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Manufacture of high heat conductivity resistant clay bricks containing perlite

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Abstract

Different methods have been investigated for achieving heat insulation in the buildings. Manufacturing of high heat conductivity resistant construction materials is an important part of these research efforts. Perlite is an extremely useful material for heat insulation and 70% of the world reserves are located in Turkey. Nearly 65% of the perlite produced today is consumed by the construction industry. Its thermal, lightness, and acoustic insulation properties make perlite an excellent material to be used as lightweight aggregate in brick manufacturing. High heat resistant brick can be produced by adding perlite into the clay in conventional brick manufacturing. In this investigation perlite of Eskişehir region and clay were collated and fired to form high heat conductivity resistant material. Binding materials such as cement, gypsum, lime, bitumen and clay were used for manufacturing perlite brick. Bricks in standard sizes manufactured at different perlite–clay ratios and unit weight, compressive strength, volume reduction and heat conductivity values were obtained. Then the mixture with the best combination of the properties was determined and cost optimization was described. Results were examined according to combination properties, and specialties of perlite bricks were determined at various weights. As a result, the best mixture was determined as the one containing 30% perlite.
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Keywords: Heat conductivity; Expanded perlite; Lightweight material; Clay brick

1. Introduction

Many studies have been conducted on lightweight and energy saving materials in the transition process of conventional to industrial construction methods. The aims of the studies are lightweight and high heat insulation. Energy can be saved in buildings with high heat resistant materials; furthermore fire resistance and bearing capability are required. Brick had been the most suitable material according to these criterions up to date but much lighter materials are needed for constructions today. Air bricks, lightweight concrete and polymers are used for insulating buildings. Perlite is a material that can be used for insulation in buildings, and most of the perlite reserves exist in Turkey. As known, expanded perlite can be used with mixing clay as high heat insulator construction material. It is a porous, lightweight, fire resistant and moisture retaining material with sound and thermal insulation properties. Especially, this material is recommended for cold regions as central and eastern Anatolia. In this investigation, perlite of Eskişehir region and clay are collated and fired to form high heat conductivity resistant material. Binding materials such as cement, gypsum, lime, bitumen and clay are needed for manufacturing perlite brick. There have been various studies on perlite low heat transferring construction materials. Clay was used as a binder in many studies. A relatively high water content of 2–5% distinguishes perlite from other hydrous volcanic glasses, such as obsidian, hydrated volcanic ash, and pumicite.

Upon rapid heating, perlite transforms into a cellular material of low bulk-density. As the chemical water held within the perlite boils (generally at temperatures in the

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range of 900–1100 °C), the resultant 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 [1]. This new material is referred to as expanded perlite. Because of its favorable physical and chemical characteristics, expanded perlite finds diverse utilization in various applications: for use as a lightweight aggregate in the construction industry; as a rooting medium and soil conditioner in horticulture; as a bleaching agent in the textile industry; as an adsorbent in the chemical industry; and as filter aid and as filler in miscellaneous processes [2]. Nearly 65% of the perlite produced today is consumed by the construction industry. Its lightness, thermal, and acoustic insulation properties make expanded perlite an excellent candidate to be used as lightweight aggregate in concrete and brick production. For insulation purposes, expanded perlite powder is utilized as filler material in hollow bricks or as an additive in plasters. Studies have focused on the lightness and insulation properties of expanded perlite so far.

Perlite is basically mineral obsidian. Perlite mineral deposits exist in many countries of the world, but the expanded product is only available in countries which have commercial expanding plants. Perlite/clay bricks are some of the lightest ceramic materials. Producing bricks with insulation materials that help to reduce cracking because the space between the bricks allows them to expand and contract as they are heated and cooled [3]. Prefabricated building materials made of expanded perlite are used widely as thermal insulation materials. Expanded perlite, with its open pore structure, is also very suitable as a sound absorbing material. It is used mostly in spray form in paints and plastering for acoustical purposes [4]. The effect of moisture on plates made of perlite has not been considered in the literature from architectural design point of view. It is possible to use these plates in any auditorium or moist space like indoor swimming pool, in order to reduce reverberation time. Rioporit is the first example of a commercial product that has been produced with 30% perlite and 70% clay in Hungary. The unit weight, compressive strength, heat conductivity, porosity ratio and fire resistance of the material are 920 kg/m^3, 3.0 MPa, 0.19 kcal/m h °C, 72% and 900 °C, respectively.

Acoustical behavior of plates made of expanded perlite was studied experimentally in a recent research. The plates were used for sound absorption. Preliminary experiments indicated that moisture reduced the sound absorption coefficient on plates and there was not much significant difference between the dry and 50% humid conditions. However, there was a significant difference in acoustical properties for the 50–95% humid conditions. A number of expanded perlite plates having different mixtures were prepared and tested. It was observed that, coating the expanded perlite particles with sodium silicate increased the moisture resistance, and the addition of mineral fibers into the mixtures increased the strength and sound absorption of the plates [5]. It is known that, for a moisture-proof material with good sound absorbing properties; porous admixtures with high tortuosity, low flow resistance and water repelling qualities are needed [6]. The coating of perlite granules with sodium silicate closes the open pores thus the water retaining property is reduced. However, this process causes the micro-size granules to stick to each other and produces new open pores. Thus it does not loose its sound absorption property. Another disadvantage of the plates made of expanded perlite is their low durability. The addition of mineral fibers into the mixture improved a number of features. It increased the durability, as well as gas permeability and the sound absorption of the plates because fibers introduced new open pores to the material.

In Czech Republic, 1982, wall dividing panels were manufactured with weight batching 27% perlite, 3% fiberglass and 70% clay. The unit weight, compressive strength, heat conductivity and porosity ratio were 950 kg/m^3, 3.2 MPa, 0.21 kcal/m h °C and 69%, respectively. In Japan, a wall material was manufactured with 20% perlite and some epoxy resin. The unit weight, compressive strength, heat conductivity and porosity ratio were 980 kg/m^3, 3.46 MPa, 0.22 kcal/m h °C and 71.2%, respectively. Alumina cement, aluminum phosphate and expanded perlite under 3 mm grain size were combined under constant pressure and temperature to manufacture insulator boards. The unit weight, compressive strength, heat conductivity and porosity ratio were 280 kg/m^3, 2.4 MPa, 0.165 kcal/m h °C and 82%, respectively. Japan Asahi firm has manufactured two types of wall material with using 30% slag, 30% gypsum, 5% cement, 5% fine SiO_2, 20% fibered material and 10% perlite. The unit weight, compressive strength and heat conductivity were 970 kg/m^3, 6.5 MPa and 0.245 kcal/m h °C, respectively. Second wall material was manufactured with using 40% slag, 40% gypsum, 5% cement, 5% fine SiO_2, 20% fibred material and 10% perlite. The unit weight, compressive strength and heat conductivity were 940 kg/m^3, 5.8 MPa and 0.21 kcal/m h °C, respectively. In 1987 Germany, acid and alkali resistant perlite block was manufactured. These were manufactured with 32% perlite, 55% quartz sand, 13% water glass and 5% gypsum. The unit weight, compressive strength, acid resistance, alkali resistance, acid absorption and heat conductivity were 945 kg/m^3, 3.5 MPa, 99%, 60%, 32% and 0.26 kcal/m h °C, respectively. Similar material was manufactured in USA with 35% gypsum, 12% fiber material, 7% asphalt, 4% amylum and 42% perlite.

According to a study on refractory perlite/clay bricks, the combination of 85% perlite aggregate and 15% clay by volume were used to give the best combination of lightness and durability. A trial batch was 418 g of perlite aggregate, 381 g of green stripe, and 950 g of water. Water was mixed and gradually stirred in the clay portion. Then it was poured and mixed in the perlite aggregate. These amounts of components compacted in a press to form a green brick with a volume of 1.881 dm^3 [7]. According to other study

on isolative ceramics for improved cooking stoves, perlite was made into a graded mix before was combined with clay to form a brick. The perlite was separated into three component sizes 9.5–4.75, 4.75–2.36, and 2.36 mm and finer. The two parts of the largest sizes were recombined; one part of the midsize, and seven parts of the smallest size formed the perlite mix. This mix was combined with clay and water and formed into a brick, which was dried and fired at 1050 °C [8]. In a recent study on humidity buffering by absorbent materials in walls, specially designed lightweight clay made from bentonite mixed with perlite gave an excellent performance. Perlite provided good cohesion to the mixture because the delicate particles were damaged during the mixing. The resulting sharp edges and fragments provided a good bond to each other and to the clay, so that when the mixture dried from its initial plastic state the shrinkage was 8% moderated, the compressive strength was 2 MPa and, the clay was presented in an open structure of shell like aggregates of the submicroscopic clay plates. These two materials were mixed together in a dough mixer in the ratio of one part bentonite to ten parts perlite by volume. Some chopped straw was added at the last moment [9]. Mostly, cement, gypsum and perlite were mixed for manufacturing perlite blocks in Turkey. In 1985, the first perlite block called A-perlite was manufactured in Turkey. The unit weight, compressive strength, tensile strength and heat conductivity of A-perlite were 325–400 kg/m^3, 1.8, 0.2 MPa and 0.035–0.040 kcal/m h °C, respectively. It was proved that compressive strength of concrete with perlite was lower and creep deformation, water absorption and capillarity were higher than concrete without perlite.

The intact rounded perlite grain is visible. The smashed grains show the foamy internal structure [8]. The deterioration of porous building materials is mainly due to the structure/water interactions, which, depending on the material characteristics, the physical state of water liquid or vapor and the environmental conditions, may be of different magnitude involving different sorption mechanisms [10]. The equilibrium moisture content of ordinary and lightweight products, fired at two different temperatures (850 and 1050 °C), was measured by Rimpel; the moisture absorbed by under fired specimens (25–52 kg/m^3) was considerably higher than that absorbed by the specimens fired at the higher temperature (1.3–6.5 kg/m^3). Moreover, the lightweight products generally show a lower capacity of moisture absorption [11]. The changes in brick porosity upon firing 700 up to 1100 °C and its relation to the mineralogical composition were examined in a recent study. The two types of raw clay with a composition representative of that used in brick making industry were selected to manufacture the brick one contains notable amounts of carbonates, with a grain size of under 1 mm, and the other is predominantly quartzitic and lacking in carbonates. It was demonstrated that the presence or absence of carbonates strongly influences the porosity development and, therefore, the brick texture and physical and mechanical properties [12].

A tentative prediction model was set up with an empirical approach [13]. Vertically perforated bricks have been developed with the view to building environmentally friendly houses since they make insulating materials unnecessary. Indeed, walls can be constructed without any other materials than clay and mortar. Furthermore, they offer better mechanical properties than horizontally perforated ones [14]. As the demands on reducing the energy consumption of buildings became tighter even for residential buildings all over Europe, the manufacturers of perforated clay bricks are trying to adapt their products to the new regulations by optimizing the perforation pattern for example by choosing more than 30 rows of thin air gaps and by using porous clay as the basic material [15]. In other study about increasing porosity spent grains are applicable in brick production as combustible material designed to increase porosity [16]. The properties of fired bricks were improved by using pulverized fly ash. The fired bricks with high volume ratio of fly ash were of high compressive strength, and low water absorption [17]. The compressive strength slightly increased as the firing temperature gradually increased from 700 to 900 °C, and the increase in strength became more pronounced, as the temperature was increased further. A gradually darkening color formed on the clay bricks as the firing temperature was raised further [18]. Thermal conductivity and compressive strength of expanded perlite aggregate concrete with mineral admixtures were investigated in a study and results showed that the thermal conductivity decreased with the increase of silica fume and fly ash as replacement for Portland cement up to 14% and 18%, respectively [19]. Also mineral fillers have high specific surface and water-holding capacities that tend to cause high shrinkage [20–27].

2. Properties of perlite

Perlite is a vitreous substance that contains 2–6% water. It has gray, silver gray, dark brown and black colors. Perlite is a lightweight material because it can expand 10–30 times of its volume when heated between 800 and 1150 °C. Density of perlite decreases as its volume increases, in this manner it is described as lightweight material. Expanded perlite was first used in USA, and spread all over the world owing to its lightweight, heat and sound insulator properties. In Turkey 8 billion tons of perlite exists, it is 70% of world reserves. It is seen that perlite is a very important material for Turkish economy, and it can be used as insulator owing to its low heat conductivity.

2.1. Chemical properties of perlite

Perlite is a substance that contains 70–75% silicon dioxide, and 12–16% alumina. Other components are

sodium oxide, potassium oxide, ferro oxide, manganese oxide, titan oxide and sulfide. Chemical components and weight batching ratios are given in Table 1.

2.2. Physical properties of perlite

Expanded perlite is fire, heat and chemical resistant material that have porous structure. Porosity is determined as the average ratio between volume of pores and total volume of perlite grains. Porous structure gives perlite volumetric and surface absorption capability. To prevent water pollution and to ensure insulation, water absorption is involuntary, because pores filled with water increase heat conductivity. Porous structure gives perlite surface absorption and lightweight property. The unit weight of perlite depends on gradation and expansion. Generally, perlite is used in prefabricated constructions as filler owing to its lightweight property. The heat conductivity of dry perlite that has unit weight of 90 kg/m^3 is calculated as 0.04 W/m K at 24 °C according to dry unit weight method. Fiberglass has heat conductivity of 0.037 W/m K at same temperature, in this manner perlite is a good insulator compared to fiberglass at same temperature. Perlite materials have advantage on sound absorption and insulation. A 5 cm thick perlite fill insulate 13 dB at 1000 Hz of sound. This is 12 dB for fiberglass and 13 dB for styrofoam at same thickness. Some properties of expanded perlite are given in Table 2.

Table 1
Physical properties of perlite

Components	Weight ratio (%)
SiO_2	71.0–75.0
Al_2O_3	12.5–16.0
Na_2O	2.90–4.00
K_2O	4.00–5.00
CaO	0.20–0.50
Fe_2O_3	0.50–1.45
H_2O	3.05–5.16
MgO	0.03–0.50
TiO_2	0.03–0.20
MnO_2	0.00–0.10
Cr	0.00–0.10
Ba	0.00–0.05
PbO	0.00–0.30
S	0.02–0.04

Table 2
Physical properties of expanded perlite

Color	White
Melting point	1300 °C
Specific heat	0.20 kcal/kg °C
Unit weight	2.2–2.4 g/cm^3
Rough density	30–190 kg/m^3
Heat conductivity	0.034–0.040 kcal/m h °C
Sound insulating	18 db (125 Hz)

2.3. Application areas of perlite

2.3.1. Constructional

In manufacturing heat and sound insulating materials, and lightweight concrete. It supplies material saving, volumetric benefit and strength.

2.3.2. Agricultural

In soil works, water storage, steel works and floriculture, artificial fertilizer, filling and transporting materials.

2.3.3. Industrial

Used as dry filling isolator and filter substitute, up to −250 °C, and also used in foundry works.

3. Experimental study

3.1. Materials

Materials used in experiments can be obtained easily from country sources. Etibank perlite and Bilecik-Söğüt clay were used in experiments. Sieve analysis and granulation of perlite that has unit weight of 90 kg/m^3 were conducted according to TS 3681. Sand existing in clay did not react with HCl in the experiment; this proved that it contains no carbonate. The unit weight of clay used in experiments was calculated as 2690 kg/m^3. Plastic and liquid limit were calculated as 28.3% and 78%, respectively. It was seen that plasticity can be provided only with water. Clay used in experiments is dark yellow colored before fired, and color turned into red after fired depending on temperature. Shrinkage limit of clay is 13%. Chemical components of clay are given in Table 3.

3.2. Manufacturing perlite bricks, and shape, size, cure conditions of specimens

Vertical axis compulsory mixer at the volumetric capacity of 75 dm^3 was used for manufacturing perlite bricks. A plastic bag was wrapped at the opening of mixer to stop fly of perlite. Then, water was added into clay–perlite mixture, and it was determined as 7.4% of total aggregate weight (Table 4). Unit weight experiments were

Table 3
Chemical components of clay

Component	Weight (%)
SiO_2	58.3
Al_2O_3	17.5
Fe_2O_3	7.5
CaO	0.8
MgO	4.0
K_2O	1.8
H_2O	2.1
H_2O (Crys.)	4.7
KK + CO_2	3.3

Table 4
Mixture ratios of perlite brick series

Series code	Perlite (%)	Clay (%)	Perlite (g)	Clay (g)	Water (g)	Total weight (g)
PB-00	0	100	0	2253	180	2433
PB-05	5	95	92	1750	147	1989
PB-10	10	90	170	1532	136	1838
PB-15	15	85	241	1369	129	1739
PB-20	20	80	285	1142	114	1541
PB-25	25	75	312	939	100	1351
PB-30	30	70	313	730	83	1126
PB-35	35	65	292	542	67	901
PB-40	40	60	262	393	52	707
PB-45	45	55	221	270	39	530
PB-50	50	50	158	158	26	342

Table 5
True weight and shrinkage of perlite brick series

Series code	Fired brick weight (kg)	Fired brick volume (dm^3)	Unit weight (kg/m^3)	Shrinkage (%)
PB-00	2.253	1.295	1740	7.95
PB-05	1.842	1.293	1425	8.10
PB-10	1.702	1.290	1320	8.25
PB-15	1.610	1.288	1250	8.40
PB-20	1.427	1.286	1110	8.60
PB-25	1.251	1.283	975	8.80
PB-30	1.043	1.278	816	9.15
PB-35	0.835	1.273	656	9.50
PB-40	0.655	1.265	518	10.10
PB-45	0.491	1.252	392	11.00
PB-50	0.316	1.245	255	11.50

conducted on specimens and $6.7 \times 10 \times 21$ cm rectangular prism specimens were cast and pressed. Specimens were cured under room temperature for 24 h, and then cured at 200 °C in drying oven for 24 h. After curing, specimens fired at 950 °C. Actual weights of specimens are given in Table 5. Production and physical tests were conducted in Eskişehir, heat conductivity tests were conducted in TSE laboratory in Ankara.

4. Results and discussion

Results were examined according to combination-specialty properties, and specialties of perlite bricks at various weights were determined in experiments. Unit weight of perlite brick was calculated less than standard brick that has unit weight of 1740 kg/m^3, as shown in Fig. 1. Unit weight of a lightweight material must be lower than 1000 kg/m^3. As the replacement ratio of perlite increases, unit weight of brick decreases owing to lower unit weight of pressed clay. Unit weight of pressed perlite and clay were calculated as 121.6 and 1349 kg/m^3, respectively. Shrinkages of standard brick and perlite brick with the replacement ratio of 50% are 7.95% and 11.5%, respectively, as shown in Table 5. The increase in the amount of perlite used in brick manufacturing causes much shrinking owing to the different shrinkage values of clay and perlite

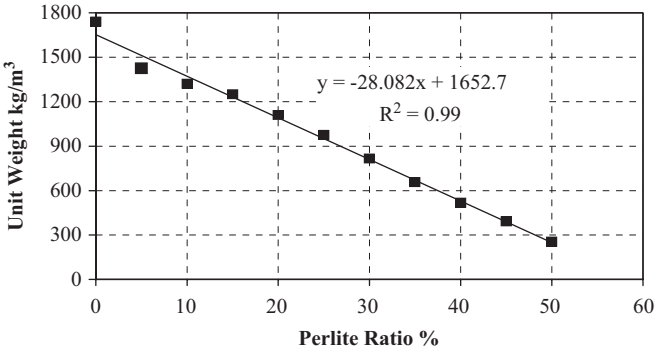


Fig. 1. Unit weight of perlite bricks according to perlite ratio.

at 900 °C, it is seen that perlite has bigger shrinkage than clay. The maximum shrinkage must be 9.5% for standard brick. This means, maximum 30% perlite can be used to manufacture perlite brick as shown in Fig. 2. The compressive strength decreases as the replacement ratio of perlite increases. While compressive strength of standard brick is 5.8 MPa, compressive strength of perlite brick decreases to 2.0 MPa depending upon replacement ratio. The compressive strength of perlite brick is 2.1 MPa when replacement ratio of perlite is 35%. The minimum compressive strength is determined as 2.4 MPa for 0.7

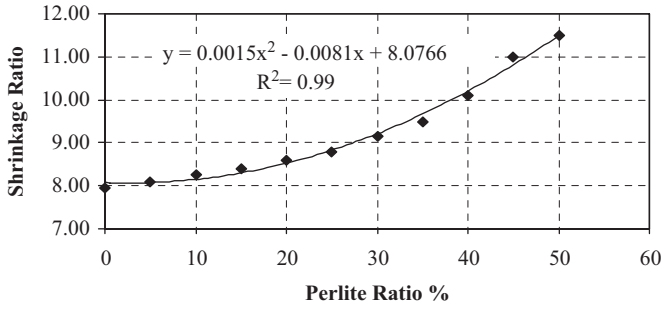


Fig. 2. Shrinkage of perlite bricks according to perlite ratio.

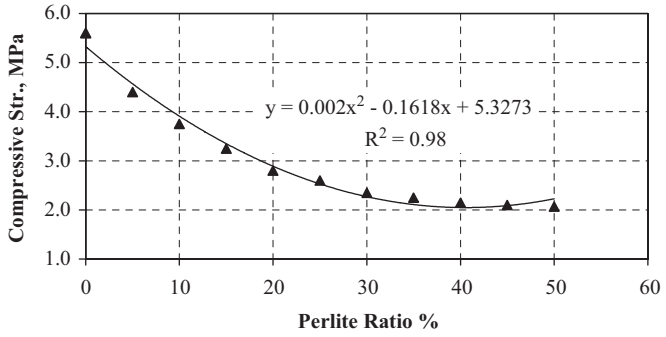


Fig. 3. Compressive strength of perlite bricks according to perlite ratio.

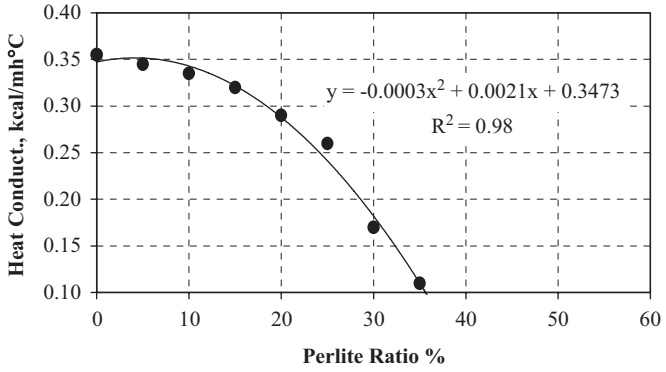


Fig. 4. Heat conductivity of perlite bricks according to perlite ratio.

class, I-Type and vertical hollowed lightweight ventilating brick according to TSE standards. This means 30% perlite can be used in perlite–clay mixture to ensure this condition. Compressive strengths of perlite bricks depending upon replacement ratios of perlite are shown in Fig. 3.

While the heat conductivity of standard mixture is 0.35 kcal/m h °C, the heat conductivity of 30% replaced perlite mixture decreases to 0.185 kcal/m h °C, as shown in Fig. 4. The heat conductivity of aerated and bims concrete are 0.14–0.25 and 0.16–0.30 kcal/m h °C, respectively. It is seen that heat conductivity of perlite brick is similar to aerated and bims concrete. Minimum unit weight of lightweight construction material must be under 1000 g/dm^3, minimum compressive strength of vertical hollowed ventilating lightweight fabric brick must be over 2.4 MPa, and the minimum shrinkage must be under 9.5% according to TSE standards. In this investigation maximum and minimum replacement ratios of perlite are determined as 30% and 24%, respectively. The lightest and best insulator mixture was obtained with 30% perlite, therefore optimum mixture was Perlite Brick-30 (PB-30) series in experiments. A unit of PB-30 series brick consists of 313 g perlite and 730 g clay. To build 1 m^2 wall, 62 unit PB-30 bricks are used, thus 1 m^2 PB-30 brick consists of 19.4 kg perlite. The unit price of perlite is 0.3$/kg in 2006, according to Turkish Ministry of Public Works, so that the cost of perlite for 1 m^2 PB-30 wall is 5.8$. The unit price of 1 m^2 standard brick wall determined as 9.8$/m^2 in the current prices of Turkish Ministry of Public Works including labor charges. Labor charges does not make difference in manufacturing perlite brick compared to standard brick, thus 1 m^2 perlite wall costs 15.6$/m^2 when extra perlite price is added to cost of a standard brick.

5. Conclusion

In this study, high heat insulator perlite bricks were manufactured with replacing expanded perlite at various replacement ratios. Compressive strength decreases, heat conductivity resistance and shrinkage of perlite bricks increase as the replacement ratio of perlite increases. Clay–perlite mixtures were separately determined considering unit weight, compressive strength, shrinkage and heat conductivity in experiments. Optimum replacement ratios were obtained with 24% perlite for unit weight, 30% for compressive strength, 31% for shrinkage and 24% for heat conductivity, if experimental results examined separately. However, 30% replacement ratio is suitable, if experimental results examined together. Maximum 30% and minimum 24% perlite were used to ensure expected heat conductivity resistance for perlite bricks. The most convenient series was determined as PB-30 due to compressive strength as upper limit and lightweight property as lower limit. It was proved that perlite brick is a good insulator according to standard brick. While heat conductivity of brick replaced with 30% perlite is 0.185 kcal/m h °C, this value is 0.40 kcal/m h °C for a standard brick.

References

[1] Gunning DF. Perlite market study report. Gunning and McNeal Associates Ltd., Crown Publications Inc.; 1994. p. 2–8.
[2] Austin GT. Salt and miscellaneous sodium compounds in Shreve's chemical process industries. 5th ed. McGraw Hill Book International, 1984. p. 11–25.
[3] Pinnell M, Ogle D, Still D, Apel B. Insulative ceramics for improved cooking stoves, BP49 2003. p. 1–8.
[4] Harris DA. Noise control manual for residential buildings. New York: McGraw Hill Book; 1997. p. 202–5.
[5] Yılmazer S, Özdeniz MB. The effect of moisture content on sound absorption of expanded perlite plates. Building and Environment 2005;40(3):311–8.

[6] Attenborough K. Acoustical characteristics of rigid fibrous absorbent and granular materials. Journal of the Acoustical Society of America 1983;73(3):785–99.
[7] Ogle D. Making lightweight refractory ceramic from perlite and clay. Aprovecho Research Center, 2003. p. 2–7.
[8] Padfield T. Humidity buffering by absorbent materials in walls. Conservation physics an online text book, 1999. p. 1–6.
[9] Padfield T. The role of absorbent materials in moderating changes of relative humidity. PhD thesis, Department of Structural Engineering and Materials, The Technical University of Denmark, series r no. 54, 1998. p. 72–97.
[10] Sciarra N. A numerical one-dimensional modeling of water transport through a porous material under saturated and unsaturated condition, parametric studies. Memorie della Società Geologica Italiana 2001. p. 367–74.
[11] Rimpel E. Examination of the influence of moisture on thermal conductivity. Ziegelindustrie International 2001. p. 39–45.
[12] Cultrone G, Sebastiána E, Elerta K, Torreb MJ, Cazallaa O, Navarroa CR. Influence of mineralogy and firing temperature on the porosity of bricks. European Ceramic Society 2004;24(3):547–64.
[13] Dondia M, Principib P, Raimondo M, Zanarinic G. Water vapour permeability of clay bricks. Construction and Building Materials 2003;17(4):253–8.
[14] Lacarrie'rea B, Lartigueb B, Monchoux F. Numerical study of heat transfer in a wall of vertically perforated bricks: influence of assembly method. Energy and Buildings 2003;35:229–37.
[15] Wakili KG, Taner C. U-value of a dried wall made of perforated porous clay bricks hot box measurement versus numerical analysis. Energy and Buildings 2003;35:675–80.
[16] Russ W, Mörtel H, Meyer-Pittroff R. Application of spent grains to increase porosity in bricks. Construction and Building Materials 2005;19:117–26.
[17] Lingling X, Wei G, Tao W, Nanru Y. Study on fired bricks with replacing clay by fly ash in high volume ratio. Construction and Building Materials 2005;19:243–7.
[18] Karaman S, Günal H, Erşahin S. Assessment of clay bricks compressive strength using quantitative values of colour components. Construction and Building Materials 2006;20:348–54.
[19] Demirboğa R, Gül R. Thermal conductivity and compressive strength of expanded perlite aggregate concrete with mineral admixtures. Energy and Buildings 2003;35:1155–9.
[20] Topçu İB, Uğurlu A. Effect of use of mineral filler on the properties of concrete. Cement and Concrete Research 2003;33:1071–5.
[21] Ediz N, Topçu İB. Investigation of the usability of Etibor Kırka boron tailings for brick manufacturing. Symposium of using industrial wastes on construction sector, Ankara, Turkey, 1995. p. 141–50.
[22] Topçu İB, Çobanlı M. Manufacturing perlite bricks with high heat conductivity resistance. Osmangazi University, Journal of Engineering and Architecture Faculty 1999;12(2):71–82.
[23] Çobanlı M. Manufacturing high heat conductivity resistant lightweight constructional material. MSc thesis, Osmangazi University, Institute of Science, Eskişehir, Turkey, 1993. p. 44.
[24] Topçu İB, Canbaz M. Determination of pozzolanic activity of powdered waste tile. 12. National Clay Symposium, Van, Turkey, 2005. p. 283–90.
[25] Topçu İB, Aksak A, Kara İ. Mechanical properties of historical Horasan mortars. Chamber of Civil Engineers, Bulletin of Eskişehir Branch 2005;9(17):28–31.
[26] Topçu İB. Concrete, Chamber of Civil Engineers, Eskişehir Branch, Publication No. 2, Eskişehir, Turkey, 2006. p. 260 [In Turkish].
[27] Topçu İB. Concrete Technology. Eskişehir, Turkey: Uğur Ofset A.Ş.; 2006. p. 570 [In Turkish].

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