

DEVELOPMENT OF THE INSULATION MATERIALS FROM COAL FLY ASH, PERLITE, CLAY AND LINSEED OIL

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Submitted January 25, 2010; accepted June 11, 2010

Keywords: Epoxidized linseed oil, Thermal conductivity, Mechanical properties, Fly ash, Perlite

The effect of coal fly ash (FA), clay (C), perlite (P) and epoxidized linseed oil (ELO) on the thermal and mechanical properties of insulation materials was investigated. The properties examined include density, thermal conductivity coefficient, compressive strength and tensile strength. A number of insulation material compositions were prepared with the FA, C, perlite and ELO. The results showed that compressive-tensile strength of the insulation material decreased when the high fly ash ratio and high epoxidized linseed oil ratio used in the preparation of the insulation material composition. The compressive and tensile strengths varied from 10.01 to 1.107 MPa and 8.38 to 1.013 MPa, respectively. The minimum thermal conductivity of 0.313 W/mK observed for the sample (L36) made with a 60% FA/30% C/10% P ratio and 50% ELO processed at 200°C. It is increased with the decrease of ELO and FA. Results indicate an interesting potential for the coal fly ash recycling and epoxidized linseed oil renewable to produce useful materials.

INTRODUCTION

The importance of renewable resource based products for industrial applications becomes extremely clear in recent years with increasing emphasis on the environmental issues, waste disposal, and depleting non-renewable resources. Renewable resource-based polymers can yield a platform to substitute petroleum-based polymers. Through innovative ideas in designing the new biobased polymers which can compete or even surpass with the existing petroleum-based materials on a cost-performance basis with the added advantage of eco-friendliness. There is a growing urgency to develop and commercialize new biobased products and other innovative technologies that can reduce widespread dependence on fossil fuel and at the same time would enhance national security, the environment, and the economy [1].

Seed oils have traditionally been used as drying oils and raw materials for uralkyds and alkyd resin [2]. Naturally occurring seed oils are triglycerides consisting of a mixture of saturated, oleic, linoleic, and linolenic fatty acid. Figure 1 shows an example of a triglyceride containing an oleic, linoleic, and linolenic fatty acid. Seed oils are classified according to the linoleic

and linolenic acid content. A convenient method of classification is drying index [2, 3]. Linseed oil has one of the highest drying indexes of the most common drying oils conventionally used in paint and varnish industry.

The carbon-carbon double bond on oleic, linoleic and linolenic fatty acid can be epoxidized by reaction with peroxyacids, dioxirane, or hydrogen peroxide [4].

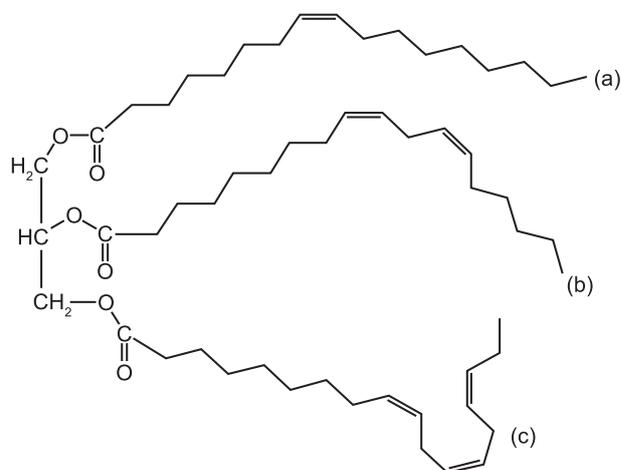


Figure 1. (a) Oleic fatty acid; (b) linoleic fatty acid; and (c) linolenic fatty acid.

These epoxides can be polymerized by the reaction with amine containing monomers through the epoxy-amine cross-linking reaction. Epoxidized seed oils are used extensively as an HCl scavenger for polyvinyl ether [5]. Epoxidized oils are also used as inks; however, epoxidized seed oils have found only modest application in specialty coating systems [6]. Epoxidized seed oils, such as epoxidized linseed oil (ELO) and octyl epoxide linseedate, are now commercially produced by various companies, e.g. Athena Chemical Company, and these epoxidized vegetable oils have found applications in coatings and in some cases as plasticizer additives [7]. An example of a commercially available vegetable oil with high iodine value is linseed oil. Linseed oil is a well known rich source of linolenic acid [8, 9]. Because unsaturated fatty acids are susceptible to autoxidation and polymerization, linolenic acid containing oils are widely used in oil-modified alkyd resins and alkyd-emulsion paints and varnishes [10,11]. Other applications are printing inks, cloth oil, soaps, automobile brake linings, linoleum and binding agents [8, 9, 12]. Figure 2 shows an example of a typical epoxidation product of linseed oil [13].

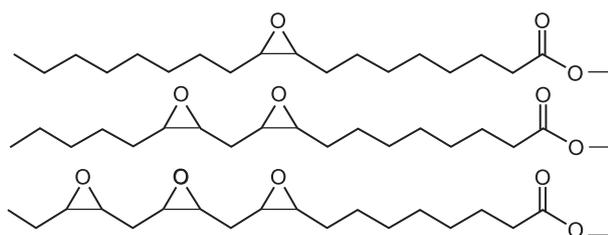


Figure 2. Chemical structure of ELO.

The recycling of by-products and wastes represents an increasingly urgent problem for the immediate future of human kind. One major by-product is coal fly ash, which is produced in significant amounts in Turkey. Currently, only a small percentage of fly ash is utilized, the remaining is being directly discharged into landfill, which is unsatisfactory solution both from ecological and economic point of view. Therefore, there is continuing interest in establishing suitable processes in which they can be efficiently reused. The major constituents of fly ash are SiO_2 , Al_2O_3 and Fe_2O_3 with some minor constituents such as CaO , MgO and other oxides. Therefore, these oxides have been mainly considered as a low cost material resource for the cement industry [14, 15]. The fly ash is also used in the manufacturing

of brick [16], fly ash mineral-based polymer composites [17] ceramic tableware and artware [18]. Recent studies have showed and alternative ways of the management of coal fly ash in using in glass [19] and glass-ceramics industry [20, 21].

Perlite is a material that can be used for insulation in buildings. In Turkey 8 billion tons of perlite exists, it is 70 % of world reserves. It is seen that perlite is a very important material for Turkish economy, and it can be used as insulator owing to its low heat conductivity. Perlite is basically mineral obsidian. It is a vitreous substance that contains 2-6 % water. Binding materials such as cement, gypsum, lime, bitumen and clay are needed for manufacturing perlite brick. Perlite/clay bricks are some of the lightest ceramic materials. There have been various studies on perlite low heat transferring construction materials. Clay was used as a binder in many studies. In Czech Republic, 1982, wall dividing panels were manufactured with weight batching 27% perlite, 3% fiberglass and 70% clay. The unit weight, compressive strength, heat conductivity and porosity ratio were 950 kg/m^3 , 3.2 MPa, 0.21 kcal/mh 1C and 69%, respectively. In Japan, a wall material was manufactured with 20% perlite and some epoxy resin. The unit weight, compressive strength, heat conductivity and porosity ratio were 980 kg/m^3 , 3.46 MPa, 0.22 kcal/m h 1C and 71.2%, respectively [22]. According to a study on refractory perlite/clay bricks, the combination of 85% perlite aggregate and 15% clay by volume were used to give the best combination of lightness and durability [23]. According to other study on isolative ceramics for improved cooking stoves, perlite was made into a graded mix before was combined with clay to form a brick. [24]. In a recent study on humidity buffering by absorbent materials in walls, specially designed lightweight clay made from bentonite mixed with perlite gave an excellent performance [25].

In this study; fly ash, clay, perlite and epoxidized linseed oil are used to produce of insulation materials. The thermal and mechanical properties of obtained novel insulation materials are investigated.

EXPERIMENTAL

Materials

ELO, FA, C and P were used as raw materials for making the insulation materials. All the materials were used as received.

Table 1. Range of chemical composition (%) of obtained FA from Afşin-Elbistan, P and C.

	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	FeO	TiO_2	Ignition loss	(unknown)
FA	21.33	4.025	2.606	36.480	1.032	-	-	-	-	29.798	4.729
C	43.645	20.259	12.954	10.150	1.534	-	-	-	-	9.650	1.808
P	76.5	13.4	-	1.3	0.30	3.0	4.1	1.2	0.20	-	-

The commercial epoxidized linseed oil [The epoxidation catalyst was prepared with quaternary ammonium tetrakis (diperotungsto) and phosphate (3-)] was purchased from Konsan Inc. (Adana, Turkey). Table 3 shows the fatty acid composition of linseed oil. The physical and chemical properties of the ELO that was used in this study are given in Table 4.

The fly ash was obtained from the coal burning power station located in Afşin-Elbistan (Maraş, Turkey). The particle size lies between 1 and 200 μm and the material has a density of 1.5 g/cm^3 and a thermal conductivity coefficient of 0.93 W/mK . According to ASTM C618, Afşin-Elbistan FA can be classified as Class C fly ash due to its chemical composition.

The clay was purchased from Aslan Corporation. It was obtained from Elazığ city (around of Sarıyakup village) of Turkey. Its density is 1.5 g/cm^3 and the thermal conductivity coefficient is 0.93 W/mK .

The perlite was supplied from Izper Company (Izmir-Turkey). Table 2 shows the physical characteristics of P.

The chemical composition of FA, C and P are shown in Table 1. The content of SiO_2 in perlite (76.5 wt.%) is much higher than that in clay (43.645 wt.%) and fly ash (21.33 wt.%), but the content of Al_2O_3 in clay (20.259 wt.%) is lower than that in perlite (13.4 wt.%) and fly ash

(4.025 wt.%). The content of CaO in fly ash (36.48 wt.%) is higher than that in clay (10.50 wt.%), but the content of CaO in perlite isn't present. The microstructure was analyzed by SEM (scanning electron microscope) whereas the main crystalline phases were identified by XRD (X-ray diffraction). According to the XRD analysis, the major mineral phases are quartz, calcite and mullite in fly ash, and that in clay are quartz and calcite. The major mineral phases are quartz and mullite in perlite. The difference of chemical compositions and mineral phases among the raw materials would cause the firing parameters and mechanism and performance of fly ash–perlite–clay samples are different from that of clay samples. According to SEM investigations, C grain thickness is between 25 and 30 μm and FA grain thickness is between 1 and 3 μm . (Figure 3). The SEM result shows that bond with sintering are developed among the C grains in the sample and can rarely be cavities. The cavities among the C grains are found about 5 μm . A combination is obtained between FA and C grains. This combination is different from the C grains.

Preparation of the samples

The samples were made with ELO, FA, C and P. The percentage ratio of the weights of FA and C are 30, 40, 50 and 60. ELO was added to the mixture in percentages of 40, 45 and 50. The P ratio of 10 % was used for all mixtures. The mix ratios for the samples are

Table 2. Physical characteristics of P.

Colour	White
Refractive index	1.50
Free moisture	% max 0.50
pH of water slurry	0.50-8.0
Specific gravity	2.2-2.4
Bulk density (loose)	50-400 kg/m^3
Mesh size	4-8 mesh & finer
Softening point	870-1093°C
Fusion temperature	1260-1343°C
Thermal conductivity at 24°C	0.04-0.06 W/mK
	* Soluble in hot conc.
	Alkali and in HF
Solubility	• Moderately soluble in (< 10 %) in IN NaOH
	• Slightly soluble in (< 3 %) in mineral acid (IN)
	• Very slightly soluble (< 1 %) in water or weak acids
Specific heat	837 J/kgK

Table 3. Fatty acid composition of LO.

Fatty acid composition	Linseed oil (% of total)
Palmitic acid (C 16:0)	5.3
Stearic acid (C 18:0)	3.1
Oleic acid (C 18:1)	18.1
Linoleic acid (C 18:2)	15.2
Linolenic acid (C 18:3)	54.1
Other	4.2

Table 4. Physical and chemical properties of ELO.

Properties	ELO
Appearance at normal temperature	Thick to yellow liquid
Brilliance	< (Pt-Co) : 402
Acid value	(KOH/g) : 1.32 mg
Iodine value	< % 0.62
Oxirane value	% 9.4
Heat conductivity coefficient	0,163 W/mK
Density (25°C)	0.991-1.002 g/cm^3
Saponification number	194-88
Flow point	7°C
Boiling point	163°C
Ignition point	321°C
Viscosity	43 dPas (at 40°C)
Refractive index (25°C'de)	2.153
Melting point in water (25°C)	< % 0.032
Loss on heating	< % 0.71
Weight per equivalent	170.4 g
Resin	131.5 g
Crosslinker	11.0 g
Pigment	75 g
Additives	
(Catalyst, antioxidant, flow agent and anti-foaming agents)	11.4 g

given in Table 5. All the samples were blended for 5min in a laboratory counter-current mixer. Standard 100 mm cube were used for the determination of compressive strength. The prism (150×60×20 mm) samples were cast for the determination of the thermal conductivity coefficient of the sample. The compaction of the samples was obtained by means of vibration. After casting, all the test samples were finished with a steel towel. The unfired samples were fired in an electric furnace using one of the three process temperatures. Predrying was obtained at temperature 100°C. Firstly, the samples were fired at temperature 100°C for 12 h and then they are fired at temperatures 160, 180 and 200°C for 10 h in electric

furnace, respectively. The thirtysix different results were obtained for the twelve samples at three different process temperatures. The standard temperatures and mix compositions were determined from the pretrial. The experimental studies were designed to determine the heating conditions most favourable for the ELO/FA/C/P samples in relation to the properties of the finished products, and to explore the possibilities of reducing the temperatures below those normally used in the brick industry.

When process temperature was lower than 180°C, the sample wasn't completely dry. When process temperature was above 200°C, deformation of sample begins; its structure starts to crack, at the same time partial fracture in sample happens. The different compositions of 100 wt.% FA-C-P volume were maintained throughout the series of sample mixes. 100 wt.%: compositions of FA, C and P were prepared using ELO and mixed in predetermined proportions to adjust the appropriate moulding consistency to desired levels. The levels of ELO were selected to give appropriate moulding consistency values ranging from 40 to 50 to sample mixes when treated with a fixed volume of sample. This volume which imparts proper moulding consistency to a sample mix was predetermined from blank trials. It was found from control tests. Figure 4 shows the products developed from ELO-FA-C-P after firing.

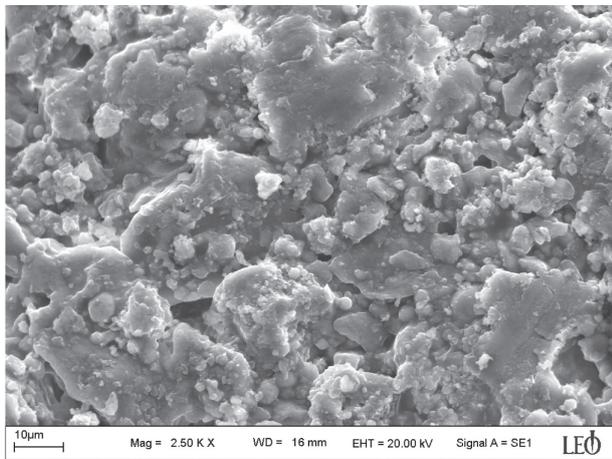


Figure 3. SEM photo of fired sample with 40 % ELO/30 % FA/60 % C/10 % P.



Figure 4. Solidified products developed from ELO, FA, P and C (after firing).

Experimental procedure

A quick thermal conductivity meter (Showa Denko) based on DIN 51046 hot wire methods were used to measure the thermal conductivity. In this method, the hot wire (Cr-Ni) and the thermoelement (Ni Cr-Ni), which is soldered in the middle of it, is placed between two samples. One sample has a known thermal conductivity coefficient whilst the other is the sample to be investigated. Here, the thermal conductivity coefficient was determined by using Eq. [1] [26]

$$k = K \frac{l^2 \ln(t_2/t_1)}{V_2 - V_1} - H \quad (1)$$

where K and H are the constants of the Shotherm-QTM apparatus that are taken as $252 \cdot 10^{-4}$ and $33 \cdot 10^{-3}$, respectively.

Table 5. The mix design and codes for samples at all temperatures.

	ELO								
	160°C			180°C			200°C		
	40%	45%	50%	40%	45%	50%	40%	45%	50%
60% Clay, 30% Fly ash, 10% Perlite	L1	L2	L3	L4	L5	L6	L7	L8	L9
50% Clay, 40% Fly ash, 10% Perlite	L10	L11	L12	L13	L14	L15	L16	L17	L18
40% Clay, 50% Fly ash, 10% Perlite	L19	L20	L21	L22	L23	L24	L25	L26	L27
30% Clay, 60% Fly ash, 10% Perlite	L28	L29	L30	L31	L32	L33	L34	L35	L36

A quick thermal conductivity meter device is a production of Kyoto Electronics Manufacturing Co., Ltd., Japan. Its sensitivity is given as + 5%+1 digit and the measurement range is stated as 0.02-10 W/mK. Measuring time is standart 100-120 s.

Each measurement was repeated three times and at three different locations for each sample. The thermal conductivity coefficient, k , was computed by using the average of these nine k values.

This method has wide applications [27-29] in determining thermal conductivity of refractory materials where, instead of measuring heat flow, the temperature variation with time at certain locations is measured. Being transient in nature, this method takes only a few minutes in contrast to the earlier methods involving steady-state conditions.

The mechanical tests were performed in the Firat University Engineering, Construction Department Laboratories. The density and compressive strength (oven dried) were evaluated for each sample using test procedures described in the TS 699 (1987) standard. The results were appraised using equations from TS 699. The compressive strength of samples was tested using a Turkish Beskom Material Testing Machine (Compressive Testing Machine) Model BC 100. The maximum rate of pressure applied for this compressive testing machine was 200 t. Results were obtained using a computer connected to the compressive testing machine. The compressive strength values after firing at different process temperatures (160, 180 and 200°C) are presented in Figure 7.

The tensile strength of samples is determined by Eq.(2) [30] and presented in Figure 8.

$$F_{Tensile} = 0.35 \sqrt{F_{compressive}} \quad (2)$$

RESULTS AND DISCUSSION

Density

Relationship between density and ELO content is shown in Figure 5. As can be seen from Figure 5, there was a reasonably good relationship between ELO and density. Taking into account the heterogeneous nature of the sample, the general relationship between ELO and density is pooled together for all results in Figure 5. The densities are varied between 1.629 and 1.039 g/cm³. The highest value of density, 1.629 g/cm³, is determined for the sample with a 10% P/30% FA/60% C ratio and 40% ELO processed at 160°C. The highest thermal conductivity coefficient is obtained for this value of density. The lowest value of density, 1.039 g/cm³, is measured for the sample with a 10% P/60% FA/30% C ratio and 50% ELO processed at 200°C. The lowest thermal conductivity coefficient is obtained for this value of density. Reduction in density is caused a reduction in

thermal conductivity. Lu-Shu et al. [31] also reported that thermal conductivity increased with increasing density. There are numerous studies [32, 33, 34] reporting that increase in density results in higher thermal conductivity coefficient. Additionally, Demirboğa [35], Uysal et al.

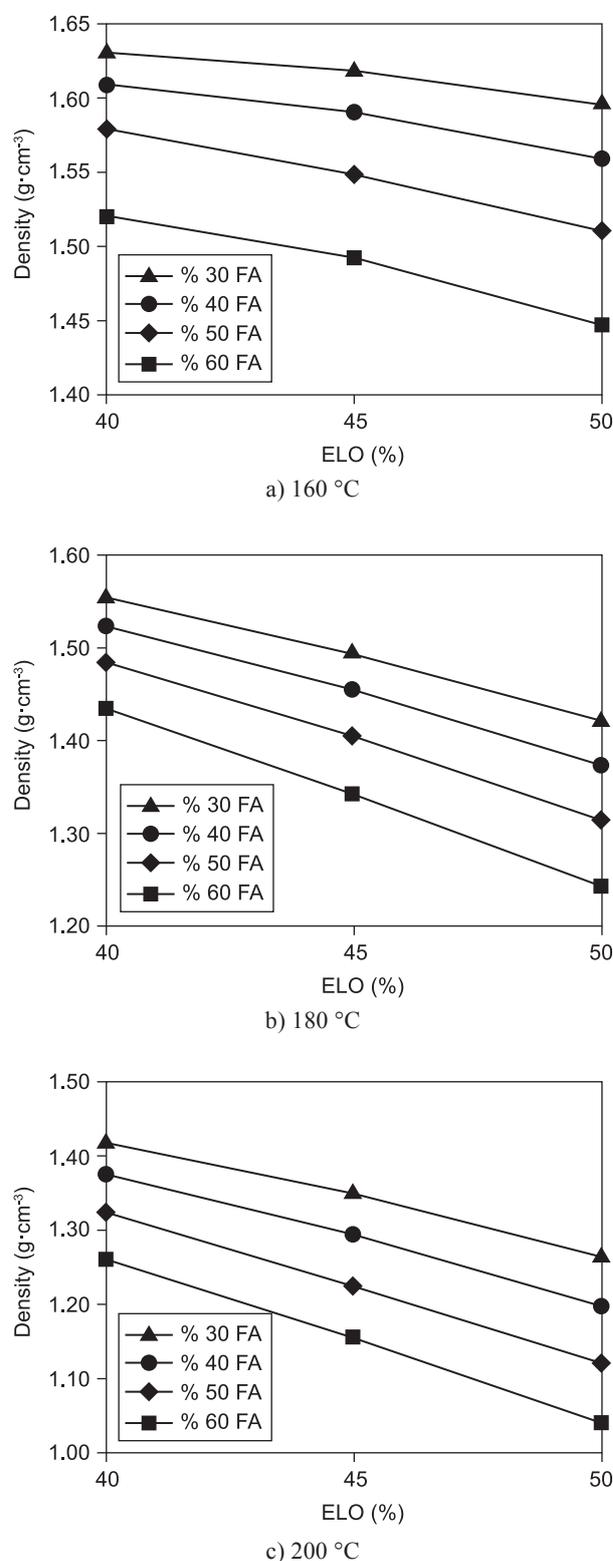


Figure 5. The density- ELO percent relation in the samples.

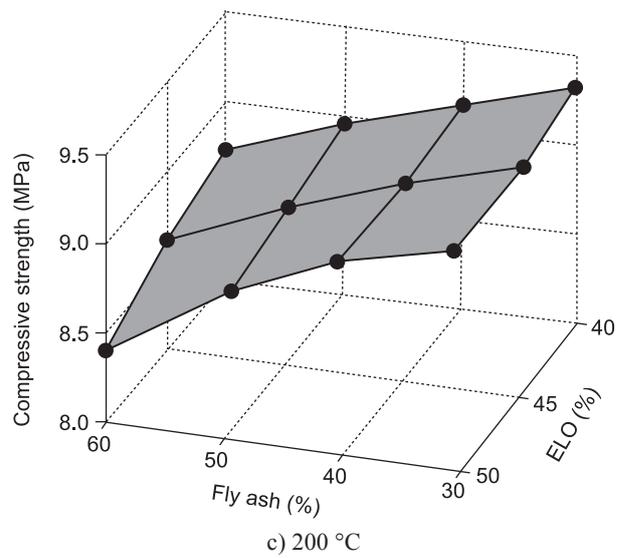
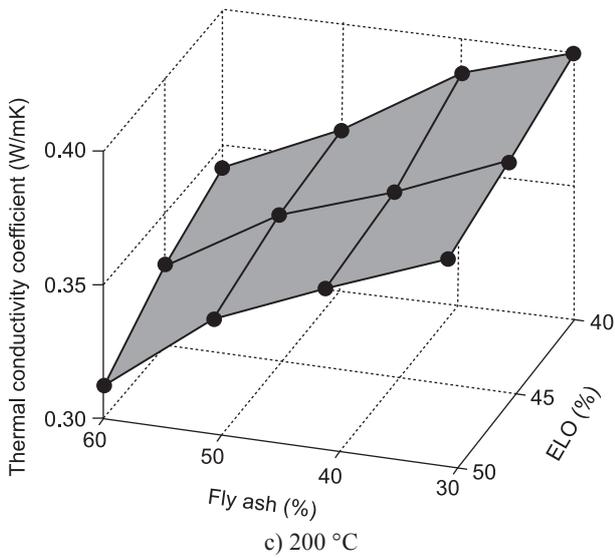
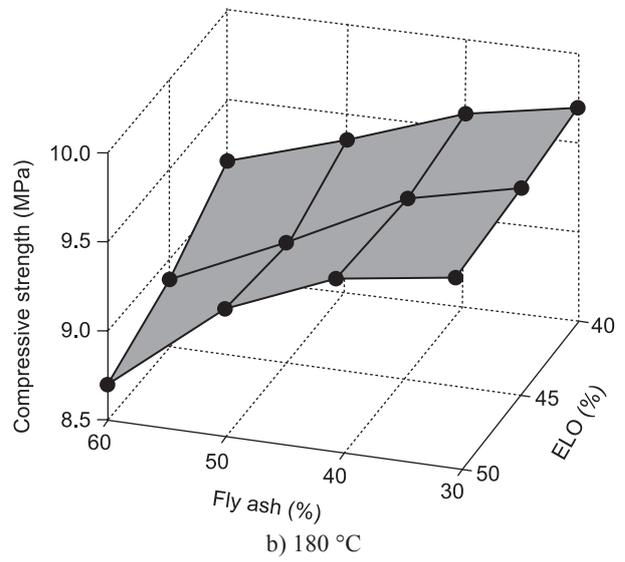
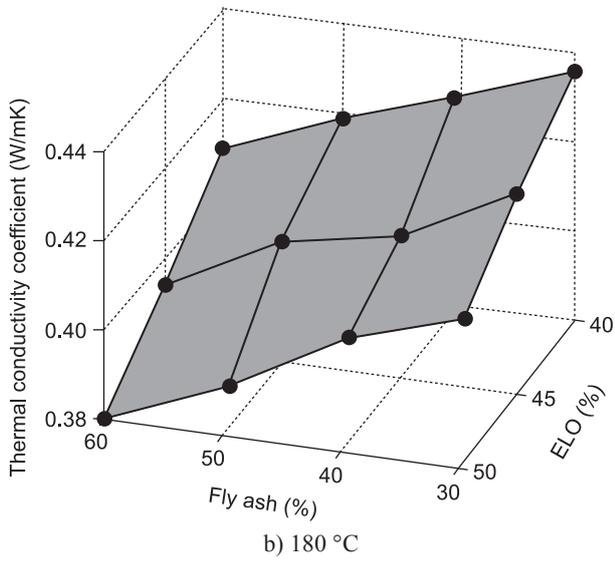
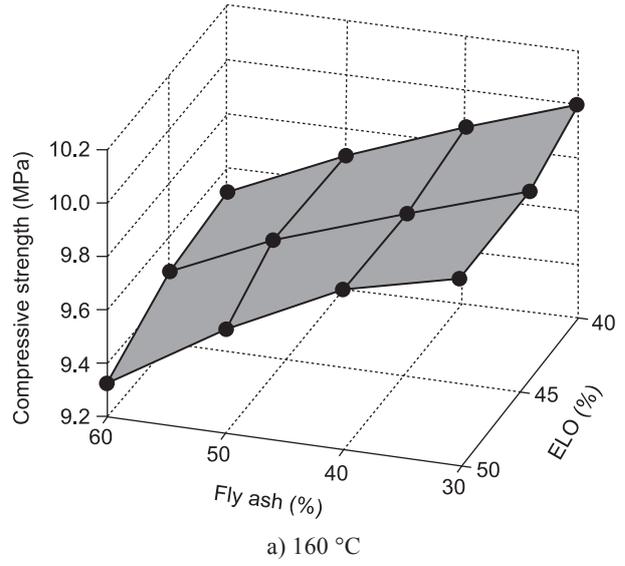
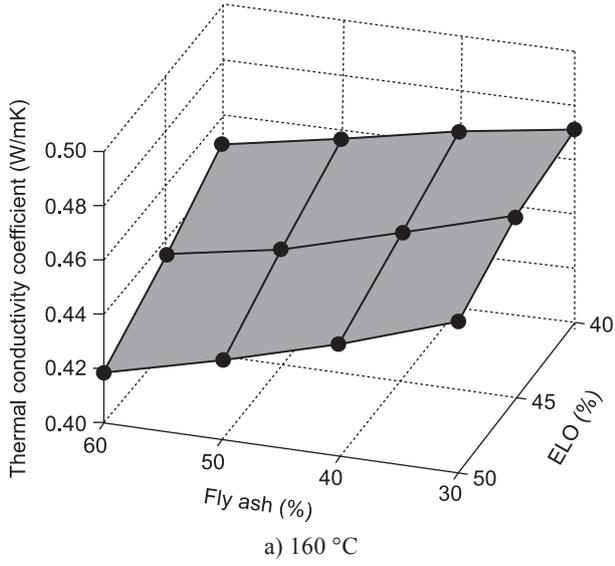


Figure 6. The thermal conductivity coefficient - ELO percent relation in the samples.

Figure 7. The compressive strength - ELO percent relation in the samples.

[36], Akman et al. [37] and Blanco et al. [38] also reported that thermal conductivity decreased due to the decrease of concrete density. Lu-Shu et al. [39] experimentally formulated a correlation between the density and thermal conductivity, and reported that the thermal conductivity increased with increasing density.

The variation of density with the temperature is given in Figure 5. From this, it can be seen that the density decreased with an increase in temperature. The maximum density (Sample code: L1) was observed at 160°C. At 180 and 200°C the density of the sample decreased 4.72 % and 12.95 %, respectively. Figure 5. shows that an increase in the amount of FA brings about a reduction in the sample body density. The main reason for such a trend is porous nature of the FA, which is a pozzolanic material. Generally, the density of the samples increases with increasing C content of the sample, a result that is mainly associated with the relatively high density of C in comparison to FA. The increase in ELO content is resulted in a decrease in density of the samples. The samples are revealed the lowest density values for 50% ELO replacement. The densities of samples are increased by 2.08-17.53 % for 40% ELO replacement and 1.42-9.88 % for 45% ELO replacement.

Thermal conductivity

The variation of thermal conductivity of samples with ELO and FA is shown in Figure 6. This figure demonstrates that the highest value of the thermal conductivity is obtained for samples produced with 60% C. Further, the graph declines drastically with increasing FA, and the maximum reduction in the thermal conductivity of sample occurred at the maximum FA (60%). For 40%, 50% and 60% FA, the reductions were 4.23%, 8.99% and 17.19%, respectively, compared to the corresponding the sample with 30% FA and 50% ELO processed at 200°C. This is because the thermal conductivity decreased with increasing FA content. The reduction in thermal conductivity of sample by means of FA is probably related to the increase of porosity due to

the addition of FA in ELO-C, the lower specific gravity of FA, and partly to the amorphous structure of FA, since the thermal conductivity of crystalline silica is about 15 times that of amorphous [40], it is natural for the samples with amorphous silica to have lower conductivity [41, 42].

The thermal conductivity values of samples measured at three different process temperatures (160, 180 and 200°C) have been shown in Figure 6. The minimum thermal conductivity of samples made at 160 180 and 200°C were 0.418, 0.380 and 0.313 W/mK, respectively. The lowest value of thermal conductivity, 0.313 W/mK, is measured for the sample with a 60% FA/30% C/10% P ratio and 50% ELO processed at 200°C. The highest value of thermal conductivity, 0.472 W/mK, is obtained for the sample with 30% FA/60% C/ 10% P ratio and 40% ELO treated at 160°C. The high process temperature decreased the thermal conductivity of sample and the reductions were 9.09% (at 180 °C) and 25.11% (at 200°C), respectively, compared to the samples at 160 °C. This is probably related to the increase of porosity due to the high process temperature. Reduction in thermal conductivity causes a reduction in density [43].

Likewise, the samples are revealed the lowest thermal conductivity values with ELO content of 50%. The thermal conductivities of samples are increased by 5.50–8.21 % with ELO content of 40 and 3.07-5.15% with ELO content of 45% at 200 °C. Thus we can say that in our study ELO (50% by weight of sample) and FA (60% by weight of sample) at 200°C are decreased thermal conductivity by 21.75%.

When the C usage increased, that is, the amounts of FA used decreased, the thermal conductivity rises accordingly. This is because of the high density and low porous properties of the C. The thermal conductivity for the sample with a 60% FA/30% C/ 10% P ratio and 50% ELO processed at 200°C, is 0.313 W/m K, which is much less than the 0.378 W/m K for the sample with a 30% FA/60% C/ 10% P ratio and 50% ELO processed at 200°C. This can be explained by the low porous structure, which lead to the high thermal conductivity.

Table 6. The thermal conductivity values measured by Shotherm QTM Aparatus in different materials [26, 44].

Material	Measure Values			Values in Literature		
	Density (gr/cm ³)	T_{avr} (°C)	k (W/mK)	Density (gr/cm ³)	T_{avr} (°C)	k (W/mK)
Gypsum thin plaster (Perlite)	0.465	34	0.244	0.40-0.50	20	0.139-0.162
Gypsum rough plaster (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
Cement Block(Perlite)	0.427	37.7	0.292	0.1046	20	0.300
Strophore	0.016	26.3	0.0308	0.200	20	0.0395
Ytong	0.617	38.7	0.180	0.800	20	0.383
Brick Wall	2.093	45.7	1.148	1.8-2.0	20	0.972
Sample with ELO, FA, C and P	1.039	32	0.313	–	–	–

Decreasing the amounts of C will increase the thermal conductivity of the sample. The increases in thermal conductivity induced by 40, 50 and 60% C are 9.01, 13.53 and 20.76% compared to the corresponding the sample with 30% C and 50% ELO processed at 200°C, respectively. Thermal conductivities of some types of plaster materials used at present [44] and the most useful of the samples prepared by ELO, FA, P and C in this study are given at Table 6. It can be seen this table that the thermal conductivity coefficient of insulation samples made by ELO, FA, P and C are less than the some values stated at T.S.E. standards.

Compressive strength

Figure 7 shows the compressive strength of the samples at various process temperatures (160, 180 and 200°C). The process temperature is affected the strength of samples to a considerable extent. As seen in the figure, compared to 160°C, the effects of the high process temperature on the compressive strength of the sample is negative. The samples produced at 160°C show higher strength than the samples produced at 180 and 200°C.

The compressive strength values are inversely proportionate with the percentages ELO and FA. The strength dramatically decreases with an increase in the replacement level of ELO and FA. The rate of increase in the compressive strength of the sample is higher when the amount of the C content increases. The FA reduced compressive strength of sample at all process temperature. Reductions were very high at 200°C, but with decrease in process temperature the reduction percent decreased. Reductions at 160°C with 50% ELO were 1.03%, 2.27% and 3.61% for 40%, 50% and 60% FA, respectively, compared to the corresponding the samples with 30% FA. Reduction rate decreased significantly with increasing process temperature. Thus, at 200°C with 50% ELO, these values reduced to 2.01%, 4.03% and 6.15% for 40%, 50% and 60% FA, respectively. These observations are consistent with the results of other studies [45-50]. Balo and coworkers produced composite materials with different epoxidized vegetable oils-FA-C and analyzed the physical-mechanical properties of these materials. Their use as an insulation material investigated. When increasing the FA ratio and increasing the epoxidized vegetable oil ratio, low compressive-tensile strength, low thermal conductivity, and high abrasion loss obtained [45-48]. The minimum thermal conductivity of 0.273 W/mK is observed with the samples containing epoxidized soybean oil-FA-C. It is increased with the decrease of epoxidized soybean oil and FA. The compressive and tensile strengths are varied from 13.53 to 6.31 MPa and 1.287 to 0.879 MPa, respectively [49]. The minimum thermal conductivity of 0.255 W/mK is observed with the samples containing epoxidized palm

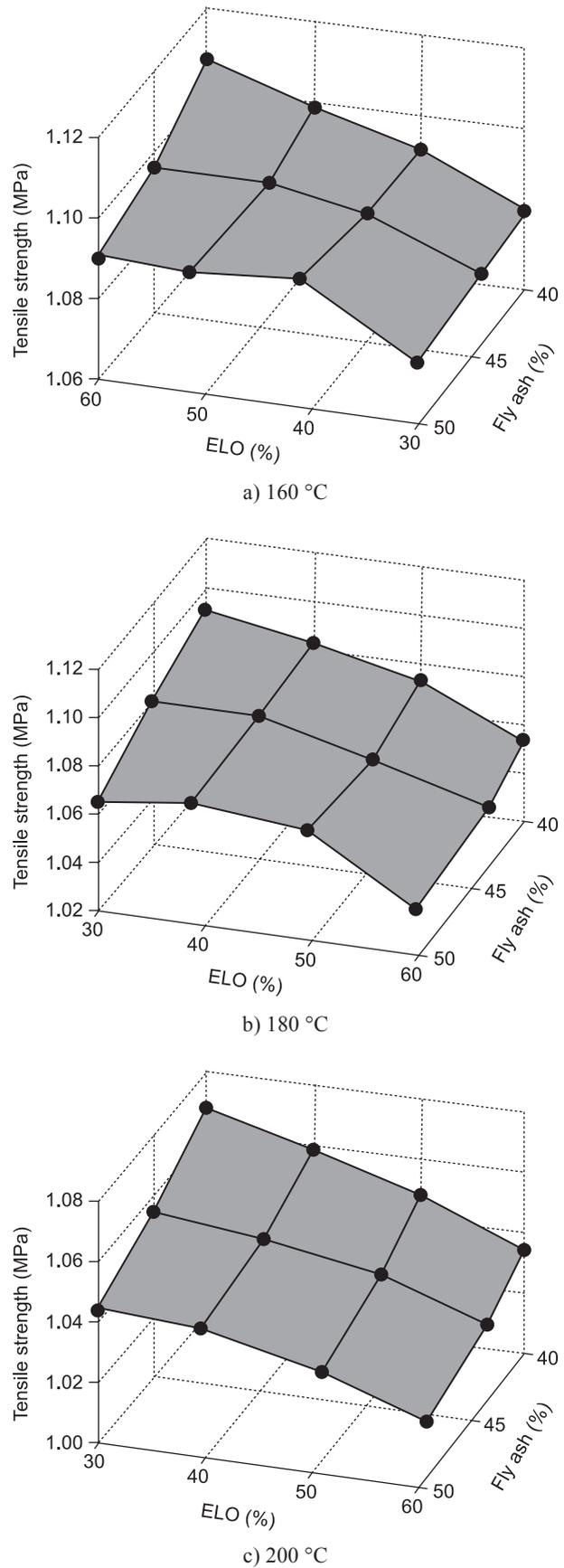


Figure 8. The tensile strength - ELO percent relation in the samples.

oil-FA-C. The compressive and tensile strengths are varied from 4.26 to 1.5 MPa and 0.722 to 0.428 MPa, respectively [50]. Thus, it can be said that sample containing FA showed a reduction in strength at 160, 180 and 200 °C as a function of weight percentage. This can be directly related to the properties of FA that decrease the compressive strength of sample and required low process temperature. In addition, the process temperature of the sample is an important factor influencing the compressive strength of various samples [50]. The best sample properties with the samples containing epoxidized olive oil-FA-C are determined as follows: thermal conductivity of 0.258 W/mK, compressive strength of 4.37 MPa, tensile strength of 0.731 MPa, abrasion loss of 1.04% and mass of 198.72 g. The lowest value of the thermal conductivity, compressive-tensile strength and mass in produces was obtained for sample produced with 50% epoxidized olive oil /70% FA/30%C. The lowest value of the abrasive loss was determined for sample produced with 40% epoxidized olive oil /30% FA/70% C [51].

The effect of ELO on compressive strength is also significant. The maximum compressive strength of samples made with 40%, 45% and 50% ELO at 160°C were 10.01, 9.83 and 9.68 MPa, respectively. The compressive strength of sample decreased with increasing of ELO. Reductions for samples produced with 60% FA at 200°C compressive strength were 1.83% and 4% for 45% and 50% ELO, respectively, compared to the corresponding the samples with 40% ELO. Increasing the process temperature resulted in a decrease of reduction values of compressive strength due to high-volume ELO, compared to the sample made with 50% ELO at 200°C compressive strength.

The use of C in samples improves the compressive strength of these products. The results show the positive effect of C on the compressive strength of sample. The highest compressive strength and the density were measured in the sample with 40% ELO processed at 160°C [sample code: L1 (10.01 MPa)], which contain highest amount of C. The compressive strengths decreased 1.39, 3.09 and 4.99%, for samples with 40% ELO processed at 160°C due to 50, 40 and 30% C, respectively. The compressive strength of the sample with 60% C and 40% ELO processed at 160°C was found to be 2.89% higher than that of sample processed at 180°C and 7.09% higher than that of sample processed at 200°C. The compressive strength [sample code: L30 (9.33 MPa)] of sample with 30% C and 50% ELO processed at 160°C was found to be 6.75% higher than that of sample processed at 180°C and 10.18% higher than that of sample processed at 200°C. Sample L1 had the highest compressive strength which was 6.79% higher than that of sample L30 and 16.28% higher than that of sample L36. The compressive strengths of the all series samples were about three times lower than that of the traditional bricks with cement.

Tensile strength

The tensile strength values are obtained by using Equation (2) and the compressive strength values. These values are plotted in Figure 8. The interpretations of graphs connected with the tensile strength values are similar to the compressive strength values. The tensile strength values are varied between 1.013 and 1.107 MPa.

CONCLUSIONS

In this study we demonstrated that it is possible to utilize fly ash, perlite, clay and epoxidized linseed oil as alternative raw material resources for the production of the insulation material. On the basis of the results reported in the present investigation, the following conclusion can be drawn:

1. The addition of FA and ELO into insulation material composition decreases the compressive-tensile strength and thermal conductivity coefficient values.
2. The lowest value of thermal conductivity is measured for the sample processed at 200°C. The highest values of compressive and tensile strength are obtained for the samples processed at 160°C.
3. The minimum density has been found to occur for samples made with a 60% FA/30% C/ 10% P ratio and 50% ELO at all the process temperatures. It is 1.447 g/cm³ (sample code: L30) at 160°C, 1.241 g/cm³ (sample code: L33) at 180°C, and 1,039 g/cm³ (sample code: L36) at 200°C, respectively.
4. At all the process temperatures, the minimum thermal conductivity coefficient value was observed for samples produced with a 60% FA/30% C/ 10% P ratio and 50% ELO. It is 0.418 W/mK (sample code: L30) at 160°C, 0,380 W/mK (sample code: L33) at 180°C, and 0,313 W/mK (sample code: L36) at 200°C, respectively.
5. The thermal conductivity coefficient value decreases as the density of the sample is decreased.
6. The maximum tensile-compressive strength occurs with 30% FA/60% C/ 10% P ratio and 40% ELO at all the process temperatures. It is 10.01-1.107 MPa (sample code: L1) at 160°C, 9.72-1.091 MPa (sample code: L4) at 180°C, and 9.30-1.067 MPa (sample code: L7) at 200°C, respectively.
7. Results of this investigation suggest that class C fly ash, ELO, C and P could be conveniently used in insulation material.

Acknowledgement

The authors gratefully acknowledge the financial support from the Scientific Research Projects Administration Unit of Fırat University (Elazığ, Turkey) for this study (project number: 1245).

List of Symbols

K	Constant of Shoterm QTM Aparatus
H	Constant of Shoterm QTM Aparatus
t_1	Temperature of startup (K)
t_2	Temperature of finish (K)
V_1	The startup voltages of thermoelement (mV)
V_2	The finish voltages of thermoelement (mV)
k	Thermal conductivity coefficient (W/mK)
T_{avr}	Average temperature (K)
I	Current density in heater wire (A)

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