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Research Article

Effect of pine resin on the thermal and mechanical properties of plaster with pumice

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ABSTRACT

This study investigated the effect of pine resin on the thermal and mechanical properties of gypsum plasters with pumice aggregate. Pumice rock was crushed and sieved into three grain sizes (2-5 mm, 5-8 mm, and 8-12 mm). Each group was mixed separately with non-resinous and resinous gypsum in the proportions of 20%, 40%, 60%, and 80%. The resin was added to the gypsum at 2% of its total weight (gypsum + pumice) to generate artificial pores and improve the binding power of the gypsum. Twenty-four samples were produced in different combinations. The test results showed that resin reduced the thermal conductivity and improved the compressive stress of the plasters. They had a water absorption of greater than 30%, suggesting that they can be used in interior plasters and painted with any paint. In conclusion, they can be used as interior plasters for both insulation and strength.

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Nomenclature

Φ : Porosity, (%)
ρ : Density, (g/cm^3)
W : Weight of sample (g)
Z : Pumice ratio, (%)
1-Z : Gypsum ratio, (%)
WAR : Water absorption ratio, (%)
P :Pumice

Subscripts

gs : Grain sizes
pumice :Pumice
pumice matrix :Pumice with 0 % porosity ratio
gypsum matrix :Gypsum with 0 % porosity ratio
d :Wet
k :Drv

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Introduction

The escalating costs of energy and building materials increase the demand for natural and cost-effective materials with high resistance to heat conduction. Natural lightweight aggregates may allow us to manufacture low-density plasters. Lightweight aggregates are generally divided into two: natural and artificial. The first group includes pumice, diatomite, volcanic slag, etc., while the second group includes perlite, schist, expanded clay (EC), vermiculite, slate, etc. [1]. Pumice is a highly porous and glassy volcanic rock. The porous structure allows it to float on water when most of it is dry. In other words, it has a specific gravity of smaller than 1. Its advantages are heat and sound insulation, fire resistance, and ease of cutting, shaping, and nailing [2].

Research on the topic can be summarized in two groups. The first group consists of studies on low-density and porous aggregate concretes. For example, Babu et al. [3] used fly ash, expanded polystyrene (EPS), and sand to manufacture concretes with a compressive strength of 12 MPa. Bicer [4] mixed fly ash aggregate and gypsum (a binder agent) at ratios of up to 90% to produce plaster with thermal conductivity of 0.248 W/mK. Devecioglu and Bicer [5] added 80% EC and 1% tragacanth resin to produce concretes with thermal conductivity of 0.140 W/mK. Many other researchers have conducted similar studies on EC aggregate concretes [6-13]. Kaya and Kar [14] added 80% EPS aggregate and 1% tragacanth to produce concrete with thermal conductivity of 0.50 W/mK. They also produced concretes with a compressive strength of 10.85 MPa out of samples with 20% EPS aggregate. Demirel [15] used EPS + pumice aggregates to produce concrete with 0.330 W/mK thermal conductivity. Nabajyoti and Brito [16], Sulkowski et al. [17], Demirboga and Kan [18], Abbes et al., [19], and Benazzouk et al. [20] have conducted similar studies

similar studies similar studies.

The second group of studies focuses on pumice aggregates. For example, Bicer and Celik [21] used pumice aggregate and pine resin to manufacture concretes with thermal conductivity of 0.231 W/mK. Akpinar et al. [22] used 80% pumice in concretes with pumice aggregate and 1% tragacanth resin to manufacture concretes with thermal conductivity of 0.186 W/mK.

This study investigated the effect of pine resin on the thermal and mechanical properties of gypsum plasters with pumice aggregate in different proportions. Pumice rock was crushed and sieved into three grain sizes (d_{gs}: 2-5 mm, d_{gs}: 5-8 mm, and d_{gs}: 8-12 mm). Each aggregate group was mixed with the binder in the proportions of 20%, 40%, 60%, and 80% (each plaster and plaster + pine resin mixture) to manufacture samples (n=24). Unlike earlier studies, this study involved the addition of resin (in the form of powder or extract) to the gypsum at 2% of its total weight (plaster + pumice) to generate artificial pores and improve the binding power of gypsum. This study made use of the property of resin hardening when it dries.

Materials and Methods

Materials

Pumice:

Pumice is a spongy-looking volcanic tuff-type material with separate macro and micropores and high heat and sound insulation (Fig. 1). It has a density of smaller than 1 kg/dm^3 and a thermal conductivity of 0.1 to 0.6 kcal/m^{2}h^{o}C.

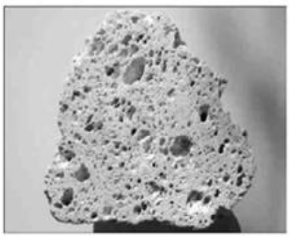


Fig.1. Porous pumice: a cross-sectional view

Gypsum:

Satin plaster was used as a binder in the plaster because it takes it longer to dry and harden. Table 1 shows the chemical composition of the pumice and gypsum.

Table 1.Chemical composition of the components

Chemical characteristics	Pumice (%)	Gypsum (%)
SiO_2	53.83	0.9
Al_2O_3	14.81	0.8
Fe_2O_3	4.61	-
CaO	4.64	94.7
MgO	2.75	3.9
Na_2O	3.64	-
K_2O	4.38	-
TiO_2	0.63	-
Loss on ignition	3.49	-
Not available	-	-

Pine tree resin:

The natural resin seeps from the bark and hardens when it interacts with oxygen, and after a while, it sticks to where it flows (Fig. 2). We ground resin into powder and then kept it in powder form or in water for 24 hours. Afterward, we mixed it with gypsum in the extract form and used it in plaster samples for two reasons. First, resin absorbs some water and expands. It then discharges that water while it dries and forms artificial micropores in the plaster structure, resulting in high insulation. Second, the dried resin hardens, resulting in improved binding properties (Fig. 2).

Fig. 2. Natural, dried, powder and extract resin

Preparation of samples

Pumice rock was crushed and sieved into grain sizes of 2-5 mm (Group A; ρ=0.94 g/cm^3), 5-8 mm (Group B; ρ=0.88 g/cm^3), and 8-12 (Group C; ρ=0.82 g/cm^3) (Fig. 3). Each group was mixed with aggregate (in 1:5, 2:5, 3:5, and 4:5 ratios) to produce samples. The ratio of gypsum (G), water (W), and diluted resin (R) was (W+R)/G=0.5. The samples were dried in 100x100x100 mm (for mechanical tests) or 20x50x140 mm molds (for thermal tests) at room temperature. They were then packaged and prepared for measurements.

Fig 3. View of different grain size pumice

Testing methods

Thermal conductivity was measured using the hot wire method in a Shotherm Quick Thermal Conductivity Meter Unit, according to DIN 51046 standards. The thermal conductivity values ranged from 0.02 to 10 W/mK, while the sensitivity ranged from -5 % to +5% (Fig. 4) [22]. All samples were measured at room temperature at three different points (22-25^{o}C). The absolute thermal conductivity was the arithmetic mean of the test values.

Fig **4.** Thermal conductivity meter unit

Mechanical strength tests were performed according to the ASTM C 109-80 standard. Compressive strength tests were performed on each sample block [23].

A water absorption test (WAR) is used to determine the amount of water absorbed under specified conditions. Water absorption is an important parameter affecting the suitability of material against freezing hazards. The critical moisture content is 30%, below which the material does not deform when freezing [14]. The experiments were performed according to the BS 812. Part 2 standard [24]. We need to calculate dry (W_d) and wet weights (W_k) to determine the water absorption rate. We used Eq. 1 (Table 3) to calculate the water absorption of the samples

$$WAR=\{[W_d-W_k]/W_k\}.100 \quad (1)$$

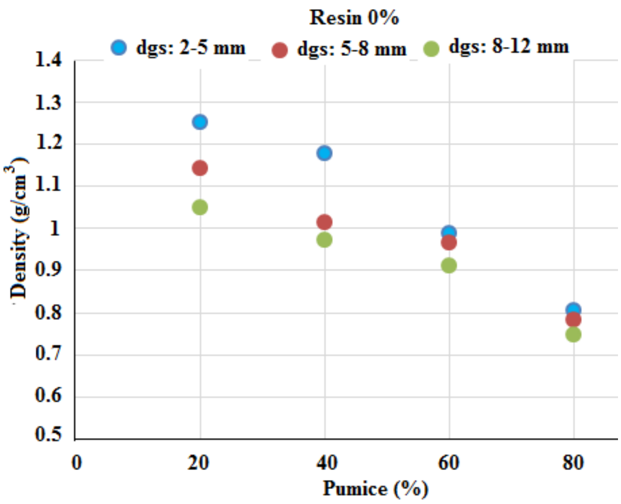
Porosity is defined by Eq (2), [17].

$$\Phi = 1 - \frac{\rho_P . Z + \rho_{gypsum} . (1-Z)}{\rho_{P\,matrix} . Z + \rho_{gypsum\,matrix} . (1-Z)} \quad (2)$$

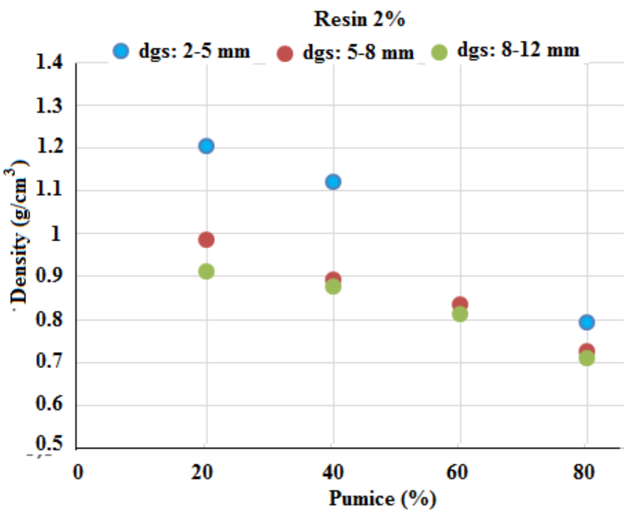
where ρ_P is the density of the pumice, $\rho_{P\,matrix}$ is the density of the pumice after milling (therefore causing no porosity), ρ_{gypsum} is the density of the mixture of gypsum + resin, $\rho_{gypsum\,matrix}$ is the density of the mixture of gypsum + resin with 0 % porosity ratio, Z is the pumice ratio (%), and (1-Z) is the gypsum ratio (%). Porosity was calculated using Table 3.

Results and Discussions

Extra artificial pores were formed in the gypsum part of the samples. Artificial pores are a result of resin absorbing water and then losing it during drying. Therefore, the resinous plaster samples with pumice had less density but more porosity than non-resinous samples. A decrease in grain diameter in the aggregate results in the disappearance of some of the pores of the pumice and an increase in density (Fig 5 and Fig. 6). While the pumice aggregate ratio increased from 20% to 80%, Groups A, B, and C had a density reduction of 35.62%, 31.44%, and 28.76%, respectively. Groups A, B, and C had a density reduction of 1.61%-3.83%, 7.51%-13.97%, 4.69-12.95%, respectively, due to the resin. Groups A, B, and C had increased porosity of 01% to 50.35%, 17.13% to 45.40%, and 11.20% to 40.47%, respectively.



a)



b)

Fig. 5. Relationship between density-pumice and resin percentage a) Resin (0%), b) Resin (2%)

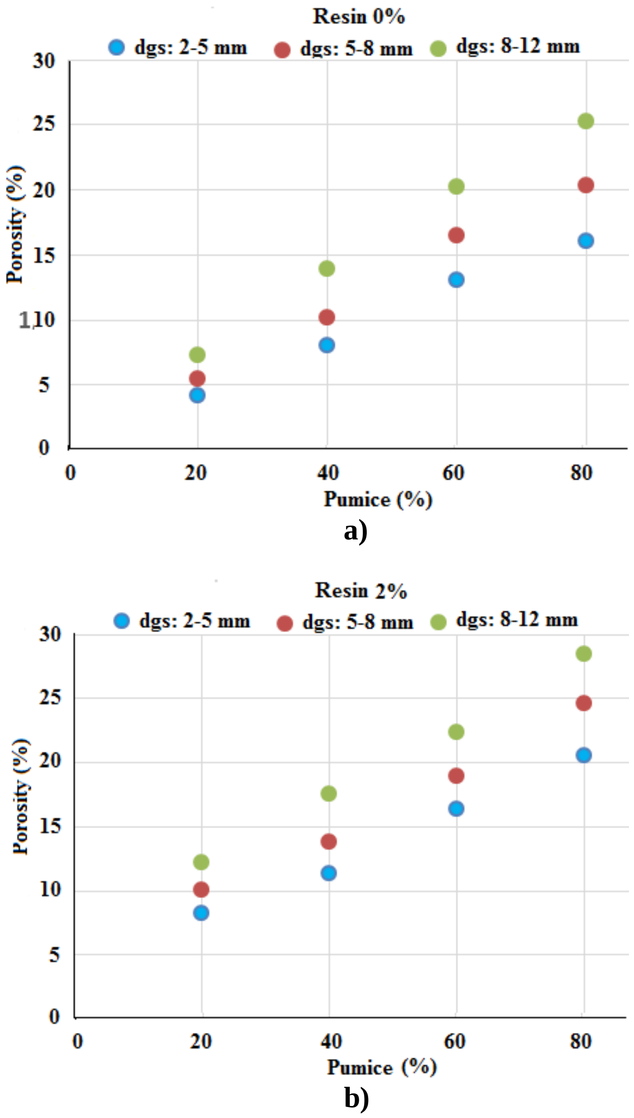


Fig. 6. Porosity ratio versus pumice percentages a) Resin (0%), b) Resin (2%)

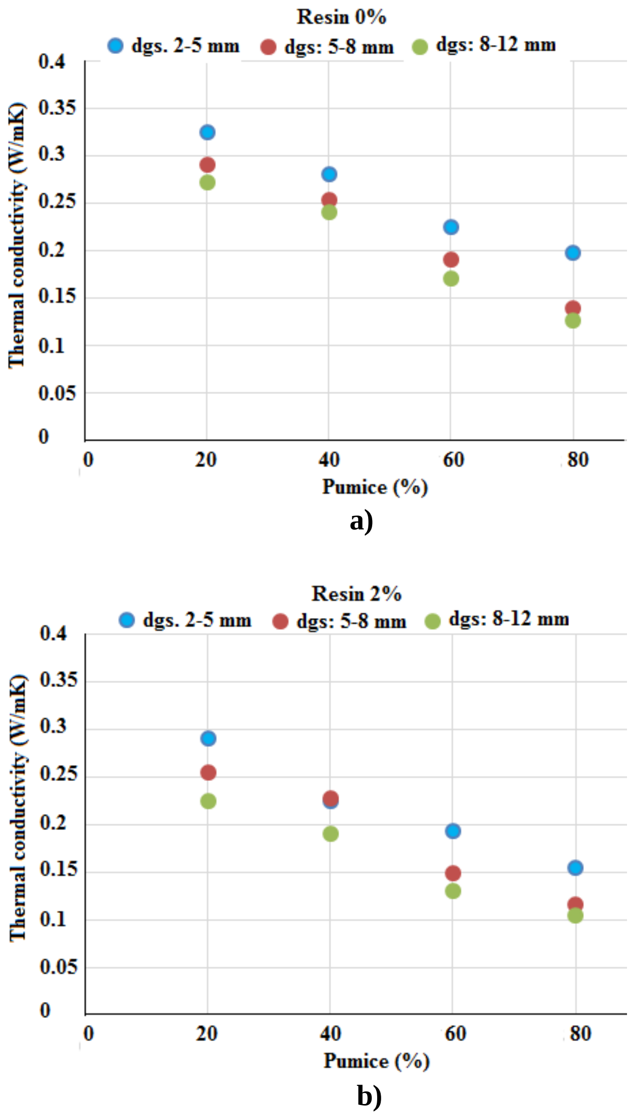


Fig. 7. The relationship between thermal Conductivity - pumice and resin percentage a) Resin (0%), b) Resin (2%)

As the aggregate ratio increased, the thermal conductivity of Groups A, B, and C decreased by 39.07%, 52.06%, and 53.30%, respectively (Fig.7). Groups A, B, and C had a reduction of 10.76%, 12.06%, and 17.27%, respectively (Fig.8). Group C had the lowest thermal conductivity because the smaller the grain size, the less the aggregate porosity due to disintegration. Groups A and B should be used in thin plasters, while group C should be used in rough plasters.

Samples with high pumice content (60% and 80%) had lower thermal conductivity than various plaster materials (Table 5), mainly due to the porous nature of the pumice and the resin added to the plaster. The samples had the same thermal conductivity values as those in Ref [5] and lower thermal conductivity values than those in Ref [2, 4, 15, 20, 21] (Table 6). The aggregate ratio and resin addition gave the plaster samples sound and thermal insulation.

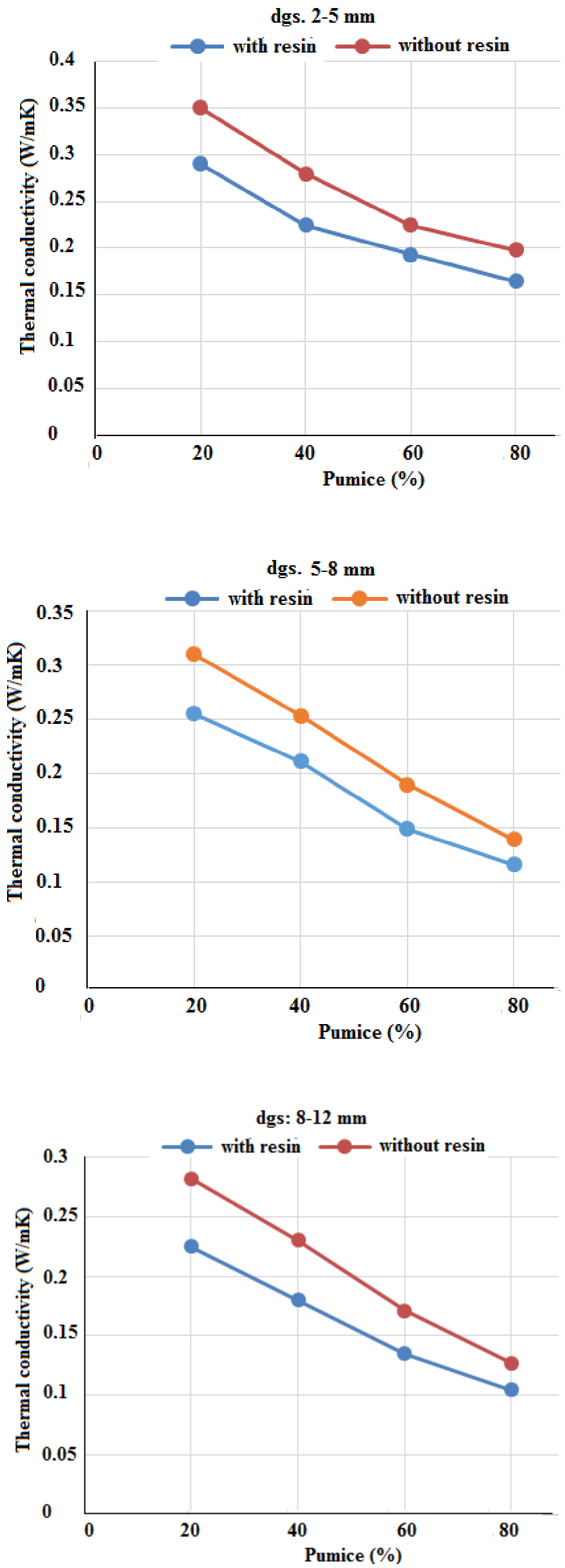
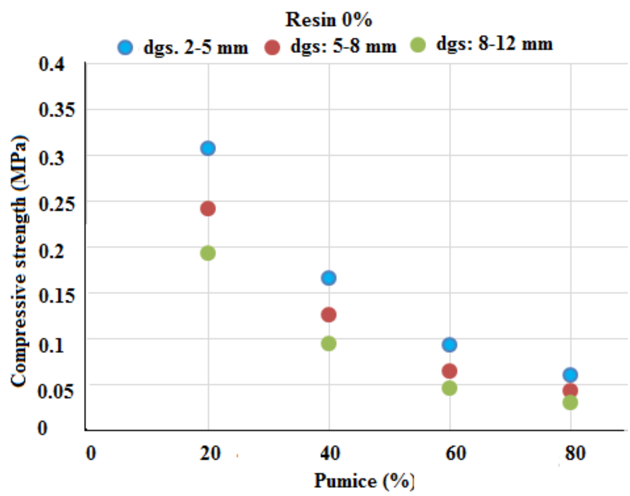
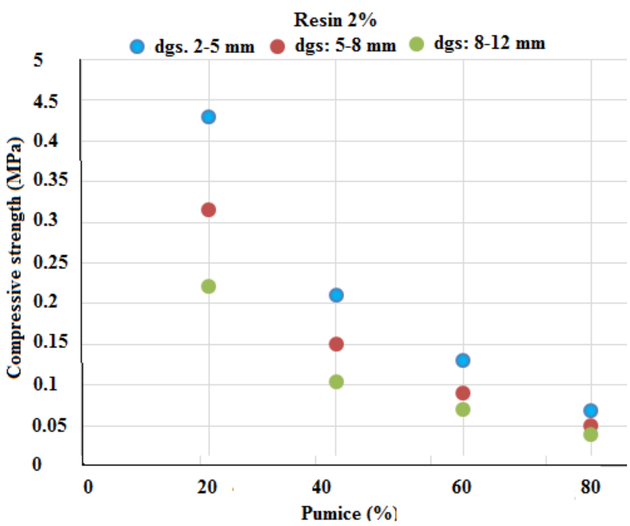


Fig. 8. The effect of aggregate size and ratio and resin on thermal conductivity

The smaller the aggregate size, the greater the compressive strength (Fig.9-a).



a)



b)

Fig. 9. Compressive strength ratio versus pumice percentages a) Resin (0%), b) Resin (2%)

The larger the aggregate size, the smaller the compressive strength. Groups A, B, and C had a reduction of 80.19%, 78.09%, and 84.02%, respectively. With the resin addition, Groups A, B, and C had an increase in strength by 13.11% - 39.28%, 30.16% - 52.83%, 14.43-29.03%, respectively (Fig. 9-b and Fig. 10), which is because the resin hardens after drying. The results suggest that resinous plasters with pumice aggregate have good enough heat and sound insulation and strength to be used as interior plasters.

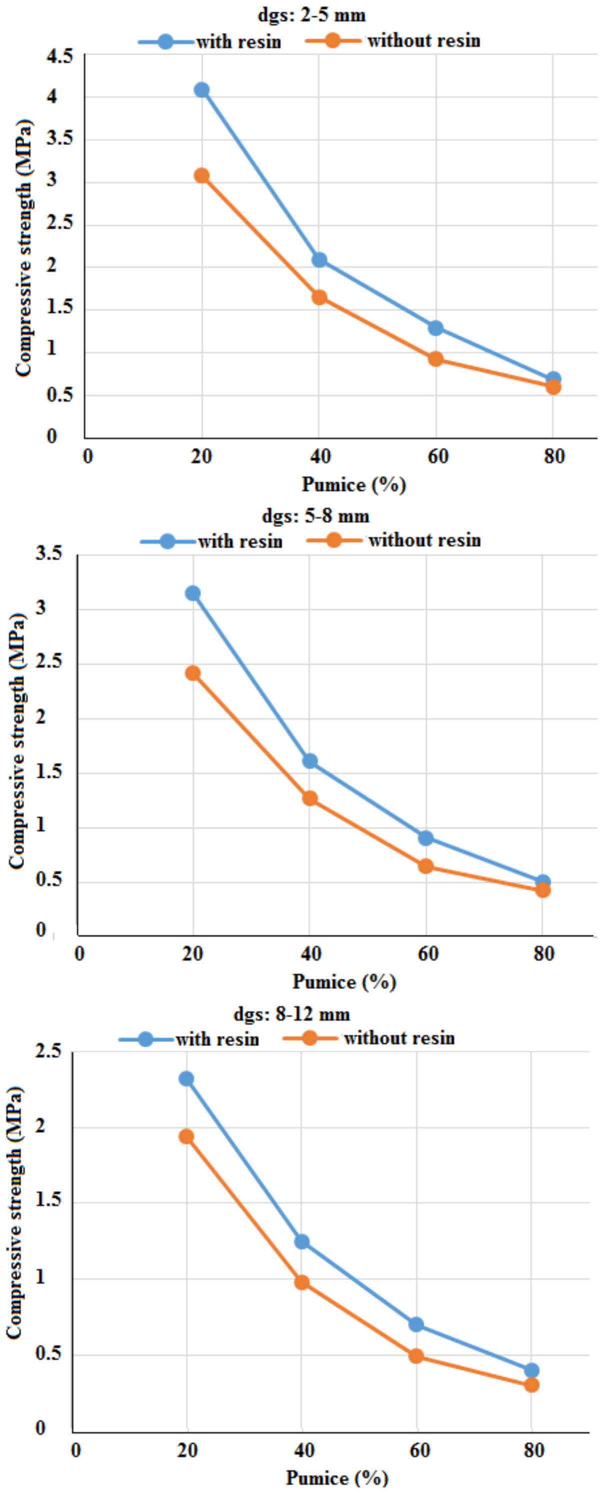
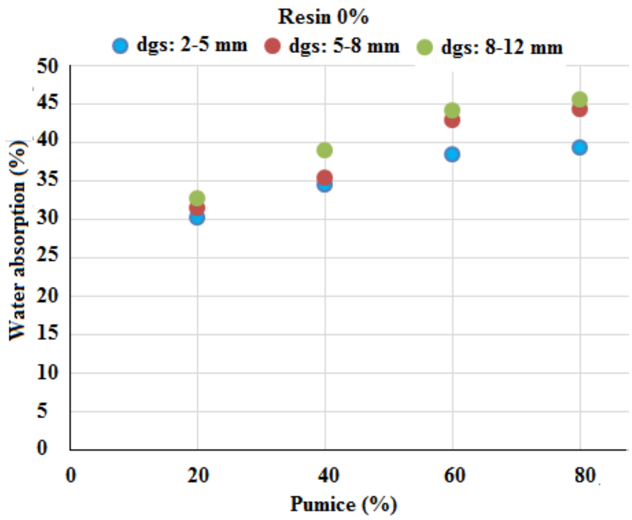
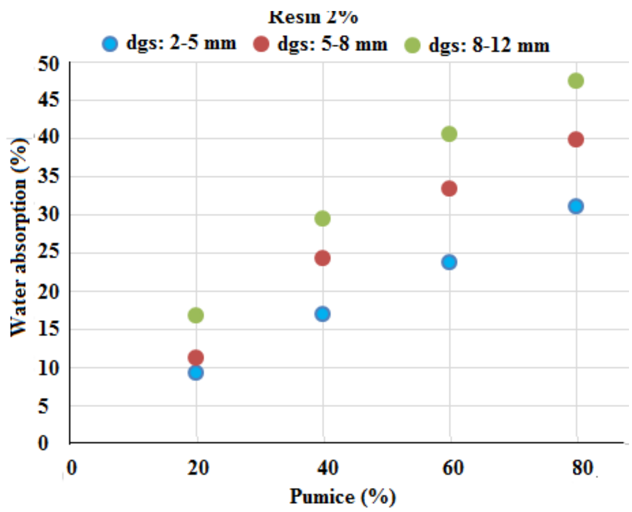


Fig. 10. Effect of aggregate size and ratio and resin on compressive strength

The samples had a greater water absorption than the critical value of 30% (Fig. 11), [17]. This shows that resinous gypsum plasters should not be used in places that come in direct contact with water because they are at risk of freezing, cracking, and splintering below 0 °C.



a)

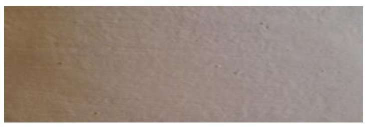


b)

Fig. 11. Water absorption ratio of samples versus pumice percentages a)Resin (0%), b) Resin (2%)

The dying tests indicated that the samples could be used as insulation or interior plasters (Fig. 12).

a)



b)

Fig. 12. Different types of dyes

a) Silicone rubber coating, b) oil painting

Table 2. Mixing ratio of samples

Samples	Weight (gram)		Total weight (gram)	Resin (gram)	Resin (liter)	(W+R)/G
	Pumice	Gypsum				
d_{gs}: 2-5, Pine resin (0 %)						
1	75.3	380	455.3	-	-	0.5
2	150.6	760	910.6	-	-	
3	220.9	1140	1360.9	-	-	
4	301.2	1520	1821.2	-	-	
d_{gs}: 5-8, Pine resin (0 %)						
5	60	380	440	-	-	0.5
6	120.6	760	880.6	-	-	
7	180.9	1140	1320.9	-	-	
8	240.2	1520	1760	-	-	
d_{gs}: 8-12, Pine resin (0 %)						
9	50	380	430	-	-	0.5
10	100	760	860	-	-	
11	150.5	1140	1290.5	-	-	
12	200.2	1520	1720.2	-	-	
d_{gs}: 2-5, Pine resin (2 %)						
13	75.3	380	455.3	9.6	0.3	0.5
14	150.6	760	910.6	19	0.6	
15	220.9	1140	1360.9	28	0.9	
16	301.2	1520	1821.2	38	1.2	
d_{gs}: 5-8, Pine resin (2 %)						
17	60	380	440	9	0.29	0.5
18	120.6	760	880.6	18	0.58	
19	180.9	1140	1320.9	27	0.87	
20	240.2	1520	1760	36	1.16	
d_{gs}: 8-12, Pine resin (2 %)						
21	45	380	425	8.5	0.28	0.5
22	101	760	860	17	0.56	
23	151.5	1140	1290.5	26	0.84	
24	202	1520	1720.2	34	1.12	

W:Water, R:Resin, G:Gypsum, Resin= Total weight (g) x Resin ratio (%)

Table 3. Pumice aggregate and gypsum density (g/cm^3)

	dgs.2-5 mm	dgs:5-8 mm	dgs:8-12 mm	matrix
Pumice	0..94	0.88	0.82	2.655
gypsum		2.25		2.485

Table 4. Thermal and mechanical properties

Code	Pumice, grain sizes (mm)	Pumice ratio (%)	Density (g/cm^3)	Porosity (%)	Thermal conductivity (W/m K)	Compre. strength (MPa)	Water absorption (%)
Pine tree resin 0 %							
1	2-5	20	1.252	4.18	0.325	3.08	30.19
2	“	40	1.180	8.09	0.280	1.66	34.46
3	“	60	0.989	13.14	0.225	0.93	38.50
4	“	80	0.806	16.07	0.198	0.61	39.43
5	5-8	20	1.145	5.53	0.290	2.42	31.58
6	“	40	1.015	10.24	0.253	1.27	35.44
7	“	60	0.968	16.51	0.190	0.65	42.86
8	“	80	0.785	20.41	0.139	0.53	44.32
9	8-12	20	1.050	7.28	0.272	1.94	32.79
10	“	40	0.975	13.97	0.240	0.95	39.06
11	“	60	0.912	20.26	0.171	0.46	44.14
12	“	80	0.748	25.36	0.127	0.31	45.61
Pine tree resin 2 %							
13	2-5	20	1.204	8.34	0.290	4.29	33.73
14	“	40	1.123	11.36	0.225	2.12	36.82
15	“	60	0.868	16.38	0.193	1.31	39.54
16	“	80	0.793	20.62	0.165	0.69	42.45
17	5-8	20	0.985	10.13	0.255	3.15	34.56
18	“	40	0.893	13.88	0.228	1.51	39.75
19	“	60	0.836	19.05	0.149	0.81	43.37
20	“	80	0.726	24.63	0.116	0.51	45.97
21	8-12	20	0.914	12.23	0.225	2.22	36.74
22	“	40	0.876	17.56	0.190	1.05	41.79
23	“	60	0.813	22.45	0.130	0.71	46.22
24	“	80	0.710	28.56	0.105	0.40	49.02

Table 5. Thermal conductivities of different materials [2]

	Measured Values			Literature		
Material	**Density (g/cm^3)**	**T_{avr} (°C)**	**Thermal Conductivity (W/mK)**	**Density (g/cm^3)**	**T_{avr} (°C)**	**Thermal Conductivity (W/mK)**
Outher Plaster	1.856	31	1.173	1.600	20	0.930
Inner Plaster	1.763	33	1.163	1.800	20	1.163
Gypsum thin plaster (Perlite)	0.465	34	0.244	0.40-0.50	20	0.139-0.162
Gypsum rough plast. (Perlite)	0.465	50.7	0.168	0.40-0.50	20	0.139-0.162
Plaster With Cement (Perlite)	0.672	51.3	0.173	0.700	20	0.244
Gypsum Block (Perlite)	1.047	40	0.372	0.900	20	0.221

Table 6. Physical properties in similar studies

Materials	Experimental values: Density (g/cm^3)	Thermal conductivity (W/mK)	Compressive Strength (MPa)	Literature
Gypsum (90%)+fly ash (%10)	1.253	0.335	-	[4]
Gypsum (50%)+fly ash (%50)	1.197	0.274	-	
Gypsum (10%)+fly ash (%90)	1.120	0.248	-	
Cement + sand + fly ash + EPS	1.150	-	3.5	[3]
Cement + sand + fly ash + EPS	1.350	-	12	
EPS (80%)+cement (20%)+tragacanth (1%)	0.536	0.050	0.89	[14]
EPS (20%)+cement (80%)+tragacanth (1%)	1.232	0.320	10.85	
Cement+expanded clay (5%)+tragacanth (1%)	1.183	0.220	2.67	[5]
Cement+expanded clay (10%)+tragacanth (1%)	1.058	0.160	2.35	
Cement+expanded clay (20%)+ tragacanth (1%)	0.867	0.140	1.35	
The pumice aggregate diameter: (8–12) mm				
Pumice (20 %)+cement (80%)+tragacanth (1%)	1.306	0.306	-	[21]
Pumice (40 %)+cement (60%)+tragacanth (1%)	1.172	0.265	-	
Pumice (60 %)+cement (40%)+tragacanth (1%)	0.978	0.226	-	
Pumice (80 %)+cement (20%)+tragacanth (1%)	0.811	0.186	-	
The pumice aggregate diameter: ≤ 20 mm				
Pumice (20 %)+cement (80%)+pine resin (1%)	1.548	0.371	19.80	[2]
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	0.231	4.58	
Cement + pumice + EPS	0.562	0.330	2.99	[15]
Cement and rubber particle (30%)	1.473	0.625	23.30	[20]
Cement and rubber particle (40%)	1.300	0.513	16.00	
Cement and rubber particle (50%)	1.150	0.470	10.50	
The pumice aggregate dimensions: 8-12 mm				
Pumice (20 %)+gypsum (80%)+pine resin (1%)	0.914	0.225	2.22	Present
Pumice (40 %)+gypsum (60%)+pine resin (1%)	0.876	0.190	1.05	
Pumice (60 %)+gypsum (40%)+pine resin (1%)	0.813	0.130	0.71	
Pumice (80 %)+gypsum (20%)+pine resin (1%)	0.710	0.105	0.40	

Conclusions

This study investigated the effect of pine resin on the thermal and mechanical properties of gypsum plasters with pumice aggregate. The following are the results

- ✓ 20%-80% pumice added 2-5 mm (Group A), 5-8 mm (Group B), and 8-12 (Group C) had a density reduction of 35.62%, 31.44%, and 28.76%, a thermal conductivity reduction of 39.07%, 52.06%, and 53.30%, and a compressive strength reduction of 80.19%, 78.09%, and 84.02%, respectively.
- ✓ The resinous plaster groups A, B, and C with pumice aggregate had a density reduction of 1.61%-3.83%, 7.51%-13.97%, and 4.69%-12.95%, respectively. They had a thermal conductivity reduction of 10.76%, 12.06%, and 17.27%, respectively. Their compressive strength increased from 13.11% to 39.28%, 30.16% to 52.83%, and 14.43% to 29.03%, respectively.
- ✓ All mixtures had a water absorption of greater than 30%, and therefore, they should be used in interior plasters but not in exterior ones.
- ✓ Pumice- and resin-added gypsum-block materials have insulation characteristics superior to those of similar materials (Table 4). Therefore, they can be used as internal or insulation plasters and decoration materials in buildings.

In conclusion, pumice aggregate and pine resin added gypsum plasters are interior plaster materials with good heat and sound insulation.

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