiency has been examined conceptually considering the studies in the literature and the role and importance of energy efficiency has been emphasized for the sustainable development of the countries.

Keywords: Energy · Efficiency · Sustainable development

1 Introduction

There are many thermal insulation materials used in thermal insulation technology. Especially in the construction industry, traditional heat insulation applications usually include expanded polystyrene foam (EPS), extruded polystyrene foam (XPS), polyisocyanurate (PIR), rigid polyurethane (PUR), and PUR/PIR. However, recent literature studies have shown that expanded perlite material can be used as the main material in thermal insulation materials [1].

S. Fırat et al. (eds.), *Proceedings of 3rd International Sustainable Buildings Symposium (ISBS 2017)*, Lecture Notes in Civil Engineering 7,
https://doi.org/10.1007/978-3-319-64349-6_6

Perlite is one of the natural insulation materials. Perlite is obtained from pumice, which is a glassy form of rhyolitic or dacitic magma. It contains 2–5% water [2]. When perlite is suddenly heated (at temperatures of 649–816 °C), the created steam forms bubbles within the softened rock to produce a frothy-like structure. The formation of these bubbles allows perlite to expand up to 15–20 times of its original volume [3]. Expanded perlite (EP) has superior properties such a light apparent density, low thermal conductivity, good chemical stability, wide use temperature scope, non-toxic, tasteless, fireproofing, sound absorption [4]. EP thermal properties make it possible to use it as thermal insulation materials [5]. In addition EP can be used as an additive in various mixtures or as a main component for composite e.g. portland cement/perlite composites for blocks, perlite/sodium silicate boards, roof insulation panels made of perlite/fibres/bituminous material, fiber reinforced perlite/cement composites, gypsum/perlite composites and light weight concrete etc. [6]. However, their applications as the main constituent of composites have been limited due to relatively poor mechanical properties low strength [7].

The expanded perlite is used as main material in thermal insulation materials and as aggregate in the production of Portland cement/perlite composites. There are some important considerations related using expanded perlite based thermal insulation materials. These considerations are the type of binder used to bond the expanded perlite particles, additive materials (fibers, waterproofing agents, fire retardant, etc.) to improve thermal, mechanical and physical properties of the thermal insulation panel, pressing pressure and curing conditions. Curing conditions are one of the important parameters to achieve the desired properties. Conventional and microwave techniques are available for curing such a thermal insulation panels [8–11].

Researchers focused on different curing methods for EPHIB. Taherishargh et al. studied mechanical properties of heat-treated expanded perlite–aluminum syntactic foam. Based on the conditions under which the optimum mechanical properties were achieved, the specimens were solution treated at 540 °C for 16 h. Then, the specimens were treated at 160 °C for 10 h to cool down. As a result, when the heat treated sample's density increase, the strength of the heat treated sample has significantly increased [12].

Arifuzzaman and Kim studied expanded perlite/sodium silicate composites. Sodium silicate was used as a binder. The diluted samples were cured in an electric fan forced air oven (Lebec Oven BTC-9090) at 65 °C for 10 h [7]. Demirboğa and Gül, investigated that the thermal conductivity and compressive strength of EP aggregate concrete with mineral admixtures. They prepared a concrete mixture using laboratory counter-current mixer for 5 min. For each mixture, all specimens were cured in lime saturated water at 20 ± 3 °C until 6th, 14th and 27th day. According to their results, the lowest value of thermal conductivity of sample was 155.3 mW/m K [13].

Shastri and Kim studied that a new consolidation process for expanded perlite particles. They cured samples after molding for characterization of formability in an oven at 80 °C for 6 h. It has been found that the compressive strength at a density of 0.3 g/cm^3 of perlite foam is similar to that of gypsum foam having densities between of 0.7–0.9 g/cm^3 [14]. Tian et al. studied the effect of pressing pressure and curing temperature on mechanical properties of EPHIB. They indicate that 0.38 MPa of compression pressure and 105 °C temperature are suitable for EPHIB [4].

Skubic et al. investigated the effect of microwave method expanded perlite based heat insulation boards. They indicated that quick drying can be achieved by microwave method. But, an appropriate temperature control should be applied to avoid hot spot inside the panel [8]. In another study by Skubic et al. sintering behavior of EPHIB theoretically and experimentally. They used microwave method to sinter the panels. Then the panels treated at high temperature. As a result, the high-temperature treatment caused shrinkage in some parts of the insulation plates. Also, the thermal conductivity of panel was obtained as 0.045 W/m K [10].

Erdoğan, studied the usage of perlite to produce geopolymers. He produced geopolymers mixing alkaline activator and expanded perlite material. He stated that the most suitable condition is dry curing for mechanical properties of geopolymers. When the curing temperature was around 1000 °C, the highest pressure, and bending strength was achieved. According to the results, perlite was found to be an effective natural pozzolan and at the same time, it could be used to produce geopolymeric binders [15].

Milano et al. studied the low-pressure thermophysical properties of expanded perlite board at the temperature under atmospheric conditions. Samples were filled with dry air until atmospheric pressure reached to 5 μbar. Temperatures ranged from 17 to 117 °C for samples. The results showed that expanded perlite based board's thermal conductivity was measured between the 0.01 and the 0.02 W/m K for vacuum condition. Also, thermal conductivity of insulation board was measured 0.04–0.05 W/m K for atmospheric pressure condition. The obtained results showed that thermal conductivity under the atmospheric conditions is approximately four times higher than thermal conductivity under vacuum conditions [16].

There are different curing methods in literature studies about expanded perlite material. When the literature studies were reviewed, it was seen that expanded perlite was used as the main material or additive material in heat insulation materials. It is clear that different curing conditions are applied preparing EPHIB. There are some different researchers about curing condition using CO_2 gas in the literature. Shi and Wu studied on some factors affecting CO_2 curing of lightweight concrete products. Samples were put into a curing chamber for CO_2 curing. There was vacuumed to a pressure of around 600 mmHg and maintained for 2 min before CO_2 was injected. The obtained results showed that the accelerated reactions between CO_2 and cement minerals happen mainly during the first 15 min. CO_2 curing degree and strength also increased as the CO_2 pressure and curing time increased [17]. In another study, Baojian et al. investigated CO_2 curing to improve the properties of concrete blocks containing recycled aggregates. Blocks were prepared according to the procedure. Then, blocks were placed in a pressurized 100% CO_2 curing chamber for 6, 12 and 24 h. According to strength, shrinkage of the CO_2 and moist results, The CO_2 cured blocks achieved higher compressive strength and lower drying shrinkage than the corresponding moist cured blocks [18].

He and Liu researched weathering properties of CO_2-cured concrete blocks. They compared steam curing and the CO_2 curing according to energy extensive process and production cost and they defined that CO_2 curing of concrete blocks consumes CO_2 and reduces energy consumption. This situation is so important to prevent of greenhouse gas. Some freshly molded lightweight concrete blocks were taken from a block manufacture plant. Then samples were cured in a CO_2 curing and steam-curing. For

CO_2 curing, samples were left on a rack between 3 and 6 h. Then they were preconditioned in a relative dry windy environment for about 4 h. After that, they were placed into a tank for CO_2 curing. It was observed that compressive strength of blocks cured with CO_2 was similar to steam-cured blocks. However, the dimensional stability of the CO_2-cured concrete blocks was better than steam-cured blocks [19]. When literature studies were reviewed, it is clear that curing expanded perlite material with CO_2 gas is a new technology for construction sector. In literature, various methods used to cure expanded perlite-based heat insulation panels. But, no studies have been found in the literature on this curing method of expanded perlite with carbon dioxide gas (CO_2). However, there are some different researches about curing condition using CO_2 gas in the literature but these researches are not related to curing of expanded perlite.

In this study, an alternative to the traditional curing methods expanded perlite-based heat insulation panels cured with carbon dioxide (CO_2) gas. Quick curing is the main aim of this method. Also, the thermal conductivity of manufactured panels measured for 30 days.

2 Materials

2.1 Expanded Perlite

The expanded perlite was provided in Çankırı, Turkey (Fig. 1). Also, the chemical and physical properties of expanded perlite, which was in this study, were given in Tables 1 and 2.

(a) (b)

Fig. 1. **a** Perlite mine location. **b** The view of the perlite mine

2.2 Sodium Silicate

Sodium silicate is one of several compounds containing sodium oxide (Na_2O) and silica (SiO_2). The pure compounds are colorless or white. In generally, sodium silicates are referred to as orthosilicate, metasilicate, disilicate and tetrasilicate, depending on the acid from which they are produced. Sodium silicates are used as a raw material to produce silica gels. Sodium silicate is mainly used in paper, soap, detergent,

Table 1. Chemical properties of expanded perlite

Content	wt%
SiO_2	74
Al_2O_3	14.33
K_2O	4.95
MgO	0.28
CaO	0.50
Fe_2O_3	0.97

Table 2. Physical properties of expanded perlite

Properties	Values
Density, kg/m^3	45–50
Grain size, mm	0–0.5
Thermal conductivity (−40 °C), W/m K	0.035–0.039
Thermal conductivity (−125 °C), W/m K	0.025–0.029
pH	4–9

construction materials, precision casting, anti-corrosive materials, textiles and minerals industries. Sodium silicate (Na_2O_3Si) was used as a binder.

2.3 Mold

The mold made of aluminum. As it can be seen in Fig. 2 the dimensions of mold are 500 × 300 × 100 mm^3. Teflon cover was used to prevent sticking the material to the mold.

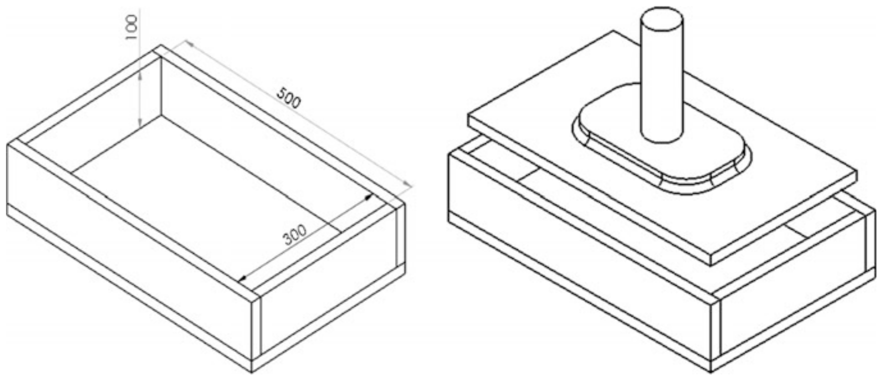

Fig. 2. Aluminum mold

3 Methods

3.1 Compression of Expanded Perlite

First of all, expanded perlite and binder were mixed together by the aid of mechanical mixer throughout 10 min and the mortar was obtained. Then the mortar had been poured into the mold. The mold size was 500 × 300 × 100 mm. The prepared mortar were compressed in thickness direction by 50% and were obtained in dimensions of 500 × 300 × 50 mm. it was compressed by hydraulic press (Fig. 3). The sample was held for 3 min under constant press force (16.67 kPa). Then test sample was obtained in 300 × 300 × 50 mm^3 dimensions by cutting the panel with a cutting machine and this size is used to measure thermal conductivity coefficient (Fig. 4).

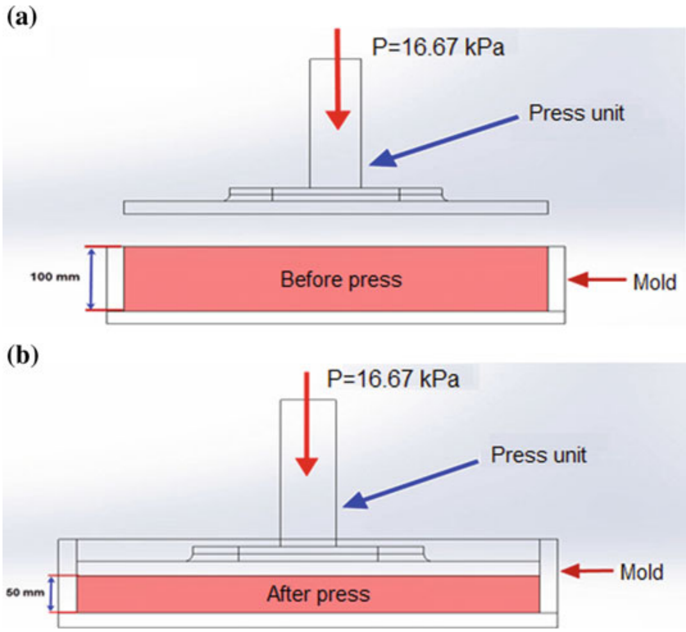

Fig. 3. Press and molding unit **a** before press. **b** After press

3.2 Curing with CO_2 Gas

The molded sample was placed in a vacuum bag. Two nozzles are placed on the bag used for vacuuming. One of the nozzles was vacuumed (5 mbar) and the other was given CO_2 gas after vacuuming. The gas was injected into the vacuum bag (Fig. 5) with 10 l/min for 30 s. The CO_2 gas has a moisture content of less than 10 ppm in 99.9% purity. The samples were kept for 15 min in a closed vacuum bag. Then the curing procedure was completed.

There is an important issue related to CO_2 curing of thermal insulation panel. This issue can be explained as follows. When the CO_2 gas reacts sodium silicate, sodium

Fig. 4. Expanded perlite-based heat insulation panel

Fig. 5. Carbon dioxide curing

silicate (Na_2O_3Si) hardened by separating sodium carbonate (Na_2CO_3) and silicon dioxide (SiO_2). This equation is formed as;

$$Na_2O_3Si + CO_2 \rightarrow Na_2CO_3 + SiO_2$$

3.3 Measurement of Thermal Conductivity

The thermal conductivity of sample was measured by HFM 300 device. The properties of the thermal conductivity testing device were given in Table 3.

Table 3. The properties of thermal conductivity testing device

Specification	Values
Temperature range (Plates), °C	0–40
Temperature control (Plate)	Peltier
Thermal resistance measuring range, m_2K/W	0.1–8.0
Thermal conductivity measuring range, W/m K	0.001–2.5
Accuracy, %	±1– 3
Variable contact pressure, kPa	0.25

4 Results

Thermal conductivity of cured panel measured periodically for 30 days. The obtained results can be seen in Fig. 6. As it can be seen, the thermal conductivity of cured panels decreased as function of time. In first 15 days, the thermal conductivity of panel has been decreased. Finally, at the end of 30 days the thermal conductivity coefficient of the panel was measured as 77.83 W/m K. At the same time, mechanical strength was also measured according to 40 × 40 × 160 mm size. Thermal insulation panel has 1.27 MPa compressive strength. Quick curing is an important advantage of carbon dioxide curing method. The expanded perlite-based heat insulation panels can be cured just in 15 min. Also, the manufactured panels have better mechanical properties. Thus, a panel has been developed which can be used more practically in heat insulation applications.

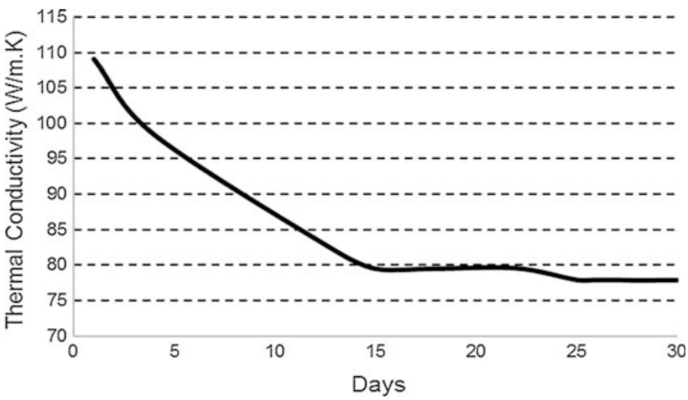

Fig. 6. Thermal conductivity variations of heat insulation panel

5 Conclusion

Expanded perlite-containing composites have been limited due to relatively poor mechanical properties low strength. This curing method, a more practical panel was produced in terms of mechanical properties. Compressive strength of manufactured expanded perlite-based heat insulation board was measured as 1.27 MPa. Also, the energy spent in curing and the curing time were decreased. These are important in terms of energy efficiency and production technique of heat insulation panel. The developed method is also important in terms of environmental factors for the production process. With the work to be done, the properties of the panel can be improved.

Acknowledgements. This study was supported by the Scientific and Technological Research Council of Turkey (Project no.: 115M041). We are indebted to TÜBİTAK for its financial support.

References

1. Arifuzzaman M, Kim HS (2014) Development of new perlite/sodium silicate composites| NOVA. The University of Newcastle's Digital Repository
2. Arifuzzaman M, Kim HS (2015) Novel mechanical behaviour of perlite/sodium silicate composites. Constr Build Mater 93:230–240
3. Demirboğa R, Gül R (2003) Thermal conductivity and compressive strength of expanded perlite aggregate concrete with mineral admixtures. Energy Build 35:1155–1159
4. Dube W, Sparks L, Slifka A (1991) Thermal conductivity of evacuated perlite at low temperatures as a function of load and load history. Cryogenics 31:3–6
5. Erdoğan S (2011) Use of perlite to produce geopolymers. In: Proceedings of 31st cement and concrete science conference novel developments and innovation in cementitious materials
6. Gunning D (1994) Perlite market study report. Gunning and Mc Neal Associates Ltd. Crown Publications Inc, Victoria
7. Milano G, Scarpa F, Timmermans G (1996) Low-pressure thermophysical properties of EPB-expanded perlite board. Therm Conduct 23:362–372
8. Mladenovič A, Šuput J, Ducman V, Škapin AS (2004) Alkali–silica reactivity of some frequently used lightweight aggregates. Cem Concr Res 34:1809–1816
9. Shastri D, Kim HS (2014) A new consolidation process for expanded perlite particles. Constr Build Mater 60:1–7
10. Shi C, Wu Y (2008) Studies on some factors affecting CO_2 curing of lightweight concrete products. Resour Conserv Recycl 52:1087–1092
11. Shi C, Wang D, He F, Liu M (2012) Weathering properties of CO_2-cured concrete blocks. Resour Conserv Recycl 65:11–17
12. Skubic B, Lakner M, Plazl I (2012) Microwave drying of expanded perlite insulation board. Ind Eng Chem Res 51:3314–3321
13. Skubic B, Lakner M, Plazl I (2013) Sintering behavior of expanded perlite thermal insulation board: modeling and experiments. Ind Eng Chem Res 52:10244–10249
14. Sun D, Wang L (2015) Utilization of paraffin/expanded perlite materials to improve mechanical and thermal properties of cement mortar. Constr Build Mater 101:791–796

15. Taherishargh M, Belova I, Murch G, Fiedler T (2014) On the mechanical properties of heat-treated expanded perlite–aluminium syntactic foam. Mater Des 63:375–383
16. Tian YL, Guo XL, Wu DL, Sun SB (2013) A study of effect factors on sodium silicate based expanded perlite insulation board strength. Appl Mech Mater 405:2771–2777
17. Uluer O, Aktaş M, Karaağaç İ, Durmuş G, Khanlari A, Ağbulut Ü, Çelik (2017) Manufacturing of expanded perlite based heat insulation material using theoretical thermal conductivity prediction model results. In: International conference on progress in applied science, pp 156–161
18. Vaou V, Panias D (2010) Thermal insulating foamy geopolymers from perlite. Miner Eng 23:1146–1151
19. Zhan B, Poon C, Shi C (2013) CO_2 curing for improving the properties of concrete blocks containing recycled aggregates. Cement Concr Compos 42:1–8