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THE EFFECT OF PINE TREE RESIN ON THE THERMAL AND MECHANICAL PROPERTIES OF PLASTER WITH EXPANDED CLAY

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Abstract

This study focused on a new type of insulation plaster consisting of pine tree resin, expanded clay (EC), and gypsum. Gypsum plaster mortars were prepared with ECs with grain diameters of 0-2 mm and 2-4 mm and gypsum binder at 20%, 40%, 60%, and 80% by volume. The resin was added to each mortar at 0.5%, 1%, and 2% of the mix weight to create artificial pores. Samples with 32 different combinations were obtained. The samples were subjected to tests (such as thermal conductivity, compressive strength, ultrasonic sound velocity, and water absorption). The results showed that the higher the pine tree resin volume, the lower the density and thermal conductivity and the higher the compressive strength and porosity. The samples had high water absorption rates. The results indicate that these plasters can be used as interior plasters for insulation purposes and can be painted with any kind of paint.
Key words: Expanded clay, pine tree resin, gypsum, insulation plaster, building material

1. Introduction

Materials resistant to heat conduction are in high demand due to high energy costs. We can use porous lightweight aggregates to produce low-density plasters. Lightweight aggregates are generally divided into two groups: natural and artificial. Natural aggregates are pumice, diatomite, volcanic slag, etc. Artificial aggregates are perlite, schist, expanded clay (EC), vermiculate, expanded polystyrene, etc (Demirdag & Gunduz, 2008).

The raw material of EC is clay, which is abundant in nature. Clay minerals are aqueous silicates composed of silica, alumina, and water. Clay minerals contain small amounts of alkali and earth alkalis. Mixing clay with water results in plasticity. They remain consistently firm when cooked. Clay contains a lot of limestone, silica, mica, and iron oxide. They are yellow, red, or brown due to the flammable substances in their composition (Devecioglu & Bicer, 2016). When treated with heat, clays expand as gas-filled pores are formed due to the release of gases. They expand 1.5 to 6 times by volume, hence the name "expanded clay." Expanded clays are unique aggregates used in different areas, especially lightweight concrete production.

There is a large body of research on EC. Some researchers have focused on the use of ECs in concrete. For example, Subasi (2009) 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. She concluded that we could produce lightweight concrete with a compressive strength of 41.27 MPa and thus reduce the building load. Othman et al., (2020) used EC and expanded perlite aggregate to produce lightweight concrete and examined their density, quality and strength. Nahhab & Ketab, (2020) investigated the properties of the lightweight concrete produced by mixing maximum-size EC with micro steel fibers. Fakhfakh et al., (2007) produced a lightweight aggregate using EC and marlstone. They then added various proportions of quartz sand and lubricating oil to the aggregate and heated it at 1180 °C. They measured those samples' mechanical strength, density, water absorption, and expansion rates. Rossignolo et al., (2003) prepared EC, sand, cement, and silica mixed specimens of various grain diameters. They analyzed the samples' density, elasticity, compressive strength, and deformation properties. Vasina et al., (2006) investigated the acoustic performance of specimens produced by mixing various diameters of EC, cement, ash, and plasticizer additives. Bicer (2021a) investigated the effect of fly ash and pine tree resin on the thermal and mechanical properties of EC aggregate concretes. Many researchers have conducted research on EC aggregate concretes (Bouvard et al., 2007; Chen & Liu, 2004; Miled et al., 2007; Xue et al., 2004; Gnip et al., 2012; Bajdur et al.,2002; Choi & Ohama, 2004).

Other researchers have investigated the utilization of natural resin in concrete. They used porous aggregates to produce lightweight concretes or mixed resins (tragacanth, apricot resin, etc.) and cement to create artificial pores.

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Devecioglu and Bicer, (2016) added 0.5%, 1%, and 1.5% tragacanth resin to cement to produce concretes with EC. They investigated their thermal and mechanical properties. Bicer & Celik (2020) used pumice, pine resin and produced concretes with a thermal conductivity of 0.230 W/mK. Kaya and Kar (2016), produced concretes with EPS aggregates, while Bicer (2019), investigated fly ash concretes' thermal and mechanical properties. Bartolini et al. (2010), mixed EC and epoxy resin to produce agglomerates. They investigated both their mechanical and sound insulation properties. As a result, they produced an easy-to-prepare material with low density, good sound absorption, and superior mechanical properties.

Some other researchers have conducted studies on gypsum plasters. For example, Gencel et al. (2014) numerically and experimentally investigated the properties of vermiculd, propylene, and gypsum mixed specimens. Bicer (2020) used 90% fly ash and gypsum and produced a plaster with a heat transfer coefficient of 0.248 W/mK. Bicer (2021b) investigated pumice-aggregated gypsum plasters' thermal and mechanical properties.

This study aimed to produce a lightweight insulating plaster by mixing EC, pine tree resin, and gypsum in different proportions. Unlike earlier studies, we added EC and pine tree resin to gypsum plasters to increase their insulation and binding properties. We investigated the thermomechanical properties of the plasters, determined the effect of pine tree resin, and compared them with similar materials.

2. Materials and Methods

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 (Figure 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. We then crushed, filtered, and added it to the plaster as a solution at 0.5%, 1%, and 2% (Figure 2).

a) b) c)

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

Gypsum: Satin gypsum was used as a binder and decoration material while preparing the samples. Table 1 shows the chemical composition of the EC and gypsum.

Table 1. Chemical composition (%) (Devecioglu & Bicer 2016**;** Bicer, 2021b)

Chemical characteristics	Expanded clay	Gypsum
SiO_2	54.83	0.9
Al_2O_3	17.71	0.8
Fe_2O_3	7.14	-
CaO	3.46	94.7
MgO	4.10	3.9
Na_2O	0.74	-
K_2O	3.58	-
TiO_2	0.55	-
Loss on ignition	7.94	-
Not available	-	-
Total	100.05	100.3

2.2. 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 (Vysniauskas & Zikas, 1988; Denko, 1990**)**.

Compressive strength: Mechanical strength tests were undertaken according to the TSE 699, (2009) standard and ASTM C 109-80 standards (1983). Tables 4 and 5 show the results.

Porosity: The density method was used to determine porosity. Porosities were calculated using the values in Table 2 and Eq (1) (Bicer & Celik, 2020).

$$\Phi = 1 - \frac{\rho_{EC} \cdot Z + \rho_{gypsum} \cdot (1-Z)}{\rho_{EC\,matrix} \cdot Z + \rho_{gypsum\,matrix} \cdot (1-Z)} \tag{1}$$

where; ρ_{EC} is the density of the porous material while $\rho_{EC\ matrix}$ is the density of solid material (the density of the sample after milling, causing no porosity). ρ_{gypsum} is the density of the resin mixture of gypsum, and $\rho_{gypsut\ matrix}$ is the density of the resin mixture of gypsum with a 0 % porosity ratio. Z is the EC ratio (%) and (1-Z) is the gypsum ratio (%).

Table 2. Density values of expanded clay aggregate and gypsum

Component	ρ_{gypsum}	$\rho_{gypsum\ matrixs}$	$\rho_{ECmatrixs}$	ρ_{EC}	
				0-2 mm	2-4 mm
Density (g/cm^3)	2.27	2.56	2.45	0.74	0.55

Water absorption ratio: The purpose of a water absorption test is to investigate maximum water absorption. Water absorption is essential to determine whether a material is suitable for freezing. The critical moisture content is 30 percent of the total dry volume. Below that percentage, the material will not deform during freezing (BS 812-109 Standards, 1990). We measured the dry and wet weights of the samples to calculate their water absorption rates. We then used Eq. 2 to calculate the water absorption rate (WAR). Tables 3 and 4 show the results.

$$WAR=\{[WS_d-WS_k]/WS_k\}.100 \tag{2}$$

Ultrasonic pulse velocity: The experiments were carried out using a Controls brand 58-E0048 model device. Measurements were made in two different directions from the surfaces of the cube-shaped samples in contact with the mold. The arithmetic means of the measurements were calculated. The device displayed the ultrasonic transit time in microseconds. The values were divided by the cube sample size to determine the ultrasound transmission rate.

The proportions of EC in all mixtures were 20, 40, 60, and 80% of the amount of gypsum. The resin was added to the water at 0%, 1%, and 2% of the extracted gypsum 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) (Fig. 3). The samples were left to dry for 28 days. Tables 3 and 4 show the results.

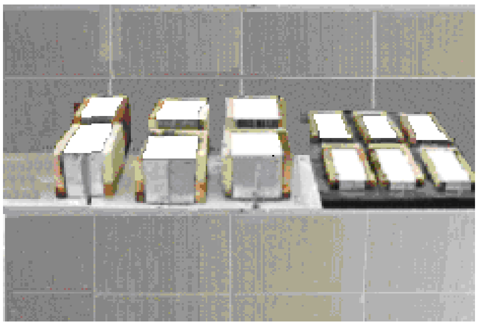


Fig. 3. Rectangular and cubic blocks samples

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 (%)**	**Ultrasonic pulse velocity (m/s)**
Cherry tree resin 0 %							
1	20	1.315	15.5	0.325	3.18	40.32	2830
2	40	1.25	29.8	0.274	1.68	35.86	2557
3	60	1.181	37.2	0.227	0.65	31.44	2364
4	80	1.112	41.5	0.198	0.47	26.68	2073
Cherry tree resin 0.5 %							
5	20	1.235	20.4	0.317	3.42	42.46	1941
6	40	1.176	34.2	0.252	1.98	38.23	1787
7	60	1.118	40.5	0.202	0.83	33.56	1624
8	80	1.065	43.8	0.184	0.58	27.19	1563
Cherry tree resin 1 %							
9	20	1.175	25.56	0.28	4.09	44.81	1686
10	40	1.119	36.33	0.233	2.35	40.33	1539
11	60	1.068	42.35	0.194	1.16	35.54	1463
12	80	1.026	46.9	0.178	0.82	28.06	1393
Cherry tree resin 2 %							
13	20	1.136	30.6	0.28	3.75	46.70	1438
14	40	1.055	39.1	0.233	2.15	45.49	1371
15	60	1.016	44.4	0.194	0.98	36.89	1329
16	80	0.981	46.7	0.170	0.71	30.14	1270

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 (%)	Ultrasonic pulse velocity (m/s)
Cherry tree resin 0 %							
17	20	1.252	18.5	0.29	2.83	37.48	2703
18	40	1.18	32.8	0.243	1.46	34.55	2504
19	60	0.989	39.2	0.204	0.57	30.95	2301
20	80	0.816	43.5	0.172	0.44	25.41	2008
Cherry tree resin 0.5 %							
21	20	1.235	22.6	0.272	3.15	38.43	1913
22	40	1.166	34.4	0.230	1.75	36.50	1718
23	60	0.973	40.5	0.175	0.78	32.49	1605
24	80	0.801	45.6	0.157	0.54	26.21	1505
Cherry tree resin 1 %							
25	20	1.185	26.7	0.251	3.51	40.44	1625
26	40	1.128	36.2	0.211	2.07	39.57	1507
27	60	0.942	41.4	0.168	1.03	34.82	1413
28	80	0.793	47.1	0.146	0.73	27.63	1328
Cherry tree resin 2 %							
29	20	1.122	32.65	0.229	3.36	42.25	1400
30	40	1.074	39.11	0.185	1.95	41.09	1350
31	60	0.896	44.47	0.153	0.88	35.71	1300
32	80	0.76	49.8	0.135	0.66	29.46	1252

3. Results and Discussions

This study investigated the thermal and mechanical properties of EC and resin-added gypsum plasters with different grain diameters.

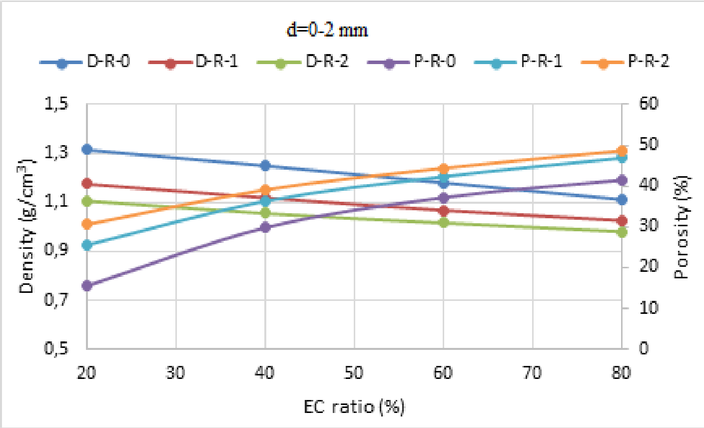
4.1. Density-Porosity

The higher the EC content, the lower the density. This is about the density of EC. The density measurements showed that EC samples with grain diameters of 0-2 mm and 2-4 mm had a density of 0.74 g/cm^3 and 0.55 g/cm^3, respectively (Table 2). As the resin content increases, density decreases, but porosity increases. Resin kept in water absorbs water and swells. During drying, it loses water, which results in artificial pores. These artificial pores and EC-induced pores increased the total porosity and decreased the density of the sample. Fig 4 shows the density and total porosity variation according to EC ratio and resin amount. Table 3, Table 4, and Fig 4 indicate the following results.

The change due to the increase in the proportion of EC from 20% to 80%:
The density of the resin-free samples with EC with a grain diameter of 0-2 mm decreased by 15.43 %, while the porosity increased by 62.65 %. The density of the resin samples with EC with a grain diameter of 2-4 mm decreased by 34.82 %, while the porosity increased by 57.47 %.

The change due to the 2% resin inclusion;
The samples with a grain diameter of 0-2 lost their density by 13.61% (20% EC) and 11.78 % (80% EC). However, their porosity increased by 49.34 % (20% EC) and 14.78 % (80% EC).
The density of resin samples with 2-4 mm grain diameters decreased by 9.26 % and 6.82 %, while their porosity increased by 43.33 % and 12.65 %.

The change due to grain diameter;
According to the EC grain diameter and ratio (20-80 %), the density decreased between 4.79 % and 26.61 %, while the porosity increased between 16.21 % and 4.59 % in the samples without resin. In the samples with resin, the density decreased by 2.11 %-22.52 %, while the porosity increased by 6.27 % - 6.22 %. Table 5 shows that the density values of the samples with EC (2-4 mm grain diameter) and resin were smaller than Ref : Demirdag & Gunduz, (2008); Biçer, (2021a); Bicer & Celik, (2020); Kaya & Kar, (2016); Bicer, (2020); Bicer, (2021b).



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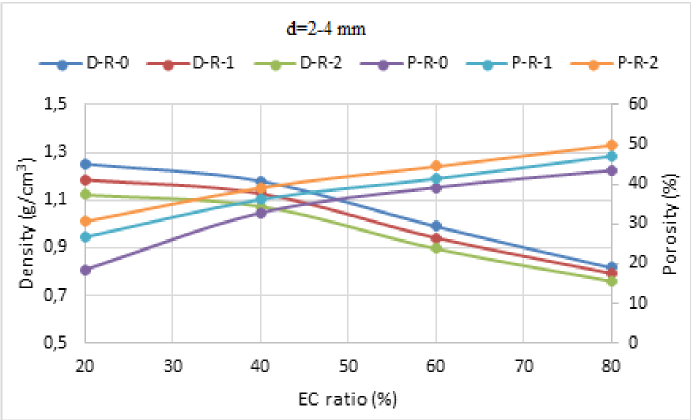


b)

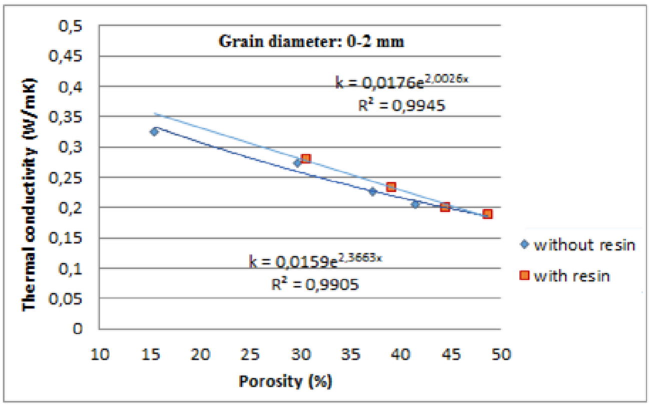
Fig. 4. Variation of the density and porosity with respect to EC ratio for the cases particle diameter a) 0-2 mm, b) 2-4 mm

4.2. Thermal conductivity

The samples with a high proportion of EC have smaller thermal conductivity than many building materials (Table 6). This has two reasons. First, EC has a porous structure. Second, the resin was added to the plaster. The samples with resin have smaller thermal conductivity than those without resin. This is due to the artificial pores provided by the resin. Fig 5 shows the thermal conductivity - porosity variation in samples with and without resin. It can be seen on the figure that due to filling on pores, thermal conductivity on some of the small pieces with 0-2 mm diameter are higher than 2-4 mm diameter pieces.

Table 6. Thermal conductivities of materials (Bicer & Celik, 2020)

	Measured Values		Literature	
Material	**Density (g/cm^3)**	**Thermal Conductiv. (W/mK)**	**Density (g/cm^3)**	**Thermal Conductiv. (W/mK)**
Outher Plaster	1.856	1.173	1.600	0.930
Inner Plaster	1.763	1.163	1.800	1.163
Gypsum thin plaster (Perlite)	0.465	0.244	0.40-0.50	0.139-0.162
Gypsum rough plast. (Perlite)	0.465	0.168	0.40-0.50	0.139-0.162
Plaster With Cement (Perlite)	0.672	0.173	0.700	0.244
Gypsum Block (Perlite)	1.047	0.372	0.900	0.221



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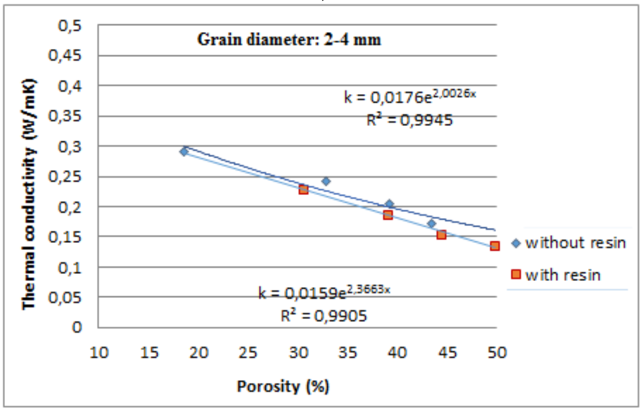
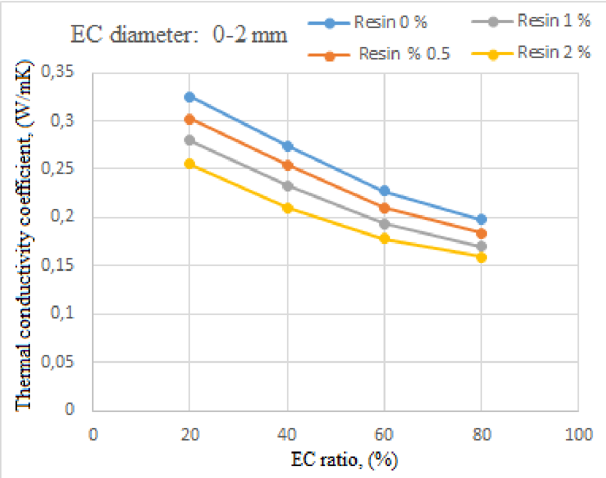


b)

Fig. 5. Thermal conductivity coefficient-porosity and resin relation in the specimens EC diameter: 0-2 mm, b) EC diameter: 2-4 mm

When the proportion of EC is increased from 20% to 80%, the thermal conductivity decreases by 39.07 % for 0-2 mm grain diameter samples without resin and 39.18 % for samples with resin. When the proportion of EC is increased from 20% to 80%, the thermal conductivity decreases by 40.68 % and 41.04 % in 2-4 mm grain diameter samples (Fig 6). The reason for the decrease in thermal conductivity in the samples with resin is the artificial pores caused by the resin and the increase in total porosity. Fig 7 shows the thermal conductivity-porosity variation together.



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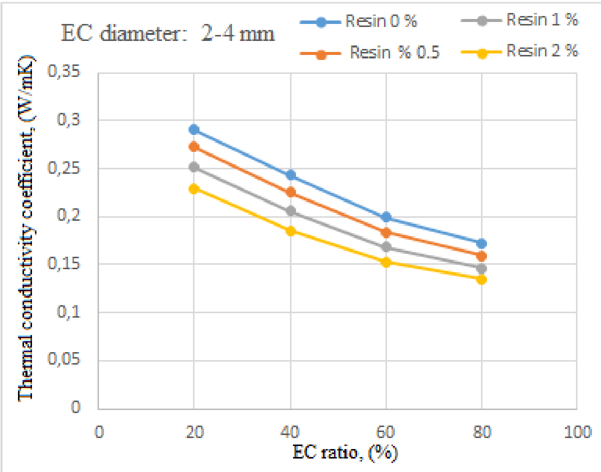
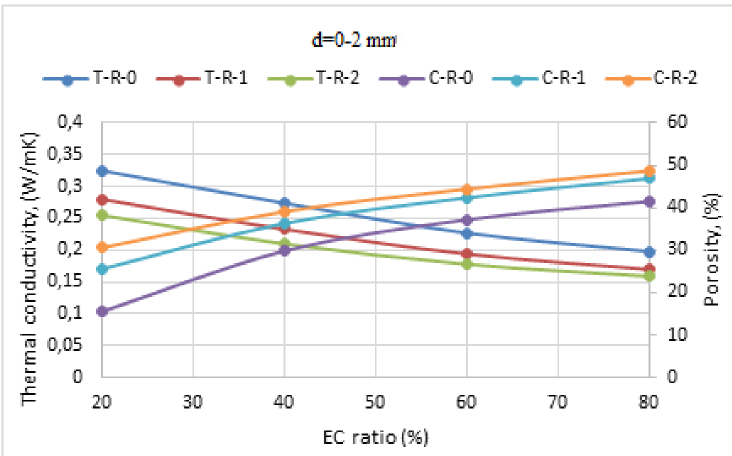


b)

Fig. 6. Thermal conductivity coefficient-EC and resin percentage relation in the specimens, a) EC diameter: 0-2 mm, b) EC diameter: 2-4 mm



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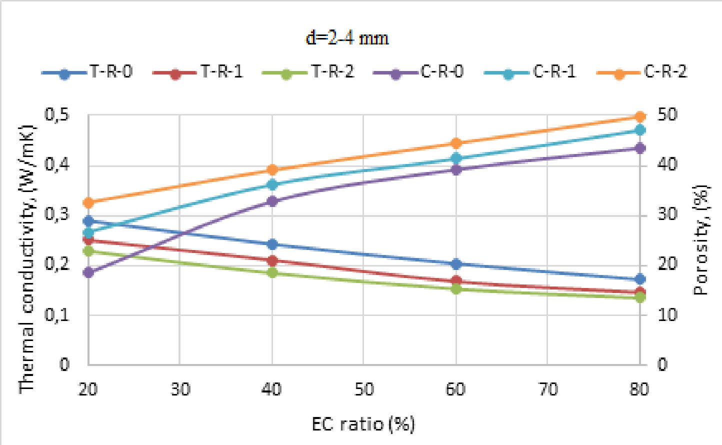


b)

Fig. 7. Variation of the thermal conductivity and porosity with respect to EC ratio for the cases of particle diameter a) 0-2 mm, b) 2-4 mm

In comparison with similar studies (Table 5), the thermal conductivity of EC- and resin-doped samples with 2-4 mm grain diameters had the same values as Ref (Demirdag & Gunduz, 2008), while they were smaller than Ref: Biçer (2021a); Bicer & Celik (2020); Bicer (2020); Bicer (2021b).

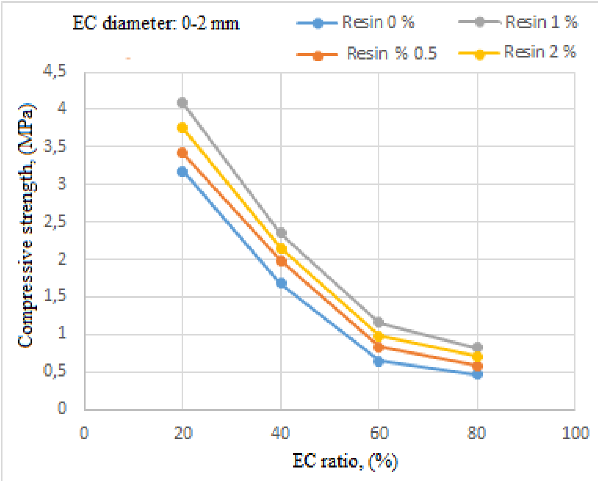
4.3. Compressive Strength

The samples have smaller compressive strength as the EC ratio increases from 20% to 80%. This is due to the weakness of the gypsum binder. In resin-free samples, 0-2 mm and 2-4 mm samples have the highest compressive strength of 3.18 MPa and 2.83 MPa, respectively. When 2 % resin is added to the samples, an increase of 15.2% - 15.77% (with 20 % EC ratio) and 3.38% -3.33% (with 80 % EC ratio) is achieved in the samples with 0-2 mm and 2-4 mm grain diameter aggregates, respectively (Fig 8 a and b). This has two reasons. First, the resin hardens as a result of drying. Second, gypsum has binding properties. Compressive strength values are negatively affected in samples with large EC grain diameters. The reason of this situation is due to decrease on binding percentage of sample with bigger diameter.

Fig 8 shows that the 1% resin-doped samples have compressive strength values than those without resin. However, this increase decreases slightly in the samples with 2% resin.

Compressive strength and thermal conductivity are the two most essential parameters for plaster samples. Fig. 9 shows the variation of compressive strength and thermal conductivity according to the ratio of EC and resin. Fig. 9 shows that the lower the thermal conductivity values, the lower the compressive strength.

Comparing the compressive strength values reported by similar studies, we see that Ref: Bicer, (2021-b) has approximately the same values, while the other studies have smaller values (because they are cement binder studies).



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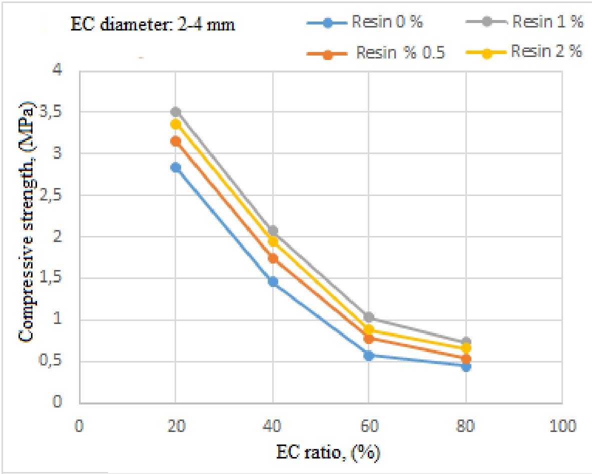
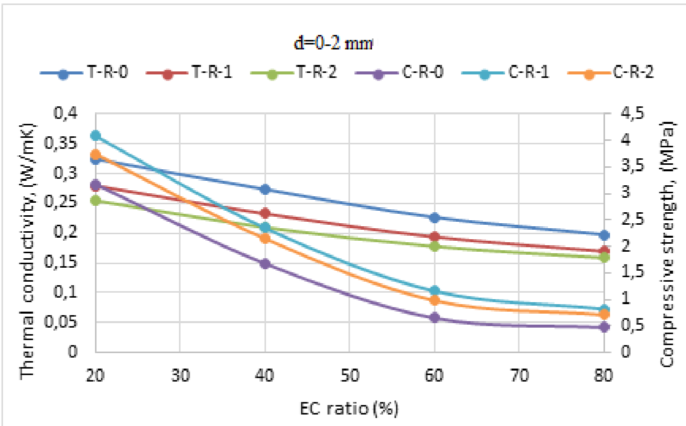


b)

Fig. 8. Compressive strength of samples versus EC percentages grain diameter: a) 0-2 mm b) 2-4 mm



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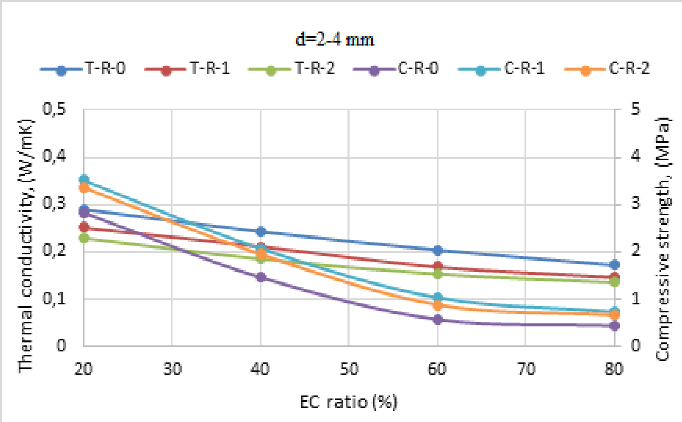


b)

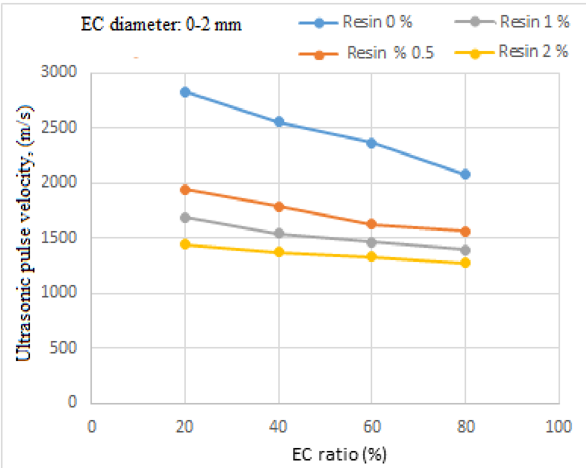
Fig. 9. Variation of the density and porosity with respect to EC ratio for the cases of particle diameter a) 0-2 mm, b) 2-4 mm

4.4. Water Absorption

Expanded clay is hydrophobic because it has a closed porous structure. Tables 3 and 4 show that the water absorption rate decreases as the EC content increases. Most samples have a water absorption rate of more than 30 percent. Therefore, resin-doped gypsum plasters should not be used directly with water due to the risk of freezing, cracking, and disintegration at temperatures below 0°C. They should be used for interior plastering for insulation purposes.

4.5. Ultrasonic Pulse Velocity

The increased EC content in the mixtures decreases the density and compressive strength. The increase in EC content in the mixtures and thermal conductivity decrease the velocity of the ultrasonic sound (Fig 10). In 0-2 mm grain diameter samples, ultrasonic sound velocities range from 2073 to 2830 m/s and 1270 to 1438 m/s in resin-free and resin-doped samples, respectively. In 2-4 mm grain diameter samples, ultrasonic sound velocities range from 2008 to 2703 m/s and 1252 to 1400 m/s in resin-free and resin-doped samples, respectively.



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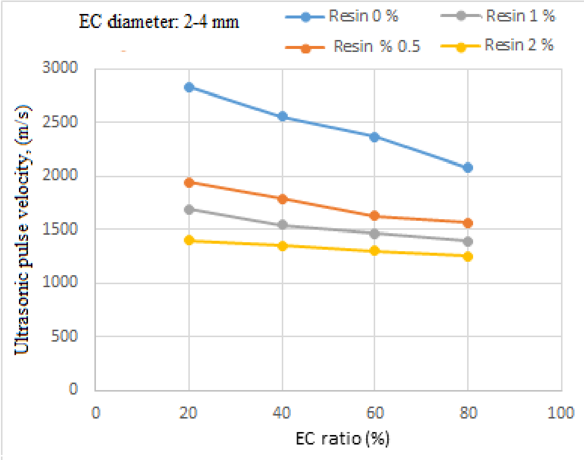

b)

Fig. 10. Ultrasonic pulse velocity of samples versus EC percentages a) EC diameter: 0-2 mm, b) EC diameter: 2-4 mm

4.6. The Usability

The tests show that the samples can be sawed and screwed. They are suitable for grooving for installation works and can be drilled. The samples were treated with various dyes to determine the dye retention of the samples. As a result, it was found that the dye retention of the samples was extremely good (Fig 11).

a) b)

Fig. 11. Samples can be different types of dyes can be applied a) Silicone rubber coating, b) Oil painting

Based on these results, resin- and EC-doped gypsum plasters can be used for thermal insulation in the interior walls of buildings.

Table 5. Similar studies

Materials	Density (g/cm^3)	Thermal conductiv. (W/mK)	Compres. streng. (MPa)	Literature
Cement + EC (5%) + tragacanth (1%)	1.179	0.221	2.68	Demirdag & Gunduz (2008)
Cement + EC (10%) + tragacanth (1%)	1.059	0.162	2.36	
Cement + EC (20%) + tragacanth (1%)	0.867	0.140	1.35	Biçer (2021a)
Cement+EC (20%)+Fly ash(30%)+Pine R.(1%)	1.430	0.328	21.43	
Cement+EC (40%)+Fly ash(30%)+Pine R.(1%)	0.846	0.127	14.21	
The pumice aggregate diameter: < 20 mm				
Pumice (20 %)+cement (80%)+pine resin (1%)	1.548	0.371	19.80	Bicer & Celik (2020)
Pumice (40 %)+cement (60%)+pine resin (1%)	1.479	0.318	13.05	
Pumice (60 %)+cement (40%)+pine resin (1%)	1.350	0.265	8.10	
Pumice (80 %)+cement (20%)+pine resin (1%)	1.241	0.230	4.58	
EPS (80%)+cement (20%)+tragacanth (1%)	0.537	0.051	0.88	Kaya & Kar (2016)
EPS (20%)+cement (80%)+tragacanth (1%)	1.233	0.322	10.95	
Gypsum (90%)+fly ash (%10)	1.254	0.335	-	Bicer (2020)
Gypsum (50%)+fly ash (%50)	1.198	0.274	-	
Gypsum (10%)+fly ash (%90)	1.121	0.248	-	

The pumice aggregate diameter 2-4 mm				
Gypsum + pumice (20%)+ pine resin (2%)	1,204	0,290	4,29	Bicer (2021b)
Gypsum + pumice (40%)+ pine resin (2%)	1,123	0,225	2,1	
Gypsum + pumice (60%)+ pine resin (2%)	0.868	0,193	1,3	
Gypsum + pumice (80%)+ pine resin (2%)	0,793	0,165	0,69	
The EC aggregate dimensions: 2-4 mm				
EC (20 %) + gypsum (80%) + pine resin (2%)	1.122	0.229	3.36	Present
EC (40 %) + gypsum (60%) + pine resin (2%)	1.074	0.185	1.95	
EC (60 %) + gypsum (40%) + pine resin (2%)	0.896	0.153	0.88	
EC (80 %) + gypsum (20%) + pine resin (2%)	0.760	0.135	0.66	

4. Conclusions

This study investigated the thermo-mechanical properties of pine tree resin- and EC-doped gypsum plasters to present them as a new insulation plaster. The following are the results.

1- Thermal conductivity, density, and compressive strength decrease while porosity increases in EC-doped gypsum plasters. In the case of resin addition, compressive strength, and porosity increase while other parameters decrease even more.

2- When 20%-80% EC is added to gypsum plaster, the resin-free samples (2-4 mm) have a thermal conductivity coefficient of 0.290 to 0.172 W/mK and compressive strength of 2.83 to 0.44 MPa. The resin-doped samples have a thermal conductivity coefficient of 0.229 to 0.135 W/mK and compressive strength of 3.36 to 0.66 MPa.

3- As the EC grain size increases, the insulation property of gypsum plaster increases while its strength weakens. With the addition of resin, the insulating properties of the plaster increase even more, while the disadvantage in strength turns into an advantage.

4- The samples have high water absorption rates. Therefore, they should be used in areas not in contact with water.

5- When we compare the EC- and resin-doped plasters with similar materials (Table 5), we see that the former is superior both in terms of insulation properties and strength. These plasters can be used as interior plaster, insulation plaster, and decoration material in buildings.

In conclusion, EC and pine tree resin-doped gypsum can be used as insulation and interior plasters.

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