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Research Article

Effects of exfoliation temperature for vermiculate aggregates modified by sodium ions on thermal and comfort properties of a new generation cementitious mortar

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ABSTRACT

Vermiculite exfoliation is based on the principle that water between the layers evaporates and the crystal layers spread out, pressured by steam. As a result, elongated, curved particles are formed. The thermal properties of the final product formed are directly related to this exfoliation amount. In this experimental work, the exfoliation characteristic of natural vermiculate is studied. A series of experimental analyses were carried out to examine the expandability of natural vermiculite at different heating temperatures using the non-modification and Na^+ modification methods. The thermal expansion process was experimentally performed by recording the exfoliation states and times at six different heating temperature values of 350 °C, 450 °C, 530 °C, 620 °C, 710 °C, and 840 °C, respectively, in a laboratory environment. In the study's second phase, the thermal properties of new-generation composite mortars produced with exfoliated vermiculite aggregates were experimentally analyzed. Parameters such as thermal conductivity, heat storage capacity, specific heat, and heat dissipation coefficient of mortar test samples prepared with exfoliated vermiculite aggregates are analyzed and discussed here. Test results showed that Na^+-modified vermiculite samples expanded better than non-modified vermiculite samples for all expansion temperatures. When Na^+-modified expanded vermiculite is evaluated in composite mortars, it reduces the unit weight of the mortar as it expands more, and the unit weight decreases. Accordingly, the compressive strength of the mortar decreases relatively. However, it has been determined that the thermal comfort properties of mortars using Na^+-modified exfoliated vermiculite are better than those with non-modified exfoliated vermiculite.

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1. INTRODUCTION

The new generation composite mortars, developed to contribute to the insulation of wall surfaces, differ from traditional mortar uses due to technical features and superior advantages. For example, unit weight values are pretty low due to the porous aggregates used in their composition. In insulation design applications in buildings, it is possible to see the development of new types of products that raise awareness, such as thermal comfort, sound transmission

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loss, and resistance to fire and water effects [1, 2]. In order to provide the desired thermal comfort conditions in buildings, especially in outer partition wall sections, up to now, most materials of different origins have been used as thermal insulation materials in buildings. However, it is also often experienced that these thermal insulation materials' expected technical thermal comfort performances cannot be achieved. In particular, to ensure thermal comfort using material derivatives with an excess clearance, a low density, and low moisture content in the structure [3–5].

Global warming and the rapidly increasing climate change are among the top priority issues of the whole world. A series of practices, initiated with the Kyoto Convention and including the measures and precaution packages that should be taken to reduce greenhouse gas emissions in the world, are mainly carried out in many countries of the world. Due to the rapid depletion of primary energy resources in the world, all countries, especially developed countries, have developed methods to control their energy needs and use energy effectively. Today, most of the energy consumed in houses is for heating and cooling purposes. This energy can be effectively used with thermal insulation [2, 6]. Research studies on minimizing energy consumption and increasing energy efficiency have been among the most critical issues today. Producing new-generation thermal insulation construction elements with high performance is a potential method for solving problems such as energy consumption and environmental pollution in new projects in the construction sector. For this, developing new-generation material designs and compositions is necessary. What kind of materials, their properties, and their use in these studies are also a subject of discussion and curiosity.

Vermiculite is a natural, eco-friendly material from a group of foliated hydrous micas. Due to its unique features, it is widely applied in various fields of industry and agriculture. Natural vermiculite is a soft, flexible, and inelastic mineral with cleavages that can be divided into thin sheets characterized by the appearance of mica. Its material structure is essentially very similar to talc. Its hardness is 1.5–2.0 or more, and its density is 2.1–2.8 gr/cm^3; its color is amber, bronze, brown, green, or black. It is similar to talc, especially when wet [1, 7]. When considering the commercial use of vermiculite, hydrobiotite is generally gaining importance. This material derivative is found in commercial deposits together with biotite or phlogopite vermiculite and is defined as hydrobiotite. Vermiculite alone represents the different mineralogical groups. It is also a general term that includes all mica group minerals with industrial expansion properties.

The use of vermiculite material plays an essential role in developing new-generation mortars. Exfoliated vermiculite aggregates generally act as lightweight aggregates and have natural fiber reinforcement properties in mortar mixes. However, vermiculite derivatives are not used as aggregate material in mortar mixtures in their natural state. The heat-treated version of vermiculite exhibits an important and lightweight material characteristic. In this context, all types of vermiculite expand when exposed to high temperatures, their permeability increases, and their volume weight decreases significantly and changes shape. Depending on the high-temperature exposure location, vermiculite derivatives show similar foliation characteristics and take on a shape resembling tiny maggots.

All present technologies of vermiculite exfoliation are based on the principle that water between the layers evaporates, and the crystal layers spread out, pressured by the steam. Due to the mechanical expansion and high-temperature interaction, vermiculite leaves resemble the opening of an accordion. As a result, elongated, curved particles are formed. The material that opens like an accordion turns into a leafy and fibrous shape. This opening phenomenon varies depending on the degree of temperature and the effect time of the temperature. The material obtained in this way is called exfoliated vermiculate.

On the other hand, although vermiculite derivatives differ in their chemical content in origin, their foliar opening characteristics in temperature interaction are similar. In order to get a successful exfoliation, heating must be fast. At slow heating, evaporating water will get enough time to diffuse to the edges of a vermiculite particle and to come out. At slow heating, the steam comes out and does not manage to create enough pressure to spread out the crystal layers. The faster vermiculite is heated, the more pressure water steam creates, and the more efficiently vermiculite is exfoliated.

The advantage of exfoliated vermiculite based on thermal insulation is directly related to time under heat treatment and the amount of expansion under the effect of temperature. Different researchers have conducted alternative experimental studies to investigate the thermal expansion behaviors of vermiculite [8, 9]. Justo et al. [10] emphasized that the expansion of vermiculite with the effect of temperature is not only dependent on the evaporation of water between the layers. The main parameters affecting vermiculite's expansion are the presence of modified mica residue, the number of hydroxide groups, and its chemical composition. Several studies show these parameters can affect expansion with the effect of temperature. Feng et al. [11] analyzed the thermal expandability of vermiculite by a new Na^+ modification method in a series of experimental studies. In particular, they investigated interactions such as expansion rate, heating temperature, and natural raw vermiculite expansion times. In addition to the traditional methods for expanding raw vermiculite, it is possible to see the results of many ongoing studies on mechanical effects, chemical effects, or microwave technology expansion processes. However, in the majority of them, energy consumption during the expansion process is also high, which is also an issue that should be considered. The critical issue to be focused on is to ensure that expansion operations can be performed with minimal energy use.

Table 1. Typical physical and chemical properties of exfoliated vermiculite

Color	:	Light to dark brown	SiO_2	:	39.2
Shape	:	Accordion shaped granules	Al_2O_3	:	18.8
Moh's Hardness	:	1 to 2	TiO_2	:	2.2
pH (in water)	:	6–9	Fe_2O_3	:	11.9
Moisture loss at 110 °C	:	4–12%	CaO	:	3.8
Specific gravity	:	2.5–2.6	MgO	:	17.8
Water holding capacity	:	>180%	Na_2O	:	0.2
Sintering temperature	:	1150–1250 °C	K_2O	:	2.7
Fusion point	:	1200–1320 °C	MnO	:	0.1

New approaches have been developed for various technical parameters and evaluations in the construction industry to determine buildings' thermal comfort and performance with more realistic values. In order to be used in these approaches, numerical values of parameters representing the thermal properties of the material to be used in insulation products should be defined separately. However, it can be seen that the exact technical values for each building material related to these parametric values are not sufficiently reached, or these values are not defined as a whole [12].

In this study, a series of experimental analyses were carried out to examine the expandability of natural vermiculite at different heating temperatures using the Na^+ modification method. Technical comparisons with the values of aggregate samples without Na^+ modification are discussed. Furthermore, the thermal comfort properties of new-generation mortar designs with exfoliated vermiculite aggregates were experimentally analyzed. The thermal properties of prepared test samples are discussed comparatively. The effects of using exfoliated vermiculite on these parameters' values were examined in detail.

2. EXPERIMENTAL STUDY

2.1. Purpose of Assessment

Experimental studies were carried out on using exfoliated vermiculite aggregate in a new generation mortar design for insulation purposes and determining the effects of Na^+ modification on aggregate expansion. It was aimed to evaluate the effects of technical factors affecting the expanding amount of the exfoliated vermiculite aggregate on the thermal performance properties of the mortar combination. It is known that expanded, and lightweight aggregates are used in thermally insulated mortar products and provide insulation benefits. However, thermal comfort is evaluated by the thermal conductivity coefficient and other thermal parameters. This study determined the thermal comfort parameters of cement mortars produced using expanded vermiculite. As a separate series, vermiculite was treated with Na^+ to increase its expansion properties and was used in cement mortar. The thermal comfort properties of this series have also been determined. As a result of the study, thermal comfort parameters obtained from both separate series were compared.

2.2. Materials

2.2.1. Vermiculite and Na^+ Modification

Raw vermiculite is a hydrated magnesium-iron aluminum silicate mineral that is cost-effective and similar to Mica [13]. Vermiculite is generally formed by hydration and oxidation from phlogopite and biotite. It flakes off when exposed to high temperatures. The general appearance characteristic during the expansion process takes a worm-like shape and expands in volume [14, 15]. It takes the shape of an accordion. This property (exfoliation) forms the basis of its commercial use for vermiculite. An internal mechanical force occurs due to the evaporation of water between the layers of raw vermiculite with the effect of temperature and creating internal pressure. With the effect of this force, there is an exfoliation and separation between the layers. This creates the expansion of vermiculite. In exfoliation, the volume of vermiculite can increase by 7–8 to 12 times, while in individual flakes, the expansion rate can reach 20 times. Vermiculite density also changes with the effect of expansion. The bulk density of raw vermiculite can decrease from 640–1200 kg/m^3 to 60–160 kg/m^3 after expansion. The decrease in the unit density value varies according to the structural properties of the raw vermiculite, the time applied in the expansion, the temperature value, and the furnace ambient conditions. In general, as a result of heat treatment, an opening and expansion of approximately 20 to 30 times in volume can be obtained [16]. Vermiculite in exfoliated form is lightweight, non-combustible, layer textured, highly porous, and chemically inert. Exfoliated vermiculite is a new-generation lightweight aggregate suitable for use at temperatures between -200 °C and 1200 °C. In this way, it gains a material feature that allows the production of innovative building elements to contribute to the high-performance sound and heat insulation [1, 4, 5, 7, 17].

The vermiculite used in this study was obtained as raw material from Sivas (Türkiye) quarries under normal market conditions. The grain size of raw vermiculite is 0.5–2 mm on average, and the thickness value varies between 0.18–0.57 mm. Some technical properties are given in Table 1. Raw vermiculite material used in the experimental studies was divided into two groups, one for use in its raw form and the other for Na^+ modification. Each group was first washed in distilled water, completely free of organic and inorganic substances, until the foreign components on the surface were cleared and dried in a ventilated circulation oven for 72 hours at 70±5 °C. Then, similar to the prescribed methodology by Feng J. et al. [11] in their research, the sample separated for Na^+ modification was placed in a container containing 0.5 mol/liter NaCl solution and subjected to ultrasonic treatment for 45 minutes and then mechanical shaking for 6 hours. This process was repeated three times; each time, the solution was replaced with a new one and left to stand for 8 hours. Then, the samples interacting in this way were washed in distilled water environment completely free of organic and inorganic substances and dried in an oven at 70±5 °C for 72 hours. By such chemical interaction, raw vermiculite aggregate samples were converted into a Na^+ modified material form before the thermal exfoliation.

Each of the raw and Na^+ modified vermiculite material groups prepared for the thermal expansion process was experimentally performed by recording the exfoliation states and times at six different heating temperature values of 350 °C, 450 °C, 530 °C, 620 °C, 710 °C, and 840 °C, respectively, in a laboratory environment. Expansion rates, expansion times, and physical changes for the temperature value of each group of materials in the furnace were determined in detail. During the expansion process with the thermal effect, each temperature and time value at which the aggregate material reaches a stable position while expanding were determined separately. Vermiculite aggregate samples that have exfoliated in an equilibrium stage were grouped to be used as the primary component aggregate in the mortar mixtures to be prepared in the next step of this study.

2.2.2. Cement

CEM 1 52.5R white cement conforming to TS EN 197–1 and TS 21 standards was used to prepare all mortar samples. It was obtained from the local market.

2.2.3. Expanded Clay and Slaked Lime

Expanded clay aggregate is a porous and lightweight aggregate obtained by heating a natural clay with expansion properties to approximately 1200 °C in a rotary kiln. Expanding gas components formed in the clay composition with the effect of temperature by causing thousands of tiny bubbles in the structure of the clay material, and an expanded aggregate material is formed in a honeycomb form. Lightweight expanded aggregate samples were obtained from the production site of a commercial enterprise in the Söğüt region of Eskişehir province of Türkiye, classified in a size range of 0–1 mm. Due to sintering during the production of expanded clay aggregate, it carries a water-impermeable shell form. In this size fraction, the average bulk density was determined as 760 kg/m^3, and the porosity rate is relatively low. It is an aggregate generally suitable for mortar mixtures requiring high strength. It can be used for fine aggregate and filling material in concrete production. Expanded clay is also a well-known lightweight concrete aggregate, and its general use is suitable for products made with dry mixes, such as masonry block construction and lightweight construction elements production.

Lime is a white-colored inorganic-based binder obtained from firing limestone at various temperatures (850–1450 °C), which, when mixed with water, solidifies in air or water, depending on its type. Lime was supplied from normal market conditions in CL 80 standard.

2.2.4. Polymer Materials

In order to facilitate the workability of mortar samples to be prepared for experimental studies, and to make it easier to settle in mold, melamine sulfonate-based superplasticizer in powder form and a small amount of cellulose were added to mixtures. A low rate of adherence-increasing powder additive was used to increase the bond strength of aggregates in mortar composition. Zinc stearate and calcium formate were added as water-repellent agents to offset exfoliated vermiculite's possible high water absorption.

2.2.5. Mixing Design

To analyze the advantages of using Na^+ modified exfoliated vermiculite aggregate and heating temperature values on aggregate expansion on the thermal and comfort properties of cement-based new-generation mortar samples, a control mix (RW0) was designed that did not use exfoliated vermiculite aggregate. A comparative experimental test was conducted. This mixture used throughout the experimental work was obtained only by mixing white cement (CE), slaked lime (LM), expanded clay (EC), and polymer additives (PL). The mix design of RW0 consists of 27% CE, 5.4% powder LM, 67% EC, and 0.67% total PL mixture, respectively. All ratios here are used by weight. RW0 mix design was used as reference test samples throughout comparative experimental analyses.

Furthermore, test samples were prepared in two separate series to evaluate the technical advantages of exfoliated vermiculite aggregate on the thermal properties of composite mortar samples. In the first batch, test specimens were prepared with exfoliated vermiculite aggregates where unmodified raw vermiculite was stabilized in expansion at six different heating temperatures (350 °C, 450 °C, 530 °C, 620 °C, 710 °C, and 840 °C, respectively). Exfoliated vermiculite aggregate was used as a fixed amount of 30% by weight in all of these samples. 27% of CE by weight, 5.4% of powder LM by weight, 37% of EC by weight, and 0.67% of polymer additives were used as remaining components in all the mixtures. In the second series, Na^+ modified exfoliated vermiculite aggregates were used in similar mixture combinations as vermiculite aggregate, provided that the weight usage rates were the same as in the first series. For each batch, test samples were prepared by designing a control mixture without using exfoliated vermiculite aggregate.

Table 2. Mix components

Mix	CE (%)	Unmodified exfoliated vermiculite vunm (%)	Na^+ modified Exfoliated vermiculite V_{Na^+} (%)	Slaked lime LM (%)	Expanded clay CA (%)	Polymer PL (%)
RW0	27	0	–	5.4	66.96	0.64
R350	27	30	–	5.4	36.96	0.64
R450	27	30	–	5.4	36.96	0.64
R530	27	30	–	5.4	36.96	0.64
R620	27	30	–	5.4	36.96	0.64
R710	27	30	–	5.4	36.96	0.64
R840	27	30	–	5.4	36.96	0.64
RN0	27	–	0	5.4	66.96	0.64
N350	27	–	30	5.4	36.96	0.64
N450	27	–	30	5.4	36.96	0.64
N530	27	–	30	5.4	36.96	0.64
N620	27	–	30	5.4	36.96	0.64
N710	27	–	30	5.4	36.96	0.64
N840	27	–	30	5.4	36.96	0.64

Fifteen samples were poured into each batch of the exfoliated vermiculite aggregate mix. A total of 210 mortar samples were poured in two series, and the test results were examined. Mixture components are given in Table 2.

Fifteen cubic test specimens of 50 mm dimensions were cast for each mixture to ensure statistically sufficient sample numbers. The samples were kept in the mold for one day and then de-molded from the mold. Test samples were left to cure in a closed environment with a wet towel. However, humidity conditions were kept under control during the curing period. All test samples were dried in an oven at 70±5 °C after 28 days. The properties of test samples were experimentally determined for dry conditions.

2.2.6. Test Methods

The methodology applied within the scope of this study consists of two main stages: The raw vermiculite material expansion process (aggregate material preparation) and the analysis of composite mortar samples prepared with exfoliated vermiculite samples. In the first stage, firstly, raw vermiculite samples were individually exfoliated at six different heating temperatures (of 350 °C, 450 °C, 530 °C, 620 °C, 710 °C, and 840 °C, respectively), and the expansion properties and the effects of the applied temperature value on the expansion were analyzed technically. Afterward, natural vermiculite samples prepared with Na^+ modification were subjected to expansion at equivalent heating temperature values as another series of studies, and the positive effects of Na^+ modification were examined in detail. Samples of both exfoliated vermiculite aggregates were prepared separately for use as aggregate material in composite mortar mixtures according to their expansion temperatures. In the second stage, 14 different batches of cement-based composite mortar samples were prepared with the exfoliated vermiculite samples belonging to two different applications. Different additives and filling materials were used as mixture components with the exfoliated vermiculite aggregate in the mixtures of these mortar samples. The technical findings of these two research stages are discussed comparatively in the following sections.

In order to determine the consistency of the prepared mixtures, a series of flow table tests were analyzed. Flow table tests were followed based on principles stipulated by ASTM C230 standard. In the experiments, the mortar taken from the mixing bowl to the tray was placed in the mold on the flow plate so that it was half filled, and after it was hit 25 times with the mallet, the other part of the mold was filled, and another 25 strokes were applied. After the upper surface of the mold was cleaned and smoothed with a trowel, the mold was pulled out. By turning the arm of the test device five times in 15 seconds, the diameter of the flow sample was measured with the help of calipers in 2 different axes, and the average of the values read was recorded as the consistency value of the mortar.

Compressive strength was analyzed according to EN 1015–11 standard for hardened test samples at 28 days of curing time. 50 mm cube samples prepared for compressive strength tests were used. A compression test device calibrated to a maximum loading force capacity of 303 kN was used in the laboratory environment for crushing all samples. The loading rate was kept at a constant value of 0.1 kN/s in whole samples. In another test study, test samples prepared in the form of plates were analyzed for dry condition conditions after 28 days of curing to determine thermal conductivity.

A calorimeter setup that has defined technical features in experimental analyzes in the literature [18, 19] at different times can be used to analyze specific heat values. This

Table 3. Research findings of EVAM samples

Mixture	Volume weight of fresh mortar (kg/m³)	Unit volume weight (kg/m³)	Consistency (mm)	Compressive strength (N/mm²)	Thermal conductivity (W/mK)	Specific heat (J/kgK)
RW0	1117	926	144	3.47	0.216	833
R350	1070	829	161	3.19	0.136	880
R450	1046	786	157	3.07	0.127	895
R530	818	534	153	2.31	0.084	918
R620	727	443	142	1.74	0.072	964
R710	657	378	136	1.28	0.065	1018
R840	566	306	132	0.82	0.055	1080
RN0	1117	926	144	3.47	0.216	833
N350	1023	774	160	3.13	0.125	918
N450	971	701	155	2.81	0.111	925
N530	710	441	151	1.69	0.072	964
N620	592	340	139	1.11	0.059	1028
N710	516	279	133	0.58	0.052	1105
N840	431	221	130	0.41	0.045	1240

experimental method is based on determining the water temperature that occurs when a certain amount of test sample with a high temperature is added to a certain amount of water at a low temperature. The water takes up the heat, and the vessel can be calculated. The specific heat value can be calculated by balancing this value with the relation of the heat given off by the hot substance. In this study, distilled water was used as the calorimetric liquid. The specific heat value of test samples was determined by measuring with a specific heat calorimeter working as a J/kgK unit.

3. RESULTS AND DISCUSSIONS

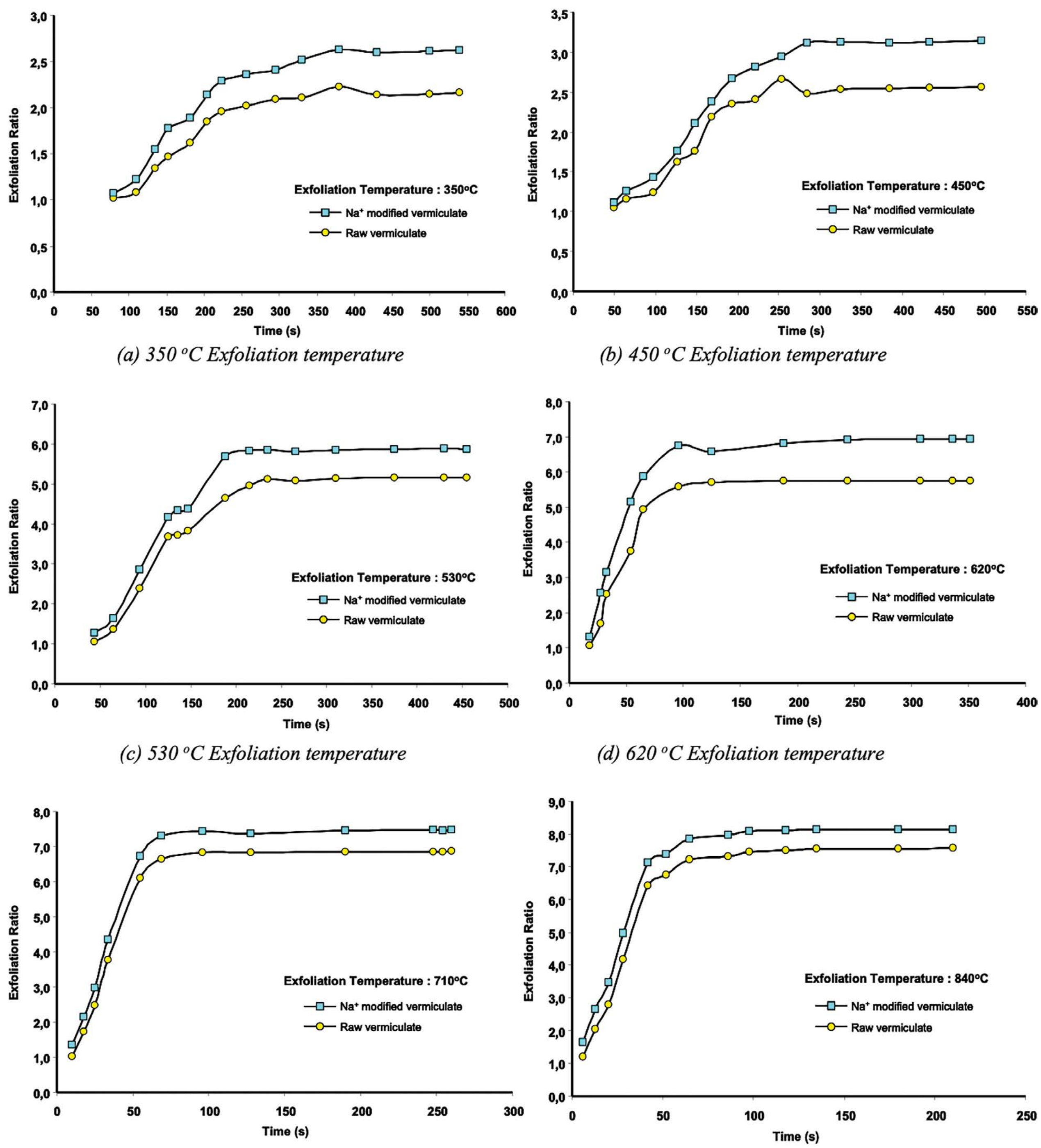
Experimental research findings of EVAM samples are summarized in Table 3.

3.1. The Influence of Exfoliation Temperature on Vermiculate Aggregate's Thermal Expansion

Each of the raw and Na^+ modified vermiculite material groups was subjected to thermal expansion in a muffle furnace for specific periods by observing expansion phenomena at six different heating temperatures of 350 °C, 450 °C, 530 °C, 620 °C, 710 °C, and 840 °C, respectively in a laboratory environment. It is worth noting that if vermiculite is heated to a temperature of 1000 °C or higher, it transforms into clinoenstatite, which can include deformation of the material and deterioration of its thermal insulation properties [20, 21]. Therefore, the maximum heating temperature should not exceed 1000–1100 °C. The experimental study determined that the furnace temperature is a direct factor in the exfoliation time and exfoliation rate of the vermiculite aggregate, and the heating time varies between 6 and 550 s. In addition, it has been observed that the exfoliation characteristics of the vermiculite material show variable values in terms of both time and temperature values, depending on whether Na^+ is modified or not. Figure 1 shows the influence of heating temperature and time on exfoliation ratios of raw vermiculite and Na^+ modified vermiculite samples.

The exfoliation ratio increased with the increase in heating temperature. To physically evaluate the expansion characteristics of the materials at each temperature value, the ratio value of the thickness reached by the aggregate after expansion to the aggregate thickness before the expansion was determined as the "exfoliation ratio." This ratio was accepted as the parameter representing how many folds the material opened up. This value was also used as an index comparison value between materials. It was determined that the raw vermiculite exfoliated between 80 s and 540 s at a heating temperature of 350 °C, while the exfoliation ratio of the unmodified vermiculite in 80 s was 1.02; this ratio reached 2.16 at 540 s. Similarly, while the exfoliation ratio of Na^+ modified vermiculite was 1.07 in 80 s, this ratio reached 2.26 in 540 s. In other words, the effect of Na^+ modification on the exfoliation of vermiculite at this equivalent heating temperature value was 21.30% higher.

As evaluating the heating temperature value of 450 °C, it was observed that the exfoliation phenomenon varies between 50 s and 496 s. It is seen that the unmodified vermiculite reached an exfoliation ratio of 1.05 in 50 s, and this value increased to 2.56 in 496 s. It was determined that the exfoliation rate change of the Na^+ modified material was between 1.11 and 3.14 at these equivalent times. In this case, it is understood that the Na^+ modification process is 22.7% more effective in the exfoliation characteristic of vermiculite. The similar exfoliation phenomenon is typical for the other four heating temperature values of 530 °C, 620 °C, 710 °C, and 840



(a) 350 °C Exfoliation temperature *(b) 450 °C Exfoliation temperature*

(c) 530 °C Exfoliation temperature *(d) 620 °C Exfoliation temperature*

(e) 710 oC Exfoliation temperature *(f) 840 oC Exfoliation temperature*

Figure 1. Influence of heating time on exfoliation ratio at different temperatures.

°C. It was observed that the exfoliation times changed as 44 s–455 s, 18 s–352 s, 10 s–260 s, and 6 s–210 s at the heating temperature changes of 530 °C, 620 °C, 710 °C, and 840 °C, respectively. The changes in the exfoliation rates of the unmodified raw vermiculite for each temperature value in these periods are 1.05–5.16, 1.06–5.76, 1.03–6.87, and 1.19–7.56, respectively. The changes in these values for Na^+ modified vermiculite were determined as 1.27–5.87, 1.32–6.94, 1.35–7.47, and 1.64–8.13, respectively. Accordingly, the effect of the Na^+ modification process on the exfoliation characteristic of vermiculite was found to be 13.76%, 20.49%, 8.73%, and 7.54% more effective for these four temperature values, respectively.

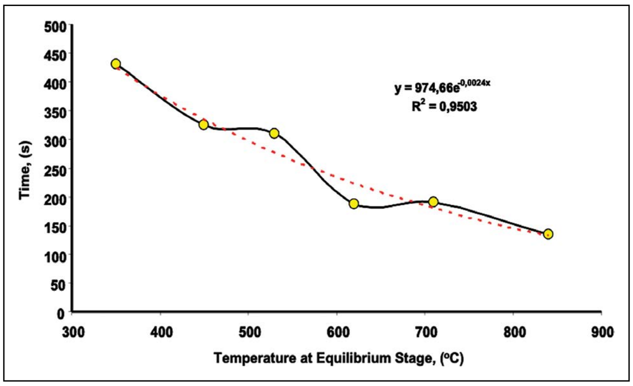


Figure 2. Heating temperature versus time at an equilibrium stage.

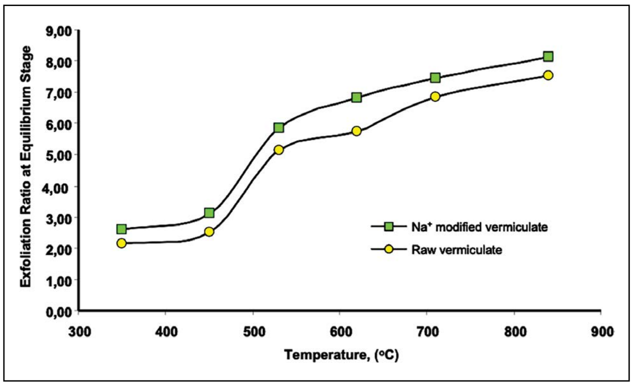


Figure 3. Heating temperature against exfoliation ratio at an equilibrium stage.

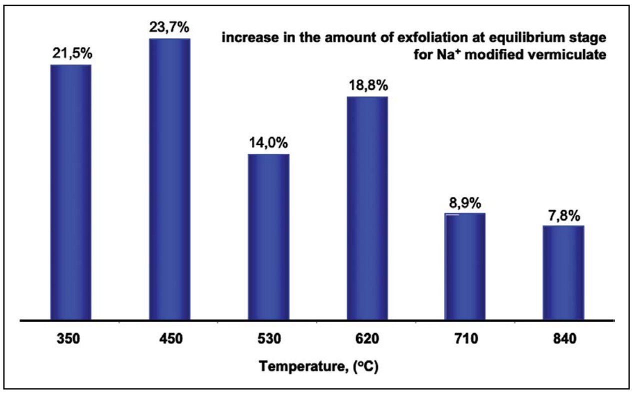


Figure 4. Heating temperature versus exfoliation ratio at the equilibrium stage.

Due to the nature of vermiculite, it consists of more than one layer. The vapor pressure formed between the layers during the expansion function directly affects the exfoliation amount of vermiculite. It has been observed that the vapor pressure formed between the layers at low heating temperatures is insufficient to cause the vermiculite to exfoliate. A similar phenomenon has been reported in Feng J. et al. [11] research results, too. The increase in heating temperature shows that the steam pressure formed between the layers is sufficient to exfoliate the vermiculite, but it is seen that this exfoliation rate reaches high levels at high heating temperature values. A similar situation was observed for the modified and unmodified raw vermiculite. However, it was also clear that the effectiveness of Na^+ modification allowed for higher exfoliation. In this context, it has been shown that heating temperature is one of the essential factors for vermiculite exfoliation behavior. Similar to statements belonging to Feng J. et al. [11] and researchers with technical experience in the study of vermiculite exfoliation, the exfoliation characteristic of vermiculite may show more than one trend depending on the heating time. As can be seen, when the time-dependent exfoliation developments at different heating temperatures are examined in Figure 1, this trend can be discussed in two main parts. The first development trend is that there is a sudden exfoliation at the beginning of the expansion due to the rapid evaporation of water contained between layers. This is a general fact. As the water evaporation continues, the amount of exfoliation increases relatively. In the test analysis, it was observed that the Na^+ modification allowed the water vapor pressure between the layers of the material to be formed at a higher rate, and for this reason, it was determined that the Na^+ modification was more effective in the exfoliation amount in an equivalent time.

It has been experienced that when this water evaporation stops, the exfoliation state gains a stable position without any volume change after this process. This new situation can be characterized as the second time-dependent improvement in the exfoliation characteristic. During this development period, vermiculite may not exhibit an effective exfoliation rate. This trend represents the situation where vermiculite stabilizes in exfoliation. This could also be called the equilibrium stage—a higher heating temperature and shorter time for vermiculite to reach exfoliation equilibrium, depending on its structure.

When the research findings are examined in terms of the equilibrium stage, as the heating temperature value increases, the exfoliation time of vermiculite decreases; this behavior is observed significantly in both groups (Fig. 2).

While the equilibration time in exfoliation at 350 °C heating temperature is 430 s, this time decreases to 135 s at 840 °C heating temperature, depending on the increase in heating temperature. When the amount of exfoliation occurring during these periods is analyzed, it is seen that a higher rate of exfoliation is obtained at high heating temperatures. It was determined that this development showed different values for Na^+ modified and unmodified vermiculite characteristics. This change is illustrated in Figure 3 for research findings.

When Figure 3 is examined, it can be seen that when the equilibrium is reached in expansion, as the heating temperature increases, the exfoliation rates also increase.

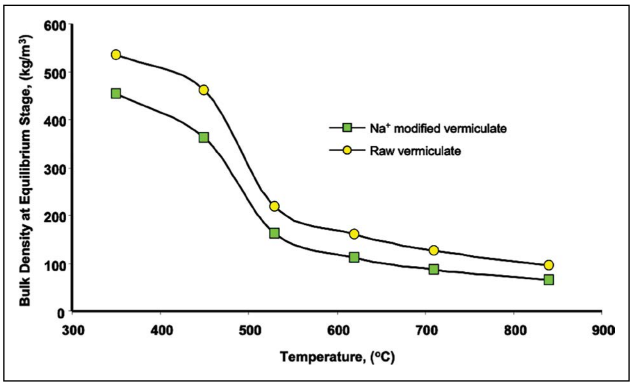


Figure 5. Heating temperature versus bulk density of vermiculites at the equilibrium stage.

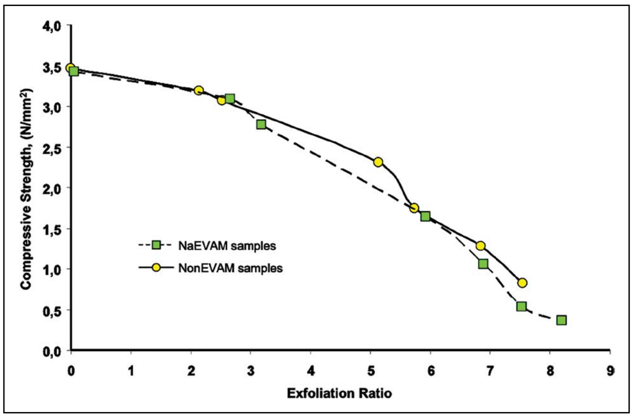


Figure 6. Effects of exfoliation ratio to the compressive strength of EVAM samples at the equilibrium stage.

Na^+ modified vermiculite, as mentioned above, exhibits an effect that significantly increases the exfoliation characteristic. The reflection of the Na^+ modification effect on the exfoliation is examined in Figure 4 as% values in the context of heating temperatures.

After the modification process, some main differences were observed in the findings. The first is that the modified samples achieve a greater exfoliation rate than the raw vermiculite samples under identical conditions. On the other hand, it exhibits lower exfoliation rates with increasing heating temperature. Another is that Na^+ modification reduces the equilibration time. In other words, modified samples need a much lower temperature value to achieve the same exfoliation rate compared to unmodified ones.

3.2. The Influence of Exfoliation Temperature on Vermiculate Aggregate's Bulk Density

The bulk density of vermiculite materials after exfoliation is essential in using this material as an aggregate. Figure 5 shows bulk density values of modified and unmodified aggregate in the exfoliation equilibrium stage at different heating temperatures. In parallel with the increase in heating temperature, it is seen that the bulk density values of the exfoliated vermiculites decrease significantly and reach more lightweight material.

For example, while the bulk density of unmodified raw vermiculite is 530 kg/m³ after exfoliation at 350 °C, it is seen that this value decreases to 465, 190, 155, 106, and 84 kg/m³, respectively, in terms of heating temperatures. Similarly, the values of vermiculite after Na^+ modification started from 454 kg/m³ and changed to 379, 149, 107, 86, and 68 kg/m³, respectively. As seen here, the Na^+ modification allows obtaining vermiculite aggregate with lower density at each temperature value after exfoliation. This makes its use as a lightweight aggregate in low-density mortar productions on the agenda. On the other hand, vermiculite aggregates with low density and high exfoliation rate become an essential primary and additive material in mortar production with higher performance due to their high pores and interlayer spaces as their thermal comfort properties. Hillier et al. [22] tried to expand raw vermiculite with grain sizes of 1–2 mm at 400 and 900 °C, and they obtained the bulk density of the exfoliated vermiculite in the range of 689–117 kg/m³. It can also be understood from the literature results that Na^+ treatment is suitable for obtaining aggregates with lower bulk density.

3.3. The Influence of Exfoliation Temperature for Vermiculite on The Consistency of Mortar Samples

Consistency test results for exfoliated vermiculate aggregated fresh mortar are given in Table 3. Flow diameters were 144 mm for RW0 samples. Consistency was changed between 132–161 mm for mortars with whole vermiculite aggregates in the exfoliation equilibrium stage at different heating temperatures. Consistency values were also changed between 130–160 mm for mortars with Na^+ modified vermiculite aggregates in the exfoliation equilibrium stage at different heating temperatures. It has been observed that the Na^+ modification function is not a very effective parameter in the flow value of the mortar. However, aggregate exhibits a lower flow value in stationary mixed water with an increased heating temperature. The main reasons for this include the exfoliation rate, the formation of voids in the matrix structure, and the fact that it reaches low-density values.

The flow value of mortar samples with low heating temperature values is higher than that of the control sample and shows a more helpful mortar consistency feature. When examined in the context of increasing heating temperature values, it was determined that the consistency of the mortar decreased and reached a flow value of 130 mm, which can be considered a lower-limit value in the consistency of the mortar. In this context, it is observed that the flow value of non-modified exfoliated vermiculite aggregated mortar (NonEVAM) samples are, on average, 2.5%, 5%, 11.8%, 15.5%, and 18% at increasing heating temperatures of 350 °C, 450 °C, 530 °C, 620 °C, 710 °C, and 840 °C, respectively, while the values of Na^+ modified exfoliated vermiculite aggregated mortar (NaEVAM) samples vary between on average 3.1%, 5.5%, 13.1%, 16.9%, and 18.8% respectively. This shows a decrease in the consistency of fresh mortars. Gündüz et al. [12] stated that the flowability of cement mortars is increased up to 0.73 cement-to-exfoliated vermiculite ratio, while higher cement-to-exfoliated ratio values decreased the flowability comparing cement mortars without using exfoliated vermiculite. Koksal et al. [4] concluded an increase in the workability of mortars with exfoliated vermiculite by increasing exfoliated vermiculite to cement ratio from 4/1 to 6/1 and 8/1. In the literature, it is observed that the workability evaluation of exfoliated vermiculite mortars is limited. However, the general opinion is that exfoliated vermiculite can slightly increase workability, according to the literature. However, there is a unique aspect of this study as there is no study showing the effect of vermiculite on the workability of the mortar when used with the classification of vermiculite according to the expansion temperature.

3.4. The Influence of Exfoliation Temperature for Vermiculite on Unit Weight of Mortar Samples

Unit volume weight of hardened NonEVAM and NaEVAM samples are given in Table 3. The effect of Na^+ modification on obtaining lower density values in the exfoliation of vermiculite aggregates appears to have a similar effect on the density values of mortars made with these aggregates. The control samples' density value was 926 kg/m^3. The unit weight values of NonEVAM samples change in the range of 306 kg/m^3–829 kg/m^3. Furthermore, the unit weight values of NaEVAM samples change in the range of 221 kg/m^3–774 kg/m^3. The density values of all samples are lower than those of the control sample and constitute a lighter composition. The increase in the heating temperature applied in vermiculite aggregate exfoliation caused the densities of NonEVAM and NaEVAM samples to decrease. In terms of thermal comfort, it is a general technical advantage that mortar samples have low-density values. The EVAM samples obtained at 710 °C and 840 °C temperature values represent having more good performance in terms of insulation properties. The unit weight reduction of NonEVAM samples prefixes due to the values of the increased change in heating temperature during the exfoliation process is 5.3%, 35.7%, 46.6%, 54.4%, and 63.1% for at increasing heating temperatures of 350 °C, 450 °C, 530 °C, 620 °C, 710 °C, and 840 °C, respectively, This development for NaEVAM examples ranges 9.4%, 43%, 56.1%, 63.9% and 71.4% for the same temperatures, too. Similar results can be found in the literature. Martias et al. [23] concluded that exfoliated vermiculite might reduce the unit weights of plasters up to 23.1–61%.

3.5. The Effect of Exfoliation Rate on Compressive Strength

Compressive strength values of test samples measured at 28 days are given in Table 3. NonEVAM and NaEVAM samples' Compressive strength values remained under the control test samples' values. An increase in the porosity of the matrix structure and a decrease in the unit volume weight of the samples created this result. The porous structure of an exfoliated material negatively affects the strength of the material. Experience has been gained in most research that is directly proportional to unit weight and compressive strength. Similar proportional situations are also shown between the exfoliation ratio and compressive strength of EVAM samples. This change is given graphically in Figure 6 for all sample values.

The compressive strength value for both NonEVAM and NaEVAM samples with an exfoliation ratio of 2.5 is approximately 3.1 N/mm^2. However, when the vermiculite aggregate exfoliation ratio reaches a value of 4 times, the compressive strength of NonEVAM samples is 2.4 N/mm^2, and the compressive strength of NaEVAM samples is 2.7. In other words, although NaEVAM samples had a lower density value, a higher compressive strength value was obtained compared to NonEVAM samples. Furthermore, as the exfoliation rate of the aggregate reached 5.6 times, the compressive strength values of both sample series were found to be equal (1.7 N/mm^2). If the exfoliation rate of the aggregate is more than 5.6 times, lower compressive strengths were obtained in the ratio of the strength value of NaEVAM samples up to 30% compared to NonEVAM samples. In addition, with the increase in the exfoliation rate, the compressive strength decreases. This can be explained by the porosity of the aggregate and the softness of the matrix structure. Similar reductions in compressive strength values can be found in the literature. Abdul Rahman and Babu [24] reported that the compressive strength of concretes is reduced by partially replacing natural sand with 5% and 10% EV, by weight. The seven days compressive strength values reduced to 19.8% and 33.42% with the inclusion of 5% and 10% EV, respectively, whilst the reduction in the 28 days was 5.55% and 13.59%, respectively.

However, in this study, compressive strength values of test samples provided the limit values specified in EN 998–1 [25] standard. According to this standard, mortars for insulation purposes are required to take part in CS-I or CS-II classes. According to the compressive strength of NonEVAM and NaEVAM, samples are located in the range CS-I or CS-II classes. Strength values of samples up to 5.6 times aggregate exfoliation value are included in the CS-II category, and strength values of both NonEVAM and NaEVAM samples above this exfoliation rate remain in the CS-I category. Therefore, these strength values can meet the mechanical limit values stipulated in the EN 998–1 standard [25].

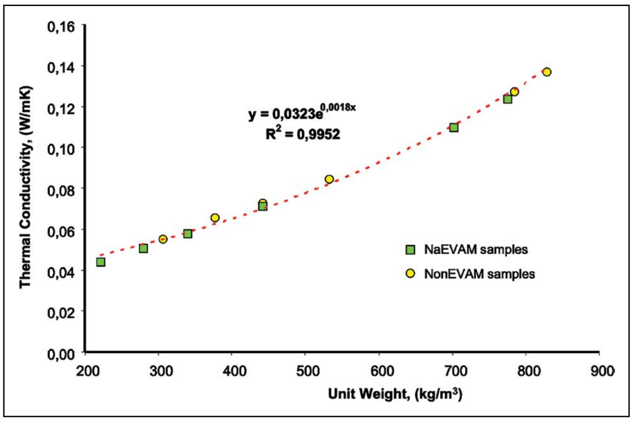


Figure 7. Density and thermal conductivity relationship.

3.6. The Effect of Na^+ Modification on Thermal Comfort Parameters

Thermal comfort properties of NonEVAM and NaEVAM samples in the form of hardened mortar were mainly analyzed in two separate groups of parameters: Parameters measured by experimental analysis and defined with the help of convergent approach calculations. Thermal conductivity (λ) and specific heat values (Cp) for test samples were determined by experimental analyses. The thermal conductivity coefficient values of NonEVAM and NaEVAM samples were determined after 28 days, and the findings are given in Table 3. It is a general technical experience that the thermal conductivity values of mortar materials that contribute to thermal insulation usually change as a function of the density value. NonEVAM and NaEVAM thermal conductivity values are lower than the thermal conductivity value of the control sample. This is also a preliminary indication that the exfoliated vermiculite aggregate mortars will have a higher added value to the thermal insulation. Lower density and lower thermal conductivity coefficient of a material are expected. Thermal conductivity changes due to the density values of NonEVAM and NaEVAM samples are given in Figure 7.

λ value of RW0 was 0.216 W/mK. λ value of NonEVAM samples using non-modified exfoliated vermiculate aggregates ranged between 0.055 W/mK and 0.136 W/mK. As the exfoliation rate for vermiculite aggregate increases due to an increase in heating temperature, λ the value of hardened mortar decreases. Although the amount of aggregate is always used at the same rate in all of these mixtures, the change in the rate of exfoliation of the aggregate has led to the fact that the mortar has acquired a structure that is more resistant to heat transfer. The phenomenon of increased porosity of the aggregate and the air gaps between the opened layers add a feature that makes the matrix structure of the material absorb less heat. A similar effect was also observed for NaEVAM samples. λ value of NaEVAM samples with using Na^+ modified vermiculate aggregates were changed between 0.045 W/mK and 0.125 W/mK. Due to the effect of Na^+ modification, a more porous structure of aggregate ensured that λ the value of mortar was lower. It has been observed that the Na^+ modification creates a more homogeneous gap geometry between the complex layers of vermiculite aggregate, and, accordingly, its thermal property improves compared with NonEVAM samples. With the use of vermiculite treated with Na^+ and expanded at 840 ˚C in the mortar, the thermal conductivity coefficient of the mortar decreased by 79% compared to the reference mortar. Similarly, Hodhod et al. [26] stated that using exfoliated vermiculite with the size of 0.08–0.5 mm in cement or gypsum plasters exhibited 74.12% and 76.1% reduction in thermal conductivity values compared to that of traditional cement plaster, respectively.

This research finding shows that an increase in exfoliation rates of vermiculate aggregates reduces λ value. There was an excellent linear relationship between λ the value and exfoliation rates of vermiculate aggregates in mixtures. According to the thermal conductivity values of mortars compliant with EN 998–1 standard [25], the cases of contributing to thermal insulation are divided into two separate categories: T1 (*providing thermal insulation*) and T2 (*contributing to thermal insulation*). The T1 category covers mortar samples with λ a value of <0.1 W/mK, and the T2 category covers mortar samples with λ a value of <0.2 W/mK. According to this, λ values of control samples are not included in both categories provided for in EN 998–1 standard [25]. However, it can be seen that both NonEVAM and NaEVAM samples with aggregates exfoliated at a heating temperature of 350 ºC and 450 ºC are in the T2 category, and the samples with aggregates exfoliated above a heating temperature of 500 ºC are in the T1 category. Over the 500 ºC heating temperature for exfoliation represents that both NonEVAM and NaEVAM samples have better insulating properties particularly. At lower heating temperatures, the thermal performance of the mortar decreases relatively.

Specific heat capacity (Cp) is evaluated as a measure of the ability of the mortar to absorb heat from the environment where it is applied. Cp value could be generally defined as two different technical parameters; "*Specific heat capacity at constant pressure*" and "*fixed volume-specific heat capacity.*" Fixed volume-specific heat is symbolized by "Cv." Both heat capacities are determined as cal/g°C or J/kgK. When it comes to specific heat capacity for new-generation mortars, "average specific heat capacity value (Cp)" is usually used at constant pressure. Average specific heat is an essential property of a thermal insulation material when used in conditions of temporary or unstable heat flow. Specific heat is an essential parameter of the topic "heat dissipation," which studies the change of thermal insulation throughout the material with an insulating property. Numerical values vary according to the chemical content of the material, its structural form, and the temperature of the material. The origin of the aggregate, the grain size of the aggregate and

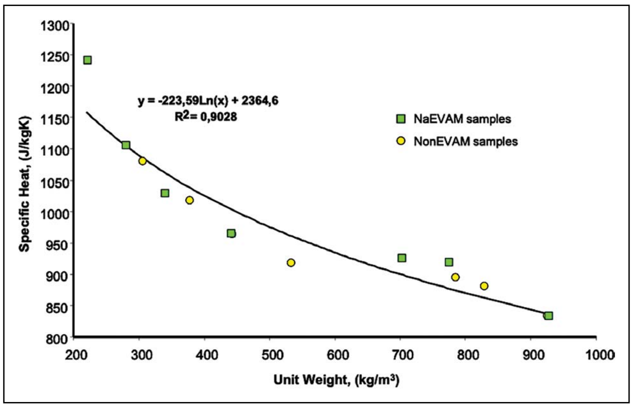


Figure 8. Density versus Cp value of tested samples.

its form of porosity, and the chemical composition of the aggregate used in the mortar combination directly affect to specific heat capacity value of a hardened mortar. However, the matrix structure and porosity that make up the dough part of the mortar are among the parameters directly affecting the specific heat value. In other words, structural form variations in the production of the aggregate also ensure the difference in the Cp value of the mortar.

The Cp value of NonEVAM and NaEVAM samples were determined after 28 days, and the findings are given in Table 3, too. Specific heat of materials could be optionally considered as a function of the density of the material. The higher the density, the lower the specific heat of the material might be expected. All research findings showed the existence of a linear relationship between specific heat and material density. This relationship for NonEVAM and NaEVAM samples is given in Figure 8.

The Cp value of the control mixture without using exfoliated vermiculate aggregates (EXVA) was 833 J/kgK. Cp values for NonEVAM samples were changed between 880 J/kgK and 1080 J/kgK. As the ratio of exfoliation for vermiculite aggregate with the increase of heating temperature increases, the Cp value of the hardened mortar increases, too. A similar effect was also observed for NaEVAM samples. The Cp value of NaEVAM samples using Na^+ modified aggregates was changed between 918 J/kgK and 1240 J/kgK. Due to the effect of Na^+ modification, a more porous structure of the aggregate ensured that the Cp value of the mortar was higher. The Cp value of NonEVAM samples develops by 1.7%, 4.3%, 9.5%, 15.7%, and 22.7% at increasing heating temperatures of 350 °C, 450 °C, 530 °C, 620 °C, 710 °C, and 840 °C, respectively, while the values of Na^+ modified exfoliated vermiculite aggregated mortar (NaEVAM) samples vary between on average 0.8%, 5%, 12%, 20.4%, and 35.5% respectively. This actually shows an improvement in the property of the specific heat capacity of the mortars. It is clearly seen that Na^+ modification on the aggregate is more effective in changing the heat capacity value of the mortar rather than in NonEVAM samples.

If heat is applied to a substance from the outside or heat is received, the temperature of the substance changes. The temperature of mortars is a measure of the energy stored in their molecules. When the temperature of the hardened mortar is increased, the molecules that gain energy generally vibrate at larger amplitudes. This growth in the vibration amplitude of a molecule causes other molecules that are close to this molecule to stay at a greater distance on average. In other words, due to the Kinetic Energy of the substance receiving heat from the outside, the vibration velocity of its particles increases. The forces that hold the particles together are defeated, and they begin to decouple from each other. This is called expansion. Suppose the substance loses heat, the Kinetic Energy of its particles decreases. The substance cools down, and the particles approach each other. When examined in this context, the ability of the mortar to conduct heat varies depending on its atomic structure. Especially in terms of materials that are considered to be used in the design or production of a new generation mortar combination for insulation purposes, it is not desirable that they have electrons moving quite freely in their structure. In a material with a minimum level of electron movement in its structure, the thermal energy transfer from one surface of the material to the other surface is almost negligible [18, 19]. As the rate of time-dependent exfoliation of vermiculite aggregates increases due to the effect of heating temperature, the electron mobility in their bodies tends to decrease. In vermiculite aggregates with Na^+ modification, the electron mobility in the exfoliated aggregate at the equivalent heating temperature is at lower levels compared to that of the whole aggregate. For this reason, the material structure also has the ability to provide higher thermal insulation by having fewer free electrons in the material. Due to increased porosity in the material and increasing exfoliation rates of vermiculite aggregates, mortar absorbs more heat from the environment. Due to the absorbed heat and mechanism mentioned above, the mortar matrix structure becomes more insulated.

Heat storage capability and heat diffusion coefficient were determined by convergent calculations. Industrially used building materials and elements have heat storage properties. During heating, it stores heat, albeit in specific amounts. In the designs of building materials that contribute to insulation, it is desirable not to store heat within the material. During heating, the building element stores the heat acting on it superficially [12, 18]. Heat storage in the structure of building elements varies depending on the unit weight of the material forming matrix structure and specific heat. The numerical value of the ability of mortar applied to the wall surface to store heat in its body gains importance in characterizing heat transfer from the applied mortar layers to contribute to the insulation [18, 19]. Storage of heat by changing the temperature of the substance is called "*sensible heat storage*," and storage by phase change is called "*latent*

Table 4. Calculation results for EVAM samples

Mixture	Heat storage (J/m^3K)	Heat diffusion coefficient ($x10^{-6}$) (m^2/sec)	Required heat for 1 °C temperature rise in 1 cm thickness (cal)
RW0	0.771	0.281	1842
R350	0.730	0.187	1743
R450	0.703	0.181	1679
R530	0.490	0.172	1170
R620	0.427	0.170	1019
R710	0.385	0.169	919
R840	0.331	0.166	790
RN0	0.771	0.281	1842
N350	0.710	0.175	1696
N450	0.649	0.171	1549
N530	0.425	0.170	1015
N620	0.349	0.169	834
N710	0.309	0.168	737
N840	0.274	0.164	655

heat storage." In sensible heat storage, besides the large heat capacity of the substance, it is desirable that it does not have combustion and flammability, that the substance maintains its properties for many years, and that it is not poisonous and corrosive. The heat storage of many materials used as building materials is generally seen as "sensible heat storage." This heat storage could be represented as heat storage capability by the expression of ρ*Cp. The abbreviation ρ indicates the density of the mortar. Heat storage of both hardened NonEVAM and NaEVAM samples is given in Table 4.

Heat storage of NonEVAM and NaEVAM samples were calculated according to the above approach. Heat storage of the control mixture without using EXVA was 0,771 J/m^3K. Heat storage of NonEVAM samples using non-modified EXVA was changed between 0.331 J/m^3K and 0.730 J/m^3K. As the exfoliation rate increases for vermiculite aggregate dependent on heating temperature, NonEVAM samples store less heat. The decrease in heat stored in the mortar represents its advantage for insulation. A similar effect was also observed for NaEVAM samples. Heat storage of NaEVAM samples using Na^+ modified EXVA was changed between 0.274 J/m^3K and 0.710 J/m^3K. Due to the effect of Na^+ modification, the low-density structure of aggregate ensured that the heat storage of mortar was much lower. To understand the effect of using EXVA in composite mortar structures based on aggregate heating temperature for exfoliation, a graphical analysis was derived for research findings. Heat storage for hardened mortar samples based on temperature is given in Figure 9.

Increasing the heating temperature for the exfoliation of the vermiculate aggregate reduces the heat storage capability of the mortar structure. Another important material property that can be taken into consideration for heat transfer in building elements is the "*heat dissipation coefficient*."

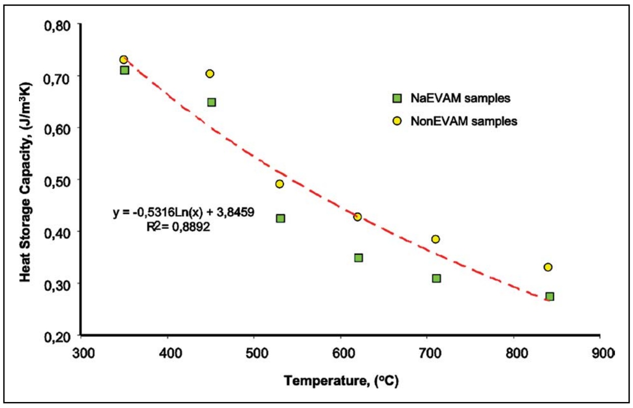


Figure 9. Heating temperature and heat storage capability relationship.

This coefficient shows how quickly heat is emitted on the surface and body of a material. Heat diffusion coefficient can be symbolized by "α, "and its unit is "m^2/sec" [12].α It is the ratio of the amount of heat transmitted in a material to the amount of heat stored in the material. α Values of hardened mortar samples are given in Table 4.

α Values of NonEVAM and NaEVAM samples were calculated based on the above approach. α The value of the control mixture without using EXVA was 0.281 m^2/sec. α of NonEVAM samples are changed between 0.166 m^2/sec and 0.187 m^2/sec. α of NaEVAM samples are also changed between 0.164 m^2/sec and 0.175 m^2/sec, too. Na^+ modification of aggregate affects the heat diffusion characteristic of the material. For example, at a heating temperature of 350 °C for the exfoliation of the aggregate, the heat diffusion property of mortar decreases by 6.42% compared to NonEVAM samples. In addition, at a heating temperature

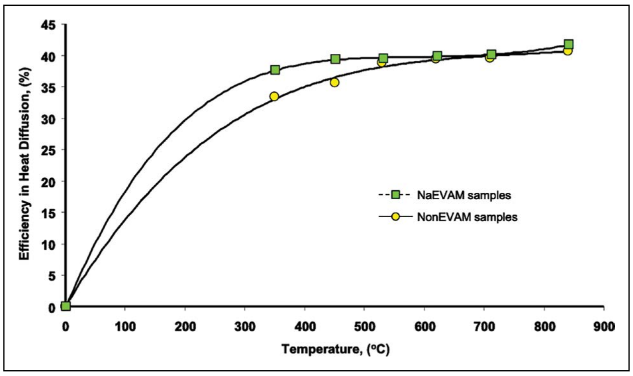


Figure 10. Heat dissipation efficiency against heating temperature.

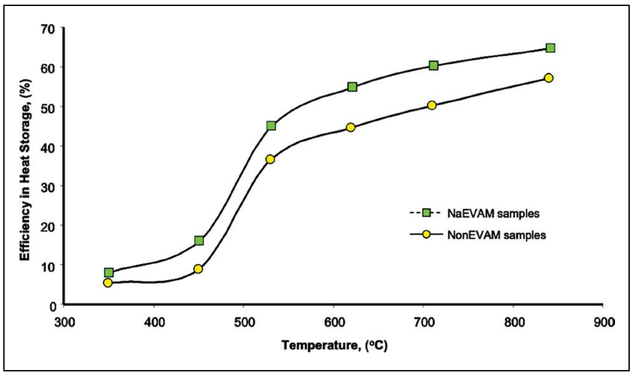


Figure 11. Heating temperature against heat storage efficiency.

of 450 °C, this property decreases by 5.52%. As reaching 710 °C heating temperature, it has been observed that the heat diffusion properties of both NonEVAM and NaEVAM samples approach each other in a convergent value. This development has shown that the effect of Na^+ modification decreases in terms of the heat diffusion property of the mortar at high exfoliation temperature values. This interaction is graphically shown in Figure 10 for NonEVAM and NaEVAM samples after 28 days of curing time.

Increasing the heating temperature for vermiculate exfoliation increases heat diffusion through composite mortar structure in the general sense. As heat dissipation for heating or cooling in the material structure decreases, insulation property improves. To measure this situation at the lowest expansion temperature, the efficiency of NonEVAM samples in heat diffusion is 33.4%, while in NaEVAM samples, this value is 37.5%. The efficiency of NonEVAM samples in heat diffusion at the highest expansion temperature value is 40.7%, while in NaEVAM samples, this value is 41.5%. This shows that materials with high thermal conductivity or low heat capacity have high heat diffusion. High heat diffusion means that heat diffusion from material to the internal environment is high, while low heat diffusion means that heat is absorbed by converting a large amount of heat into heat energy in the material. The amount of heat conduction in such materials is also at low levels. In terms of insulation performance, low heat diffusion values are required for new-generation mortars. The presence of components that will provide low heat dissipation gains importance in the design of a new-generation mortar to contribute to the insulation. While the heat capacity of the mortars using the aggregates obtained by expansion is low, the heat dissipation value of the same material may be higher. This behavior represents that the material will not absorb heat on its surface and inside, but a faster heat flow will be reflected in the indoor environment. This becomes more meaningful when the amount of heat required to increase the temperature of 1 cm thick mortar by 1 °C is determined. This behavior of the cured mortar samples is numerically summarized in Table 4.

The amount of heat required to increase the body temperature by 1 °C decreases significantly in mortar samples prepared with vermiculite aggregates with low density and high exfoliation rate. For example, vermiculite aggregate mortar samples expanded at 710 °C by 1 °C is 919 cal in NonEVAM mixtures. The value of this amount of heat is 737 cal, with a lower heat requirement for NaEVAM mixtures. When these heat requirement amounts are compared with those of the control samples, the NonEVAM mixture combination gives 50% more efficient results, and the NaEVAM mixture combination gives 60% more efficient results, too. In order to evaluate the effect of the use of EXVA on the thermal comfort properties of the mortar, a graphical analysis was made in which the comparison was made with the control mortar values. Analysis of the heat storage efficiency of hardened NonEVAM and NaEVAM samples is given in Figure 11.

Increasing the rate of vermiculate exfoliation in mortar mixes increases efficiency in heat storage. The heat is stored in the mortar and gains a more resistant characteristic against heat flow.

4. CONCLUSIONS

The exfoliation characteristics of natural vermiculate were investigated experimentally in this work. In particular, the effect of Na^+-modification on the natural vermiculate on exfoliation behavior has been revealed. In the second phase of the study, Na^+-modified and non-modified expanded vermiculite were used in lightweight composite mortar mixtures, and physical, mechanical, and especially thermal comfort properties of mortars were determined:

1. The exfoliation ratio increased with the increase in heating temperature.
2. The effect of the Na^+ modification process on the exfoliation characteristic of vermiculite was found to be 21.30%, 22.70%, 13.76%, 20.49%, 8.73%, and 7.54% more effective for 350 °C, 450 °C, 530 °C, 620 °C, 710 °C, and 840 °C, respectively.

3. Since Na^+-modified vermiculite can expand more, aggregate density is lower. Therefore, the density and strength of composite mortars produced with Na^+-modified exfoliated vermiculite were lower than composite mortars produced with non-modified exfoliated vermiculite.
4. Mortar density, which decreased due to the decrease in aggregate unit weight, improved the thermal properties of the mortar.
5. λ The value of NonEVAM samples using non-modified EXVA is changed between 0.055 W/mK and 0.136 W/mK. λ value of NaEVAM samples with using Na^+ modified EXVA are changed between 0.045 W/mK and 0.125 W/mK.
6. The specific heat of the control mixture without using EXVA was 833 J/kgK. The Cp value of NonEVAM samples using non-modified EXVA ranged between 880 J/kgK and 1080 J/kgK. The Cp value of NaEVAM samples using Na^+ modified EXVA was changed between 918 J/kgK and 1240 J/kgK.
7. Heat storage of control samples without using EXVA was 0,771 J/m^{3}K. Heat storage of NonEVAM samples using non-modified EXVA ranged between 0.331 J/m^{3}K and 0.730 J/m^{3}K. Heat storage of NaEVAM samples using Na^+ modified EXVA are between 0.274 J/m^{3}K and 0.710 J/m^{3}K.
8. Heat diffusion of the control mixture without EXVA was 0,281 m^2/sec. α of NonEVAM samples were between 0.166 m^2/sec and 0.187 m^2/sec. α of NaEVAM samples were also changed between 0.164 m^2/sec and 0.175 m^2/sec, too.
9. NonEVAM mixture combination gives 50% more efficient results, and NaEVAM mixture combination gives 60% more efficiency compared to reference mortar.

According to the results of the study, Na-modification considerably improves the expansion characteristics of vermiculite samples. Accordingly, the thermal comfort properties of expanded vermiculite aggregate and composite mortars produced with this aggregate have improved considerably.

ETHICS

There are no ethical issues with the publication of this manuscript.

DATA AVAILABILITY STATEMENT

The authors confirm that the data that supports the findings of this study are available within the article. Raw data that support the finding of this study are available from the corresponding author, upon reasonable request.

CONFLICT OF INTEREST

The authors declare that they have no conflict of interest.

FINANCIAL DISCLOSURE

The authors declared that this study has received no financial support.

PEER-REVIEW

Externally peer-reviewed.

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