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Thermal Properties of Gypsum Plaster with Fly Ash

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Abstract

In this study, grain size of fly ash's, which is used in gypsum plaster, impact on thermal performance of composite material has been investigated. Used in the testing processes, the fly ash is obtained from the Afsın-Elbistan and Soma Thermal Power Plants and divided into the different grain size classes as unsieved, $>75.10^{-6}$ m, $(45\text{-}75).10^{-6}$ m and $<45.10^{-6}$ m. For every fly ash and gypsum mixture. The mixing ratio of the fly ash is taken as 10, 30, 50, 70 and 90% in the mixture. Gypsum is used as a binder agent and there are 20 sample available, which are prepared based on the grain diameter and the amount of fly ash. New products have undergone severalto determine their properties, such as density, thermal conductivity and porosity. It was observed from the tests that, as the diameter of the grain reduced, the density of the ash increased by 16.12 per cent, and the porous layer left its place to full-grain ash and became light brown. While the added ash ratio increased by 10-90% in ash mixtures of gypsum, thermal conductivity values were detected to decrease by (14.47-24.52) % and (1.25-9.4) % respectively. In addition, the fly ash has given the plaster an insulation property.

Keywords: Fly ash, Satin gypsum, Thermal conductivity coefficient, Insulation plaster, Waste management.

Uçucu Küllü Alçı Sıvaların Isıl Özellikleri

Özet

Bu çalışmada, uçucu küllü alçı sıvada, uçucu kül tane çapının, kompozit malzemenin termal performansına etkisi araştırılmıştır. Testlerde kullanılan uçucu kül, Afsın-Elbistan ve Soma Termik Santrallerinden temin edilmiş ve tane çaplarına göre elenmemiş, $>75.10^{-6}$ *m,* $(45\text{-}75).10^{-6}$ *m ve* $<45.10^{-6}$ *m gruplandırılmıştır. Tüm uçucu kül ve alçı karışımında uçucu külün ağırlık yüzdeleri 10, 30, 50, 70 ve %90 olarak alınmıştır. Bağlayıcı olarak saten alçı kullanılmış olup, tane çapı ve uçucu kül miktarına bağlı olarak 20 örnek hazırlanmıştır. Hazırlanan numuneler,* *yoğunluk, termal iletkenlik ve porozite gibi testlere tabi tutulmuştur. Yapılan testlere göre tane çapı azaldıkça, külün yoğunluğunun %16.12 arttığı ve gözenekli külün yerini dolu taneciklere bıraktığı ve kül renginin açık kahverengiye dönüştüğü gözlenmiştir, Buna ek olarak uçucu kül-alçı karışımında ilave edilen kül oranı %10 dan %90 oranına arttıkça, ısıl* iletkenlik *değerleri sırasıyla %14.47-24.52 ve %1.25-9.4 küçüldüğü belirlenmiş ve uçucu kül ilavesinin alçı sıvaya yalıtım özelliği kazandırdığı sonucuna varılmıştır.*

***Anahtar Kelimeler:** Uçucu kül, Saten alçı, Isı iletim katsayısı, Yalıtım sıvası, Atık yönetimi.*

Nomenclature

Φ	[%]	Porosity
ρ	[g/cm^3]	Density
W	[g]	Weight of sample
Z	[%]	Fly ash ratio
1-Z	[%]	Gypsum ratio
TPP	-	Thermal Power Plants
W/C	-	Water and cement ratio
Subscripts		
fly ash		Fly ash
gypsum		Cement
fly ash matrix		Fly ash with 0 % porosity
gypsum matrix		Gypsum with 0 % porosity ratio

1. Introduction

The fly ash is about $15 \cdot 10^6$ tons per year in Turkey, which is generated from thermal power plants. Two of these factories are Afsin-Ejbistan and Soma Power Plants. Storing fly ash or waste from the site is one of the power plant's main problems. That is why it is necessary to extinguish the evaluation of the negative environmental impacts of the waste fly ashes. Fly ashes are in the artificial pozzolan group. The fact that it is to be used in sufficient amounts instead of cement has intensified the studies within the concrete. Until now, no studies have been conducted on fly ash. Such studies have been summed up in two groups. The first group comprises of the analysis on the determination of fly ashes as an additive to concrete. Many of the studies completed are summed up below.

It was presented by Thirumal and Harish, (2016) which is a high-concrete substance flowing under its own weight without mechanical pressure by means of minimizing concrete costs by processing self-concrete with the addition of fly ash or silica fumes at a 10%, 30%, concrete ratio. In concrete samples compressive, tensile and flexural strength tests have been applied. Arif, (2016) produced a new building material created by adding building materials such as fly ash, cement, concrete and clinker. Terzic et al., (2013) suggested the use of fly ash released from Serbian Power Plants burning lignite coal as waste, and the use of cement, mortar, clicker and tile. Rivera et al.,

(2015) reached compressive strength values of more than 30 Mpa by using cement and aggregate in concrete.

The second group is an analysis of the idea that fly ash is used partly or entirely in concrete instead of traditional aggregates. The studies are summarized below.

Babu et al., (2005) investigated of the mechanical properties of light concrete by using fly ash in combination with mineral wool instead of standard aggregate. In the study they performed, Nordin et al., (2016) explored the possible use of waste fly ash as a construction material to be used annually in power plants in Malaysia in the amount of one hundred thousand tons. In the analysis they performed, Rafieizonooz et al., (2016) investigated the physical properties of concrete made using fly ash rather than sand 0, 20, 50 and 100 percent base ash and 20 percent instead of concrete. Yildirim et al., (1996) examined thermal and mechanical properties of emerging materials that have insulation characters made of waste material and concrete such as fly ash and polypropylene. Bicer et al., (2010) analyzed the thermo mechanical properties of concrete with brown rice ash additives of 5%, 10%, 15% and 20%, which suggests the idea that 15% of brown rice additives had improved the mechanical properties of concrete. Yoshitake et al., (2016) worked the concrete surface abrasion and skid tolerance of fly ash additives (40 per cent). Weerachart et al., (2013) examined the effect of ash Karaşin and Dogruyol, (2014) suggested that no improvement was seen within concrete strength values by applying fly ash to concrete in the total of 20 percent. Siddique, (2003) investigated improvements in the mechanical properties of concrete made using fly ash rather than sand in amounts of 10%, 20%, 30%, 40% and 50%. Duran, (2004) in study findings are indicated the pressure strength of the concrete mixtures, accelerated carbonation depth and porosity characteristics generated using standard portland cement fly ash. Don, (2004) studied the impact of fly ash use on fresh concrete properties, rather than partly sand. Bicer, investigated the influence of grain diameter and resin usage (Bicer, 2018 and 2019) on thermal and mechanical properties of fly ash as aggregate in concrete. In addition, Kaya and Kar, (2015) analyzed physical properties of gypsum plasters with EPS aggregates in different proportions. Bicer, (2020) investigated the effect of production temperature on thermal and mechanical properties of polystyrene - fly ash composites.

In this study, it was investigated by using fly ash supplied from two thermal power plants, grouped according to grain diameters, and evaluating it as interior insulation plaster by mixing with gypsum in certain proportions. The difference of the study from similar work is that fly ash is used in gypsum plasters.

2. Materials and Method

2.1. Materials

Fly ash is deeper gray in color than cement, very fine grained and when handled by the hand becomes a soft substance. Fly ashes have collected from Afsin-Elbistan TPP in Kahramanmaras and Soma TPP in Turkey's Kutahya district. Ash fineness typically ranges from (1-200) $x10^{-6}$ meters. Table 1 lists fly ashes and gypsum belonging to determining density values. When viewed with the microscope it shows a form of varying shapes and sizes, usually globe-like, translucent, often light in color, often purple, often less brunette red in grains of color. Darkness in color, lightness depends on the characteristics obtained from the coal and burning. The primary elements are silica, magnesium and iron oxide, based on the burning properties.

Satin gypsum was used for the plastering process within the scope of preparing the samples. They are commonly used for construction activities with a particular benefit of lightness and good fire resistance.

Table 1. The density values of gypsum and fly ashes (g/cm^3)

Materials	**Unsieved**	**>75.10^{-6} m**	**(45-75).10^{-6} m**	**<45.10^{-6} m**
Fly ash (Afsin Elbistan)	2.24	2.00	2.50	2.75
Fly ash (Soma)	2.03	1.94	2.27	2.42
Gypsum	2.27			

The chemical component of materials which are used within the scope of this study and the details of mix proportion have seen in Table 2. The ratio of water and cement is fixed to 0.5.

Table 2. Chemical composition of the materials (%)

Chemical characteristics	**Gypsum**	**Fly ash (Afsin-Elbistan TPP)**	**Soma (TPP)**
SiO_2	0.9	33.9	51.25
Al_2O_3	0.7	12.5	26.15
Fe_2O_3	-	5.9	5.29
CaO	94.7	35.5	7.85
MgO	3.5	1.9	1.66
SO_3	-	7.2	0.23
K_2O	-	0.7	1.3
TiO_2	-	0.7	0.83
LiO_2	-	-	0.13
Na_2O	-	0.3	0.67
Loss on ignition	-	1.6	4.68
Not available	-	-	-
Total	100.2	100.2	100.4

Prepared mortars were formed to 20x50x140 mm formwork for thermal processing and left to dry for 28 days.

2.2. Methods

Thermal conductivity is subjected to measurement using the Shotherm-QTM unit (Denko, 1990) and the hot wire method in compliance with DIN 51046 standards. Its range and intensity were 0.02-10 W/mK and ± 5 percent of its scale. Measurements are rendered at room temperature (22-25^{o}C) with all materials at their 3 separate stages. The values of thermal conductivity are measured by the estimated numerical average of the calculation. Porosity (Φ) is defined by Eq (1), (Kaya and Kar, 2016).

$$\Phi = 1 - \frac{\rho_{\text{fly ash}} \cdot Z + \rho_{\text{gypsum}} \cdot (1\text{-}Z)}{\rho_{\text{fly ash matrix}} \cdot Z + \rho_{\text{gypsum matrix}} \cdot (1\text{-}Z)} \tag{1}$$

where; $\rho_{\text{fly ash}}$ is density of fly ash, ρ_{gypsum} is the density of the gypsum, and the $\rho_{\text{fly ash matrix}}$ is the density of the fly ash for a porosity ratio of 0 percent (the value of the material following milling and therefore having little porosity), the $\rho_{\text{gypsum matrix}}$ is the density of the gypsum. Z is the ratio of fly ash (percent) and (1-Z) is the ratio of gypsum (percent). The matrix density of fly ash can be shown as measured in Table 3.

Table 3. Determination of waste fly ash matrix density

		Fly ash (Afsin-Elbistan TPP)		**Soma (TPP)**	
Component	**Density of component (g/cm^3)**	**Component ratio (%)**	**Density x component ratio (g/cm^3)**	**Component ratio (%)**	**Density x component ratio (g/cm^3)**
SiO_2	2.56	33.9	0.8678	51.25	1.312
Al_2O_3	4.0	12.5	0.5	26.15	1.046
Fe_2O_3	5.2	5.9	0.3068	5.29	0.275
CaO	3.3	35.5	1.1715	7.85	0.259
MgO	3.6	1.9	0.0684	1.66	0.0597
SO_3	4.82	7.2	0.345	0.23	0.011
K_2O	1.9	0.7	0.0133	1.3	0.0247
TiO_2	4.26	0.7	0.0298	0.83	0.03515
LiO_2	0.85	-	-	0.13	0.0011
Na_2O	2.3	0.3	0.0069	0.67	0.01541
Loss on ignition	-	1.6	-	4.68	-
Total		100.2	**3.303**	100.4	**3.039**

The measured thermal conductivity coefficients and the porosity values (calculated using Equation 1) of the samples are shown collectively in Table 4.

Table 4. Thermal properties of samples

			Fly ash (Afsin-Elbistan TPP)			**Fly ash (Soma TPP)**		
Code	**Fly ash diameter (10^{-6} m)**	**Fly ash ratio (%)**	**Density (g/cm^3)**	**Porosity (%)**	**Thermal conductivity (W/m K)**	**Density (g/cm^3)**	**Porosity (%)**	**Thermal conductivity (W/m K)**
1	Unsieved	10	1.253	5.02	0.335	1.214	4.97	0.315
2	“	30	1.213	13.41	0.295	1.190	13.46	0.290
3	“	50	1.197	20.15	0.274	1.179	20.44	0.269
4	“	70	1.165	25.67	0.237	1.128	26.27	0.255
5	“	90	1.120	30.29	0.248	1.111	31.23	0.240
6	<45	10	1.325	2.16	0.350	1.305	2.68	0.342
7	“	30	1.251	6.12	0.338	1.286	7.54	0.325
8	“	50	1.185	9.63	0.329	1.211	11.84	0.318
9	“	70	1.142	12.78	0.321	1.163	15.66	0.311
10	“	90	1.122	15.60	0.311	1.112	19.07	0.302
11	45-75	10	1.266	3.80	0.345	1.260	3.80	0.338
12	“	30	1.215	10.15	0.320	1.251	10.29	0.318
13	“	50	1.188	15.25	0.300	1.164	16.63	0.298
14	“	70	1.125	19.43	0.285	1.031	20.09	0.278
15	“	90	1.051	22.93	0.271	0.980	23.88	0.265
16	>75	10	1.238	5.58	0.333	1.206	5.20	0.306
17	“	30	1.196	15.34	0.290	1.100	14.25	0.288
18	“	50	1.172	23.60	0.263	1.045	21.85	0.260
19	“	70	1.095	30.67	0.246	1.022	28.31	0.252
20	“	90	0.969	35.5	0.222	0.942	33.88	0.228

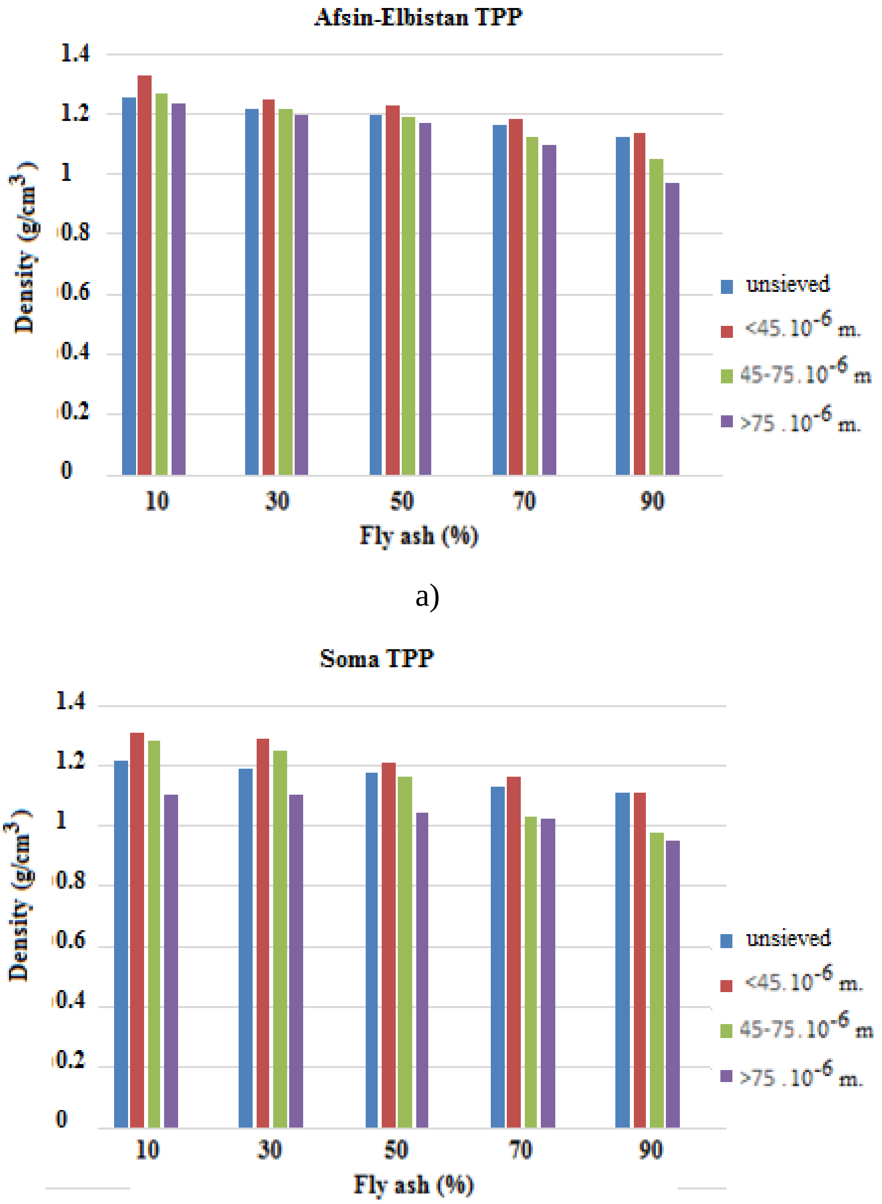
3. Results and Discussions

3.1. Density

Dry densities at 28 days of sample curing have seen in Table 4. The findings indicate that the dry density reduces as the amount of fly ash aggregates increases. While the fly ash content of Afsin-Elbistan TPP and Soma TPP has not been eliminated, the fly ash rate has increased from 10% to 90%, values of dry density decrease from 1.253 g/ m^3 to 1.120 kg/m^3 and from 1.214 kg/m^3 to 1.111 kg/m^3, respectively. Shrinkage ratios are 10.61% and 8.48%. These ratios are as follows <45.10^{-6} m, (45-75).10^{-6} m and >75.10^{-6} m for grain diameters, 14.11%, 16.98%, 21.72% (Afsin Elbistan TPP) and 14.79%, 21.6% 21.9% (Soma TPP), respectively (Fig. 1). The reason for these shrinkages is because of the porous composition of the fly ash. The more the fly ash diameter decreases, density values increase. In other words, most of the porous samples in small-grain samples have been replaced by filled grain fly ash, causing an increase in sample density.

3.2. Porosity

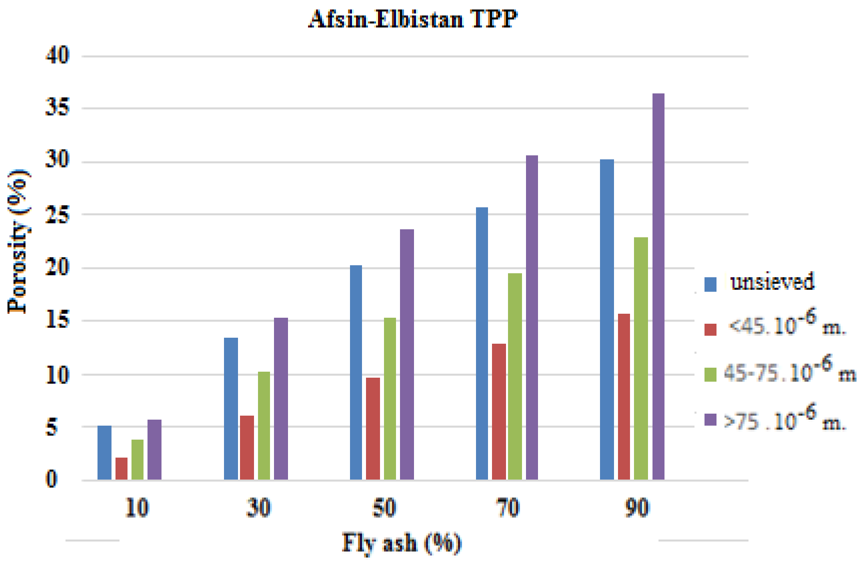
When the grain diameter of the fly ash grows, the density declines, whereas the porosity amount rises. The largest porosity values were determined as 35.80% for Afsin Elbistan TPP and 33.88% for Soma TPP in samples with a fly ash ratio of 90% and grain diameter >75.10-6 m. Growth rates in porosity increased from 10% to 90%, while the grain rates were 51.05%, 55.73%, 58.28% (for Afsin Elbistan TPP) and 52.07%, 56.90%, 57.56% (for Soma TPP). The reason for this is arising out of the mentioned reasons for density (Fig. 2).



a)

b)

Fig 1. Density change as per fly ash ratio and grain diameter
a) Afsin-Elbistan TPP, b) Soma TPP



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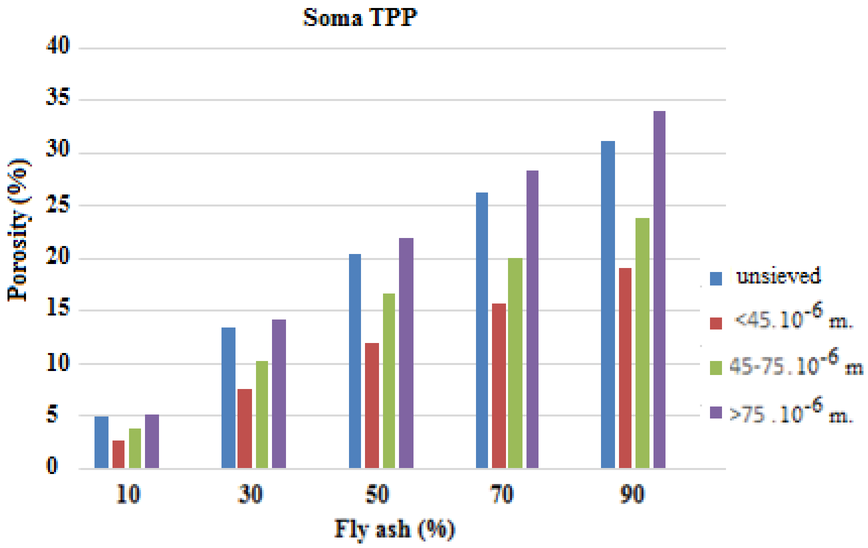


b)

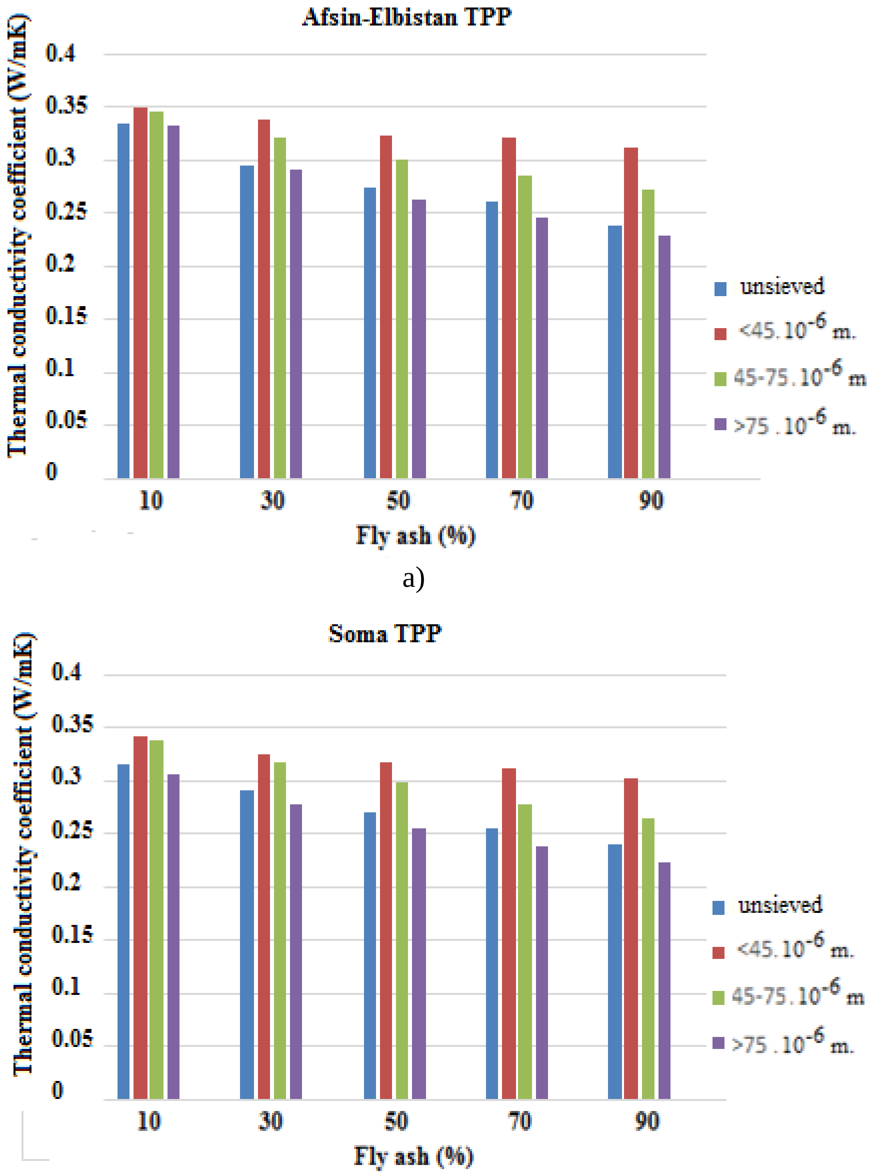
Fig 2. Porosity change as per fly ash ratio and grain diameter
a) Afsin-Elbistan TPP, b) Soma TPP

3.3. Thermal conductivity

The thermal insulation properties of the composite specimens are identified by means of a thermal conductivity control. Thermal conductivity levels are decreased with increasing in the amount of fly ash (Table 4).

The reason for shrinkages is that the pores in the microstructure being filled with gases formed as a result of combustion, and the thermal conductivity coefficient for stagnant gases is approximately 0.0214 W/mK (Kaya and Kar, 2016). The thermal conductivity coefficient values were measured as 0.222 W/mK (Afsin-Elbistan TPP) and 0.228 W/mK (Soma TPP) in the grain diameter >75.10-6 m and 90% fly ash sample.

In samples of non-sieved fly ash, the concentration of fly ash rises from 10% to 90%, while on the other hand the values of thermal conductivity decline by 19.66% (Afsin-Elbistan TPP) and 17.24% (Soma TPP). According to this increase rate of fly ash, the thermal conductivity coefficient values decreased by 11.14%, 21.44%, 33.33% (Afsin Elbistan TPP) and 11.69%, 21.59%, 25.55% (Soma TPP), respectively (Fig.3).

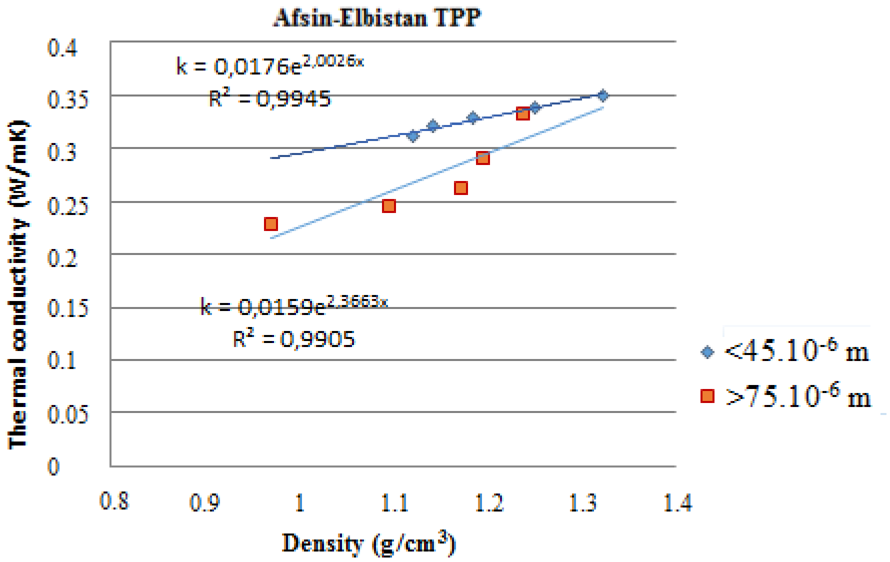


a)

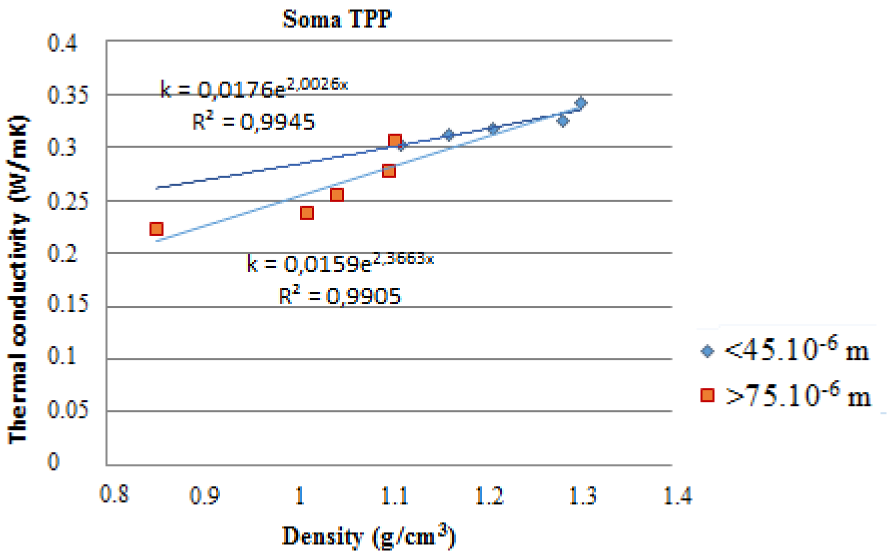
b)

Fig 3. Thermal conductivity coefficient change as per fly ash ratio and grain diameter a) Afsin-Elbistan TPP, b) Soma TPP

While the density values of the samples prepared using the fly ash of two thermal power plants increase, also the thermal conductivity coefficients increase (Fig. 4). On the other hand, while the porosity values increase, the heat transmission coefficient decreases (Fig. 5).

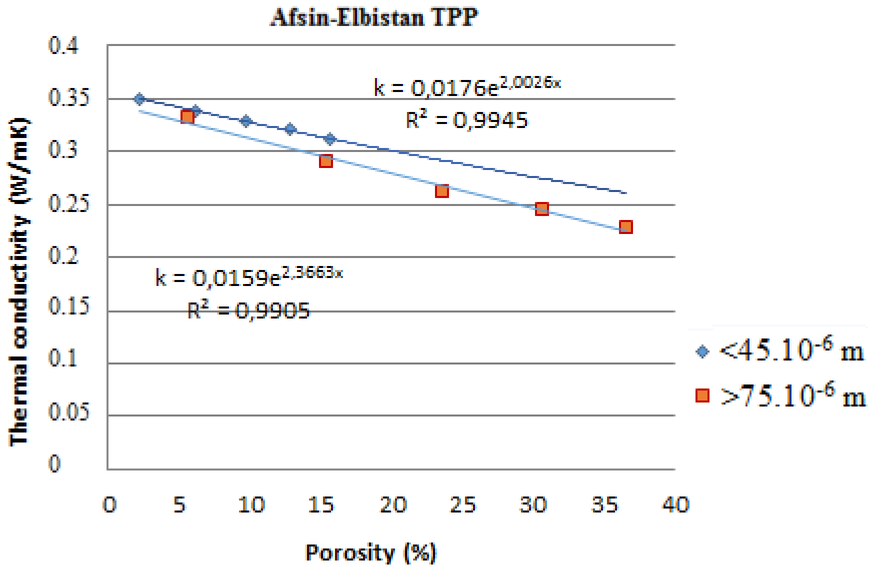


a)



b)

Fig 4. Change in thermal conductivity according to density
a) Afsin-Elbistan TPP, b) Soma TPP



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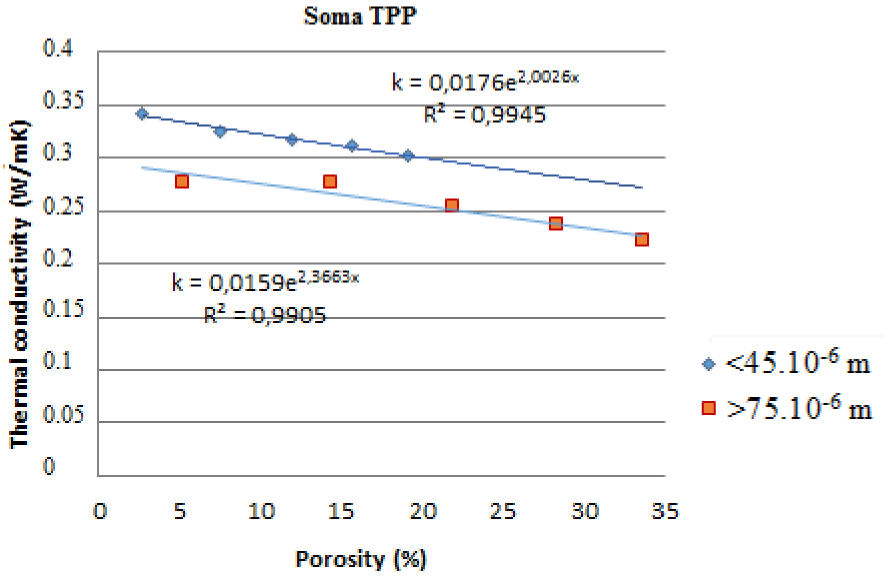

b)

Fig 5. Change in thermal conductivity according to porosity
a)Afsin-Elbistan TPP, b) Soma TPP

Gypsum plasters with a diameter of >75.10^{-6} m and 90% of fly ash have a smaller heat transfer coefficient than many conventional gypsum plasters shown in Table 5.

Table 5. Thermal conductivity coefficients of some plasters (with perlite), (Kaya and Kar, 2015).

	Measured Values			**Literature**		
Material	**Density (g/cm^3)**	**T$_{avr}$ (^{o}C)**	**Thermal cond. (W/mK)**	**Density (g/cm^3)**	**T$_{avr}$ (^{o}C)**	**Thermal cond. (W/mK)**
Inner plaster	1.763	33	1.163	1.800	20	1.163
Gypsum thin plaster	0.465	34	0.244	0.40-0.50	20	0.139-0.162
Gypsum rough Plaster	0.465	50.7	0.168	0.40-0.50	20	0.139-0.162
Gypsum block (perlite)	1.037	38	0.370	0.902	20	0.220

The thermal conductivity coefficient of samples in the group > 75.10^{-6} was smaller than the value given in Table 6 [(Kaya and Kar, 2016), (Sariisik, 2002), (Khedari et al, 2001) and (Benazzouk et al, 2008)].

Table 6. Physical properties of similar studies.

Materials	**Density (g/cm^3)**	**Thermal conductivity (W/mK)**	**Literature**
Cement + sand + fly ash + EPS	1.150	-	Babu et al., 2005
Cement + fly ash + sand + EPS	1.350	-	
Cement (80%) + EPS (20%)	1.567	0.390	(Kaya and Kar, 2016)
Cement (80%) + EPS (20%) + resin (1%)	1.232	0.320	
Cement + pumice + EPS	0.562	0.330	(Sariisik&Sariisik, 2002)
Cement + sand + coconut fiber (10%)	1.410	0.654	(Khedari et al., 2001)
Cement + sand + coconut fiber (20%)	0.959	0.254	
Cement and (30%) rubber particle	1.473	0.625	(Benazzouk et al., 2008)
Cement and (40%) rubber particle	1.300	0.516	
Cement and (50%) rubber particle	1.150	0.470	
Cement + wood pellet (10%) + clay	1.010	0.220	(Rim et al., 1999)
Cement + wood pellet (20%) + clay	0.870	0.160	
Cement + wood pellet (30%) + clay	0.700	0.140	

It achieves bonding properties without using any bonding agent when the pozzolanic properties of fly ashes combined with water. Mortars thus prepared can be used as sub-roof insulation cement, or as intermediate backfill material on sandwich walls. In this case, the coefficient of heat conductivity in the shape of a plaster is 0.220-0.230 W/mK, and if it is in dust from being used as an intermediate backfill medium, it is empirically found that the value is 0.140 W/mK.

4. Conclusions

This research was carried out to determine the suitability of gypsum products for the usage of fly ash in plaster. The following results can be obtained from this experimental analysis.

- ✓ Utilizing the insulating properties of fly ash and evaluating them as a building material in plaster applications will provide versatile benefits. Storage and transportation of this waste material, especially in thermal power plants, will bring solutions to the undesirable effects and problems of the environment.
- ✓ As the diameter of the grain reduced, the density of the ash increased by 16.12 per cent, and the porous layer left its place to full-grain ash and became light brown.
- ✓ While the added ash ratio increased by 10-90% in ash mixtures of gypsum, thermal conductivity values were detected to decrease by (14.47-24.52) % and (1.25-9.4) % respectively.
- ✓ As the fly ash has provided the plaster and the insulation properties, the heating costs in the buildings will be smaller. It is anticipated that the findings of this analysis would support the development of the community
- ✓ It will be possible to produce interior plasters with fly ash and gypsum mix 0.225-0.228 W/mK heat transmission coefficient values.
- ✓ Fly ashes can be used as underfloor insulation plaster or intermediate filling material on sandwich walls without using any binder. In this case, it has been determined on an experimental basis that the heat transmission coefficient in the form of plaster is 0.220-0.230 W/mK and if it is used as powder and intermediate filling material, it is 0.140 W/mK.
- ✓ The inner surface plasters that are produced by means of using fly ash, bear the same properties with the ordinary plasters in terms of respiration capability, nailing, boring, cutting, sticking on the wall, while also presenting a smooth surface and painting.

On the basis of these findings, plaster content including fly ash and gypsum may be a possible construction material such as inner plaster, decorative materials and insulation materials and, at the same time, may address the environmental crisis through recycling the waste fly ash.

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