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Determination of The Properties of Noise and Temperature Reducing Lightweight Building Material Produced From Expanded Vermiculite With Simple İnstruments

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ABSTRACT

Recent developments in the world have once again revealed the importance of energy and energy saving. In addition, sound insulation in both high-rise residences and workplaces is also important in terms of life and social aspects. In this study, in order to determine the production of blocks that will provide heat and sound insulation by mixing expanded vermiculite mineral and cement material in different ratios with simple instruments, it is aimed to carry out preliminary tests within the scope of graduate studies. For this purpose, cylindrical and cubic specimens with cement/vermiculite mixture ratio of 1/2, 1/4 and 1/6 were prepared by keeping the cement ratio constant. The hardness and strength of the specimens exposed to water curing were observed and then ultrasonic sound transmission velocity, compressive strength, temperature changes and sound transients were measured on the specimens. No burning and deterioration of the specimens was observed in the temperature measurements. The average dry density of all samples was 700 kg/m^3. It was determined that the compressive strength of the samples decreased as the vermiculite ratio increased, while the sound and heat transmission decreased. These test studies revealed that vermiculite mineral, which has very large reserves in Sivas region, can be used sustainably in heat and sound insulation and detailed research should be continued for lightweight building material.

Keywords: Vermiculite, Cement, Decibel, Concrete

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Introduction

Building materials account for 30-50% or more of the building cost. However, extra costs are also incurred for heat, sound and water insulation in existing or newly constructed environmentally friendly buildings. With the increasing population and industrialization in the world and in our country, energy consumption and need increases every year. According to the data of the Ministry of Energy and Natural Resources, the share of industry in energy consumption in our country in 2020 is 34.4% and the share of the residential and service sector is calculated as 40,1 % [1]. Fig. 1 below shows the current and future energy consumption of our country according to sectors. As seen in the graph, energy consumption is expected to increase gradually. On the other hand, our country is dependent on foreign energy and we purchase 50 billion dollars of energy annually. As in all sectors, it is clear how important it is to use energy-saving insulation materials in the housing sector. It is stated that with 10 percent energy savings to be achieved in houses, it will be possible to bring 132 million dollars back to the national economy annually [2]. As a matter of fact, the variety and use of energy-saving construction materials have started to increase in the world and in our country. It is extremely important to produce energy-saving materials that have a significant impact on the economy of our country with local resources. Insulation materials with water, sound and radiation-proof properties are also important for construction structures. Materials such as glass wool, rock wool, perlite, pumice, XPS (Extrude Polystyrene Foam board) and EPS (Expanded Polystyrene), which have both heat and sound insulation properties, are available. In waterproofing, petroleum-based bitumen, geo-membrane and geotextile materials are widely used.

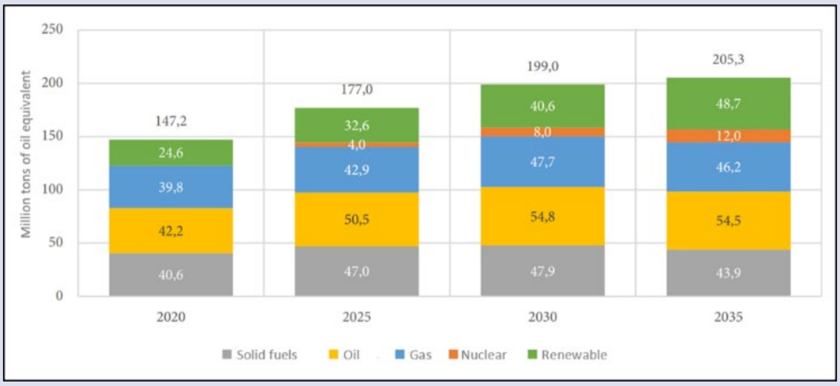

Figure 1. Final energy consumption by sector in Türkiye [1].

In the literature, there are many studies on the construction of building materials with vermiculite materials [3-11]. While many of these researches are in the form of vermiculite substitution instead of fine aggregate in the existing concrete material, some of them have investigated the construction of lightweight building materials by using materials such as thermal power plant fly ash, silica fumed, wood shavings, PVC shavings together with vermiculite. Prince et al. [6] experimentally investigated the compressive, flexural and tensile strength parameters by replacing 5, 10 and 15% of vermiculite with fine aggregate. They concluded that 10% exfoliated vermiculite substitution was good in terms of compressive strength, split tensile strength and flexural strength. Rehman et al. [3] expanded vermiculite from Swat region of Pakistan at 750 °C and determined the physical and mechanical properties of composite samples such as density, water absorption, compressive strength, tensile strength and thermal conductivity by selecting resin: vermiculite ratio as 65:35, 60:40, 55:45 and 50:50. It was found that the composite product made of resin and vermiculite can be easily made and can be applied in the interiors of buildings instead of traditional ceramic tiles and the product offers lower density, lower water absorption, lower thermal conductivity and higher strength. Rashad [10] summarized the studies on the applications of expanded vermiculite in civil engineering, chemical industry and agriculture. Studies have shown that vermiculite can be used as aggregate in lightweight concrete and plaster due to its good thermal insulation, fire resistance and sound insulation as a construction material.

Sevinç et al [4] investigated the flexural and compressive strength, thermal conductivity coefficient, density, water absorption, ultrasonic impact velocity, ultrasonic impact velocity tests and radiation permeability of the samples using epoxy as binder material with different ratios of waste sawdust, waste PVC sawdust, waste eggshell and vermiculite. It was determined that the mechanical properties of epoxy-based composites were low, but the water absorption of the composites was significantly reduced by using PVC chips. While thermal conductivity coefficients were negatively affected by the use of waste eggshells, the use of vermiculite reduced these values and suggested that waste eggshells can be used as an additive for gamma radiation shielding. The addition of vermiculite slightly contributed to the radiation absorption capacity. Kim et al. [8] observed that when expanded vermiculite was included as a sand substitute at 30% and 60% replacement levels, vermiculite had a positive effect on providing heat resistance and thermal stability to mortars and reduced compressive strength losses when mortars were exposed to high temperatures. The study states that the inclusion of expanded vermiculite as a partial sand substitute increases the flow diameter of fresh mortars.

Sütcü [11] added 2.5%, 5%, 7.5% and 10% expanded vermiculite by weight to clay brick mix and determined the properties of the samples such as drying and firing shrinkage, loss on ignition, bulk density, porosity, water absorption, compressive strength, thermal conductivity and microstructure. He found that the use of expanded vermiculite addition reduced the bulk density of the samples containing 10 wt. % additive from 1.76 to 1.34 g/cm^3. He suggested that brick samples produced with vermiculite additive can be used as insulation material in construction applications.

In this study, unlike other studies, it is aimed to conduct preliminary trial tests of a lightweight building material with sound and heat insulation properties without any other additives, using only expanded vermiculite mineral and cement, which is a local and natural material.

Material and Methods

Vermiculite is generally a 2:1 layered phyllosilicate mineral formed by the alteration of mica minerals and chlorite. Four types of formation have been observed in nature; macroscopic, soil, autogenic and metamorphic. There are Mg, Fe, Al complexes and water molecules between the layers. The chemical formula of the standard Vermiculite mineral is as follows: $(Si, Al)_4 (Mg, Al, Fe)_3 O_{10} (OH)_2 Mg_2 (H_2O)_n$

Its chemical composition varies between the following values: 37-42% SiO_2, 10-13% Al_2O_3, 5-17% Fe_2O_3, 1-3% FeO, 14-23% MgO, 8-18% H_2O, and up to 5% K_2O. Vermiculite crystal structure is formed by placing an octahedral coordinated layer formed by Mg and Fe ions between two tetrahedral layers formed by SiO_4 (Fig. 2). Hydroxide cations are placed between these 2:1 composite layers. The charge difference caused by the substitution of Al for Si is usually balanced by interlayer Mg. Surface oxygen and cations in the same layer are connected to each other by H-bonds, while the layers formed by water molecules are connected to each other by Mg [12].

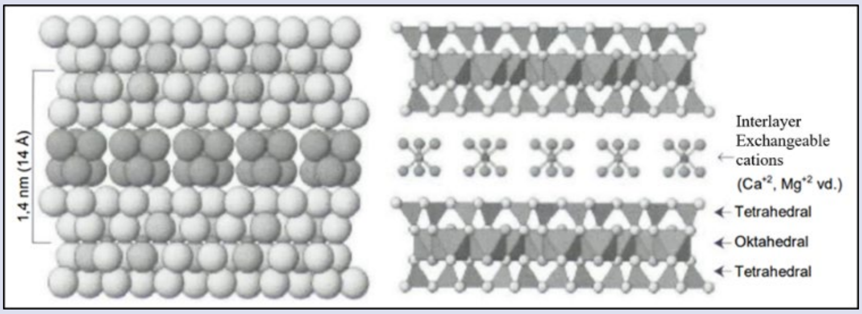

Figure 3. View of vermiculite mineral layers [13].

Table 1. Chemical composition of vermiculite used in the experiments

Oxides	%
SiO_2	36-37
Al_2O_3	15-16
Fe_2O_3	11-13
MgO	15-16
CaO	2-4
K_2O	5-6
TiO_2	2-3
Na_2O	0.2-0.3
BaO	05-0.7
P_2O_5	0.02-0.08
LOI	6-8

Table 2. Chemical composition of Portland Cement (C42,5) used in the experiments

Oxides	%
SiO_2	18.25
Al_2O_3	4.59
Fe_2O_3	3.48
MgO	1.97
CaO	63.97
SO_3	2.89
K_2O	0.69
Na_2O	0.31
LOI	3.85

When vermiculite with a density ranging between 800-1040 kg/m^3 is heated very rapidly at high temperatures such as 900-1000°C, it increases 8-20 times in volume due to the sudden evaporation of water between the layers and expanded vermiculite with a bulk density of 56-192 kg/m^3 can be obtained. Since the use of vermiculite in its raw form is quite low, the expanded form is preferred in the industry. Vermiculites with low bulk density obtained by the expansion process are chemically inert, have heat and sound insulation and ion exchange properties and are mostly used in the construction/building and agriculture/horticulture sectors. In addition to these, expanded vermiculite is also used in refractory industry, thermal insulation, packaging, automotive industry and animal feed. It can also be used in other areas such as removal of various metal ions and oils from wastewater, paints, ceramic and composite material compositions, desiccant carrier etc. [12, 13, 14]. Although the existence of vermiculite deposits in Turkey is not well known, vermiculite formations have been encountered in ophiolite belts during geological studies. So far, the most important vermiculite deposits have been identified in Sivas-Yıldızeli and Malatya regions with reserves of 6-7 million tons [12, 15].

The expanded vermiculite mineral we used in our study was obtained from a factory located near Sivas Yıldızeli district. The chemical compositions of expanded vermiculite used in the experiments are given in Table 1. Six different size classifications of expanded vermiculite are commercially produced in the factory. In the experimental studies, +5mm sized expanded vermiculite produced under the name "Coarse Vermiculite" was used (Fig. 3).

C 42.5 class Portland cement was obtained from the market as binder. The properties of the cement obtained from the market are given in Table 2. Tap water was used as mixing liquid.

Cubic and cylindrical molds were prepared to perform mechanical, sound and thermal tests with the materials brought to the laboratory. Cubic sample molds were prepared in the dimensions of 15x15x15 cm as specified in the standards [16] (Fig. 4a), cylindrical molds with a diameter of 20 cm and heights of 2.5 cm, 5 cm and 7.5 cm (Fig. 4b), cylindrical molds with a diameter of 20 cm and a wall thickness of 3 cm (Fig. 4c) were prepared for sound transmission experiments and a vase with a cement/vermiculite ratio of ½ was made. Specimen sizes and thicknesses were prepared to be investigated uniquely for this study.

Figure 4. Trade name "Coarse Vermiculite" used in the experiment.

Figure 5. Sample molds to be used in the experiments. (a) cubic molds, (b) cylindrical molds, (c) cylindrical vase molds and (d) cylindrical vase.

For the specimens to be used in the experiments, mixtures were prepared by increasing the vermiculite ratio by volume as 2, 4 and 6 with a constant cement ratio. Fixed volume cubic moulds were used for sample quantities.

A total of nine cubic specimen mortars, three from each series, were prepared with cement vermiculite ratios of 1/2, 1/4 and 1/6 by volume. These ratios are designed for initial tests. In a study [17], cement, aggregate and vermiculite mix ratios of 1:1.5:1.5 and 1:2:1 were selected. During the preparation of the specimens, the cement and water mixture was mixed thoroughly with a spatula / trowel. Then the coarse vermiculite material was slowly poured into the cement-water mixture and mixed continuously. The vermiculite mortar, which was brought to a workable consistency, was poured into the cubic moulds prepared by applying oil with a brush beforehand to prevent sticking. During pouring, vibration was created from outside the mould with a mallet in order to settle the mortar and prevent the formation of an air gap. The concrete specimens were smoothed with a trowel and kept in the mould for 24 hours until solidification. The specimens were removed from the moulds using compressed air without breaking and placed in a water pool to gain hardness and strength.

The samples kept in the sample pool for curing were removed from the pool after 14 days. The water on the surface was drained for a certain period of time and wetness was removed with a cloth. The samples were kept in an oven at 105 °C for 24 hours for complete drying. The cubic samples were weighed using a precision balance before and after placing in the oven and the results were written down. Then, ultrasonic P- wave sound velocity transients were measured in meters/second with the Pundit device for the pre-numbered samples. Since the compression test specimens were 15x15x15cm in size, the volume of each specimen was determined as 3375 cm^3. The masses of each sample in dry natural state were measured with a precision balance. The densities of each sample were calculated as the ratio of their masses to their volumes. The surfaces of the cubic samples were smeared with Vaseline and the ultrasonic sound transmission velocities were simply determined with the Pundit device. The surface area of each cubic sample was determined as 22500 mm^2. The cubic specimens were placed between the platens of the press machine and load was applied until the specimen broke and the breaking load was read in kN.The fracture load was determined and recorded by applying 0.6±0.2 MPa/s [18] rate on the specimens with a computer controlled Concrete Press machine (Fig. 5).

Figure 6. P-wave (Vp) velocity measurement and compression test of cubic specimens

The 1/2, 1/4 and 1/6 cement to vermiculite ratios prepared for cubic specimens were also prepared for cylindrical specimens. Similar mixture preparation and casting processes were applied for the cylindrical specimens. Cylindrical concrete specimens with a diameter of 20 cm and heights of 2.5, 5 and 7.5 cm were kept in the mould for 24 hours until solidification. The demoulded specimens were left to dry and harden at room conditions for 14 days. 75% of normal concrete strength is obtained after 14 days. For the experimental tests, 14-day strength was considered sufficient for the evaluations and 28-day post-curing strengths will be examined in future studies. The dried and hardened cylindrical specimens were weighed on a precision balance and placed on a 20 cm diameter furnace with 1500 W heat capacity. The last level was selected from the furnace adjustment knob to produce approximately constant temperature. Before starting the experiments, the furnace top temperature was measured with an Infrared laser thermometer at a fixed height of 70 cm. The numbered cylindrical samples were placed one by one on the furnace and the temperature readings were taken every 5 minutes for 60 minutes with the laser thermometer and recorded in a table (Fig. 6).

Figure 6. Temperature transition test for cylindrical specimens

The cylindrical specimens used in the temperature transmission test were also used in the sound transmission test. For the sound transmission test, a cylindrical vase with an outer diameter of 20cm and an inner diameter of 14 cm and a height of 20 cm and a depth of 17 cm was prepared with F-19 fiber/fiber reinforced mortar with a cement vermiculite ratio of ½. The vase was removed from the mold and allowed to dry and harden for 14 days. In order to increase the durability of the vase or the sound insulation measuring cabinet and to remove the roughness, slaked lime obtained by endothermic reaction by heating limestone was supplied and mixed with water to obtain lime paint by exothermic reaction and painted around the vase. In order to measure the sound transmission, a cell phone was placed inside the sound booth vase as a constant and continuous sound source. The sound of the indoor environment was measured at a fixed distance with a Svantek sound meter. The top of the sound booth vase was covered with a cylindrical sample smeared with vaseline to prevent sound escape and the outdoor sound was measured in decibels (dB) with a sound meter (Fig. 7). The same procedures were performed for three numbered cylindrical specimens of three different mixtures and three different thicknesses and/or heights, and the indoor and outdoor sound levels were measured and recorded.

Figure 7. Sound transmission experiment. Internal and external sound measurement

Results and Discussion

Experiments were carried out on cubic and cylindrical concrete specimens prepared with different proportions of vermiculite mineral and the following findings were obtained.

The measurements and calculations for all specimens are summarized in Table 3.

The masses of the cubic specimens prepared for the experiments were measured and given graphically in Fig. 8. As can be seen from the Fig., as the cement/vermiculite ratio increased, the mass of the specimens and therefore the density values decreased significantly. Lightweight concrete with a dry density ranging from 320 kg/m^3 to1920 kg/m^3. [19]. In this study the densities of the samples vary between 510 kg/m^3 and 960 kg/m^3. This is considerably lower than the 1920 kg/m^3 limit required for lightweight construction concrete material. In other words, all of the specimens were lighter than water and were found to be a suitable lightweight construction material.

Table 3. Mass, density, Vp sound transmission velocity and pressure values of cubic specimens.

Sample No	Cement / Vermiculite mix ratio	Sample Dimensions (cmxcmxcm)	Sample Volume (cm³) V	Sample Mass (g) M	Sample density (g/cm³) M/V	Ultrasonic velocity Vp-ort (m/s)	Specimen cross-sectional area (mm²) A	Specimen breaking load (kN) F	Compressive strength (N/mm²) F/A	Compressive strength (kg/cm²)	Average Compressive strength (kg/cm²)
VR1	1/2	15x15x15	3375	3228	0.96	1940.00	22500	88.77	3.945	40.231	
VR2	1/2	15x15x15	3375	3187	0.94	1910.00	22500	80.08	3.559	36.293	37.420
VR3	1/2	15x15x15	3375	3258	0.97	1860.00	22500	82.85	3.682	37.548	
VR4	1/4	15x15x15	3375	2094	0.62	1333.33	22500	24.9	1.107	11.285	
VR5	1/4	15x15x15	3375	2121	0.63	1390.00	22500	23.84	1.060	10.804	11.045
VR6	1/4	15x15x15	3375	2113	0.63	1306.67	22500	22.88	1.017	10.369	
VR7	1/6	15x15x15	3375	1783	0.53	1120.00	22500	15.78	0.701	7.152	
VR8	1/6	15x15x15	3375	1671	0.50	807.33	22500	14.15	0.629	6.413	6.694
VR9	1/6	15x15x15	3375	1734	0.51	1060.00	22500	14.38	0.639	6.517	

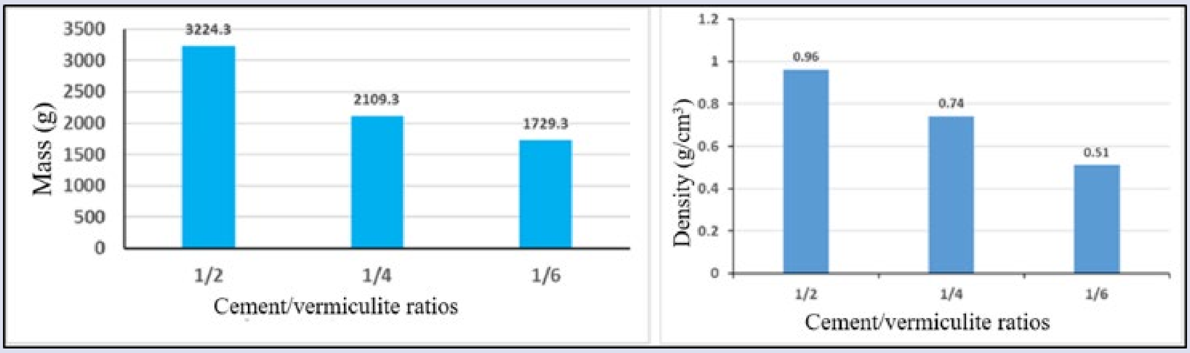

Figure 8. Mass and density of cubic specimens according to cement/vermiculite ratios

Compressive strength and P-wave (Vp) velocity test results

The compressive strength of each sample was calculated by dividing the fracture load by the surface area of the cubic sample. Average compressive strength of the samples vary between 6.694 kg/cm^2 (0.67 MPa) and 37.420 kg/cm^2 (3.74 MPa). (Fig. 9.). On the other hand, P wave velocity values decreased with increasing vermiculite ratio in parallel with the compressive strength results. The results are shown graphically in Figure 10. The compressive strength of low-density light weight concrete are vary between 0.7 MPa and 2.0 MPa and the compressive strength of moderate-strength of lightweight concrete are vary between 7 MPa and 14 MPa. and compressive strength of structural-strength of lightweight concrete are vary between 17 MPa and 63 MPa. [19, 20]. In this study, according to the 14-day curing results the compressive strength of the samples is in the category of low density lightweight concrete. After 28 days of curing, it may be in the medium strength lightweight concrete class and it is estimated that this will be the case in the later study.

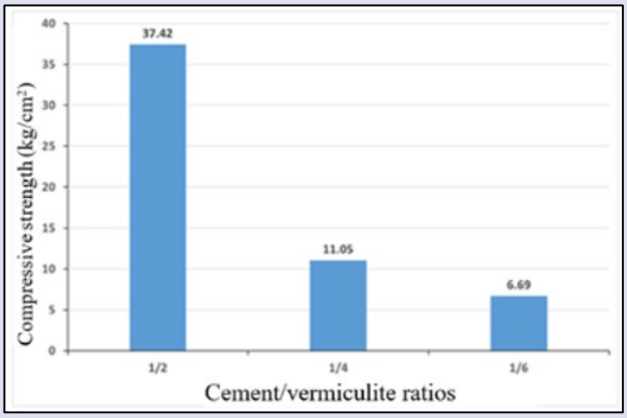

Figure 9. Variation of compressive strength of cubic specimens according to cement/vermiculite ratios

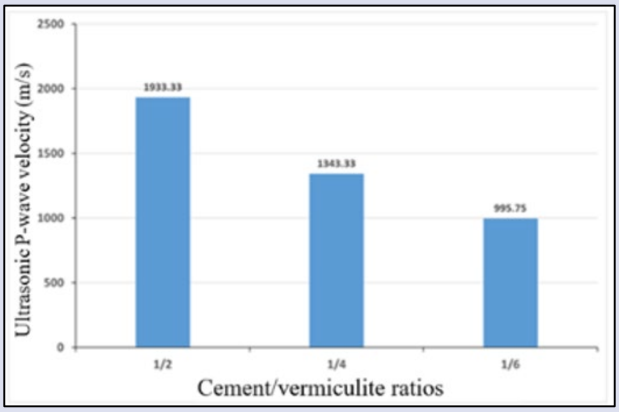

Figure 10. Variation of Vp sound transmission velocity of cubic specimens according to cement/vermiculite ratios

Heat transfer experiment results

In this study, the heat transfer of the samples was carried out with simple test tools for preliminary trials and will be studied with equipment in accordance with the standards in further studies. The temperature readings of cylindrical specimens of three different thicknesses with three different cement vermiculite ratios at 5 min intervals are given in Table 4.

It was observed that the variation of cement/vermiculite ratios and the thickness of the cylindrical specimens varied the temperature transition and therefore the temperature changes on the surface. The temperature on the surface of the cylindrical specimens made at 5 min intervals for 60 min increased slowly at first, but at the end of 60 min, it changed between 39.7 °C and 103.2 °C (Fig. 10). In other words, while the surface temperature of the furnace used in the experiment was 355 °C, the temperature transition decreased significantly in all samples. No burning or cracking of the specimens was observed. As seen in Fig. 11, the temperature transition decreased as the thickness of the cylindrical specimen increased. Similarly, the temperature transfer decreased with increasing cement/vermiculite ratio. It was observed that all specimens significantly prevented heat transfer and thus temperature transfer.

Table 4. Heat transfer temperature measurement values of cylindrical specimens

Sample No	Cement / Vermiculite ratio	Sample diameter (cm)	Specimen height (cm)	Sample mass (g)	Heater average surface temperature (°C)	Measured Surface Temperature °C												
						1. Min.	5. Min.	10. Min.	15. Min.	20. Min.	25. Min.	30. Min.	35. Min.	40. Min.	45. Min.	50. Min.	55. Min.	60. Min.
1	1/6	10	2.5	649.8	335	15.1	26	60	61.8	72	73.5	71.8	72.2	75.6	81.2	87.6	92.1	**95.2**
2	1/6	10	5	1390.3	335	15	20.5	22.3	34.2	51	62.1	64.1	65.4	65.6	66.5	66.4	65.6	**65.3**
3	1/6	10	7.5	2178.1	335	14	15.6	16	16.3	17.8	19.1	21.6	26.8	32.2	36.1	38.7	44.1	**46**
4	1/4	10	2.5	698.1	335	15.6	28	57	71	74.3	76	76.6	75.8	77.5	83.1	88.8	96	**99.5**
5	1/4	10	5	1632.8	335	15.1	16.8	18.6	23	30.6	40.1	49.8	55.6	61.3	63	64.4	65.8	**68.1**
6	1/4	10	7.5	2474.1	335	15	16.2	16.5	16.7	17.1	18.5	19.8	21.8	24.8	29.3	34.2	35.8	**39.7**
7	1/2	10	2.5	779	335	17	29.4	50.5	75	76	82.5	83.9	84.3	84.2	84.5	86.2	97.1	**103.2**
8	1/2	10	5	1862.5	335	16.2	17.2	21.7	24.6	38.1	48.3	55.4	62.7	63.5	65.2	71.9	71.5	**73.75**
9	1/2	10	7.5	2702.1	335	17	17.2	17.3	17.8	18.9	23.4	26.3	28.8	32.6	35.4	40.1	41.4	**46.7**

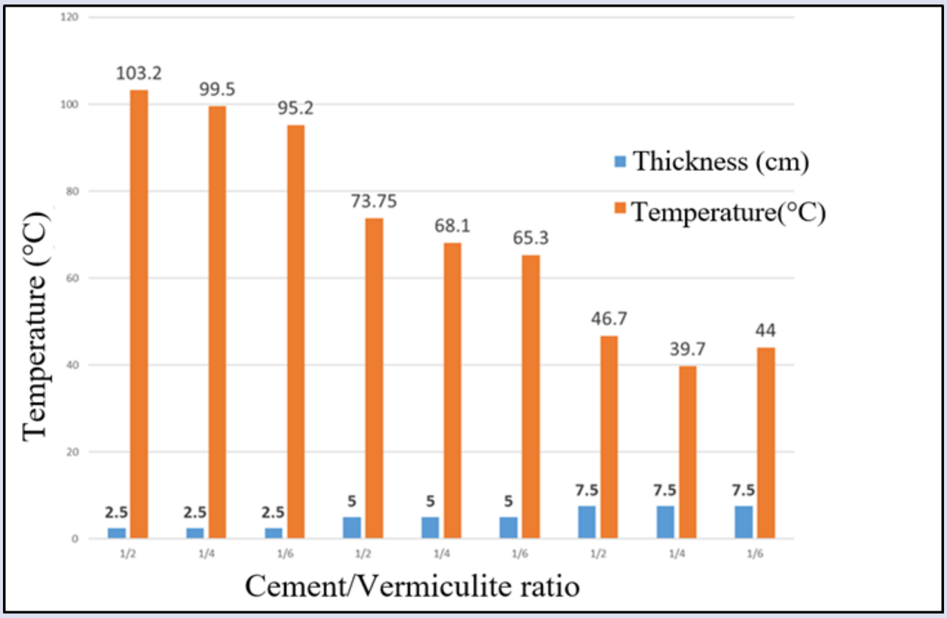

Figure 11. Temperature variation of cylindrical specimens according to cement/vermiculite ratios and thicknesses

Sound Transmission Experiment Results

In this study, the sound transmission of the samples was carried out with simple test tools for preliminary trials and will be studied with equipment in accordance with the standards in further studies. The sound transmission of cylindrical specimens of three different thicknesses with three different cement to vermiculite ratios were measured in decibels. The results obtained are shown in Table 5.

It was observed that the change in cement/vermiculite ratios and thickness of the cylindrical specimens also changed the sound transmission differences. While the noise intensity of the sound source in the sound booth was 85 decibels (dB), it was observed that the noise intensity decreased to 52 to 60 decibels with the cylindrical sample barrier. The relationships between specimen mix ratio and thickness and sound transmission difference are shown in the graph in Fig. 12. As the specimen thickness and cement/vermiculite ratio increased, the sound transmission decreased.

Table 5. Sound transmission measurement values of cylindrical specimens

Sample No	Cement/Vermiculite ratio	Sample diameter (cm)	Specimen height (cm)	Sample mass (g)	A Average Internal sound value (dB)	B Average external sound value (dB)	Sound transmission difference (A-B)
1	1/6	10	2.5	649.8	85	56	29
2	1/6	10	5	1390.3	85	54	31
3	1/6	10	7.5	2178.1	85	52	33
4	1/4	10	2.5	698.1	85	59	26
5	1/4	10	5	1632.8	85	56	29
6	1/4	10	7.5	2474.1	85	54	31
7	1/2	10	2.5	779	85	60	25
8	1/2	10	5	1862.5	85	57	28
9	1/2	10	7.5	2702.1	85	55	30

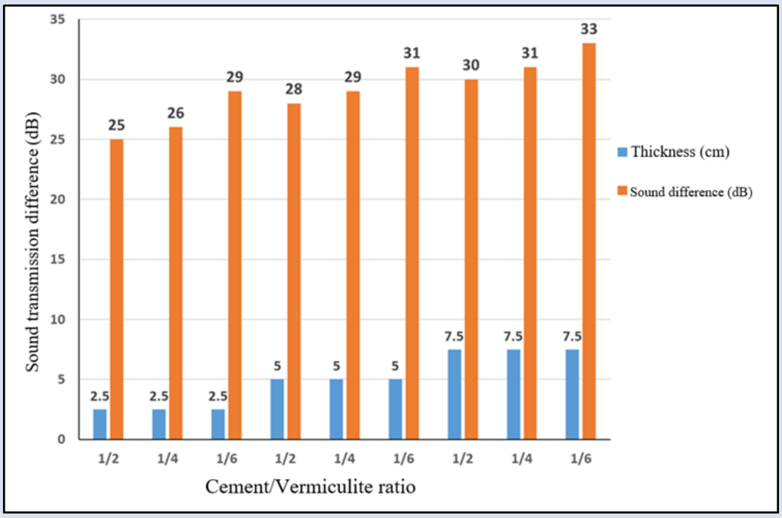

Figure 12. Variation of sound transmission difference of cylindrical specimens according to cement/vermiculite ratios and thicknesses

Conclusions

In this study, according to the 14-day curing results the compressive strength of the samples is in the category of low density lightweight concrete. After 28 days of curing, it may be in the medium strength lightweight concrete class and it is estimated that this will be the case in the later study. Preliminary research experiments have shown that the lightweight and durable concrete obtained from expanded vermiculite and cement mixtures is not only durable, but also very good at heat and/or temperature and sound insulation. These initial trials, carried out in a short period of time, will be investigated with a large number of different mixtures with other binders instead of cement to determine the optimum mix proportions. Radiation transmittance will also be investigated with the addition of some chemical materials. This study, which was carried out with existing resources and simple devices, is planned to be carried out with more scientific devices to be procured with the support of a scientific research project.

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