International Journal of Innovative Engineering Applications

Journal homepage: https://dergipark.org.tr/ijiea

THE THERMAL ANALYSIS OF PLASTER WITH WASTE EXPANDED POLYSTYRENE GYPSUM AND RESIN

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Abstract

Original scientific paper

This study investigated the physical properties of plaster or decorative materials made of waste expanded polystyrene (EPS) and pine tree resin (as a binder). Thirty-two samples were produced by adding waste EPS in 0-3mm and 0-6mm grain diameters in two groups and at 20-80% addition rates and resin at 0, 0.5, 1, and 2% of the dry mix weight. Density, thermal conductivity coefficient, and compressive reduced by 50.64%, 82.68%, and 84.91% in samples with a diameter of 0-3 mm. Density, thermal conductivity coefficient, and compressive reduced by 51.03%, 86.55%, and 84.13% in samples with a diameter of 0-6 mm. Density and thermal conductivity decreased by 13.32-10.42% and 25.37-22.41%, respectively, while compressive strength increased by 29.50-19.56% in samples with a diameter of 0-3 mm and 2% resin. Density and thermal conductivity decreased by 19.60-13.68% and 17.24-10.25%, respectively, while compressive strength increased by 16.27-8.85% in samples with a diameter of 0-6 mm and 2% resin. The results show that the samples can be used as interior plaster, insulation plaster, and decoration material due to their grooving and paint adherence properties. This plaster and decoration material can help us i) reduce heating and cooling energy, ii) reuse waste EPS and prevent environmental pollution, and iii) reduce building load in tall buildings.

Keywords: *Expanded polystyrene, pine tree resin, insulation plaster, decoration material*.

ATIK GENLEŞTİRİLMİŞ POLİSTİREN VE REÇİNELİ ALÇI SIVALARIN ISIL ANALİZİ

Özet

Orijinal bilimsel makale

Bu çalışma, atık genleşmiş polistiren (EPS) ve çam ağacı reçinesinden (bağlayıcı olarak) yapılmış sıva veya dekoratif malzemelerin fiziksel özelliklerini araştırmıştır. İki grup halinde 0-3 mm ve 0-6 mm tane çaplarında atık EPS ve kuru karışım ağırlığının %20-80'i oranında reçine ve %0, 0.5, 1 ve 2 oranında reçine ilave edilerek 32 adet numune üretilmiştir. 0-3 mm çaplı numunelerde yoğunluk, termal iletkenlik katsayısı ve basınç %50.64, %82.68 ve %84.91 oranında azaltılmıştır. 0-6 mm çapındaki numunelerde yoğunluk, ısıl iletkenlik katsayısı ve basınç %51.03, %86.55 ve %84.13 oranında azalmıştır. 0-3 mm çapında ve %2 reçineli numunelerde yoğunluk ve ısıl iletkenlik sırasıyla %13.32-10.42 ve %25.37-22.41 azalırken basınç dayanımı %29.50-19.56 artmıştır. 0-6 mm çapında ve %2 reçineli numunelerde yoğunluk ve ısıl iletkenlik sırasıyla %19.60-13.68 ve %17.24-10.25 azalırken, basınç dayanımı %16.27-8.85 artmıştır. Sonuçlar, numunelerin kanal açma ve boya tutma özelliklerinden dolayı iç cephe sıvası, yalıtım sıvası ve dekorasyon malzemesi olarak kullanılabileceğini göstermektedir. Bu sıva ve dekorasyon malzemesi kullanılarak i) ısıtma ve soğutma enerjisinin azaltılması, ii) atık EPS'yi yeniden kullanmasına ve çevre kirliliğinin önlemesine iii) yüksek binalarda bina yükünü azaltmasına yardımcı olacaktır.

Anahtar Kelimeler: *Genleştirilmiş polistiren, çam ağacı reçinesi, yalıtım sıvası, dekorasyon malzemesi*.

1 Introduction

Expanded polystyrene (EPS) foam is a white thermoplastic material with closed pores. It is widely used in different industries and disposed of after only one use. It causes environmental pollution as it takes 500 to 1,000 years to biodegrade. Every year, a larger quantity of EPS is generated and ends up as waste. Therefore, it is important to recycle waste EPS in an efficient and clean manner for environmental concerns. Expanded polystyrene is recycled mechanically, thermally, or chemically. If we reuse waste EPS as aggregate in concrete and plaster, we both contribute to the economy and solve an environmental problem.

Porous materials (EPS, fly ash, pumice, expanded clay, etc.) can be used as aggregates to increase the insulating property of gypsum plasters. If we use resin together with porous aggregates, we can further increase the insulation properties of gypsum plasters. In the present study, we used pine tree resin. The resin absorbs water and

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Received 30 September 2022; Received in revised form 20 May 2023; Accepted 02 June 2023

 Doi: https://doi.org/10.46460/ijiea.1212678

swells a little. It loses that water as the sample dries and causes artificial pores in the plaster. These artificial pores increase the total porosity of the material and decrease its density.

There is a large body of research on how to recycle EPS. Most researchers use it as an aggregate in concrete [1-10]. This study focused on using it as a filling material to increase the insulation properties of gypsum plasters. Similar studies on porous gypsum plasters are summarized below.

Bicer [11] added 10-90% of fly ash (from Afsin-Elbistan and Soma thermal power plants) to gypsum plasters and produced building interior plasters with thermal conductivity of 0.220-0.230 W/mK. Bicer [12] also investigated the thermal and mechanical properties of pine tree resin (PR) reinforced pumice aggregate gypsum plasters. She added pumice aggregate (2-5 mm, 5-8 mm, and 8-12 mm grain sizes) to the plaster and produced plasters with 10.76%. 12.06%, and 17.27% less thermal conductivity.

However, this study aimed to use waste EPS aggregate and PR-reinforced gypsum plasters as insulation plaster and decoration material. To that end, waste EPS was crushed into granules and divided into two groups with grain diameters of 0-3 mm and 0-6 mm. Samples were prepared using gypsum with and without PR. The samples were subjected to thermal and mechanical tests and compared with similar materials.

2 Materials and Methods

2.1 Materials

2.1.1 Expanded Polystyrene

Expanded polystyrene is made of small, plastic beads that are heated and then blown into a foam-like substance. It consists of cells with small closed pores filled with stagnant air (Fig 1-a). Of the three to six billion small closed-pore cells, 98% are inert air and 2% are polystyrene. Expanded polystyrene is used for both insulation and packaging thanks to its flexible structure, shock absorption, and mechanical durability. Expanded polystyrene is not toxic and is not a food source for bacteria and fungi. It is disposed of as waste after only one use.

2.1.2 Pine Tree Resin

The resin seeps from an opening in the bark of a tree and hardens when it interacts with oxygen. After a while, it sticks to where it flows (Fig. 2-a). We ground the resin into powder and then kept it in powder form or in water for 48 hours. Afterward, we mixed it with gypsum in the extract form and used it in plaster samples for two reasons (Fig 2-b and c). First, it forms artificial micropores in the plaster structure, resulting in high insulation. Second, the dried resin hardens, resulting in improved binding properties.

2.1.3 Gypsum

Satin plaster used in interior plasters and decorative materials was used to prepare samples.

2.2 Preparation of Samples

The mixing ratio of the samples was determined using a measuring cylinder (Table 1). The resin must be prepared to produce test samples. Eighty grams of resin was dissolved in five liters of water and passed through a filter (Fig 2-c). Resin amounts were determined (Table 1). The mixtures were mixed with sufficient water. They were poured into molds of 20x60x150 mm (for thermal tests) and 100x100x100 mm (for mechanical tests) and left to dry (Fig 1).

Table 1. Mixing ratio of samples (g).

Materials	Mixing ratio			
	20 (%)	40 (%)	60 (%)	80 (%)
EPS (0-3 mm)	5.2	10.4	15.6	20.4
EPS (0-6 mm)	2.26	4.52	6.76	9.04
Gypsum	350	700	1050	1400

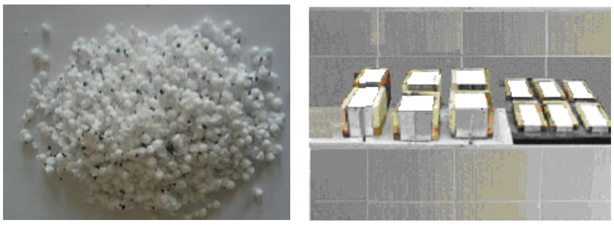


Figure 1. View waste EPS and samples.

a) b) c)

Figure 2. View of resin. a) natural. b) powder resin c) extract resin

2.3 Methods

Thermal conductivity was measured using the hot wire method in a Shotherm-QTM Thermal Conductivity Meter Unit, according to DIN 51046 standards [14, 15]. Tables 2 and 3 show the results. Compressive strength tests were performed using an Ele International according to TS 699 [16, 17]. Compressive strength was converted into tensile strength according to TS 500 using the following Eq. (1) [18]:

$$f_{ctk} = 0.35\sqrt{f_{ck}} \quad (1)$$

Water absorption and drying tests were conducted according to TSE 4045 [19] and BS 812-109 [20]. Water absorption and drying ratio values were calculated using Eq. 2 and Eq. 3, respectively

Water absorption percent= [(Wd-Wk)/Wk].100 (2)

Drying ratio= [(Wd-Wk)/Wd].100 (3)

Porosity is defined by Eq (4), [21].

$$\emptyset = 1 - \frac{\rho_{EPS}.Z+\rho_{gypsum}.(1-Z)}{\rho_{EPSmatrix}.Z+\rho_{gypsum}matrix.(1-Z)} \quad (4)$$

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

Code	EPS ratio (%)	Density (g/cm³)	Porosity (%)	Thermal conductivity (W/mK)	Compressive strength (MPa)	Tensile strength (MPa)	Water absorption (%)	Drying ratio (%)
Pine tree resin 0 %								
1	20	1.088	12.92	0.335	3.05	0.73	44.32	24.41
2	40	0.948	28.30	0.190	1.4	0.51	42.86	19.26
3	60	0.741	46.93	0.115	0.56	0.32	35.44	15.73
4	80	0.537	69.93	0.058	0.46	0.28	30.19	13.53
Pine tree resin 0.5 %								
5	20	1.048	13.94	0.314	3.68	0.67	46.61	26.63
6	40	0.914	30.12	0.180	1.78	0.47	45.14	23.17
7	60	0.698	49.11	0.110	0.64	0.28	40.08	17.68
8	80	0.522	71.71	0.055	0.51	0.25	32.79	14.07
Pine tree resin 1 %								
9	20	0.985	18.42	0.285	4.29	0.61	48.17	27.25
10	40	0.881	31.07	0.170	2.1	0.41	45.27	25.39
11	60	0.658	50.22	0.098	0.8	0.26	41.05	20.42
12	80	0.502	72.58	0.050	0.62	0.23	34.16	16.23
Pine tree resin 2 %								
13	20	0.943	19.72	0.250	3.95	0.52	49.00	28.22
14	40	0.808	32.90	0.146	1.92	0.37	47.41	26.39
15	60	0.633	52.31	0.088	0.7	0.24	44.28	22.18
16	80	0.481	74.19	0.045	0.55	0.21	35.47	18.73

Table 3. Thermal and mechanical properties of samples (EPS particle diameter 0-6 mm).

Code	EPS ratio (%)	Density (g/cm³)	Porosity (%)	Thermal conductivity (W/mK)	Compressive strength (MPa)	Tensile strength (MPa)	Water absorption (%)	Drying ratio (%)
Pine tree resin 0 %								
17	20	1.015	12.98	0.290	2.71	0.62	36.48	25.06
18	40	0.885	28.44	0.168	1.38	0.39	34.55	20.52
19	60	0.512	47.15	0.090	0.51	0.27	31.95	16.11
20	80	0.497	70.26	0.039	0.43	0.25	28.41	14.16
Pine tree resin 0.5 %								
21	20	0.939	14.12	0.275	2.88	0.57	38.42	26.44
22	40	0.814	30.27	0.147	1.46	0.34	36.51	24.08
23	60	0.627	49.34	0.081	0.63	0.25	34.46	19.86
24	80	0.483	72.05	0.037	0.45	0.23	30.58	16.04
Pine tree resin 1 %								
25	20	0.890	14.56	0.260	3.22	0.51	42.45	28.64
26	40	0.764	24.55	0.131	1.75	0.29	39.54	25.58
27	60	0.605	42.22	0.073	0.75	0.23	37.82	21.51
28	80	0.457	65.95	0.036	0.55	0.22	32.73	17.67
Pine tree resin 2 %								
29	20	0.816	15.64	0.240	2.95	0.48	45.58	29.37
30	40	0.696	33.06	0.115	1.51	0.29	43.54	27.31
31	60	0.548	52.56	0.065	0.65	0.21	42.58	22.88
32	80	0.429	74.55	0.035	0.50	0.19	34.71	20.80

3 Results and Discussion

The samples with high EPS (Tables 2 and 3) had smaller thermal conductivity coefficients than similar construction materials (Table 4) due to the porous structure of EPS and resin addition.

Table 4. Measured thermal conductivities of different materials [24].

Material	Density (g/cm³)	Thermal Conductivity ($W.m^{-1}.K^{-1}$)
Outher plaster	1.600	0.930
Inner plaster	1.800	1.163
Gypsum thin plaster (Perlite)	0.40-0.50	0.139-0.162
Gypsum rough plaster (Perlite)	0.40-0.50	0.139-0.162
Plaster with cement (Perlite)	0.700	0.244
Gypsum block (Perlite)	0.900	0.221

The samples with a particle diameter of 0-6 mm had smaller thermal conductivity coefficients than those with a particle diameter of 0-3 mm (Fig. 3) because the smaller the particle size during fragmentation, the lower the porosity and the higher the density and thermal conductivity coefficient in EPS. The higher the resin content, the lower the thermal conductivity coefficients and higher the total porosity because the samples lose water during the 28-day drying, resulting in artificial micropores in addition to the EPS pores.

The density and thermal conductivity decreased by 50.64% and 82.68%, respectively, in the samples with a particle diameter of 0-3 mm when the EPS content increased from 20% to 80%. Sample 4 had the lowest density (0.537 g/cm³) and thermal conductivity (0.058 W/mK) (80% EPS and 2% PR). The density and thermal conductivity decreased by 51.03% and 86.55%, respectively, in the samples with a particle diameter of 0-6 mm when the EPS content increased from 20% to 80%. Sample 20 had the lowest density (0.497 g/cm³) and thermal conductivity (0.039 W/mK).

The samples with EPS and PR had small thermal conductivity coefficients than Ref [11, 12, 22, 23, and 24] and close to Ref [25] (Table 5).

The samples with high particle diameter and EPS content had small compressive strength values (Figures 4 and 5). In the nonresinous samples, the compressive strength decreased by 84.91% in the samples with a grain diameter of 0-3 mm and by 84.13% in the samples with a grain diameter of 0-6 mm when the EPS content increased from 20% to 80%. The samples with PR had slightly higher compressive strength values. In the resinous samples, the compressive strength increased by 19.56%-29.50% and 8.85%-16.27% in the samples with a grain diameter of 0-3 mm and 0-6 mm, respectively. The increase in the compressive strength was higher in the samples with 1% resin, while it slightly decreased in the samples with 2% resin. The samples had compressive strength values similar to Ref [12, 22, and 25]. The 1% resin-reinforced samples with a grain diameter of 0-3 mm had higher compressive strength values than Ref [12, 22, and 25] (Table 5).

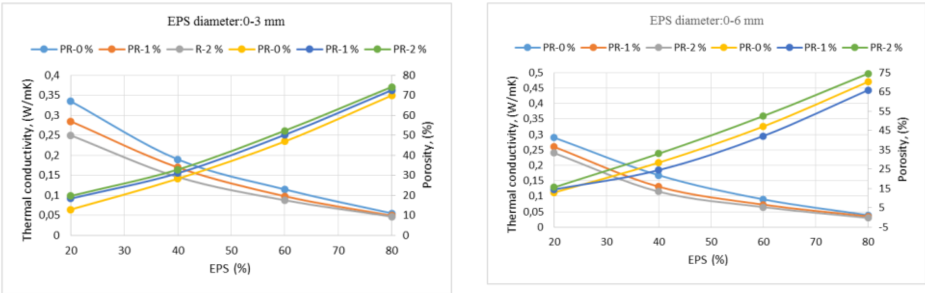


Figure 3. Thermal conductivity and porosity-EPS and PR percentage relation in the specimens.

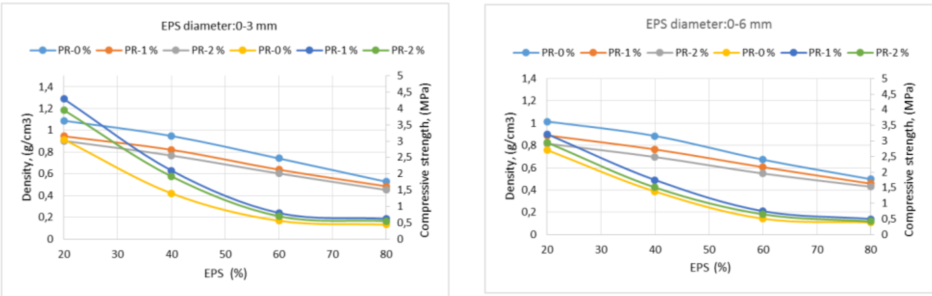


Figure 4. Compressive strength and density-EPS and PR percentage.

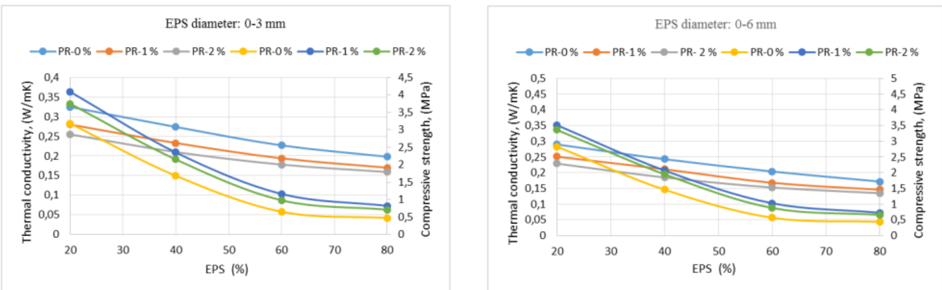


Figure 5. Compressive strength and thermal conductivity-EPS and PR percentage relation in the specimens.

We can use large-grain EPS in rough interior plasters, while we can use small-grain EPS in fine interior plasters and decorative materials. Our results show that EPS and PR-reinforced gypsum plasters can help us reduce building loads, allowing us to save heating and cooling energy and reduce earthquake damage.

All samples had water absorption ratios above 30%, which is the critical value (Fig. 6). Therefore, these materials should not be used in exterior plasters because they are in danger of frost in case they come into contact with water below 0 oC temperature.

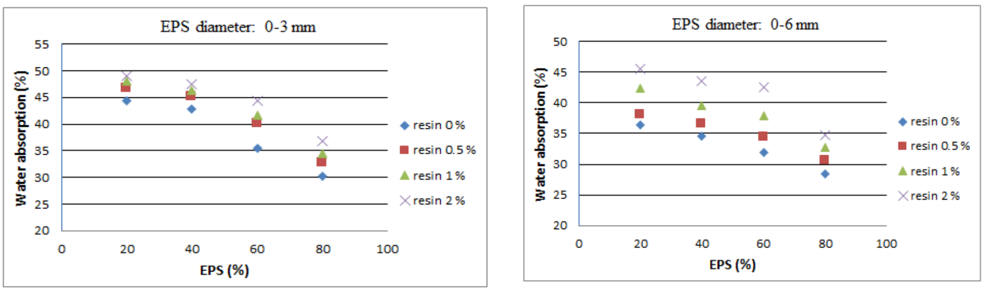
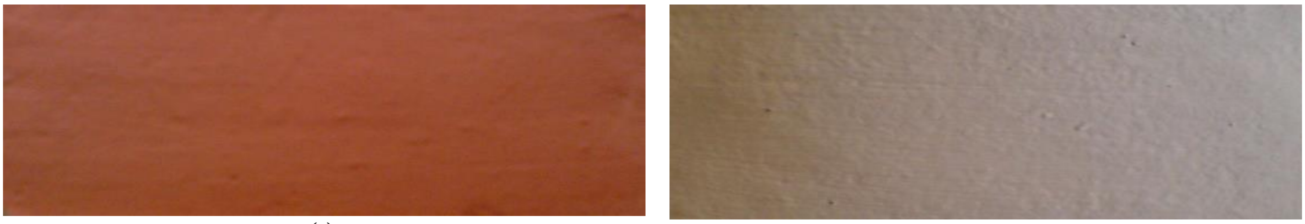


Figure 6. Water absorption ratio of samples versus EPS and resin percentages.

The higher the EPS content, the lower the drying rates (Tables 2 and 3) because EPS does not absorb water. The water loss through the capillary channels towards the material surface shows that the samples have a little breathing ability.

The tests showed that the samples could be sawn, screwed, drilled, and channeled. The tests also showed that the samples had high paint adherence (Fig. 7).



(a) (b)

Figure 7. Samples can be different types of dyes can be applied a) silicone rubber coating, b) oil painting.

Table 5. Physical properties of similar studies.

Materials	**Density (g/cm^3)**	**Thermal conductivity (W/mK)**	**Compressive strength (MPa)**	**Literature**
Fly ash (10%) + gypsum	1.253	0.335	-	
Fly ash (30%) + gypsum	1.213	0.295	-	[11]
Fly ash (50%) + gypsum	1.197	0.274	-	
Fly ash (90%) + gypsum	1.165	0.248	-	
Pumice (20%) + gypsum + pine tree resin (0%)	1.252	0.325	3.08	
Pumice (80%) + gypsum + pine tree resin (0%)	0.806	0.198	1.66	[12]
Pumice (20%) + gypsum + pine tree resin (2%)	1.204	0.290	0.93	
Pumice (80%) + gypsum + pine tree resin (2%)	0.793	0.165	0.61	
EPS (20%) + cement (20%) + tragacanth resin (0%)	1.567	0.390	16.87	
EPS (80%) + cement (20%) + tragacanth resin (0%)	0.648	0.061	1.82	[21]
EPS (20%) + cement (80%) + tragacanth resin (1%)	1.232	0.320	10.85	
EPS (80%) + cement (20%) + tragacanth resin (1%)	0.536	0.050	0.89	
Cement + pumice + EPS	0.562	0.330	2.99	[22]
Cement and rubber particle (30%)	1.473	0.625	23.30	
Cement and rubber particle (40%)	1.300	0.516	16.00	[23]
Cement and rubber particle (50%)	1.150	0.470	10.50	
Pumice (20%) + cement + PT resin (0%)	1.645	0.446	24.34	
Pumice (80%) + cement + PT resin (0%)	1.355	0.309	6.67	[24]
Pumice (20%) + cement + PT resin (1%)	1.608	0.407	21.05	
Pumice (80%) + cement + PT resin (1%)	1.338	0.262		
EPS (20) + gypsum + tragacanth resin (0%)	1.088	0.260	3.29	
EPS (80) + gypsum + tragacanth resin (0%)	0.527	0.055	0.82	[25]
EPS (20) + gypsum + tragacanth resin (1.5%)	0.903	0.190	1.20	
EPS (80) + gypsum + tragacanth resin (1.5%)	0.451	0.147	0.35	
EPS (20) + gypsum + PT resin (0%) diameter:0-3 mm	1.088	0.335	3.05	
EPS (80) + gypsum + PT resin (0%) “	0.537	0.058	0.46	
EPS (20) + gypsum + PT resin (2%) “	0.985	0.285	3.95	
EPS (80) + gypsum + PT resin (2%) “	0.502	0.050	0.55	Present
EPS (20) + gypsum + PT resin (0%) diameter:0-6 mm	1.015	0.285	2.71	
EPS (80) + gypsum + PT resin (0%) “	0.492	0.050	0.43	
EPS (20) + gypsum + PT resin (2%) “	0.890	0.240	2.95	
EPS (80) + gypsum + PT resin (2%) “	0.457	0.035	0.50	

4 Conclusions

This study was conducted to recycle waste EPS. The results showed that waste EPS could be used as aggregate in thin plasters, thick plasters, and decorative materials. In conclusion;

- If we take advantage of the insulation properties of EPS and use it in plasters, we will solve an environmental problem.
- EPS-related pores and PR-related micropores reduce density and thermal conductivity, resulting in a larger total porosity. Therefore, EPS and PR improve the insulating properties of plasters. These plasters can be used for both heat and sound insulation.
- If we use EPS aggregate, we can produce plasters with thermal conductivity coefficients of 0.058-0.335 W/mK (nonresinous with a grain diameter of 0-3 mm), 0.045-0.250 W/mK (resinous; 2%), 0.039-0.290 W/mK (nonresinous with a grain diameter of 0-6 mm), and 0.035-0.240 W/mK (resinous).
- EPS-reinforced plasters have the same nailing, drilling, cutting, sticking, smooth surface, and painting properties as conventional plasters.

This study recommends that plasters reinforced with expanded polystyrene, pine tree resin, and gypsum be used as a potential building material for interior plastering and decoration for insulation purposes.

Nomenclature

F	[%]	Porosity
r	[g/cm^3]	Density
W	[g]	Weight of sample
Z	[%]	EPS ratio
1-Z	[%]	Gypsum ratio
WAR	[%]	Water absorption ratio
EPS		Expanded polystyrene
PR		Pine tree resin
fck	[MPa]	Compressive strength
fctk:	[MPa]	Tensile strength
EPS matrix		EPS with 0 % porosity ratio
gypsum matrix		Gypsum with 0 % porosity ratio
d		Wet
k		Dry

Declaration

Ethics committee approval is not required.

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