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Investigation of Expanded Clay Aggregate and Pine Resin Added Plaster with Cement in Biomedical Material Storage Insulation

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ABSTRACT

In this study, the aim was to produce cement-plaster with expanded clay aggregate and pine resin as additives to enhance the strength for the preservation of medical and biomedical materials in storage facilities, without being affected by heat and humidity, instead of traditional aggregates. In the prepared samples for the experimental study, expanded clay aggregate with particle sizes of 0-2 mm and 2-4 mm was mixed with cement binder in weight percentages of 20%, 40%, 60%, and 80%. Additionally, resin was added to the mixtures in weight percentages of 0%, 0.5%, 1%, and 2%. A total of 32 samples were produced. In the study, resin-enhanced CEM IV/B 32.5 R type pozzolanic cement were used. As the amount of resin added to the samples increased, the thermal conductivity and compressive strength decreased. The lowest thermal conductivity was observed in samples with 2-4 mm particle size, 80% expanded clay aggregate, and 2% resin content in cement-based samples at 0.152 W/mK.

The highest compressive strength was observed in cement-based samples, with 22.5 MPa for the resin-free sample containing 0-2 mm particle size and 20% expanded clay aggregate. The water absorption rate of the samples remained below the critical value of 30% in cement-based samples.

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1. Introduction

Today, approximately 20 thousand different types of medical devices and systems are used in hospitals. For this reason, it is necessary to carry out design and development efforts for biomedical systems and have technical and scientific knowledge of how to use them efficiently. It will bring to the fore the importance of insulating warehouses against heat and moisture to store, preserve, and ship medical and biomedical materials under specified conditions without being damaged.

Humidity generally occurs in packaging and transport containers due to sudden temperature changes or condensation of moisture in the air. Products that collect moisture may damage the product by forming mold and other harmful microorganisms and cause product loss.

Aggregates make up approximately 70-80% of concrete. Low-density concrete is essential to minimize structural load and save energy. To produce this type of concrete, traditional aggregates must be wholly or partially replaced with porous alternatives. Commonly used porous aggregates include expanded perlite, expanded polystyrene (EPS), pumice, and expanded clay (EC). Lightweight aggregates have low unit volume weights due to their high void ratios and provide higher water absorption, lower heat conduction, and lower strength than normal aggregates [1].

There is a large body of research on EC. Some researchers have focused on the use of ECs in concrete. For example, Subaşı used EC (grain diameters of 0-2, 2-4, and 4-8 mm) with natural sand to produce lightweight concretes and then investigated their mechanical properties. He concluded that we could produce lightweight concrete with a compressive strength of 41.27 MPa and thus reduce the building load [1]. Othman et al., used EC and expanded perlite aggregate to produce lightweight concrete and examined their density, quality and strength [2]. Nahhab et al., investigated the properties of the lightweight concrete produced by mixing maximum-size EC with micro steel fibers [3]. Fakhfakh et al., produced a lightweight aggregate using EC and marlstone [4]. Rossignolo et al., prepared EC, sand, cement, and silica mixed specimens of various grain diameters. They analyzed the samples' density, elasticity, compressive strength, and deformation properties [5]. Bicer, investigated the effect of fly ash and pine tree resin on the thermal and mechanical properties of EC aggregate concretes [6]. Many researchers have conducted research on EC aggregate concretes (Bouvard et al.,[7]; Chen &

Liu [8]; Miled et al., [9]; Xue et al., [10]; Gnip et al., [11]; Bajdur et al., [12]; Choi & Ohama, [13].

This study aimed to produce a lightweight concrete by mixing EC, pine tree resin, and cement in different proportions. It is to minimize both earthquake damage and energy losses in buildings and protect medical and biomedical materials from being affected by temperature and humidity while stored in warehouses by using new concrete. Thermal and mechanical properties of the prepared samples were analyzed.

2. Experimental

2.1. Materials

Expanded clay: When heated above 1000 °C, natural clays have a structure with gas-filled pores due to the expansion of the gases in them (Fig. 1), resulting in a sintered hard shell on the outside, which provides those materials with high compressive strength. Therefore, natural clays can be used as aggregates. Expanded clay can be used as lightweight concrete aggregate or as brick, plaster, and filling material. We obtained EC in particle diameters of 0-2 mm and 2-4 mm and used them in two batches.

Fig 1. Expanded clay

Pine tree resin: It is a yellow substance that oozes from the bark of trees. It also has a pleasant odor. The resin, which has a liquid structure when it first leaks, solidifies when it comes into contact with oxygen. After a while, it sticks to where it flows pretty hard. We procured dry resin and soaked it in water for 48 hours to swell and expand (Fig. 2).

a) b) c) d)

Fig. 2. Resin a) natural, b) dried, c) powder, d) resin extract

Cement: Concrete mortars were produced using pozzolanic cement (CEM IV/B(P)32.5 R) as a binder for EC and sand mixtures. The cement had a density value of 3.1 g/cm^3 and thermal conductivity of 0.751 W/mK.

Table 1 shows the chemical composition of the components used in the concrete samples.

Table 1. Chemical composition (%)

Chemical characteristics	**Expanded clay**	**Cement**
SiO_2	54.83	18.08
Al_2O_3	17.71	6.15
Fe_2O_3	7.14	3.25
CaO	3.46	57.71
MgO	4.10	2.34
SO_3	-	2.91
Na_2O	0.74	-
K_2O	3.58	0.7
TiO_2	0.55	-
Loss on ignition	7.94	2.84
Not available	-	6.05
Total	100.05	100.03

2.2. Testing methods

Thermal conductivity:

Thermal conductivity was determined using the hot wire method. It was estimated by applying *a Shotherm Quick Thermal Conductivity Meter* unit that complies with *DIN 51046* standards. It had a range and sensitivity of 0.02-10 W/mK and ± 5 %, respectively [14]. All samples were measured at room temperature at three points (22-25°C). The thermal conductivity was the arithmetic mean of the measurements.

Compressive strength:

Mechanical strength tests were undertaken according to the TSE 699 [15] standard and ASTM C 109-80 standards [16].

Porosity:

The density method was used to determine porosity. Porosities were calculated using the values in

Table 2 and Eq (1) [17].

Table 2. Density values of expanded clay aggregate and cement

Component	ρ_{cement}	$\rho_{cement\ matrix}$	$\rho_{EC\ matrix}$	ρ_{EC}	
				0-2 mm	2-4 mm
Density (g/cm^3)	3.1	3.31	2.45	0.74	0.55

$$\Phi = 1 - \frac{\rho_{EC} \cdot Z + \rho_{cement} \cdot (1-Z)}{\rho_{EC\ matrix} \cdot Z + \rho_{cement\ matrix} \cdot (1-Z)} \quad (1)$$

Water absorption (WAR):

The water absorption test serves to examine the capacity of building materials to absorb water and provide a dry volume for the expansion of ice crystals during freezing [18]. The rates of water absorption were determined using Equation 2.

$$WAR = \{[W_d - W_k]/W_k\}.100 \quad (2)$$

In Equation 2, where W_d represents the dry weight of the sample, and W_k denotes the weight of the sample after water impregnation. The water absorption rates obtained from the calculations are presented in Table 3, 4.

2.3. Preparation of Samples

The proportions of EC in all mixtures were 20, 40, 60, and 80% of the amount of cement. The resin was added to the water at 0%, 1%, and 2% of the extracted cement and EC mixture. The water, resin, and cement ratio was fixed as (W+R)/C=0.5. After being mixed for about three minutes, the mixtures were poured into metal molds. The mortars were poured into molds for thermal (20x60x150 mm) and mechanical tests (100x100x100 mm). The samples were kept in the molds for 24 hours. They were removed from the molds and left to dry for 28 days. Tables 3 and 4 show the results.

Table 3. Thermal and mechanical properties of samples (EC particle diameter 0-2 mm)

Code	**EC ratio (%)**	**Density (g/cm^3)**	**Porosity (%)**	**Thermal conductivity (W/mK)**	**Compressive strength (MPa)**	**Water absorption (%)**
Pine tree resin **0 %**						
1	20	1.680	15.8	0.429	22.35	20.7
2	40	1.538	28.2	0.351	18.48	21.4
3	60	1.387	35.9	0.305	12.52	23.5
4	80	1.250	38.7	0.295	6.36	24.3
Pine tree resin 0.5 %						
5	20	1.564	19.7	0.362	18.98	22.86
6	40	1.435	31.6	0.317	15.26	23.6
7	60	1.310	38.5	0.265	9.88	24.0
8	80	1.188	40.6	0.246	4.85	25.6
Pine tree resin 1 %						
9	20	1.428	24.9	0.311	14.10	23.2
10	40	1.318	36.3	0.263	10.17	24.9
11	60	1.188	41.8	0.238	7.09	25.8
12	80	1.066	45.1	0.218	3.75	27.7
Pine tree resin 2 %						
13	20	1.288	30.1	0.287	9.02	25.6
14	40	1.187	28.1	0.247	6.91	26.2
15	60	1.093	43.8	0.214	4.39	27.3
16	80	0.989	46.4	0.184	2.85	29.1

Table 4. Thermal and mechanical properties of samples (EC particle diameter 2-4 mm)

Code	**EC ratio (%)**	**Density (g/cm^3)**	**Porosity (%)**	**Thermal conductivity (W/mK)**	**Compressive strength (MPa)**	**Water absorption (%)**
Pine tree resin **0 %**						
17	20	1.514	17.0	0.395	20.12	20.8
18	40	1.426	29.1	0.331	16.95	21.2
19	60	13.21	37.7	0.286	11.17	23.8
20	80	1.215	39.7	0.271	5.61	24.1
Pine tree resin 0.5 %						
21	20	1.463	20.8	0.329	17.62	23.8
22	40	1.368	32.3	0.293	14.02	24.1
23	60	1.248	39.7	0.247	9.11	26.4
24	80	1.119	41.5	0.228	4.20	28.6

Pine tree resin 1 %						
25	20	1.385	23.7	0.300	12.51	24.6
26	40	1.228	35.2	0.258	9.08	25.8
27	60	1.122	41.4	0.218	5.49	27.7
28	80	0.973	44.1	0.184	3.02	29.1
Pine tree resin 2 %						
26	20	1.222	27.6	0.249	8.87	27.5
30	40	1.087	38.1	0.211	5.54	28.0
31	60	0.976	43.4	0.188	4.08	29.1
32	80	0.876	48.8	0.152	2.15	29.6

4. Results and Discussion

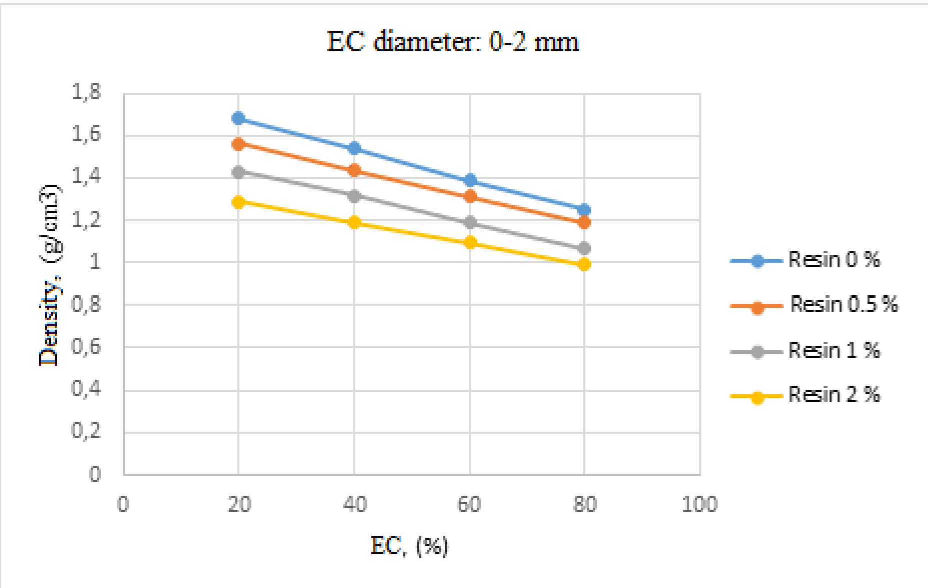
In the samples, artificial pores were generated in the cement section of the samples (pores were formed with the swelling of resin in water and removal of the absorbed water during the drying process) in addition to the pores existing in the expanded clay aggregate. Therefore, density of the samples dropped and porosity increased as shown in Fig. 3 and 4. The higher the EC content, the less density and the higher porosity.

Properties of thermal insulation of samples were determined by using thermal conductivity tests. Based on the measurement results of the samples, it may be suggested that, exclay aggregated concretes are used in buildings as panel walls, bricks, concrete briquettes, internal and external plastering and concrete partitioning components for building's thermal comfort.

Thermal conductivity values versus EC ratios are presented in Fig 5a and 5b respectively EC grain diameter 0-2 mm and 2-4 mm. The thermal conductivities reduced with increasing expanded clay ratio and resin ratio. The reason of the decrement is arising from the fact that, micro structured pores inner parts are full of air. As the grain diameter increased, porosity of the samples increased and the thermal conductivity dropped. Minimum thermal conductivity was measured as 0.271 W/mK (sample 20 - without resin) and as 0.152 W/mK (sample 32- with resin) in the 80% expanded clay sample with a grain size of 2-4 mm.

Thermal conductivity decreased further and insulation characteristics of the material improved as a result of increase in total porosity due to formation of artificial pores in resin added samples. Fig 6 shows the thermal conductivity-porosity variation together.

In comparison with similar studies (Table 5), the thermal conductivity of EC (20, 40 %) and pine resin-doped samples with 2-4 mm grain diameters had the same values as Ref [6,22], while they were smaller than Ref [17, 21].



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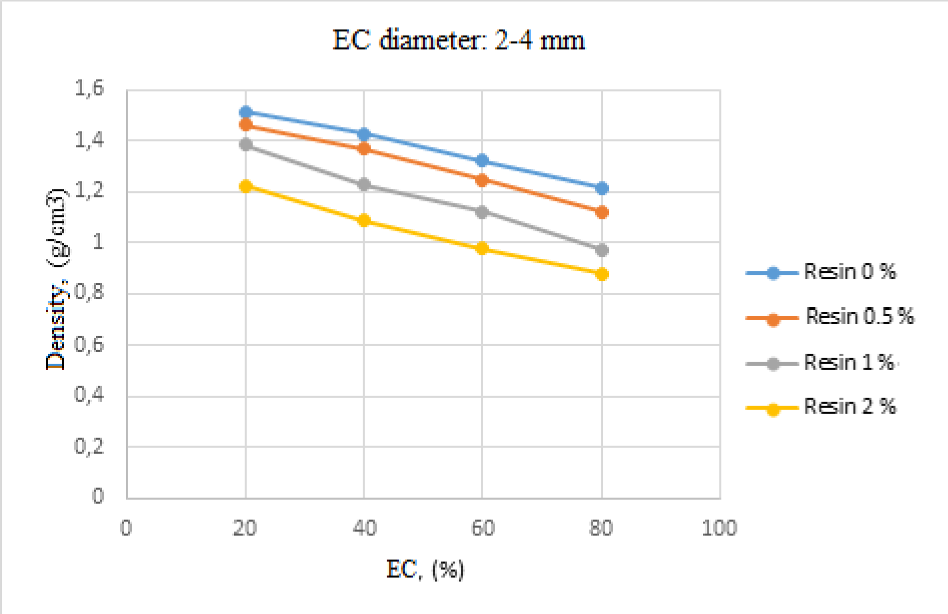
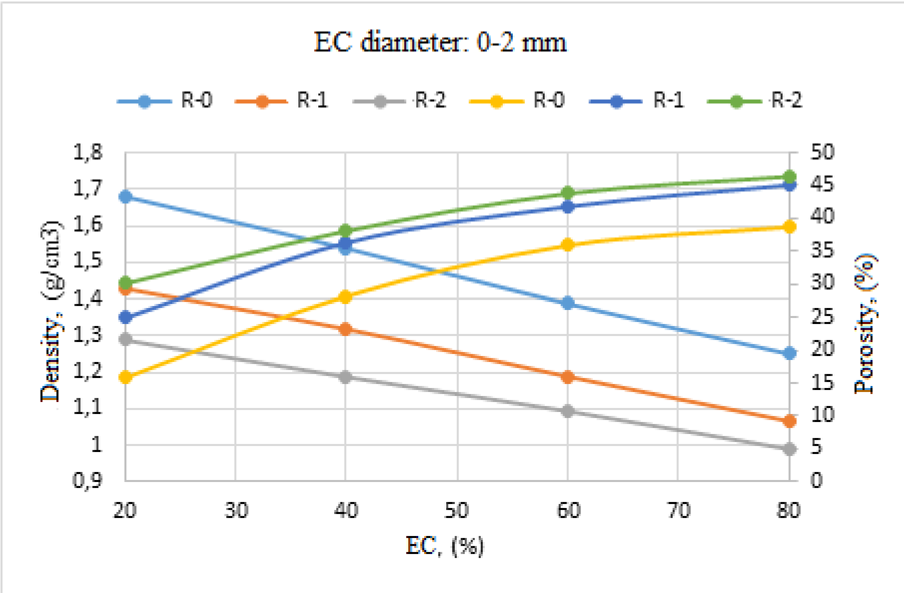


(b)

Fig 3. Density of samples versus EC and resin



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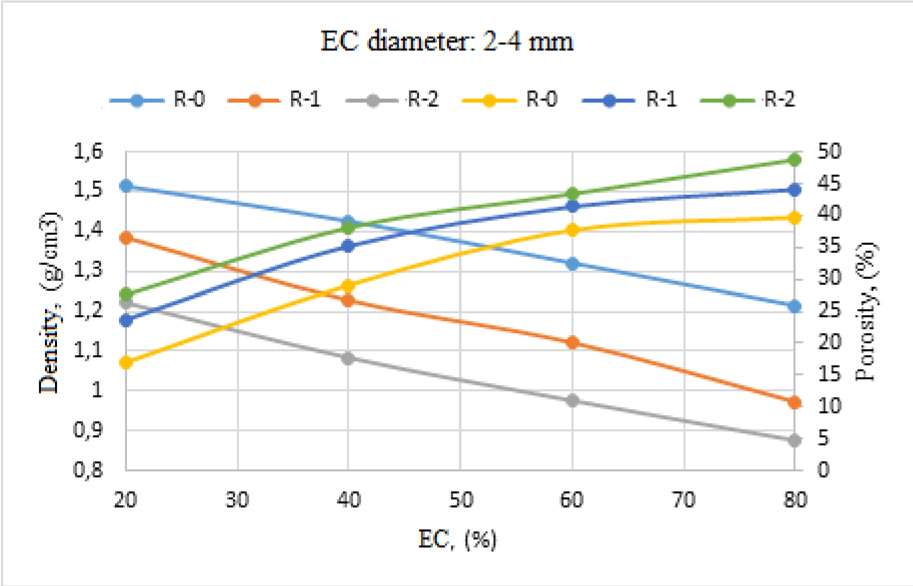

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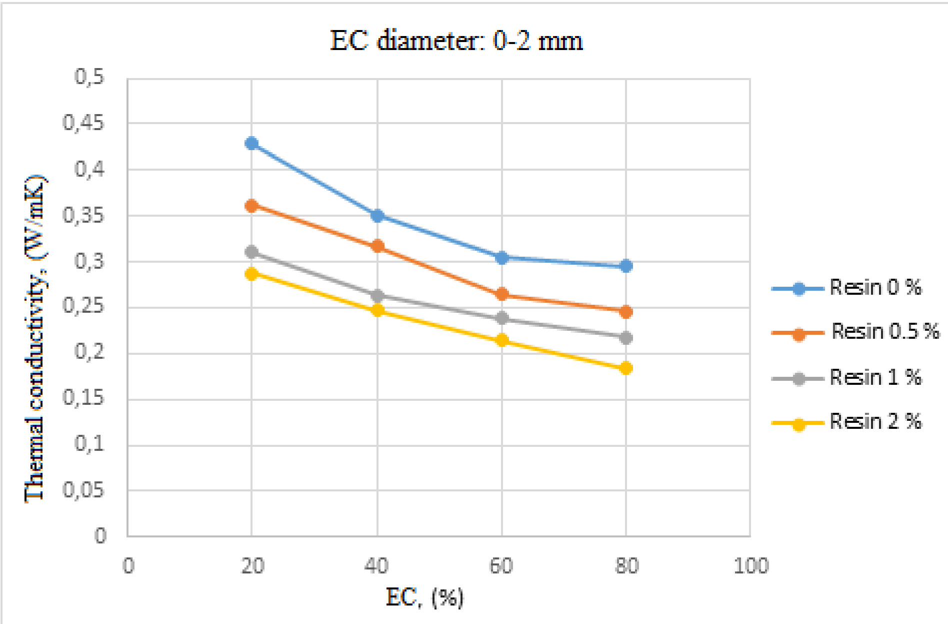
Fig 4. Porosity and density variations with respect to expanded clay ratios



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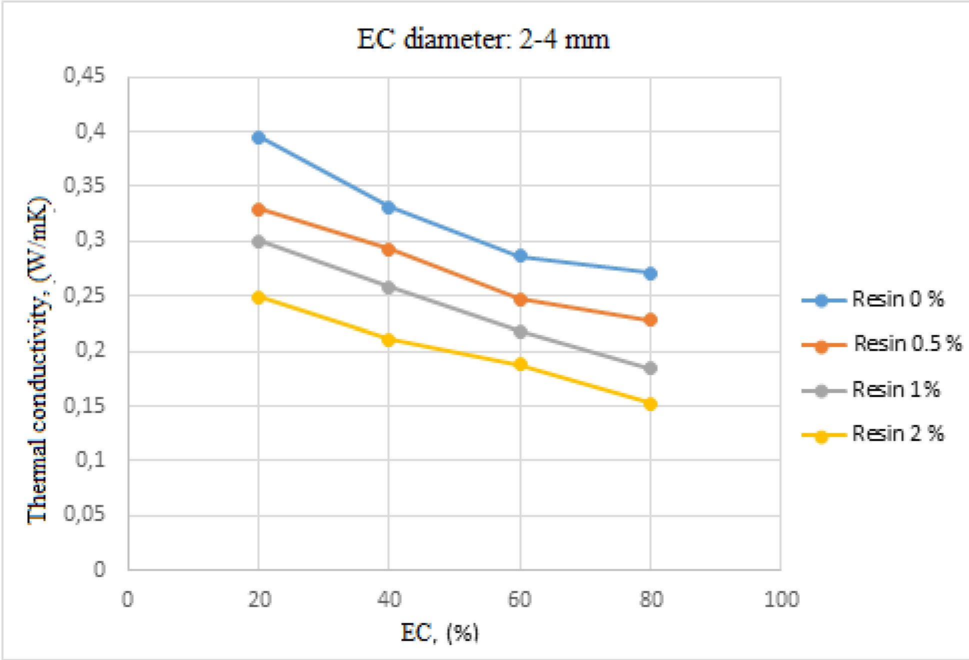

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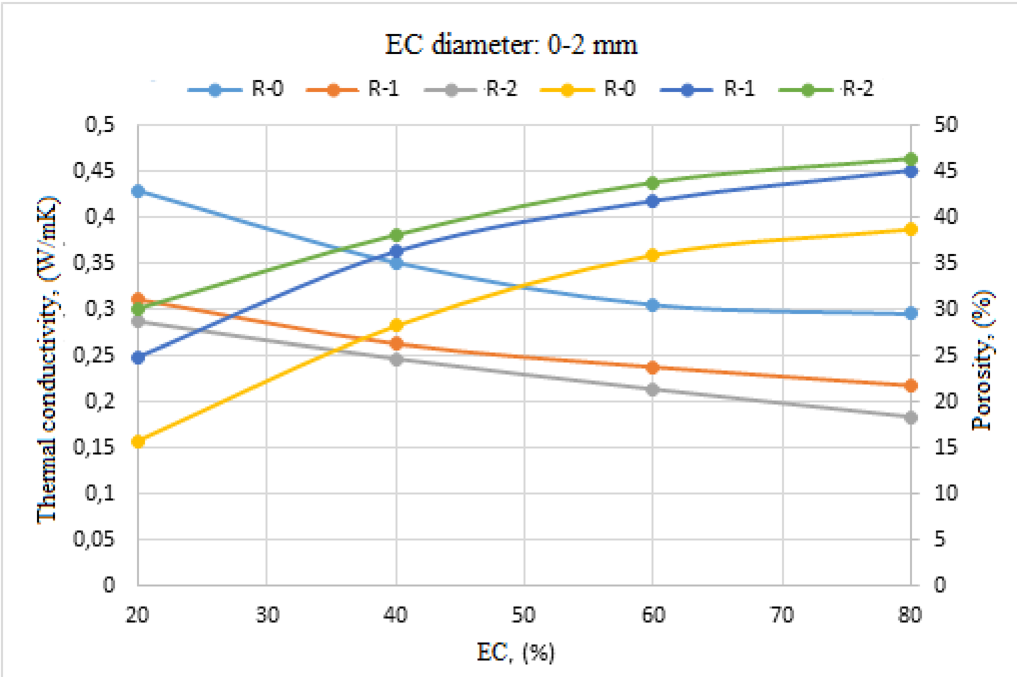
Fig 5. Thermal conductivity variations with respect to EC ratios



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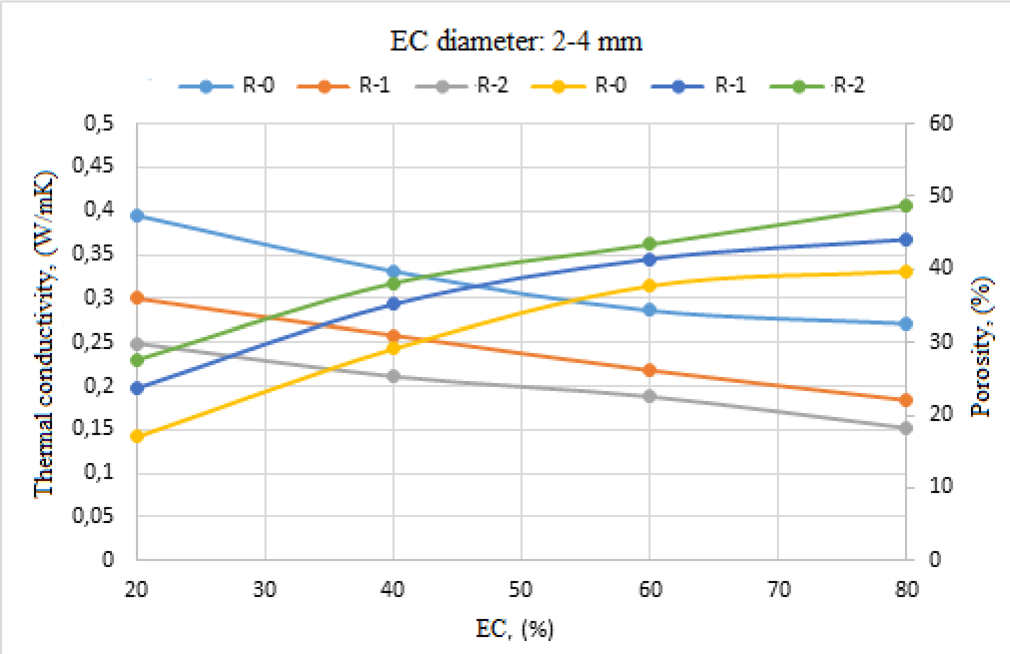


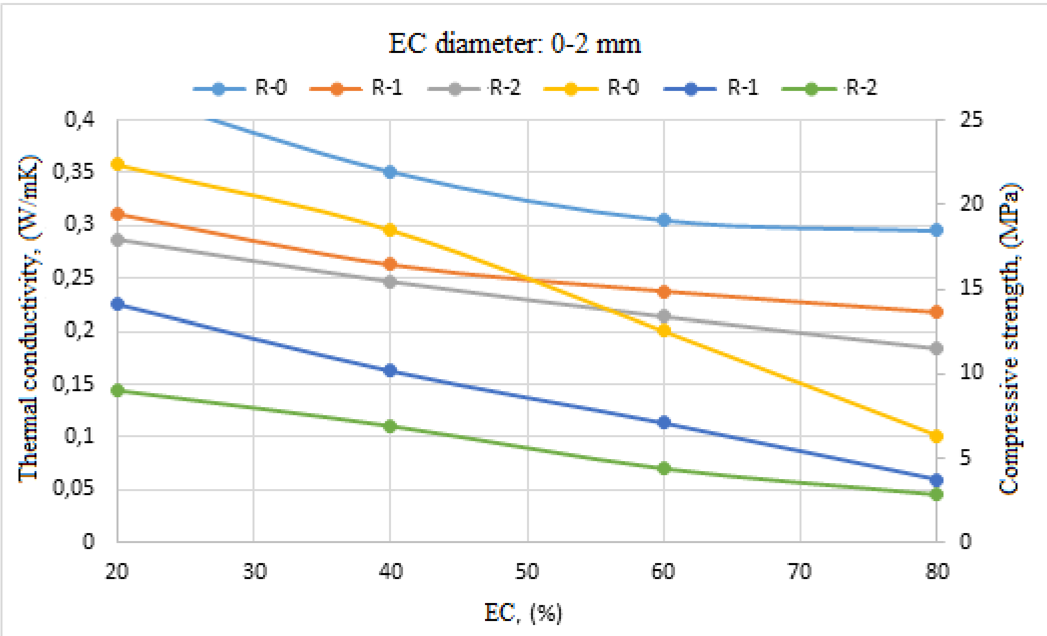
b)

Fig 6. Variation of the thermal conductivity and porosity with respect to EC ratio for the cases of.

Compressive strength and thermal conductivity are the two most essential parameters for concrete and plaster samples. Fig. 7 shows the variation of compressive strength and thermal conductivity according to the ratio of EC and resin. It shows that the lower the thermal conductivity values, the lower the compressive strength.

The samples have smaller compressive strength as the EC ratio increases from 20% to 80%. In resin-free samples, 0-2 mm and 2-4 mm samples have the highest compressive strength of 22.35 MPa (sample 1) and 20.12 MPa (sample 17) respectively.

Comparing the compressive strength values reported by similar studies, we see that Ref [19,20] has approximately the same values, while the other studies have smaller values.



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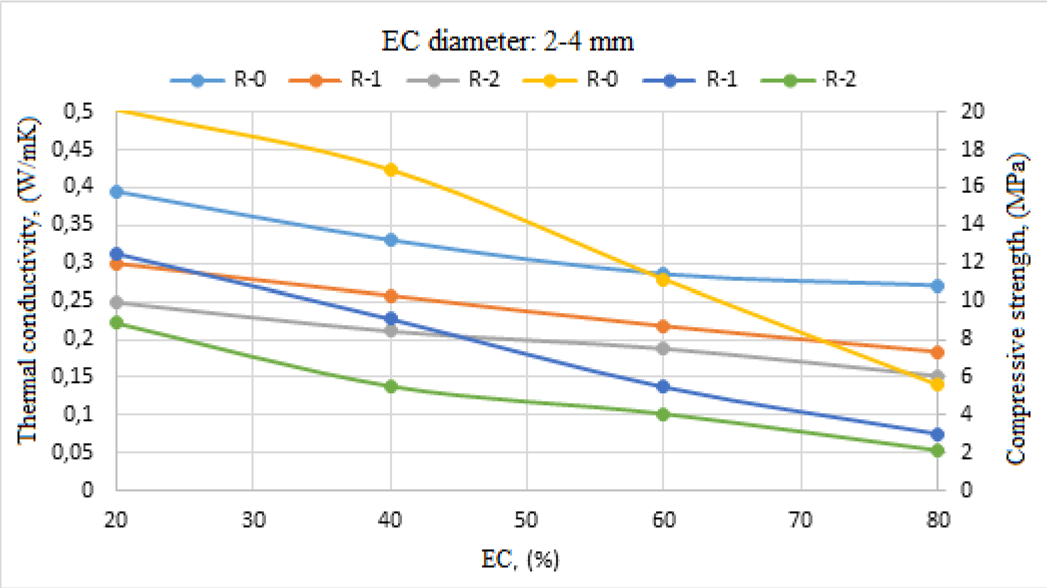
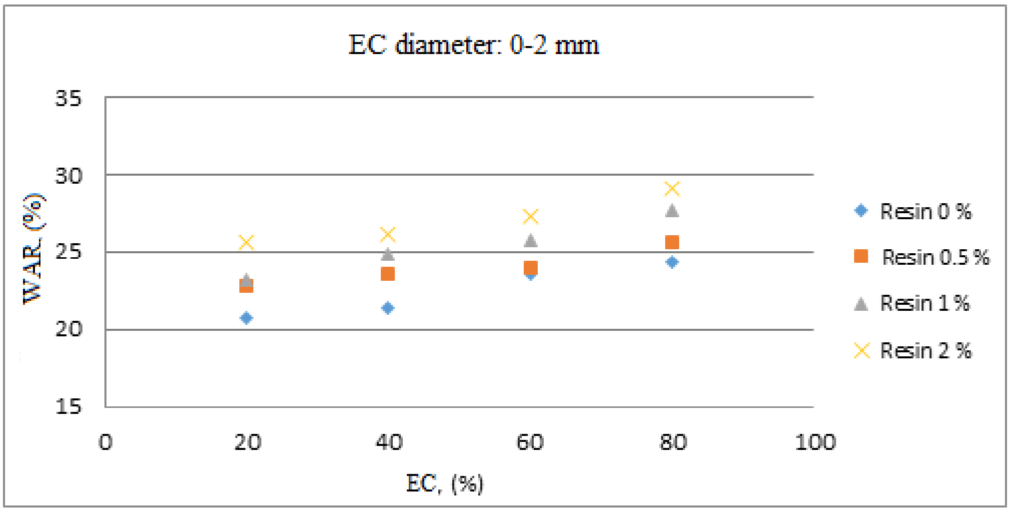


(b)

Fig 7. Variation of the thermal conductivity and compressive strength with respect to EC ratio for the cases of particle diameter.

Fig. 8a and 8b show the water absorption values of various EC and resin. The water absorption values increased as the EC aggregate ratio increased. The increase in water absorption ratio in the specimens was lower than the critical value of 30%. Thus, it is possible to use such type of concretes in humid environments.



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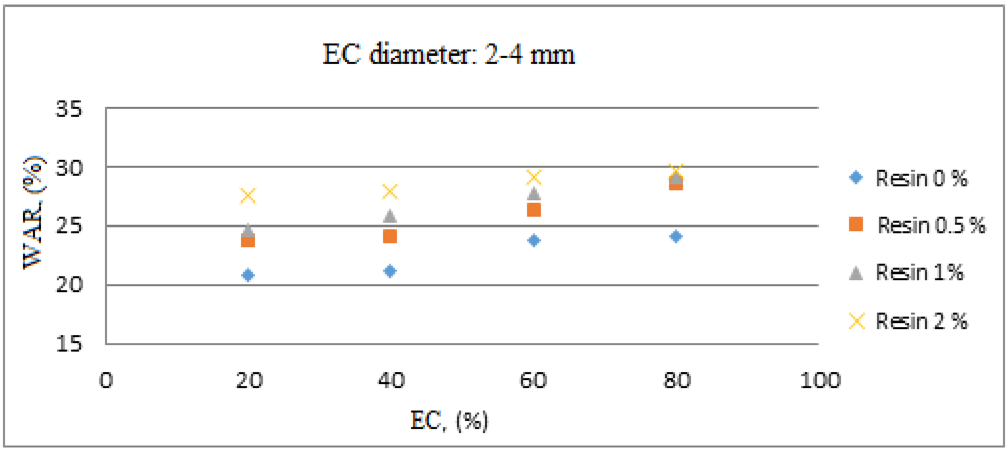

b)

Fig 8. Water absorption ratio of samples versus expanded clay ratios

Table 5. Similar studies

Agregate	Grain diameter (mm)	Ratio	Resin 1 (%)	Thermal conductivity (W/mK)	Compressive strength (MPa)	Reference
Fly ash (20%) & EC (20, 40%)	4-6 (EC)	20 40	Pine tree resin	0.311 0.245	19.73 16.6	6
Pumice	≤20	20 40 60 80	Pine tree resin	0.371 0.318 0.265 0.231	19.80 12.05 8.10 4.58	17
Expanded polystyrene	3-6	20 40 60 80	tragacanth	0.320 0.190 0.112 0.050	10.82 5.07 1.61 0.89	19
Expanded polystyrene	3-6	20 40 60 80	Apricot	0.322 0.205 0.135 0.060	13.05 6.43 4.3 1.50	20
Fly ash	$75x10^{-6}$	20 40	tragacanth	0.315 0.263	20.1 15.4	21
EC	4-6	20 40	Chery	0.304 0.230	19.46 15.61	22

FA: Fly ash, EC: Expanded clay,

5. Conclusion

The following results emerged in this study, which used EC and resin as aggregates in concrete or gypsum plasters in medical or biomedical warehouse structures.

- ✓ In the resin added samples, the density decreased and total porosity increased in the resin added samples due to the artificial micro pores generated by resin. Therefore, thermal conductivity of the samples dropped and there was improvement in insulation characteristics of the material.
- ✓ The lowest thermal conductivity coefficient of the samples with 80% expanded clay and 2% resin samples (grain diameter 2-4 mm) was measured as 0.271 W/m K in samples and 0.152 W/m K in samples without resin.
- ✓ Considering compressive strengths of the specimens, compressive strengths of the specimens with diameter of 0-2 mm, and 2-4 mm respectively were 6.36-22.35 MPa, 5.61-20.12 MPa.
- ✓ In all samples with and without resin, water absorption ratios were lower than the critical value of 30%. Hence, such type of structure materials may be used as interspace packing material in places having direct contact with water, as concrete and plaster material.
- ✓ Composite materials of EC-cement-pine 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 concrete and plaster mixed with pumice and resin and furthermore, insulation property of the material will be improved to achieve energy saving.

As a result, expanded clay and pine tree resin added building material can be recommended as a potential insulation material for the insulation of medical or biomedical warehouse structures.

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