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EXPANDED PERLITE AGGREGATE CHARACTERIZATION FOR USE AS A LIGHTWEIGHT CONSTRUCTION RAW MATERIAL

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Abstract: The purpose of this study is to investigate the use of İzmir (Menderes-Cumaovası) expanded perlite as a construction raw material by determining its characteristic properties, as well as its physical properties at different temperatures (up to 600°C). The perlites, having glassy, porous structure, were found to contain 70.68% SiO₂ and 13.04% Al₂O₃. The physical properties of the perlites changed with temperature. The highest surface area, 524 m²/g, was obtained at 400°C. The physical properties were found to have high statistical relation. It was concluded that expanded perlite aggregates could be used as a construction raw material.

Keywords: *perlite, lightweight aggregate, characteristic property, physical property, temperature, construction raw material*

Introduction

Perlite, which is obtained from pumice, contains 2–5% water and has a glassy form of rhyolitic or dacitic magma. The commercial product, commonly designated as expanded perlite, is produced by heating the material to 760–1100 °C, thereby converting its indigenous water to vapor and causing the material to expand to 4 to 20 times its original volume while forming lightweight high-porosity aggregates (Dogan and Alkan, 2004; Harben and Bates, 1990). The heating process does not change the perlite density (2.2–2.3 kg/dm³) but the bulk density decreases to 60–80 g/dm³. During the thermal treatments, a structural transition from amorphous to crystalline occurs, accompanied by increased cation exchange capacity (CEC) from 20–30 to 35–50 cmol/kg, as a result of the multiplication of broken edges, and increased specific surface area from 1.2 to 2.3 m²/g (Dogan and Alkan, 2004).

Perlite is basically the 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 (Topcu and Isikdag, 2007). The world reserves of perlite are estimated as 700 million tons. In 2011, 1.7 million tons had been produced, mostly by Greece (500.000 Mg), United States (375.000 t) and Turkey (220.000 Mg); however, no information for China, leading producer, was available (Bolen, 2011). Turkey's 160.000 tons of probable perlite reserves are located in Menderes, İzmir. Although our country has rich resources and capacity of perlite, domestic demand is very limited and most of the produced perlite is imported.

Perlite is used in various areas such as construction materials, agriculture, medical and chemical industry. Moreover, expanded perlite aggregate (EPA) has been used within the constructional elements such as brick, plaster, pipe, wall and floor block; however has not been industrially utilized in concrete yet. EPA is a heat and sound insulator, and lightweight material which ensures economic benefits in constructions (Topcu and Isikdag, 2008). Many researchers have studied the characteristic properties of the perlites and their use as construction materials (Singh and Garg, 1991; Demirboga et al., 2001; Demirboga and Gul, 2003; Lanzon and Garcia-Ruiz, 2008; Sari et al., 2009; Sengul et al., 2011; Çelik, 2010). In these studies, mainly the use of perlite as a thermal insulator in lightweight concrete and brick production was examined.

The aim of this study is to determine the characteristic properties of Menderes expanded perlite aggregate and investigate changes in their physical properties depending on temperature. Also, the analyses, to determine the use of EPA as a raw material for construction, are performed. This study will be the basis of the forthcoming studies in which Menderes expanded perlite aggregate is used as a construction raw material.

Materials and method

Expanded perlite was obtained from Menderes-Cumaovası Perlite Processing Plant of Eti Mine Works (İzmir, Turkey). Perlites were expanded to 0.2-2 mm size and 150-300 kg/m³ density at 1000 °C by using high-temperature furnaces at Eti Mine Menderes Works.

To determine the characteristic properties of the expanded perlite at ambient temperature, chemical analysis, petrographic analysis, qualitative mineralogical analysis (XRD); scanning electron microscopy (SEM) analysis, energy dispersive X-ray spectroscopy (EDS) analysis, thermo-gravimetric/differential thermal (TG-DTA) analysis, and surface area measurements were performed. At the same time, to find out some of the important physical properties of the expanded perlites at ambient temperature and temperatures up to 600 °C, specific gravity, bulk density, porosity, water absorption and compactness ratio analyses were carried out on five different samples. The sieve analysis, fine matter analysis, organic matter content and loss on

ignition analyses were also performed to determine the use of expanded perlite as a construction raw material. Analyses were performed at Mining Technical Research Institute (MTA), Ankara, Turkey and Middle East Technical University (METU) Chemical Engineering Department, Ankara, Turkey.

Petrographic analysis was done by Olympus BH-2 microscope. Chemical analysis of the 105 °C dried samples was performed by using the Siemens SRS 300 X-ray Fluorescence Spectrometer (XRF) instrument. XRD of the powdered samples was carried by using Rigaku XRD Geigerflex equipped with Cu X-ray tube. XRD patterns were recorded from $20^{\circ} < 2\theta < 60^{\circ}$ with step of 0.02° . Images and elemental composition of the samples were obtained by SEM instrument using FEI Quanta 400 MK2 equipped with EDAX Genesis XM 4i detector. Proportional elemental distribution was found by EDS analyzer. The amount of weight loss of the perlite samples were determined by TG-DTA using TG/DTA 6300 S11 EXSTAR 6000. The measurements were performed up to 1000 °C under air flow using uniform heating rate of 20 °C/min. The sample holder was cylindrical-shaped platinum crucible having a diameter of 6 mm and height of 10 mm.

BET (Brunauer, Emmett and Teller) surface area measurements were performed by Nova Instruments Quantochrome 2200. To determine the bulk densities, the samples were grinded, sieved through 16 mesh sieves (1 mm sieve opening) and impurities were removed. The bulk density analyses were done according to TS 3529 and ASTM C-127-42 standards. Specific gravities were determined by means of a pycnometer in accordance with TS 1114 EN13055-1 standards. Porosity measurements were performed by Autopore IV 9220 mercury porosimeter. Before the above mentioned analyses, the samples were put into the furnace at the preset temperature for two hours.

Water absorption properties of the particles smaller than 4-8 mm were found according to TS 1114 EN 13055-1 and ASTM C 127-42 standards. The compactness ratio was determined in accordance with ASTM C 127-42 and 128-57 standards.

The sieve analysis and fine matter analysis, which was done to determine the usability of EPA as a construction material, was performed according to TS 1114 EN 13055-1 standards. Organic matter content was determined according to TS EN 1744-1, in which expanded perlite aggregate having 2-4 mm size was exposed to 3-6% NaOH for 24 hours. The presence of organic matter after 24 hours was determined according to the light yellow, dark brown or red color of the aggregates. The loss on ignition analysis of expanded perlite aggregates were carried out according to TS 1114 EN 13055-1 standards.

Results and discussion

Mineralogical and petrographic analyses of EPA

Perlite, in terms of color and chemical composition, resembles mostly to pumice. The most effective way of separating perlite from diatomite, pumice and other volcanic originated rocks is their mineralogical and petrographic analyses. The chemical analysis results are given in Table 1. As a result of the chemical analysis, it was observed that perlite has an average SiO_2 and Al_2O_3 amount of 70.68% and 13.04%, respectively, which is compatible with the literature (Topcu and Isikdag, 2007; Tekin et al., 2010). Also as a result of the XRD analysis (Figure 1), perlite samples were found to consist of amorphous silica and opal-CT (98%) and trace amounts of feldspar and quartz. A similar XRD pattern was also found by Sodeyama et al. (1999).

Table 1. Chemical analysis and loss on ignition analysis results of EPA samples (%)

Sample No	SiO_2	Al_2O_3	Na_2O	K_2O	Fe_2O_3	CaO+MgO	*LoI
1	70.7	13.0	3.6	4.6	0.8	3.9	3.1
2	69.8	12.1	3.3	4.2	1.1	3.5	3.0
3	71.4	13.8	3.8	3.9	1.6	3.6	3.2
4	70.4	13.4	3.5	4.4	1.0	3.9	3.1
5	71.1	12.9	3.5	4.6	0.7	4.0	3.0
Average	70.68	13.04	3.54	4.34	1.04	3.78	3.08

*LoI: Loss on ignition

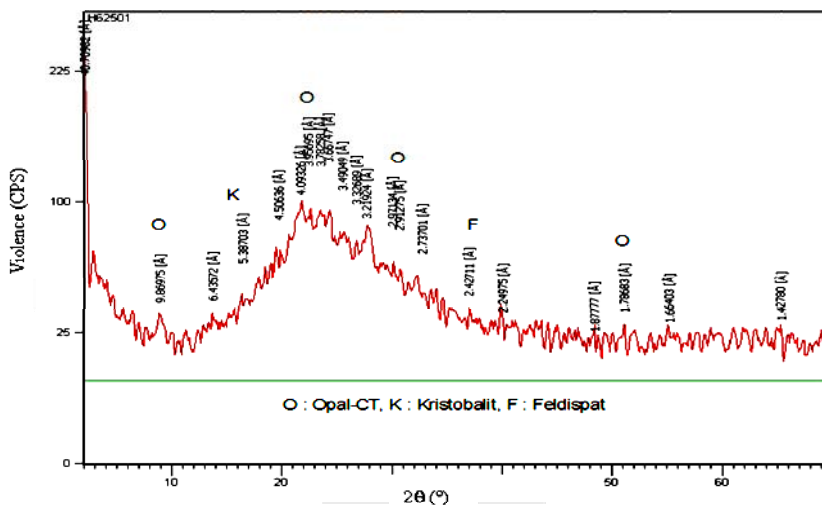


Fig. 1. XRD analysis of EPA

The petrographic investigation on the expanded perlite is given in Figure 2. As seen from the microphotograph, perlite had a glassy and porous structure. There was countless number of pores, each having different micron sizes. This structure of the perlite makes it lighter, while providing a big advantage in terms of heat and sound transmission. In the analysis, the presence of opal-CT, feldspar, mica, illite and quartz minerals were determined within the perlite structure (Figure 2).

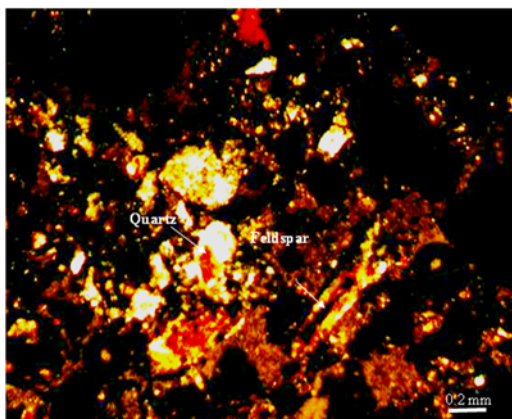


Fig. 2. Microphotograph showing feldspar and quartz in EPA

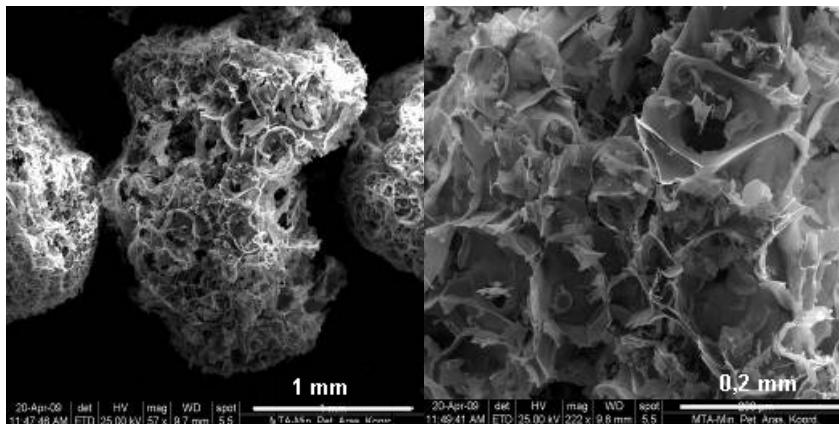


Fig. 3. SEM images of EPA

SEM images of EPA, Figure 3, also had a crystal-like porous and glassy structure. SEM images are similar to the image given by Sarı et al. (2009). The proportional distribution of the elements, determined by EDS analysis (Figure 4), showed that within the expanded perlite samples, silicon (45.13%), oxygen (38.91%), aluminum (8%), potassium (5.58%) and sodium (2.37%) were present.

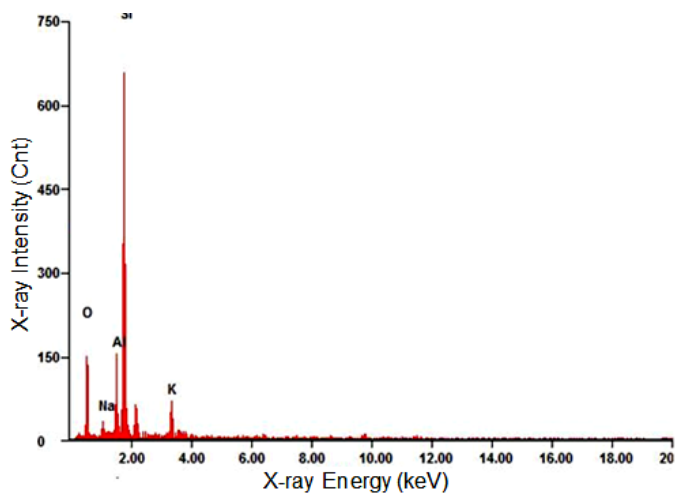


Fig. 4. EDS analysis of EPA

Thermal analyses of EPA

From the TGA analysis (Figure 5), it was found that the perlite sample lost all its moisture till 200°C and had a weight loss of 1.4% at 450 °C. At temperatures above 500°C, no considerable weight loss (0.3%) was observed. At 1000 °C, perlite had a total weight loss of 1.8%, which shows that it can be used at high-temperature applications. Roulia et al., 2006 also found that expanded perlite retains 1.6–1.9 wt% water for all studied temperatures (till 950°C). The dehydration in perlites is divided to three temperature ranges by Roulia et al., 2006: 0–250°C, 250–550°C and 550–950°C. In the first temperature range, the molecular water bound loosely either superficially or adsorbed in pores are released. In the second temperature range molecular water trapped into the inner pores of the material is released. At the last temperature range – OH groups associated to the oxygen atoms through strong hydrogen bonding are released.

Besides, DTA curve gave an exothermic peak at 250 °C. This broad peak corresponds to the release of water either bound loosely or trapped into the inner pores of expanded perlite. The exothermic peak can also be attributed to the glass compression and internal surface area diminution. Roulia et al. (2006) also found an exothermic peak in the DTA curve for expanded perlite at around 250°C. The phase change started in the temperature range of 500-600 °C and completed at 1000 °C.

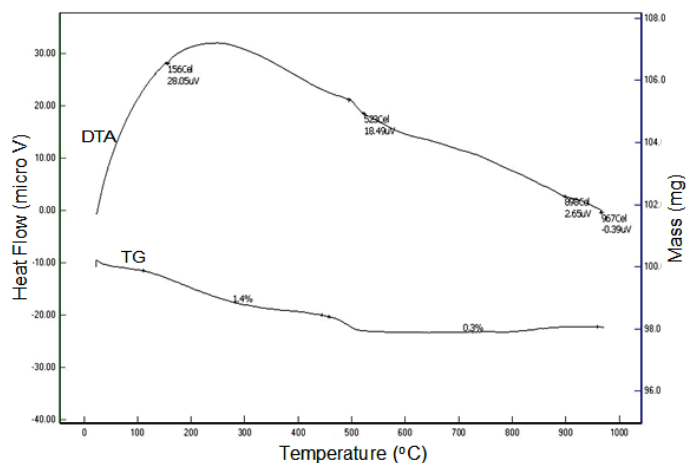


Fig. 5. TG-DTA curves of EPA (heating rate = 20 °C/min.)

To determine the mass loss of expanded perlite with heat, loss on ignition test was performed and the results are given in Table 1. As seen in Table 1, the loss on ignition of EPA was less than 5% ($3.08 \pm 0.09\%$). This result confirms that EPA can be used as a construction raw material when tested according to TS 1114 EN 13055-1 standard.

Variation of physical properties of EPA with temperature

Surface area, bulk density, specific gravity, porosity, water absorption and compactness ratio values of EPA were determined at different temperatures and given in Table 2. The highest surface area ($523.8 \pm 18.5 \text{ m}^2/\text{g}$) was obtained at 400 °C which decreased with the increase in temperature. As temperature was increased above 400°C, thermolysis began and the perlite samples started to decompose. At temperatures above 600 °C, the decomposition of perlite samples was practically

Table 2. Physical properties of EPA at different temperatures

Temperature (°C)	Surface area (m^2/g^{-1})	Specific gravity (kg/m^3)	Bulk density (kg/m^3)	Porosity (%)	Water absorption (%)	Compactness ratio
Ambient	108.7 ± 7.1	1973 ± 90	230 ± 10	79 ± 1.30	71.1 ± 1.0	0.12 ± 0.04
100	295.4 ± 4.3	1958 ± 50	220 ± 20	68 ± 1.90	67.8 ± 0.9	0.11 ± 0.07
200	308.5 ± 11.2	1936 ± 95	210 ± 20	56 ± 2.00	63.7 ± 0.9	0.11 ± 0.03
300	442.9 ± 16.7	1922 ± 60	190 ± 10	48 ± 1.10	59.8 ± 0.7	0.10 ± 0.01
400	523.8 ± 18.5	1905 ± 80	150 ± 40	43 ± 1.10	51.5 ± 0.8	0.08 ± 0.04
500	265.5 ± 8.9	1886 ± 40	100 ± 10	36 ± 0.95	48.5 ± 0.6	0.06 ± 0.01
600	73.0 ± 6.4	1845 ± 60	85 ± 10	30 ± 0.85	44.5 ± 0.6	0.05 ± 0.01

finished and the surface area decreased. Bulk density, specific gravity, porosity and compactness ratio values decreased depending on the temperature. The highest values were reached at 100 °C, whereas the lowest values were attained at 600 °C. EPA has a specific gravity of $1973 \pm 90 \text{ kg/m}^3$ and bulk density of $230 \pm 10 \text{ kg/m}^3$ at 100°C, whereas these values decreased to $1905 \pm 80 \text{ kg/m}^3$ and $150 \pm 40 \text{ kg/m}^3$ at 400°C, respectively. The porosity, water absorption and compactness ratio of EPA decreased from $79.00 \pm 1.30\%$ to $43.00 \pm 1.10\%$, $71.1 \pm 1.0\%$ to $51.5 \pm 0.8\%$, and $0.12 \pm 0.04\%$ to $0.08 \pm 0.04\%$ at 400°C, respectively.

Sieve, fine matter and organic content analyses

Sieve analysis, fine matter analysis and organic matter content analyses were performed to investigate if EPA could be used as a construction raw material. From the sieve analysis (Figure 6), performed according to TS 1114 EN 13055-1 standards, it was observed that EPA was within the standard range. So it can be concluded that it can be used during the production of construction materials.

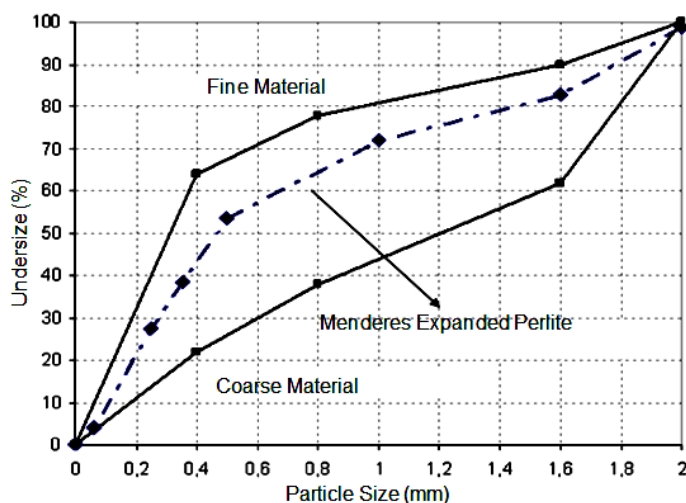


Fig. 6. Sieve analysis curve

Fine matter analysis of EPA, given in Table 3, was performed to determine the suitability of 0-4 mm particle size to TS 1114 EN 13055-1 standard. The fine matter analysis defined in the standard was the percent ratio of the oversized material to the undersized residue when 0.063 mm sieve opening was used. The evaluation of the results showed that fine matter content was less than 5% ($3.68 \pm 0.07\%$) as specified in the standard. Presence of organic matter in EPA is inconvenient and unfavorable. According to the experimental criteria given in TS EN 1744-1 standard, no organic matter formation was detected in EPA. These analyses together with mass loss on ignition analysis showed that EPA can be used as a construction raw material.

Table 3. Fine matter amounts of EPA (0-4 mm sieve opening)

Sample No	1	2	3	4	5
Dry weight (g)	1030	1050	1100	1050	1000
0.063 mm – Oversize weight (g)	480	456	502	483	448
1.0+0.5 mm – Oversize weight (g)	212	198	225	211	204
1.6+1 mm – Oversize weight (g)	146	165	174	150	142
2+1.6 mm – Oversize weight (g)	106	119	111	124	109
4+2 mm – Oversize weight (g)	44	73	52	49	56
Total oversize material weight (g)	988	1011	1064	1017	958
Total undersize residue weight (g)	42	39	36	33	42
Fine matter ratio (%)	4.07	3.71	3.27	3.14	4.20
Average (%)	3.68				

Comparison of characteristic properties

When the characteristic properties of perlite were examined, it was observed that chemical analysis, petrographic analysis, XRD, SEM and EDS analysis results support each other. TG-DTA analysis showed changes in direct proportion to the mass loss on ignition. Besides, significant statistical relations exist between the physical properties of the perlite; especially between specific gravity and bulk density ($R^2 = 0,9252$) (Fig. 7), bulk density and porosity ($R^2 = 0,9246$) (Figure 8), water absorption and specific gravity ($R^2 = 0,9501$) (Figure 9), compactness ratio and specific gravity ($R^2 = 0,9297$) (Fig. 10). It can also be seen that although there exists sets of relationships between the physical properties of the expanded perlite, they also decrease with temperature.

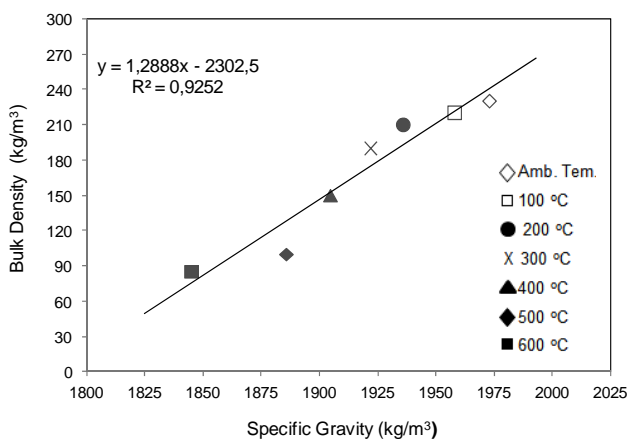


Fig. 7. Relationship between specific gravity and bulk density

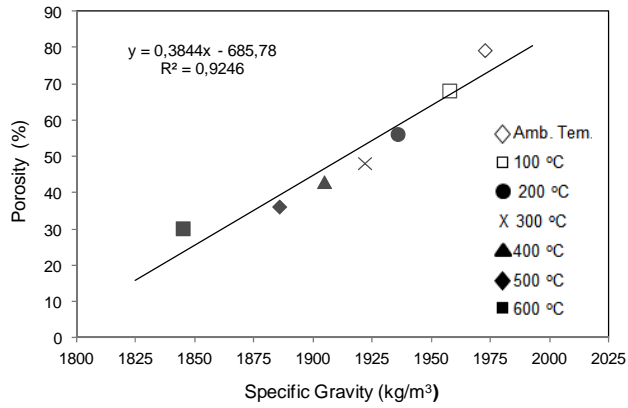


Fig. 8. Relationship between specific gravity and porosity

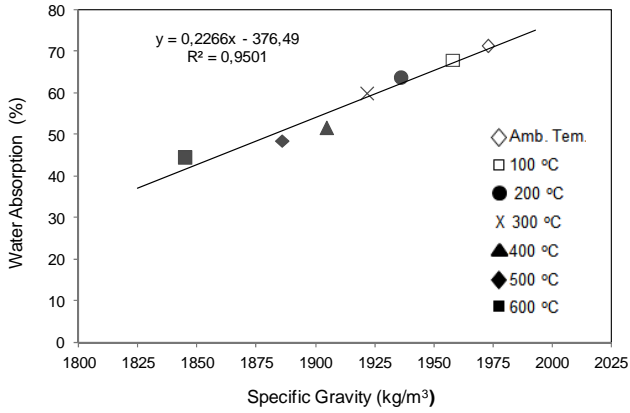


Fig. 9. Relationship between specific gravity and water absorption

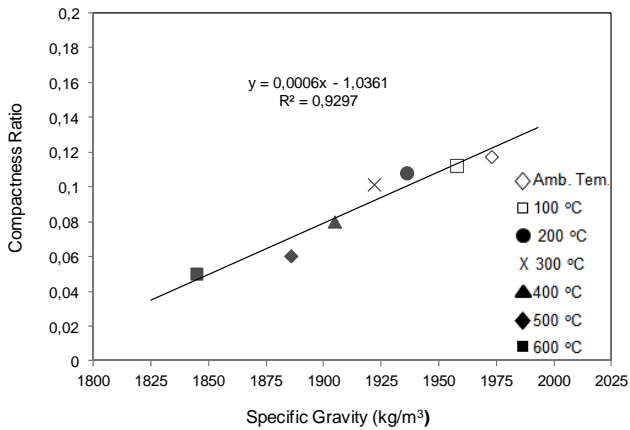


Fig. 10. Relationship between specific gravity and compactness ratio

Conclusions

During the studies aiming to investigate characteristic properties of EPA and find its suitability as construction raw material, many of its properties were determined. The chemical composition of the expanded perlite was found to consist of 70.68% SiO₂ and 13.04% Al₂O₃. The petrographic observations showed presence of opal-CT, feldspar, mica, illite, and quartz in the perlite structure. SEM images showed a crystal like porous and glassy structure. EDS analysis showed the presence of 45.13% silicon and 38.91% oxygen within the EPA structure. A weight loss of 1.8% at 1000 °C was found from the TG-DTA analysis meaning that expanded perlite can be utilized at high temperature applications. Although specific gravity, bulk density, porosity, water absorption and compactness ratios differ at different temperatures, they were found to have high statistical relation. In addition, surface area was also affected by temperature. To determine whether EPA could be used as a construction raw material or not, sieve analysis, fine-matter content and mass loss on ignition analysis and organic matter content were performed and it was found that EPA was appropriate to be used as a lightweight construction raw material.

Acknowledgements

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