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Thermomechanical Properties of a Concrete Composed of Cherry Tree Resin and Expanded Clay (Exclay) Aggregate

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Abstract: Expanded clay (exclay) aggregate and cherry tree resin are used in this study to produce a lightweight construction material. Based on the grain diameter, exclays are classified as d = 2–4 mm and d = 4–6 mm. Cement is added to each group as the binder material. The exclay ratios vary as 10%, 20%, 30%, 40% and 50% of the total volume in the samples. The cherry tree resin is poured into the concrete mixture with a ratio of 1% and 1.5% of cement + exclay mixture in order to form artificial pores in each sample group. The produced samples are subjected to some tests, such as thermal conductivity, water absorption and compressive strength. It is determined that due to the increase in exclay ratios and particle diameter, there is an increase in porosity along with water absorption, but there is a decrease in density, thermal conductivity and compressive strength. Hence, these newly produced concretes are recommended for panel walls, brick, concrete briquettes, inner and outer plaster and concrete partition elements.

Keywords: expanded clay aggregate; cherry tree resin; cement; light concrete

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Citation: Bicer, A.; Celik, N.; Ozgen, F.; Kistak, C.; Taskiran, A. Thermomechanical Properties of a Concrete Composed of Cherry Tree Resin and Expanded Clay (Exclay) Aggregate. *Appl. Sci.* **2024**, *14*, 336. https://doi.org/10.3390/app14010336

Academic Editor: Jong Wan Hu

Received: 28 November 2023
Revised: 25 December 2023
Accepted: 27 December 2023
Published: 29 December 2023

1. Introduction

A mixture of aggregates, water, cement and various additives makes up concrete. The word "lightweight" can be applied to various concrete varieties that have a common criterion of "lower density" than regular-weight concrete. In fact, certain mixes are added to the lightweight concrete mixture to fulfill certain needs. For example, aggregates have a significant impact on the mechanical and rheological characteristics of cement mortars. Similarly, resins have the effect of binding the concrete and so improve the thermal and mechanical properties of the concrete. Therefore, the type of aggregate material and the resin have great importance in both normal and lightweight concretes.

The present study aims to analyze the effect of exclay as an aggregate and cherry tree resin as a binder in lightweight concrete. The following literature survey consists of two parts: the effects of exclay and the effects of natural resins in lightweight concrete.

1.1. Effects of Exclay in the Concrete

Concrete mixtures become more compact with the addition of aggregate elements. They are essential components in the building and upkeep of stiff structures because they reduce the need for cement and water and increase the mechanical strength of the concrete. In lightweight concrete, instead of using traditional aggregates, porous aggregates are used to reduce the density. Expanded perlite, expanded polystyrene, pumice, exclay and fly ash are well-known examples of porous aggregate materials [1]. Since porous structures have resistance to heat transfer, lightweight concretes with porous materials also have low thermal conductivity [2].

Subasi [3] investigated some mechanical properties of light concrete blocks produced by using exclays of 0–2, 2–4 and 4–8 mm diameters and natural sand. It is reported that it is possible to produce light concrete with a density of 1.7 kg/m^3 and compressive strength of 41.27 MPa by using exclay. Bartolini et al. [4] mixed exclay and epoxy resin. They studied both the noise insulation and mechanical strength of the produced agglomerates. Moreover, they determined the densities and porosity properties. As a result, they produced an easily prepared novel material with low density and superior mechanical strength, providing good sound absorption. Othman et al. [5] used exclay aggregate and expanded perlite aggregate to produce lightweight concrete. Nahhab et al. [6] investigated the effects of the maximum size of aggregate, exclay coarse aggregate content and volume fraction of micro-steel fibers on the properties of self-compacting lightweight concrete. Fakhfakh et al. [7] produced exclays and marlstones as raw materials. They added quartz sand and lubricating oil to the samples in various ratios for higher expansion and production at a low temperature. The mechanical strength, apparent density, water absorption and expansion rates were measured. Rossignolo et al. [8] prepared samples by mixing the exclay, sand, cement and silica of various grain diameters. They analyzed the density, compressive and tensile strength and elasticity of the produced samples. Vasina et al. [9] mixed exclays of various diameters with cement, fuel ash and plasticizer additive and studied the acoustic performance of the samples.

1.2. Effects of Resin in the Concrete

Previous studies have reported that the application of cement-type adhesive mortar (e.g., dry cement mortar) may cause cracks as a result of the concentrated stress owing to changes in the volume during shrinkage and expansion [10]. To mitigate this type of construction defect, epoxy resin has been used by many authors. For example, Lee et al. [11] injected epoxy resin into cement mortar, which was then applied to tiles. The adhesion performance of the tiles was subsequently evaluated in terms of the permeability and drying shrinkage under various curing conditions. In addition to the advantages of high adhesion strength and low shrinkage, Ohama et al. [12] reported that epoxy resin is particularly beneficial in constructions that utilize dry cement mortar as the adhesive.

Recent studies have shown that cement mortars with natural resins have various advantages, and natural resins can be used as an alternative to epoxy resin. There are some experimental studies related to mixing natural resins (tragacanth, apricot resin, etc.) into cement to generate artificial pores besides the porous aggregates used in light concrete production. The total porosity of the material increases by generating artificial pores in the cement section of concrete in this way. For example, by adding tragacanth resin, cement and exclay aggregates, Devecioglu and Bicer [13] produced new concrete samples and investigated the thermal and mechanical properties of those concretes. Kaya and Kar [14] tested the effects of natural resin on the properties of lightweight concrete and showed that artificial micropores are caused by the resin, so the density decreases and total porosity increases. Bicer [15] added tragacanth resin into the concrete mixture and improved the porosity of the concrete. Araz [16] produced concrete samples by mixing pine cones in powder form and particle form with cement and pine tree resin at certain ratios. Thermal and mechanical tests were measured, and it was shown that the presence of resin in the concrete increases the porosity and thus reduces the thermal conductivity and compressive strength. Bicer and Celik [17], who are also the co-authors of the present study, tested the effects of pine tree resin on the thermo-mechanical properties of newly produced pumice–cement composites. It was shown that some artificial pores (in addition to pumice pores) are generated in concrete blocks because of the pine tree resin’s effect, which is an improvement in the insulation properties of the concrete. Furthermore, Bicer and Kar [18] investigated the thermal and mechanical characteristics of concretes with apricot resin and expanded polystyrene aggregates.

Turkey has important potential in terms of expanding clay reserves and cherry tree planting. Hence, combining the two to produce light concrete material is an important area of research. The main purpose of this research is to minimize both earthquake damage and energy loss in buildings by producing new low-density concrete for partition walls, floorings, ceiling concretes, briquettes or bricks and plaster. For this aim, two different grain diameters of exclays, cherry tree resin and Portland cement are mixed to form low density and low conductivity materials. The parametric analysis is carried out by varying the volumetric ratio of exclay and resin.

2. Materials and Methods

2.1. Materials

2.1.1. Expanded Clay

The type of clay that has a rapid sintering process and undergoes a volume increase between 1100 and 1300 °C is called expanded clay (or exclay). Exclay is one of the lightest building materials with the highest compressive strength. Common raw materials used for exclay are early sintering clay, sandy clay, clayey schist and chiferton (Figure 1). These materials are generally used in the construction industry in the production of lightweight construction elements. However, their usage areas in the construction industry are also expanding due to their chemical composition and structural form [19].

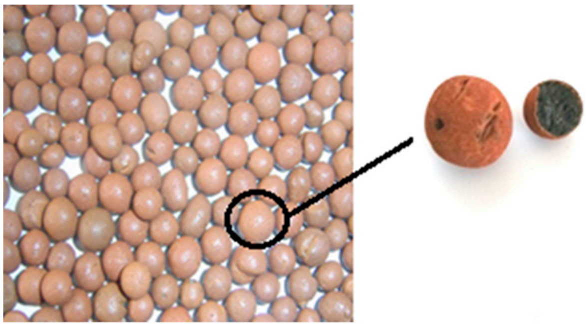


Figure 1. View of the exclay aggregate.

Exclay aggregates, which are evaluated in the light building materials and aggregate group, are one of the main raw material sources that are indispensable in the production of lightweight construction elements, especially in the construction sector, as well as being used for different purposes in Europe and the USA.

The form of exclay is basic. The gases produced from heating expand the clay as small bubbles form during heating, producing a honeycomb structure. Since the exclays have no unique movement in the heater, the produced pores in the exclays have non-uniform sizes and densities (for example, densities are 280, 330 and 510 kg/m^3 for the sizes 0–4 mm, 4–10 mm and 10–25 mm).

The exclay used in this project was obtained from Afsin-Elbistan Thermal Power Plant located in Kahramanmaras, Turkey. As per our special request from the company, clay aggregates were sent in different packages, separated according to their diameters. It would be worth noting that the exclays sent to us by the Thermal Power Plant are included in the waste material group of the facility. In other words, the exclay used in this study means the reuse of a waste product. Thus, it can be said that concrete production with exclay is beneficial to the economy and nature.

2.1.2. Cherry Tree Resin

Long before conventional binders were developed for concrete production, adhesives from renewable resources, namely tree resins, were known and were in use from ancient times up to the middle of the last century [20]. The most well-known tree resin type is the resin of pine trees (Figure 2). Although various types of tree resins are used as adhesives or polishes in the building industry and raw materials in the cosmetics industry, the individual usage areas of each tree are not clarified. For example, the co-authors of the present study previously used pine tree resin with pumice and cement and obtained light concrete [17]. In order to see the available usage areas of other tree resins, the present paper will be a guide since it includes cherry resin. To the best of the co-authors' knowledge, cherry tree resin has not been used in the construction industry before.

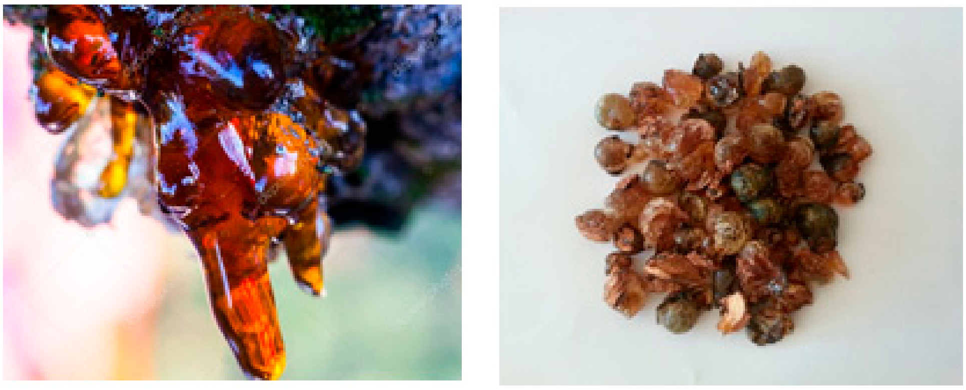


Figure 2. Some fresh and dried views of cherry tree resin.

It is possible to obtain the resin of many trees from companies selling herbal products. The cherry resin used in this study is purchased from an herbalist who sells resins collected from cherry trees in Elazig, Turkey. The purchased resins are in solid form and are high-binding resins that have been collected for about 1–2 months before the usage date.

2.1.3. Portland Cement

CEM IV/B (P-W) 32.5 R Portland Cement (Pozzolanic Cement) was added to the concrete. The density of used cement was 3.1 g/cm^3, and its thermal conductivity was 0.751 W/mK. Table 1 shows the chemical components of exclay and cement used in this study.

Table 1. Chemical composition of the cement components (%).

Chemical Characteristics	Exclay	Cement
SiO_2	54.83	17.08
Al_2O_3	17.71	7.25
Fe_2O_3	7.14	4.15
CaO	3.46	56.61
MgO	4.10	2.44
SO_3	--	2.91
Na_2O	0.73	--
K_2O	3.58	0.7
TiO_2	0.55	--
LOI	7.94	3.73
Not available	--	5.15
Total	100.04	100.02

2.2. Methods

2.2.1. Preparation of Samples

The exclay, cement and cherry tree resin are the major elements in the concrete mixture. Table 2 shows the masses and volumetric ratios of the components in the mixture.

Volumetric ratios of exclay vary as 0, 10, 20, 30, 40 and 50%. Dry cherry resin is grounded and pulverized and then added into mixture at the ratios of 1% and 1.5%. To understand the components' values in the mixture, Sample 14 will be defined now: First of all, in a container with a volume scale on it, approximately 10% of the container was filled with exclay. The net exclay mass was determined by taring the container. Then, the remaining 90% of the container was filled with cement. The total mass was then measured again to determine the mass of the added cement. For Sample 14, the mass of the exclay was 41 g, and the mass of the cement was 2025 g. Total cement + exclay mass was then 2066 g. Especially in samples that do not contain resin (Samples 1 to 12), water was added, which is nearly 10% of the total exclay + cement mixture. The reason a certain mass value of water is not given is because the amount of water required in each experiment was not exactly equal but similar.

Table 2. Mass amounts and volumetric ratios of samples.

Sample	d (mm)	Volumetric Ratio (%)		Mass (g)		Total Mass (g)	Resin Mass (g)	Resin Ratio (%)
		Exclay	Cement	Exclay	Cement	Exclay + Cement		
S1	2–4	0	100	0	2250	2250	0	0
S2	2–4	10	90	41	2025	2066	0	0
S3	2–4	20	80	82	1800	1882	0	0
S4	2–4	30	70	123	1575	1698	0	0
S5	2–4	40	60	164	1350	1514	0	0
S6	2–4	50	50	205	1125	1330	0	0
S7	4–6	0	100	0	2250	2250	0	0
S8	4–6	10	90	37	2025	2062	0	0
S9	4–6	20	80	74	1800	1874	0	0
S10	4–6	30	70	222	1575	1797	0	0
S11	4–6	40	60	148	1350	1498	0	0
S12	4–6	50	50	185	1125	1310	0	0
S13	2–4	0	100	0	2250	2250	22.5	1
S14	2–4	10	90	41	2025	2066	20.7	1
S15	2–4	20	80	82	1800	1882	18.9	1
S16	2–4	30	70	123	1575	1698	17.0	1
S17	2–4	40	60	164	1350	1514	15.1	1
S18	2–4	50	50	205	1125	1330	13.3	1
S19	4–6	0	100	0	2250	2250	22.5	1
S20	4–6	10	90	37	2025	20.62	20.6	1
S21	4–6	20	80	74	1800	1874	18.7	1
S22	4–6	30	70	222	1575	1797	18.0	1
S23	4–6	40	60	148	1350	1498	15.0	1
S24	4–6	50	50	185	1125	1310	13.1	1
S25	2–4	0	100	0	2250	2250	33.8	1.5
S26	2–4	10	90	41	2025	2066	30.1	1.5
S27	2–4	20	80	82	1800	1882	28.2	1.5
S28	2–4	30	70	123	1575	1698	25.5	1.5
S29	2–4	40	60	164	1350	1514	22.7	1.5
S30	2–4	50	50	205	1125	1330	13.5	1.5
S31	4–6	0	100	0	2250	2250	33.8	1.5
S32	4–6	10	90	37	2025	20.62	30.9	1.5
S33	4–6	20	80	74	1800	1874	28.1	1.5
S34	4–6	30	70	222	1575	1797	27.0	1.5
S35	4–6	40	60	148	1350	1498	22.5	1.5
S36	4–6	50	50	185	1125	1310	19.6	1.5

The resin was added to Sample 14. When adding resin, water is no longer added to the cement + exclay mixture because the water in which the resin is dissolved is sufficient. When adding resin, 1% of the total cement + exclay mass, that is, 20.7 g of resin dissolved in water, was added. Therefore, the volumetric ratio values given in the table are the relative values of the exclay (10%) and cement (90%) in the mixture.

First, as shown in Table 2, each of the samples, starting with S1 and ending with S36, were produced, that is, 72 in total. Then, 36 of these samples were cast into molds of 20 × 60 × 150 mm in size to be measured on the thermal conductivity test device. The remaining 36 samples were cast into molds with dimensions that will be measured on the compressive strength test device, that is, 100 × 100 × 100 mm. That is, both thermal and mechanical tests can be applied to each sample. For water permeability tests and suitability tests, such as drilling and painting, samples of both sizes were used mixed, regardless of the size difference.

All elements were well-mixed by hand for 5 min in a container; then, the concrete mixture was poured into the mold and appropriately tempered so as not to have any voids. After 24 h, molds were removed, and test samples were put in water for curing. The top surface of these specimens was made even and smooth. This was done by adding cement paste and spreading it smoothly on the whole area of the specimen. The samples were left in the molds for 24 h and then kept at room temperature for 28 days.

2.2.2. Determining the Density

The density of each sample was calculated by the ratio of the mass of the sample to the volume of the sample.

$$\rho = \frac{M_d}{V} \quad (1)$$

where M_d is the mass of the dry sample in g, and V is the volume of the mold in cm^3. The mass of each sample was measured by a Weather Forecast brand scale WF digital precision balance. The porosity is defined as follows:

$$\Phi = 1 - \frac{\rho_p x + \rho_r (1 - x)}{\rho_s x + \rho_{cm} (1 - x)} \quad (2)$$

where ρ_p is the density of the porous material, while ρ_s is the density of the solid material (the density of the sample after milling, causing no porosity). ρ_r is the density of the resin mixture of cement, and ρ_{cm} is the density of the resin mixture of cement with a 0% porosity ratio. Finally, x is the exclay ratio (%), and $(1 - x)$ is the cement ratio (%).

2.2.3. Thermal Conductivity Tests

In order to measure the thermal conductivities of the specimens, a *Shotherm-QTM* unit (*Showa Denko*) operating based on the DIN 51046 hot wire methodology was used (Figure 3). The tests were repeated three times at three locations of each sample block to represent the average of nine values.

Figure 3. Velocity measurement device.

2.2.4. Compressive Strength Tests

The compressive strength (f_{cs}) tests on the samples were undertaken according to the ASTM C109-80 test standard. The ASTM C109 test standard is a pressure test that determines the compressive strength of hydraulic cement and other mortars. For testing, rectangular prism-shaped samples of 100 mm × 100 mm × 100 mm were used. The samples were tested by a compression testing machine after 28 days of curing, as previously mentioned. Load is applied gradually till the sample fails. Load at the failure divided by area of sample concrete gives the compressive strength of concrete.

2.2.5. Water Absorption Tests

The water absorption tests were used to determine the influence of water absorption on physical properties. Test specimens were stored in water at an elevated temperature for a defined time. The test procedure was as follows: first, the sample surface was cleaned thoroughly to remove any dirt, oil or other contaminants. The mass of the sample was measured, and the result was recorded. The sample was then immersed in water for 24 h. After 24 h, it was taken from the water tank and wiped with a dry paper. The sample was weighed after drying. Calculating the water absorption ratio was the final step. Subtracting the initial weight of the sample from the final weight and dividing the result by the initial weight gives the dimensionless water absorption ratio:

$$WAR = \frac{M_w - M_d}{M_d} \times 100 \quad (3)$$

2.3. Uncertainty Analysis

The uncertainty analysis method introduced by Kline and McClintock [21], which is based on careful specifications of the uncertainties in the various primary experimental measurements, was applied to the measurement results. The method aims to estimate the total uncertainty of the measured or calculated values, such as thermal conductivity, porosity, compressive strength, tensile strength and water absorption ratio.

According to this method, let the quantity that needs to be measured in the system be R, and the n independent variables affecting this quantity be $x_1, x_2, x_3, \ldots\ldots, x_n$. In this case, it can be written as $R = f\,(x_1, x_2, x_3, \ldots\ldots, x_n)$. If the uncertainty of each independent variable is $w_1, w_2, \ldots, w_n$, and the uncertainty of the magnitude R is w_R, the uncertainty was calculated as follows according to Kline and McClintock [21]:

$$w_R = \sqrt{\left(\frac{\partial R}{\partial x_1} w_{x_1}\right)^2 + \left(\frac{\partial R}{\partial x_2} w_{x_2}\right)^2 + \cdots + \left(\frac{\partial R}{\partial x_n} w_{x_n}\right)^2} \quad (4)$$

The uncertainty of each variable was estimated with the help of the instruments' catalogs. Then, the total uncertainties for each independent variable were found for thermal conductivity, porosity, compressive strength and water absorption ratio as ±4.7%, ±6%, ±4% and 3%, respectively.

3. Results and Discussions

The results of the measurement details summarized in the previous section are listed in Table 3.

Table 3. Thermal and mechanical properties of the samples.

Code	d (mm)	x (%)	ρ (g/cm^3)	Φ (%)	k (W/mK)	f_{cs} (MPa)	WAR (%)
1	2–4	0	1.608	3.42	0.452	25.82	22.5
2	2–4	10	1.395	10.56	0.381	23.54	23.0
3	2–4	20	1.175	14.82	0.319	21.77	23.8
4	2–4	30	0.958	18.66	0.275	19.45	24.3
5	2–4	40	0.820	22.45	0,241	17.17	25.1
6	2–4	50	0.731	26.14	0.220	15.64	25.6
7	4–6	0	1.608	3.42	0.452	25.82	24.4
8	4–6	10	1.319	11.38	0.364	22.68	25.0
9	4–6	20	1.124	16.62	0.305	19.46	25.6
10	4–6	30	0.892	21.13	0.258	17.74	26.3
11	4–6	40	0.757	24.88	0.230	15.61	27.1
12	4–6	50	0.685	28.10	0.207	14.55	27.5

Table 3. *Cont.*

Code	d (mm)	x (%)	ρ (g/cm^3)	Φ (%)	k (W/mK)	f_{cs} (MPa)	*WAR* (%)
13	2–4	0	1.509	5.28	0.441	24.22	23.3
14	2–4	10	1.278	12.38	0.362	21.81	24.2
15	2–4	20	1.038	16.86	0.298	19.23	24.8
16	2–4	30	0.848	21.41	0.252	17.01	25.5
17	2–4	40	0.729	24.72	0.218	14.74	26.4
18	2–4	50	0.627	28.38	0.198	13.13	27.6
19	4–6	0	1.463	5.88	0.435	23.95	26.3
20	4–6	10	1.224	12.81	0.338	20.43	26.8
21	4–6	20	1.012	18.28	0.279	17.86	27.5
22	4–6	30	0.813	22.86	0.235	15.89	28.0
23	4–6	40	0.652	26.53	0.208	14.15	28.4
24	4–6	50	0.583	30.10	0.187	13.06	28.7
25	2–4	0	1.410	6.56	0.434	22.61	25.8
26	2–4	10	1.133	14.04	0.343	20.12	26.2
27	2–4	20	0.910	19.03	0.281	17.84	26.6
28	2–4	30	0.742	23.48	0.238	15.33	26.9.
29	2–4	40	0.604	27.01	0.204	13.42	27.2
30	2–4	50	0.532	30.15	0.181	12.83	27.8
31	4–6	0	1.374	6.56	0.414	22.45	27.8
32	4–6	10	1.093	14.22	0.319	19.12	28.2
33	4–6	20	0.893	20.16	0.261	16.75	28.6
34	4–6	30	0.711	24.41	0.220	14.65	29.0
35	4–6	40	0.582	28.18	0.193	13.13	29.3
36	4–6	50	0.545	32.21	0.171	11.82	29.9

3.1. Density and Porosity Variations

Some views under SEM of a selected sample (Sample 36) are presented in Figure 4. In the sample, it was observed that artificial pores were generated, especially in the cement part of the samples (pores are formed with the swelling of resin in water and removal of the absorbed water during the drying process), in addition to the pores existing in the exclay aggregate. As a result, the pores decreased the density.

Table 3 shows that there is an inverse relationship between density and porosity. When porosity increases, the density decreases. In Figure 5, the density values are plotted with bar graphs for better evaluation. According to Figure 5, the density decreases with an increasing exclay ratio in the concrete. Although the effect of exclay diameter on density is not very apparent, the density of samples with 4–6 mm diameter exclay aggregates is slightly lower than the samples with 2–4 mm diameter aggregates. Finally, regardless of the exclay particle diameter, increasing the resin ratio causes a decrease in density, as expected.

As is known, lightweight concrete has a lower density than normal-weight concrete. This reduction in density is achievable by different methods, such as using lightweight aggregate in concrete, foamed concrete or autoclaved aerated concrete or by any other techniques that reduce the final specific weight of the product, thus achieving a lower weight than normal weight concrete mixtures. Whereas the density of normal-weight concrete varies from 2240 to 2450 kg/m^3, the density of lightweight concrete is ~300–2000 kg/m^3, but the practical range of density for lightweight concrete is 500–1850 kg/m^3 [19]. In the present study, the lowest and highest densities were measured as 532 kg/m^3 and 1608 kg/m^3, which shows that all produced samples can be classified as lightweight concretes.

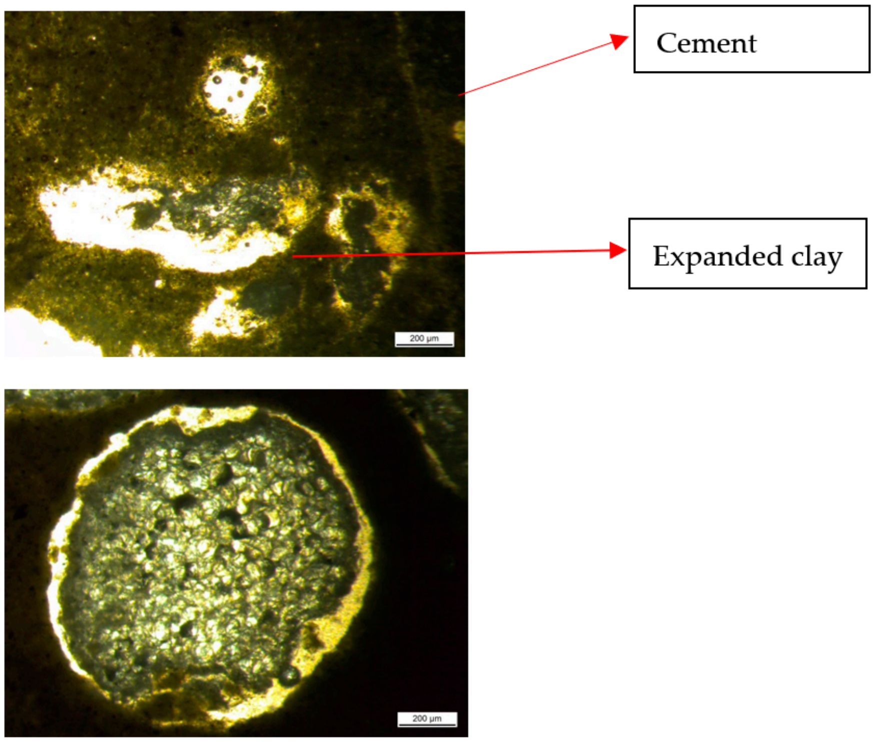
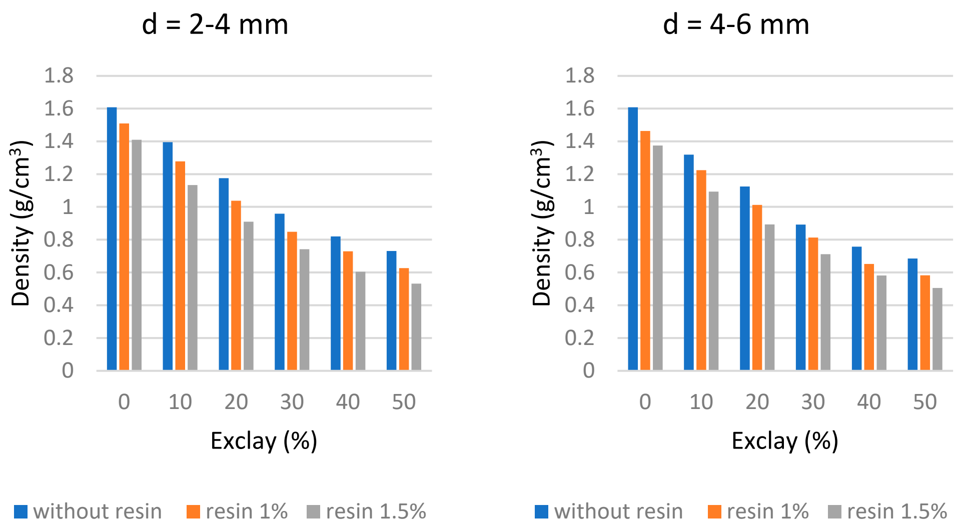


Figure 4. Scanning electron microscopy (SEM) views of a sample.



(**a**) (**b**)

Figure 5. Densities with respect to exclay ratios: (**a**) 2–4 mm, (**b**) 4–6 mm.

3.2. Thermal Conductivity Variations

The thermal insulation properties of the samples were determined by thermal conductivity tests. Based on the measurement results of the samples, it may be suggested that exclay aggregate concretes are used in buildings as panel walls, bricks, concrete briquettes, internal and external plastering and concrete partitioning components for the building's thermal comfort. Thermal conductivity values versus exclay ratios are presented in Figure 6.

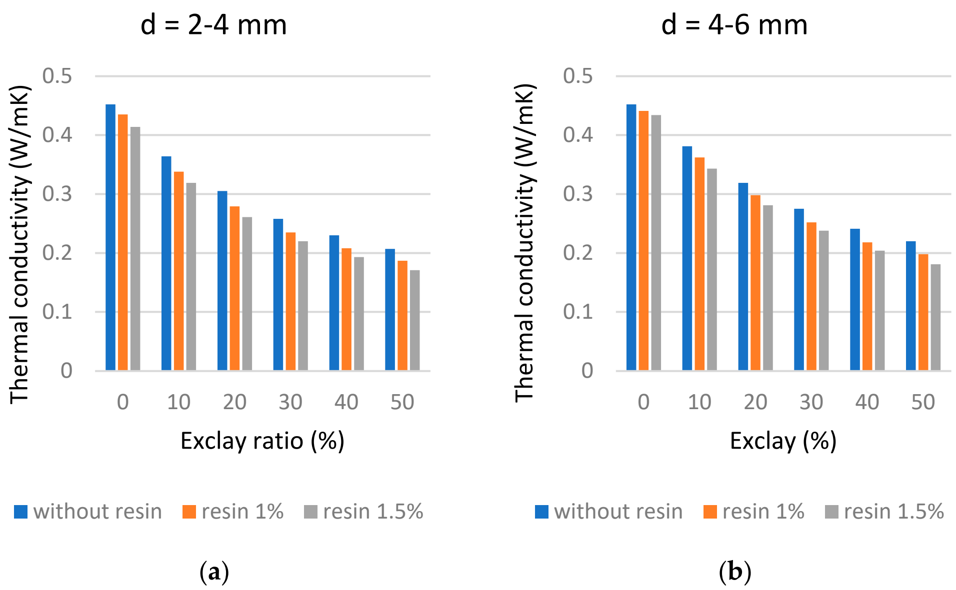


Figure 6. Thermal conductivities with respect to exclay ratios: (**a**) 2–4 mm, (**b**) 4–6 mm.

The thermal conductivities decrease with increasing exclay ratio and resin ratio since the inner parts of micro-structured pores are full of air. As the grain diameter increases, porosity increases, and the thermal conductivity decreases. Minimum thermal conductivity is measured as 0.207 W/mK (Sample 12—without resin) and as 0.171 W/mK (Sample 36—with resin) in the 50% exclay sample with a grain size of 4–6 mm.

Thermal conductivity decreases further, and insulation characteristics of the material improve as a result of an increase in total porosity due to the formation of artificial pores in the resin-added samples. These decreased ratios were 3.98%−17.72% and 8.40%−17.39% according to the grain diameter.

3.3. Compressive Strength Variations

Compressive strength can be defined as the capacity of concrete to withstand loads before failure. Of the many tests applied to the concrete, the compressive strength test is the most important, as it gives an idea about the characteristics of the concrete. Compressive stress is the stress on materials that leads to a smaller volume. When compressive stress is applied to brittle materials, they fracture as there is a sudden release of the stored energy. When the compressive stress is applied to the ductile materials, they compress, and there is no failure. Hence, the results of the test gain importance. The results of compressive strength tests are presented in Figure 7a,b.

Figure 7a,b shows that as the exclay ratio in the samples increases, the compressive strength of the samples decreases. For example, in samples produced with 2–4 mm diameter of exclay aggregates without resin, the compressive strength decreases by 39.42% as the exclay ratio increases. In samples produced with exclay aggregates with a diameter of 4–6 mm, compressive strength decreases by approximately 43.64% as the exclay ratio increases. In samples containing resin, these reduction values are around 37.5% in samples made with 2–4 mm diameter aggregates and 34.43% in samples made with 4–6 mm diameter aggregates. It can be concluded that by means of compressive strength, adding expanded clay as an aggregate into the concrete mixture diminishes the strength of the concrete. Since compressive strength is the ability of the material or structure to carry the loads on its surface without any crack or deflection, the samples with high exclay ratios cannot be recommended in buildings under high compression.

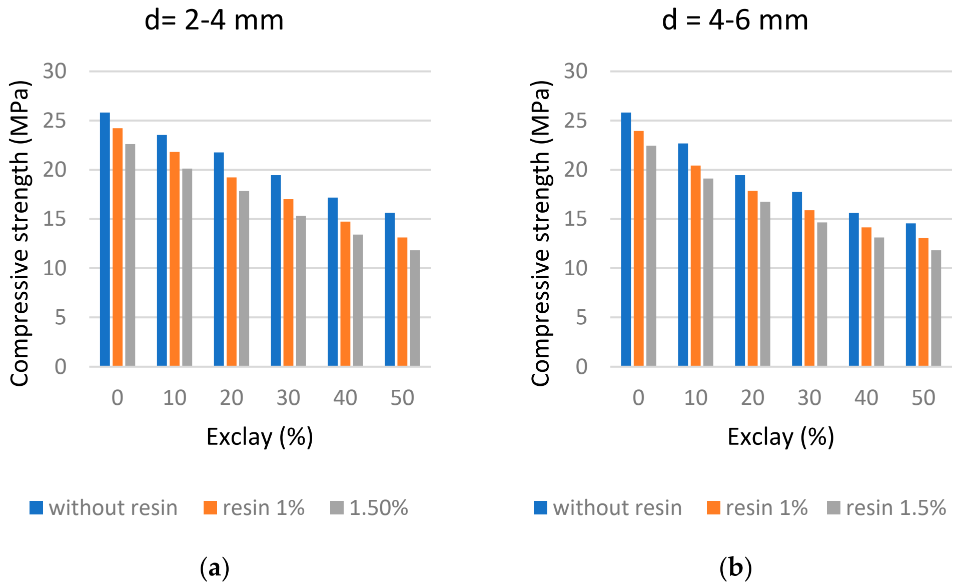


Figure 7. Compressive strength with respect to exclay ratios: (**a**) 2–4 mm, (**b**) 4–6 mm.

If the effect of cherry tree resin on the compressive strength is analyzed, it will be seen that, whether the concrete includes exclay with 2–4 mm diameter or the exclay with 4–6 mm diameter, the compressive strength decreases with the addition of resin. This shows that the porous structure formed by the resin reduces the strength of the material. As the resin ratio in the samples increases, the compressive strength value naturally decreases.

The compressive strengths of the samples with diameters of 2–4 mm and 4–6 mm were, respectively, 15.64–25.82 MPa and 14.55–25.82 MPa.

With the test results, the usage areas of the prepared samples needed to be designated clearly. According to these outcomes, it may be suggested that concretes prepared by using exclays be utilized as columns and building beam concretes in multistore buildings instead of tall buildings. Moreover, low-density concretes with exclay aggregates may be recommended for use as panel walls, bricks, concrete briquettes, internal and external plasters, and concrete partitioning components to minimize building weight.

3.4. Water Absorption Variations

The water absorption of concrete is expressed as a percentage of the initial weight of the sample. The lower the water absorption, the more water-resistant and durable the concrete is considered to be. Figure 8 shows the results of water absorption tests.

Before evaluating the results of the tests, the necessity of these tests should be briefly introduced. Concrete's water absorption is reported as a percentage of the sample's initial weight. Concrete is said to be more water-resistant and long-lasting when the water absorption rate is lower. The water absorption test is a crucial technique used by engineers and contractors to assess the water resistance and durability of concrete. Test results are useful in determining the uniformity and quality of the concrete mix and in confirming that the concrete satisfies the criteria and requirements needed for a certain application. In addition to helping choose the best type of concrete for a given project, the results of the water absorption test can also be used to guarantee that the concrete will function as planned for the duration of its anticipated service life.

For concrete pavers, the test procedure involves drying a specimen to a constant weight, weighing it, immersing it in water for a specified amount of time and weighing it again. The increase in weight as a percentage of the original weight is expressed as its absorption (in percent). For normal concrete, the water absorption is typically in the range of 10–15%. For high-performance concrete, the water absorption is typically lower, in the range of 5–10%. For lightweight concrete, the water absorption is typically higher, in the range of 20–25%. The critical value is accepted as 30%.

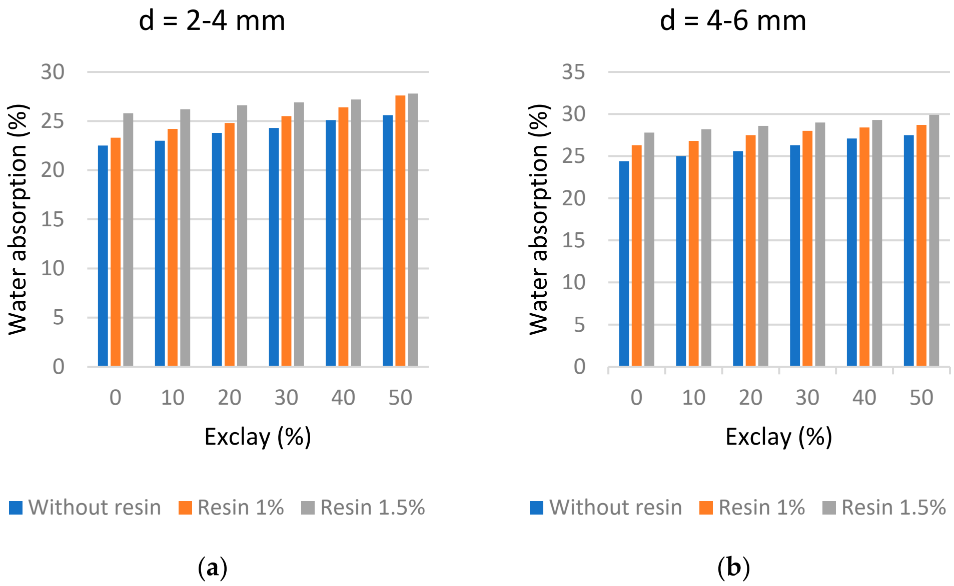


Figure 8. Water absorption ratio of samples versus exclay ratios: (**a**) 2–4 mm, (**b**) 4–6 mm.

In Figure 8, the water absorption ratio increases as the exclay ratio increases. The increase in water absorption ratio in the specimens is lower than the critical value of 30%. Thus, it is possible to use such concretes in humid environments. Furthermore, such structure materials may be used as materials in places having direct contact with water, in internal plasters and sandwich walls and as roof sheeting plaster material.

3.5. Comparison to the Literature

Table 4 shows some comparison results of the density, thermal conductivity and compressive strength. The densities of the samples that are found in the present study are in agreement with the cited references.

Table 4. Comparison to the literature of physical properties.

Materials	ρ (g/cm^3)	k (W/mK)	f_{cs} (MPa)	Literature
Cement (450 kg/m^3)—exclay (22%) + sand (20%)	1710	--	41.27	[3]
Cement (440 kg/m^3)—exclay + sand + silica fume	1.460	--	39.5	[8]
Cement + exclay (10%) + tragacanth(1%)	1.056	0.263	3.97	[13]
Cement (80%) + EPS (20%) + tragacanth (1%)	1.230	0.220	10.85	[14]
Cement + fly ash (20%) + tragacanth (1%)	1.151	0.315	20.4	[15]
Cement (80%) + pumice (20%) + tragacanth (1%)	1.306	0.306	-	[18]
Cement (80%) + EPS (20%) + apricot resin (1%)	1.291	0.322	13.05	[19]
Cement + clay + wood pellet (20%)	0.870	0.160	2.35	[22]
Cement + exclay (10%) + cherry resin (1%)	1.278	0.351	22.31	
Cement + exclay (20%) + cherry resin (1%)	1.081	0.291	20.13	
Cement + exclay (30%) + cherry resin (1%)	0.848	0.251	18.22	Present study
Cement + exclay (40%) + cherry resin (1%)	0.789	0.228	15.14	
Cement + exclay (50%) + cherry resin (1%)	0.603	0.208	13.73	

If the attention is turned to the thermal properties, it will be seen that the thermal conductivities of the prepared samples are lower than the ones with fly ash [15] and of the samples with pumice [19] (since exclay has a more porous structure); furthermore, the thermal conductivity of the prepared samples are higher than the thermal conductivity of the samples used in the studies numbered [13–15,22]. Thermal conductivity is high because the tragacanth resin used in [13] absorbed more water and released the water from its structure during drying, generating a high number of artificial pores. In study [14], EPS is used along with the tragacanth resin, and the EPS structure has more micropores.

Now, it is time to compare the compressive strength. Table 4 illustrates that the compressive strength of concretes with exclay aggregates and cherry resin approximated the values reported in [3,15], but they are better than the values given in [13,14,19,22]. This may be due to the formation of a hard cluster around the exclay during production. Compressive stress is lower than the value reported in [13] because of the resin addition.

3.6. Usability of the Concretes

In the usability tests on samples, the capabilities of being paintable, drilled, grooved, etc., are questioned.

Some dying materials, such as water-based silicone, oil paint, acrylic paint and golden metallic paint, are applied on the samples' surfaces, as shown in Figure 9, which demonstrates a good result of painting. The capability of drilling, screw nailing and grooving with a chainsaw are applied to samples, as shown in Figure 10, which shows how good the result obtained on most of the samples are.

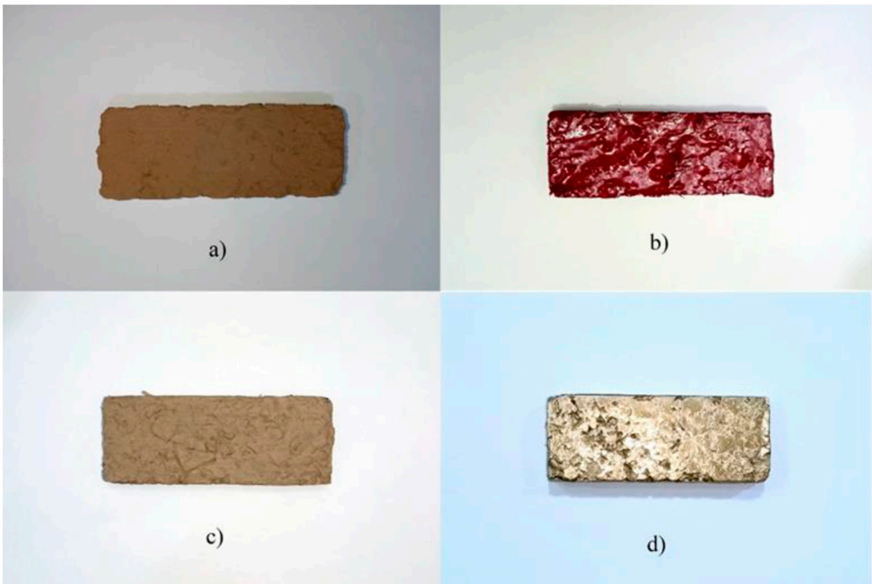


Figure 9. Painted samples. (**a**) Water-based silicone, (**b**) oil paint, (**c**) acrylic paint, (**d**) golden metallic paint.

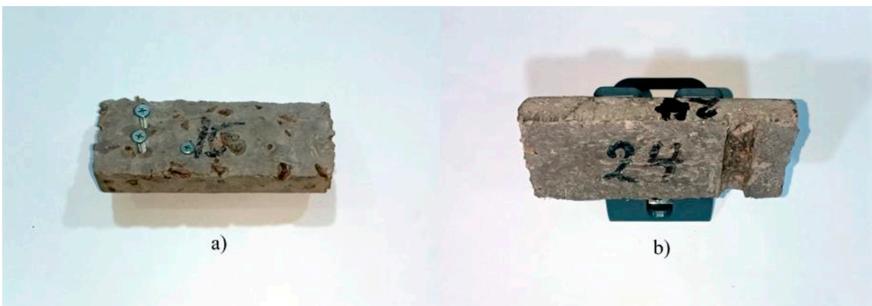


Figure 10. Mechanical applications on samples: (**a**) screwing and drilling, (**b**) grooving.

After the paint ability, drilling, grooving and nailing tests were conducted, and it was concluded that most of the samples had good operability. It was concluded that, particularly, the samples with small grain diameters and low exclay ratios were appropriate for the processes of drilling by a drill, driving nails and guttering.

4. Conclusions

The purpose of this manuscript is to demonstrate the effect of cherry tree resin on the thermal and mechanical characteristics of concretes with exclay aggregate. Some conclusions can be made considering the results of the density (porosity) calculations, thermal conductivity tests, compressive strength tests, water absorption tests and usability tests.

- ✓ Concretes, including exclay–cement–cherry tree resin, can be utilized as low-density concrete platen walls, apron concretes, briquettes and brick walls. The damages of earthquakes can be minimized with the usage of lightweight concretes.
- ✓ In the cherry tree resin and exclay-added samples, the density decreases and the total porosity increases due to the artificial micropores generated by the resin. Therefore, the thermal conductivity of the samples decreases. The thermal conductivity value is the lowest around 0.3 W/mK, which indicates that even if there is a low thermal conductivity value, it is not low enough to be an insulating material. Hence, the insulation property of the material should be improved to achieve energy savings. If an insulation material is desired to be produced by exclay and cherry tree resin, new mixing ratios of resin and exclay should be tried.
- ✓ According to the tests, the samples produced are in good condition in terms of water permeability. Water absorption ratios of the samples with cherry tree resin and exclay are lower than the critical value of 30%, meaning the use of such construction materials is recommended in places that have direct contact with water. However, it is also possible to use them as interior plastering materials, internal filling materials, roof-sheathing plastering materials or applied in sandwich walls.
- ✓ Compressive strength values show that the materials have low strength. In view of these results, the use of concretes with exclay and cherry tree resin in columns and building beams is not recommended. Regardless of this, these low-density concretes are accepted as panel walls, brick, concrete briquettes, inner and outer plaster and concrete partition elements.
- ✓ Various usability tests performed on the samples determined that they were appropriate for drilling, nailing and grooving processes.

Author Contributions: Conceptualization, A.B.; methodology, A.B. and N.C.; data curation, F.O., A.T. and C.K.; writing—original draft preparation, A.B. and N.C.; writing—review and editing, N.C. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: The datasets generated during and/or analyzed during the current study are not publicly available due to the Turkish language used in all files but are available from the corresponding author upon reasonable request.

Conflicts of Interest: The authors declare no conflict of interest.

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