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Examination of effective parameters for the production of expanded clay aggregate

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ABSTRACT

It is important to know which parameters are effective for the manufacture of expanded clay aggregate and to determine how effective these parameters are on expansion. In this study, expansion tests were conducted by using samples from three separate fields to determine how different parameters influence manufacturing. Clay grain size, pellet size, temperature in the furnace and firing time were selected in the expansion tests as parameters. Their effect on production was evidenced separately. It was found that decreasing the clay size has a positive effect on expansion while a decrease in pellet size has a negative effect on it. Also, temperature in the furnace and the time period during which the clay remains in the furnace are critical values for the resultant aggregate quality. The conditions for optimum manufacturing were explained in detail.

1. Introduction

Expanded clays are clays which may expand up to 5–6 fold by volume as a result of gas release when they are treated with heat. A hard sintered crust is formed on the outer surface, while quite light and highly durable aggregate with a porous clinker-like structure may be produced inside it [1].

Typical characteristics of the concrete masonry units made of expanded clay aggregates are [2]:

(1) Low density.
(2) Optimum capacity in load carrying.
(3) Low water absorption ratio.
(4) High resistance to freezing.
(5) Optimum plaster holding.
(6) Thermal insulation.
(7) High resistance to fire.
(8) Noise insulation.
(9) Resistance to chemicals.

Many studies have been conducted on lightweight aggregate production and aggregate technology since 1908, when it was discovered that some clays may expand when heated [3].

Hayde invented the horizontal rotating furnace process with clay and shale before 1917 and produced highly durable low-density aggregate. Thus, it was used in concrete reinforced vessel building, multi-story buildings, bridges and platforms, especially after World War I [4,5].

Expanded clay aggregates are used in many different industries thanks to their high technical features and numerous advantages when compared to many other industrial raw materials.

One of the materials with the greatest compressive strength among lightweight aggregates is expanded clay aggregates. This gives it a significant position in the construction industry. 20% may be saved in reinforcing steel while up to 50% may be saved in heating–cooling expenses in buildings containing expanded clay aggregate in Turkey [1,6].

Expanded clay aggregates are a new topic for Turkey and detailed studies on their production have begun to be conducted recently. Considering that there is no factory manufacturing expanded clay aggregate in Turkey, this study is an original study, especially for Turkey. It is also very important to note that Turkish clays are spread over a large area and the reserves are high. Therefore, it is very important that studies on the use and production of expanded clay aggregate should be conducted rapidly and the use of it should be made more popular in Turkey considering its superior advantages to current alternatives.

If lightweight aggregates are required to compete with natural aggregates successfully, then manufacturing methods should be developed and comprehensive studies on the factors that, which are effective in expansion, should be conducted to ensure higher-quality lower-price aggregate manufacturing.

Knowing which parameters have an effect on expanded clay aggregate manufacturing is important to understand the expansion

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mechanism and to improve manufacturing quality. The factors influencing the expansion process include [1,7]:

(1) Temperature in the furnace.
(2) Firing time.
(3) Grain size of the clay.
(4) Pellet size.
(5) Furnace design.
(6) Furnace's atmosphere.
(7) Firing rate.
(8) Additives.
(9) Mineralogical and chemical structure.
(10) Viscosity of the melt.

The effective parameters mentioned above designate the selected manufacturing method.

2. Materials and methods

Different types of clay should be studied to quantify the effect that any parameter has on expanded clay aggregate manufacturing. Therefore, samples were collected from three different clay fields, in Turkey (Fig. 1). The studies were conducted in Ankara City's Kalecik County, Kastamonu City's Küre County and Bartın City's Kozcağız County.

From a geological point of view, of the expanding clay fields under study, the Ankara Kalecik field has a greyish metallic luster, while it is seen as dark grey–black when wet. Secondary calcite was developed in some places. It has sandstone-shale alteration with a schist-like view behind limestone lenses. This unit is overlain by greyish-grey color sandstone-shale faces. It is a unit exposed in macro scale achieving 100 m from place to place along approximately a 1 km path in the form of 25–30 m lenses along the north–south direction.

The Kastamonu Küre field consists of shale containing blackish-greenish brown laminated phyllite with mica in some localities, blackish-grey, fine-grained, tight-sandstone–limestone intermediate levels and a black-yellowish-brown color, thin–medium–thick layered hard and strictly tied sandstone. Secondary pyrite formation and capillary quartz are encountered. It has a metallic luster and a lubricated feeling.

The Bartın Kozcağız field is made up of alteration of autochtonous rocks such as shale, marn, and limestone, and consists of turbiditic deposits such as sandstone, limestone with sand and conglomerates. Moreover, it contains various olistolites. Black-greyish schist is a unit containing secondary calcite formations, although there are not too many. It is in the form of schist laminated on the surface and coarse grains beneath. The fractured surfaces are a kidney-like-conchoidal shape.

X-ray diffraction patterns belonging to the samples obtained from the fields under study are given in Fig. 2 and the results from the X-ray diffraction analysis are seen in Table 1.

The samples collected from the fields were broken and then milled. To show the effect of clay size clearly, samples in different clay sizes (100, 200 and 300 μm) were prepared separately considering these clay sizes as those used generally in the production of expanded clay aggregate. Ground clay was mixed with only water without any additive to produce clay dough. This was for showing how much the clay spontaneously expanded. Dough preparations were left for maturation for one day and shaped through an extruder. To evaluate the effect of pellet size on expansion, pellets were prepared in different sizes (5, 10 and 15 mm) by using caps with different mesh sizes (5, 10 and 15 mm) (Fig. 3). The prepared pellets were dried in ovens and then expanded in a furnace.

When the sample preparation and shaping operations are well performed, greater expansion of the clay can be obtained. Only optimum furnace conditions produce the desired expanded clay aggregate. In this study, a high volume stationary furnace, which is resistant to sudden temperature shocks, allowing the temperature to be raised rapidly, was employed.

Studies were conducted at different furnace temperatures to determine at which temperature expansion was effective, at which temperature raw pellets began to expand, and which temperature yielded optimum expansion. Firing processes took place at different temperatures beginning from 900 °C up to 1200 °C.

Another significant point in the expansion process is how long raw pellets stay inside the furnace. Thus, raw pellets were kept inside the furnace for different time periods at the same temperature to find the optimum time period for remaining inside the furnace and these time periods were specified as 5, 10, 15 or 20 min. Fired pellets were removed from the furnace and cooled suddenly. Fig. 4 shows a sample of the produced aggregates.

The mass of a unit volume of the produced aggregates was measured by using the ASTM C493-98 [8] standard to determine which manufacturing conditions yielded reasonable results. Because the unit volume of the aggregates is very small and it is impossible to weigh them inside water, the mass of a unit volume was found by using the method employing mercury. The found unit volume masses of the expanded clay aggregates were compared with Unit Volume Masses (UVM) of the raw pellets to calculate the expansion ratio. The expansion ratio is calculated as (UVMorj/UVMexp) $\times$ 100. The method used in this study can be seen in Fig. 5.

Fig. 1. Locations in which the study was conducted in Turkey.

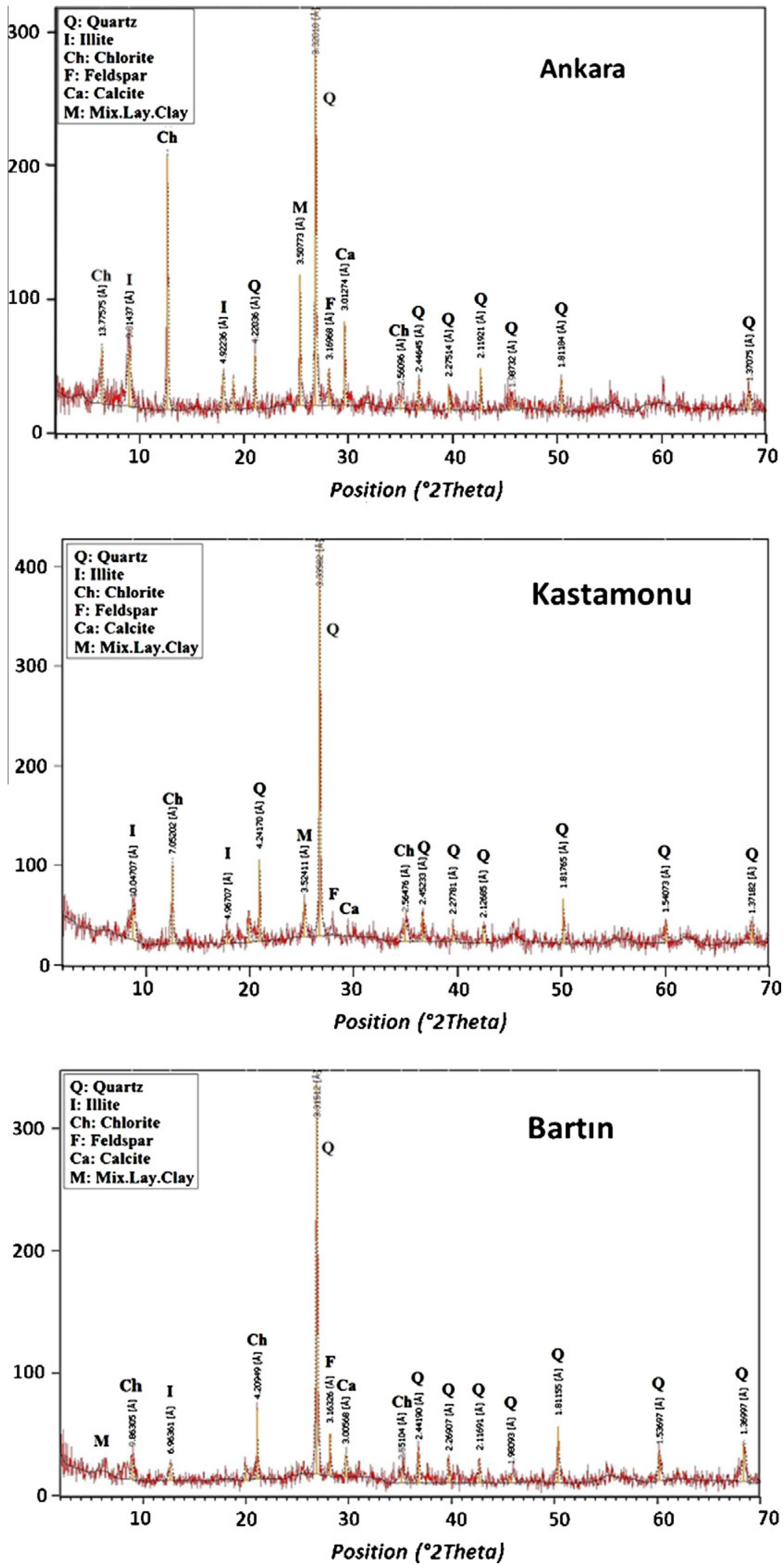

Fig. 2. X-ray diffraction patterns belonging to the samples.

3. Experimental results and discussion

To find out the effects of the production parameters on expansion in the best way, four different parameters were investigated. For this purpose, 756 expansion experiments in total were conducted by using the samples collected from three different fields. The results from which the best expansion had been obtained were assessed to show the effects of each parameter. Each manufacturing parameter was evaluated and the obtained results are explained below.

Table 1
XRD analysis results of the clays under study.

Fields under study	Minerals
Ankara	Quartz (ASTM No. 5-0490), Illite, Chlorite, mixed layered clay minerals, Feldspar, Calcite (ASTM No. 5-0586), (Graphite)
Kastamonu	Quartz (ASTM No. 5-0490), Illite, Chlorite, mixed layered clay minerals, Feldspar, Calcite (ASTM No. 5-0586), (Graphite)
Bartın	Quartz (ASTM No. 5-0490), Illite, Chlorite, mixed layered clay minerals, Feldspar, Calcite

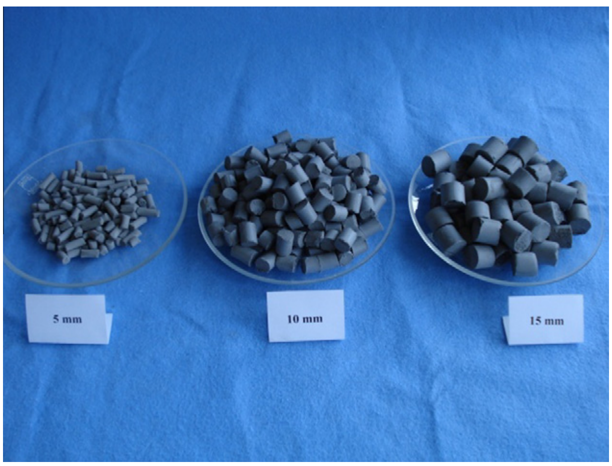

Fig. 3. Different pellet sizes prepared for expansion.

3.1. Effect of clay grain size

Samples from three different fields were prepared in three different grain sizes. Clay was shaped in a constant pellet size of 15 mm to find the effect of clay size and the results obtained from the expansions tests are seen in Table 2. Samples from Ankara and Bartın melt at 1200 °C and samples from Kastamonu melt at 1250 °C, therefore the given results were expansion results obtained at 1150 °C, while results for the samples from Kastamonu were obtained at 1200 °C.

The following conclusions can be made from the data in Table 2.

- Ankara clay produces 0.42 g/cm^3 aggregate, Kastamonu clay produces 1.01 g/cm^3 aggregate and Bartın clay produces 0.74 g/cm^3 aggregate under the same operational conditions at a clay size passing through a −300 μm mesh size, while aggregates in sizes of 0.36, 0.88 and 0.61 g/cm^3 were manufactured when the grain size decreased to −100 μm, respectively.
- More expansion was obtained by decreasing the clay size from −300 μm to −100 μm by 14.3% in the case of Ankara clay, by 13% in the case of Kastamonu clay and 17.6% in the case of Bartın clay.
- It is seen that different clay sizes (−200 μm and −100 μm) yielded the same expanded unit volume mass only in the case of Ankara clay.
- Because reducing the clay size is an undesired situation from an economical point of view, the maximum grain size should be employed depending on the application.

3.2. Effect of pellet size

Samples from three different fields having the same clay size were prepared in three different pellet sizes and the obtained results are seen in Table 3. Samples from Ankara and Bartın melt at 1200 °C and samples from Kastamonu melt at 1250 °C, therefore the given results were expansion results obtained at 1150 °C, while results for the samples from Kastamonu were obtained at 1200 °C.

Fig. 4. The produced clay aggregates.

The following conclusions can be made from the data in Table 3.

- A 5 mm pellet diameter produced 0.66 g/cm^3 aggregate from Ankara clay, 1.21 g/cm^3 aggregate from Kastamonu clay and 0.90 g/cm^3 aggregate from Bartın clay. However, when the pellet size increased to 15 mm by keeping operational conditions constant, unit weights decreased to 0.36, 0.88 and 0.61 g/cm^3, respectively, and as a result, lighter aggregates in weight were obtained.
- When the pellet size increased from 5 mm to 15 mm, expansion increased by 45.5% for Ankara clay, by 27.3% for Kastamonu clay and 32.2% for Bartın clay.
- It is clearly seen that pellets that were 10 and 15 mm expanded much more than the 5 mm pellets did.
- 10 and 15 mm pellets' unit volume masses are close to each other.
- Considering the Bartın clay, it is seen that if the pellet size is too big, a recovery in expansion to some extent may be seen. The reason may be that sufficient heat cannot be transferred to the center of a big pellet for gas formation and for arresting any released gas within the formed sintered crust.

3.3. Effect of temperature

Samples from three different fields were prepared and fired at different temperatures with different holding times in the furnace. The relationships between temperature and unit volume mass for three samples are given in Fig. 6 and the expansion test results obtained at different temperatures are given in Table 4.

The following conclusions can be made from Fig. 6 and the data in Table 4.

- It was determined under identical operational conditions that the Ankara clay began to expand at 1050 °C, the Kastamonu clay at 1150 °C, and the Bartın clay at 1100 °C. The highest expansion ratios occurred at 1150 °C in the case of Ankara and Bartın clays. Unit masses were reduced to 0.36 and 0.65 g/cm^3 respectively, while Kastamonu clay achieved the highest expansion ratio at 1200 °C and the density obtained was 0.88 g/cm^3.

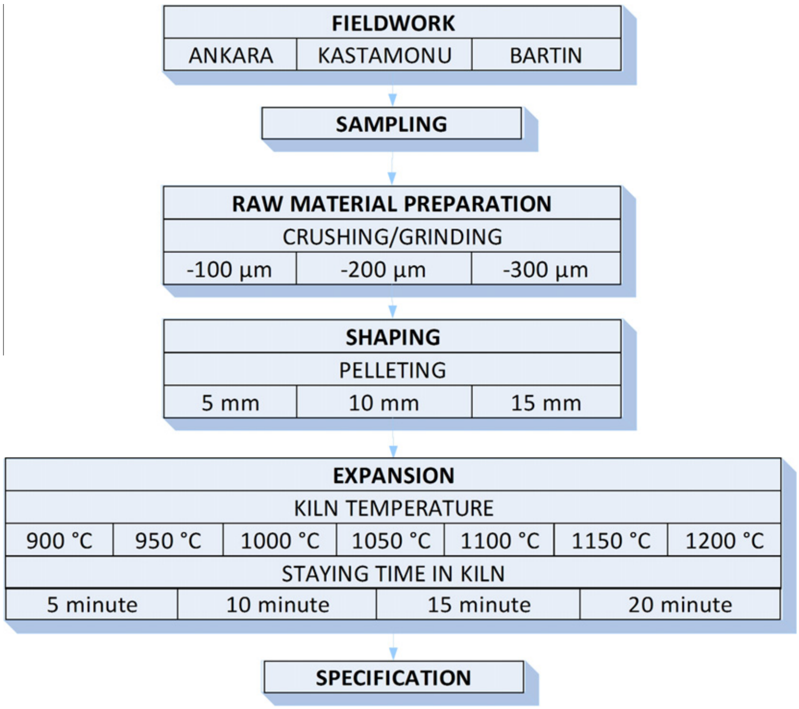

Fig. 5. Methodology of the study.

- Because clay from Ankara and Bartın melt at 1200 °C, 1150 °C values show the optimum results; on the other hand, Kastamonu clay expands best at 1200 °C because it melts at 1250 °C.
- Ankara and Bartın clays melted at 1200 °C, while Kastamonu clay melted at 1250 °C. It was found that expansion occurred within 150 °C temperature intervals for Ankara clay while it occurred within 100 °C temperature intervals for Kastamonu clay and 50 °C temperature intervals for Bartın clay.
- Considering clay's behavior according to heat, it expands to a certain extent and then begins to melt; melting causes irregular and big pores and decreases the aggregate's mechanical resistance.
- It is seen that a sufficient temperature should be found to ensure optimum manufacturing conditions.
- Increasing the operational temperature is an undesired situation due to economical concerns; this increases unit manufacturing costs.

3.4. Effect of holding time period inside furnace

Samples from three different fields were prepared and fired at the same temperatures in the furnace during different time periods and the results are given in Table 5. Samples from Ankara and Bartın melt at 1200 °C, and therefore the given results were expansion results obtained at 1150 °C, while results for the samples from Kastamonu were obtained at 1200 °C because it melts 1250 °C.

The following conclusions can be made from the data in Table 5.

- Under identical operational conditions, the Ankara clay produced aggregates with a density of 0.36 g/cm^3 at 1150 °C after staying in the furnace for 15 min, Kastamonu clay produced aggregates with a density of 0.88 g/cm^3 at 1200 °C after staying in the furnace for 10 min, and Bartın clay produced aggregates with a density of 0.58 g/cm^3 at 1150 °C after staying in the furnace for 20 min.
- Optimum expansion rates were obtained with 15 min for Ankara clay, 10 min for Kastamonu clay and 20 min for Bartın clay.
- The time period spent in the furnace becomes significant after clay has been sufficiently heated for gas formation; shorter time periods cannot suffice for sufficient gas release and the formation of a pyroplastic structure, but on the other hand, when

Table 2
Results from the expansion tests conducted with different clay sizes.

Clay size	Sample location	Mass of unit volume (g/cm^3)		Expansion ratio (%)
		Original	Expanded	
−300 µm	Ankara	1.96	0.42	470
	Kastamonu	1.90	1.01	190
	Bartın	1.88	0.74	260
−200 µm	Ankara	1.93	0.36	550
	Kastamonu	1.88	0.98	190
	Bartın	1.86	0.65	280
−100 µm	Ankara	1.90	0.36	530
	Kastamonu	1.82	0.88	210
	Bartın	1.76	0.61	290

Table 3
Results from the expansion tests conducted with different pellet sizes.

Pellet size (mm)	Sample location	Mass of unit volume (g/cm^3)		Expansion ratio (%)
		Original	Expanded	
5	Ankara	1.83	0.66	280
	Kastamonu	1.51	1.21	120
	Bartın	1.55	0.90	170
10	Ankara	1.93	0.39	490
	Kastamonu	1.78	0.94	190
	Bartın	1.74	0.58	300
15	Ankara	1.90	0.36	530
	Kastamonu	1.82	0.88	210
	Bartın	1.76	0.61	290

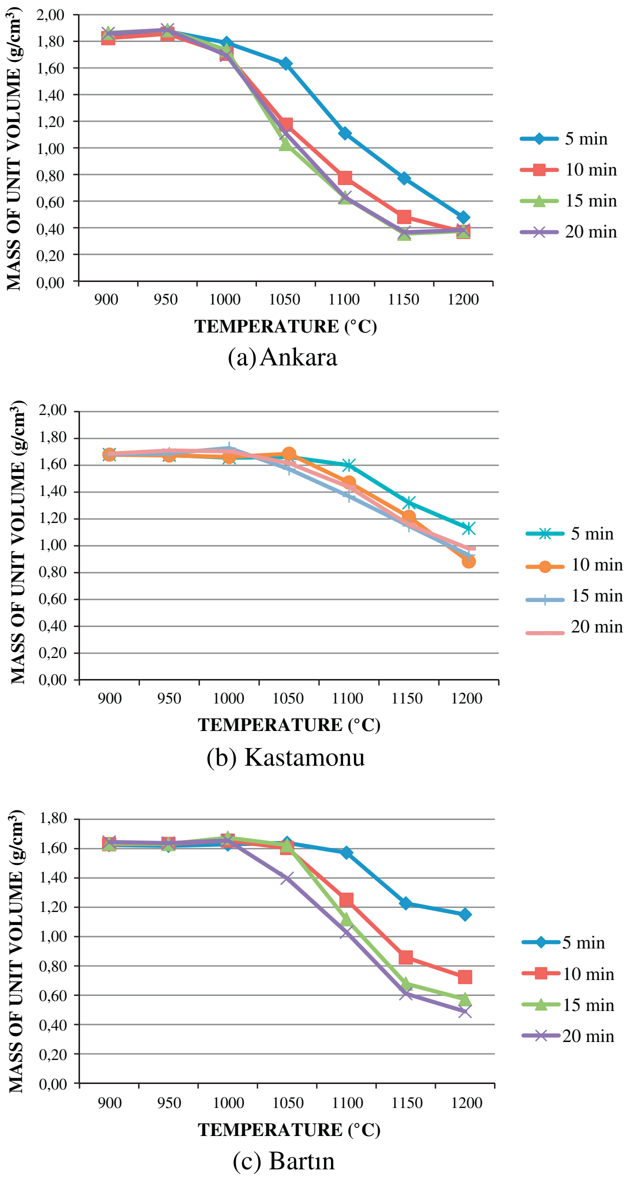

Fig. 6. The relationships between temperature and unit volume weight for different staying time in the furnace.

Table 4
Expansion test results obtained at different temperatures.

Temperature (°C)	Sample location	Mass of unit volume (g/cm^3)		Expansion ratio (%)
		Original	Expanded	
900	Ankara	1.96	1.84	110
	Kastamonu	1.88	1.72	110
	Bartın	1.86	1.68	110
950	Ankara	1.97	1.81	110
	Kastamonu	1.88	1.64	110
	Bartın	1.86	1.67	110
1000	Ankara	1.96	1.73	110
	Kastamonu	1.88	1.61	120
	Bartın	1.86	1.66	110
1050	Ankara	1.96	1.03	190
	Kastamonu	1.90	1.56	120
	Bartın	1.86	1.43	130
1100	Ankara	1.96	0.63	310
	Kastamonu	1.88	1.38	140
	Bartın	1.86	1.15	160
1150	Ankara	1.96	0.36	550
	Kastamonu	1.88	1.16	160
	Bartın	1.86	0.65	280
1200	Ankara	1.93	0.34	560
	Kastamonu	1.82	0.88	210
	Bartın	1.86	0.47	400

Table 5
Expansion test results obtained during different time periods in the furnace.

Time (mins)	Sample location	Mass of unit volume (g/cm^3)		Expansion ratio (%)
		Original	Expanded	
5	Ankara	1.96	0.77	250
	Kastamonu	1.82	1.13	160
	Bartın	1.74	1.17	150
10	Ankara	1.96	0.48	410
	Kastamonu	1.82	0.88	210
	Bartın	1.74	0.88	200
15	Ankara	1.96	0.36	550
	Kastamonu	1.82	0.93	200
	Bartın	1.74	0.71	250
20	Ankara	1.96	0.37	540
	Kastamonu	1.82	0.98	190
	Bartın	1.74	0.58	300

the material stays in the furnace for a time period which is longer than required, the generated gas leaks outside before the sintered crust is formed, thus the projected expansion cannot occur.

4. Conclusions and recommendations

The following conclusions were made according to the conducted study:

- Decreasing the clay grain size, which is one of the manufacturing parameters, results in an increase in expansion. To produce aggregate that meets the requirements of its intended application, while reducing manufacturing cost, clay size should be optimized.
- As pellet size increases, expansion also increases. If a lower density is required in manufacturing aggregates in a desired size, a pellet size close to the maximum point within that pellet size range may be chosen.
- The temperature inside the furnace is the most significant parameter, which must be ensured. Expansion increases as temperature increases up to near the melting point, which varies according to clay type. Thus, an optimum temperature should be specified according to the type of clay.
- To reduce unit manufacturing cost, the lowest possible temperature should be employed in manufacturing to achieve the desired aggregate density.
- The effective time period in the furnace varies between types of clay. Thus, tests should be conducted to find the effective time period for each clay to be used in manufacturing.

Significant data was obtained relating to expanded clay aggregate production, which is a new task in Turkey. This determination of the effects of the four parameters (clay grain size, pellet size, temperature in the furnace, and firing time) serves as a reference point for production and studies to be conducted in the future.

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